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I. LEGISLATIVE MANDATES GUIDING THE GRYN

The legislative mandates guiding the I&M Program, and the GRYN in particular, can be divided into two sections: 1) general, overriding legislative Acts and 2) specific Acts and Executive Orders that influence a particular resource area or species or Acts that guide the development and implementation of monitoring.

A. GENERAL, OVERRIDING LEGISLATIVE ACTS

The general, overriding legislative Acts guiding the I&M Program include such Acts as the National Park Service Organic Act of 1916 and the National Parks Omnibus Management Act of 1998, which led to the creation of the Natural Resource Challenge in 2000. Along with these Acts, the enabling legislation of each park unit contains general guidelines for the management of resources. The content of these pieces of legislation follow.

Legislation	Summary content
National Park Service Organic Act of 1916	This Act created the National Park Service within the U.S. Department of the Interior and gave it jurisdiction over parks, monuments, and reservations acquired by the U.S. government for the purpose of wilderness conservation and public enjoyment. *"The service thus established shall promote and regulate the use of the Federal areas known as national parks, monuments, and reservations hereinafter specified by such means and measures as conform to the fundamental purposes of the said parks, monuments, and measures as conform to the fundamental purposes of the said parks, monuments, and reservations, which purpose is to conserve the scenery and the natural and historic objects and the wildlife therein and to provide for the enjoyment of the same in such manner and by such means as will leave them unimpaired for the enjoyment of future generations."*
National Parks Omnibus Management Act of 1998	The Omnibus Act is the precursor to the Natural Resource Challenge, the prime directive guiding the NPS I&M Program. The goal of the act is to use state-of-the-art methods of scientific research to improve management decisions within the NPS. This act also made the superintendents of each park unit responsible for the care and condition of the resources within the parks. *"The Secretary shall undertake a program of inventory and monitoring of National Park System resources to establish baseline information and to provide information on the long-term trends in the condition of the National Park System."* In addition, the act created the Natural Resources Challenge, which provides the funding for the I&M Program and doubles the natural resources staff within the NPS. *"The Committee applauds the Service for recognizing that the preservation of the diverse natural elements and the great scenic beauty of America's national parks and other units should be as high a priority in the Service as providing visitor services. A major part of protecting those resources is knowing what they are, where they are, how they interact with their environment and what condition they are in. This involves a serious commitment from the leadership of the National Park Service to insist that the superintendents carry out a systematic, consistent, professional inventory and monitoring program, along with other scientific activities, that is regularly updated to ensure that the Service makes sound resource decisions based on sound scientific data."*

Legislation	Summary content
BICA Enabling Legislation	Bighorn Canyon National Recreation Area was established on October 15, 1966, following the construction of the Yellowtail Dam along the Bighorn River. The purpose of BICA, as stated in its enabling legislation, is to *"provide for public outdoor recreation use and enjoyment of Yellowtail Reservoir and lands adjacent thereto and for the preservation of the scenic, scientific and historic features contributing to public enjoyment of such lands and waters."*
GRTE Enabling Legislation	Grand Teton National Park was established on September 14, 1950. Within its enabling legislation, GRTE is specifically mandated to conserve elk within park boundaries: *"...a program to insure the permanent conservation of elk within the Grand Teton National Park established by this Act. Such program shall include the controlled reduction of elk in such park by hunters licensed by the State of Wyoming and deputized as rangers by the Secretary of the Interior, when it is found necessary for the purposes of proper management and protection of the elk."*
YELL Enabling Legislation	Yellowstone National Park was established on March 1, 1872. Within its enabling legislation, YELL is mandated to preserve *"from injury or spoilation...all timber, mineral deposits, natural curiosities, or wonders within said park, and their retention in their natural conditions."*

B. SPECIFIC LEGISLATIVE ACTS

Many specific legislative Acts, such as the Geothermal Steam Act, guide the protection and/or monitoring of certain natural resources within park boundaries. The implementation of these Acts will be ongoing during the collection and analysis phase of monitoring. The information contained within these mandates is summarized below.

Legislation (Acts)	Summary content
American Indian Religious Freedom Act of 1978	This Act ensures the freedom of Native Americans to practice the religion of their choosing, including the use of scared lands. *"It shall be the policy of the United States to protect and preserve for American Indians their inherent right of freedom to believe, express, and exercise the traditional religions of the American Indian, Eskimo, Aleut, and Native Hawaiians, including but not limited to access to sites, use and possession of sacred objects, and the freedom to worship through ceremonials and traditional rites."*
Archaeological Resources Protection Act of 1979	This Act protects archaeological resources found on public and Indian lands and ensures cooperation between government agencies with respect to these resources. *"The purpose of this chapter is to secure, for the present and future benefit of the American people, the protection of archaeological resources and sites which are on public lands and Indian lands, and to foster increased cooperation and exchange of information between government authorities, the professional archaeological community, and private individuals having collections of archaeological resources and data..."*
Clean Air Act	This Act promotes the protection of airsheds against sources of pollution through regional air pollution prevention programs. *"The purposes of this title are: (1) to protect and enhance the quality of the Nation's air resources so as to promote the public health and welfare and the productive capacity of its population; (2) to initiate and accelerate a national research and development program to achieve the prevention and control of air pollution; (3) to provide technical and financial assistance to State and local governments in connection with the development and execution of their air pollution prevention and control programs; and (4) to encourage and assist the development and operation of regional air pollution prevention and control programs. A primary goal of this Act is to encourage or otherwise promote reasonable Federal, State, and local governmental actions, consistent with the provisions of this Act, for pollution prevention."*

Legislation (Acts)	Summary content
Federal Water Pollution Control Act (Clean Water Act) of 1972	This Act protects the biological, chemical, and physical nature of the Nation's waters through the elimination of pollutants and the creation of wastewater treatment plants. *"It is the policy of the Congress to recognize, preserve, and protect the primary responsibilities and rights of States to prevent, reduce, and eliminate pollution, to plan the development and use (including restoration, preservation, and enhancement) of land and water resources..."*
Endangered Species Act of 1973	*"It provides for the designation and protection of invertebrates, wildlife, fish, and plant species that are in danger of becoming extinct and conserves the ecosystems on which such species depend. The Act defines an endangered species as any species that is in danger of becoming extinct throughout all or a significant portion of its range. A threatened species is one that is likely to become endangered in the foreseeable future. The Act makes it illegal for any individual to kill, collect, remove, harass, import, or export an endangered or threatened species..."*
Federal Caves Resources Protection Act of 1988	This Act notes the value of protecting caves found on Federal lands from the dangers of increased recreational use and urban sprawl. *"The purposes of this Act are-- (1) to secure, protect, and preserve significant caves on Federal lands for the perpetual use, enjoyment, and benefit of all people; and (2) to foster increased cooperation and exchange of information between governmental authorities and those who utilize caves located on Federal lands for scientific, education, or recreational purposes."*
Fish and Wildlife Coordination Act of 1958 and 1980	*"The FWCA, as amended, proposes to assure that fish and wildlife resources receive equal consideration with other values during the planning of water resources development projects. The Act was passed because the goals of water-related projects (e.g., flood control, irrigation, navigation, hydroelectric power) may conflict with the goal of conserving fish and wildlife resources. Conversely, developers can design water development projects to enhance the quality and enjoyment of fish and wildlife resources if such goals are incorporated into project plans."*
Forest and Rangeland Renewable Resources Planning Act of 1974 and 1976	This Act assesses the importance of renewable resources found in the Nation's forests and rangelands to the economy. The Act also cites the importance of sustainable use of these resources. *"It is the policy of the Congress that all forested lands in the National Forest System shall be maintained in appropriate forest cover with species of trees, degree of stocking, rate of growth, and conditions of stand designed to secure the maximum benefits of multiple use sustained yield management in accordance with land management plans."*
Geothermal Steam Act of 1970	This Act is the only one that specifically mandates monitoring within the GRYN. The Act requires the Secretary of the Interior to maintain a list of significant thermal features within the NPS and to undertake a system of monitoring and researching such features. *"The Act directs the Secretary to maintain a list of significant thermal features within National Park System units, including 16 specified units. The Secretary must maintain a monitoring program for these features and establish a research program on geothermal resources within units with these features. If the Secretary determines that exploration, development or utilization of lands subject to a lease application is reasonably likely to have a significant adverse effect on a significant thermal feature within a National Park System unit, the Secretary is prohibited from issuing the lease. If these activities are reasonably likely to have an adverse effect, the Secretary must include specified stipulations in leases or drilling permits to protect the significant thermal features."*
Government Performance and Results Act of 1993	This Act works to improve the confidence of the American people in the work of the American government by creating goals for government agencies and holding them accountable for meeting these goals. Specific goals related to the park units of the GRYN can be found in the GPRA Table at the end of this section of Acts.

Legislation (Acts)	Summary content
Migratory Bird Treaty Act of 1974	This Act prohibits the hunting or collection of migratory bird species and is an agreement between the U.S. and the following countries: Canada, Mexico, Japan and Russia. *"Establishment of a Federal prohibition, unless permitted by regulations, to "pursue, hunt, take, capture, kill, attempt to take, capture or kill, possess, offer for sale, sell, offer to purchase, purchase, deliver for shipment, ship, cause to be shipped, deliver for transportation, transport, cause to be transported, carry, or cause to be carried by any means whatever, receive for shipment, transportation or carriage, or export, at any time, or in any manner, any migratory bird, included in the terms of this Convention . . . for the protection of migratory birds . . . or any part, nest, or egg of any such bird."*
Mining in the Parks Act of 1976	This Act regulates the operation of mining claims within the National Park System in order to protect landmarks and resources. *"Congress finds: that continued application of U.S. mining laws to National Park System lands conflicts with the purposes for which they were established; all mining operations on National Park System lands should be conducted to prevent or minimize damage to the environment and other resource values; surface disturbance from mineral development should be halted temporarily in certain National Park System areas while Congress determines whether to acquire valid mineral rights in these areas."*
National Environmental Policy Act of 1969	This Act creates regulations to prevent damage by humans on natural environments and ensure a healthy environment for generation to come. *"In order to carry out the policy set forth in this Act, it is the continuing responsibility of the Federal Government to use all practicable means, consistent with other essential considerations of national policy, to improve and coordinate Federal plans, functions, programs, and resources to the end that the Nation may: 1) fulfill the responsibilities of each generation as trustee of the environment for succeeding generations; 2) assure for all Americans safe, healthful, productive, and aesthetically and culturally pleasing surroundings; 3) attain the widest range of beneficial uses of the environment without degradation, risk to health or safety, or other undesirable and unintended consequences; 4) preserve important historic, cultural, and natural aspects of our national heritage, and maintain, wherever possible, an environment which supports diversity, and variety of individual choice; 5) achieve a balance between population and resource use which will permit high standards of living and a wide sharing of life's amenities; and 6) enhance the quality of renewable resources and approach the maximum attainable recycling of depletable resources."*
National Historic Preservation Act of 1966	This Act calls for the preservation of historical sites and structures in order to ensure the spirit of the Nation. *"The preservation of this irreplaceable heritage is in the public interest so that its vital legacy of cultural, educational, aesthetic, inspirational, economic, and energy benefits will be maintained and enriched for future generations of Americans..."*
Taylor Grazing Act of 1934	This Act manages grazing on public lands through the use of districts and permitting schedules. *"The Secretary must: provide for the protection, administration, regulation and improvement of the grazing districts; adopt regulations and enter into cooperative agreements necessary to accomplish the purposes of the Act; regulate occupancy and use; preserve the land and resources from destruction or unnecessary injury; provide for orderly improvement and development of the range. The Secretary may continue the study of erosion and flood control and perform work to protect and rehabilitate areas subject to the Act."*

Legislation (Acts)	Summary content
Wilderness Act of 1964	This Act maintains lands within the U.S. as designated wilderness areas, set aside for preservation and conservation in their natural state. *"In order to assure that an increasing population, accompanied by expanding settlement and growing mechanization, does not occupy and modify all areas within the United States and its possessions, leaving no lands designated for preservation and protection in their natural condition, it is hereby declared to be the policy of the Congress to secure for the American people of present and future generations the benefits of an enduring resource of wilderness. For this purpose there is hereby established a National Wilderness Preservation System to be composed of federally owned areas designated by Congress as "wilderness areas", and these shall be administered for the use and enjoyment of the American people in such manner as will leave them unimpaired for future use and enjoyment as wilderness; and no Federal lands shall be designated as "wilderness areas" except as provided for in this Act or by a subsequent Act."*

NPS GPRA GOALS	**Bighorn Canyon National Recreation Area**	Exotic Vegetation Species: by September 30, 2005, exotic vegetation on 70.25 (2.81%) acres of an estimated 2,500 targeted acres of Bighorn Canyon lands, as of FY 1999, is contained.
		Water Quality: by September 30, 2005, Bighorn Canyon has unimpaired water quality.
		Natural/Cultural Resource Inventories: by September 30, 2005, 4 (66.6%) of 6 Bighorn Canyon primary natural/cultural resource inventories are completed.
		Vital Signs: by September 30, 2005, Bighorn Canyon has identified its vital signs for natural resource monitoring.
	Yellowstone National Park	Natural Resources Fauna: by September 30, 2005, 356 (95%) of the 375 self-sustaining and free-ranging wildlife, native fish and birds identified in Yellowstone National Park as of 1999 are preserved and maintained.
		Geothermal Features: By September 30, 2005, 90 (90%) of the 100 indicator geothermal features identified in Yellowstone National Park as of 1999 are in good condition.
		Native Species of Special Concern: by September 30, 2005, four of Yellowstone National Park's native species of special concern (trumpeter swan, white pelican, pronghorn antelope and Yellowstone sand verbena), as of 1999, have an improved or stable status.
		Exotic Plant Species: by September 30, 2005, invasive exotic vegetation species on 20-22 (2.6%) of 822 targeted acres of Yellowstone National Park lands, as of FY 1999, are eradicated or contained.
		T&E Species Improved: by September 30, 2005, one (the gray wolf) (33%) of Yellowstone National Park's three identified populations of federally listed threatened and endangered species with critical habitat on park lands and/or requiring NPS recovery actions, as of 1999, has an improved status.
		T&E Species Stable: by September 30, 2005, two (the grizzly bear and bald eagle) (66%) of Yellowstone National Park's three identified populations of federally listed threatened and endangered species with critical habitat on park lands and/or requiring NPS recovery actions, as of 1999, have a stable status.
		Air Quality: by September 30, 2005, air quality in Yellowstone National Park has remained stable or improved relative to FY 1998 conditions.
		Water Quality: by September 30, 2005, Yellowstone National Park has unimpaired water quality.
		Vital Signs: by September 30, 2005, Yellowstone National Park has identified its vital signs for natural resource monitoring.
	Grand Teton National Park	Exotic Plant Species: by September 30, 2005, spotted knapweed and other alien vegetation species are contained on 20,000 (100%) of 20,000 acres targeted in Grand Teton National Park and the John D. Rockefeller Jr. Memorial Parkway.

		T&E Species: by September 30, 2005, 2 of the 4 federally listed threatened and endangered species NOT having critical habitat in Grand Teton and the Parkway and NOT requiring NPS recovery actions, as of 1997, have an improved status. Monitoring continues on the remaining 2 federally listed species.
		Native Species of Species Concern: by September 30, 2005, 1 of 2 (50%) of Grand Teton National Park and Parkway populations of plant and/or animal species of special concern (e.g. state-listed threatened and endangered species, endemic or indicator species, or native species classified as pests) are at scientifically acceptable levels.
		Air Quality: by September 30, 2005, air quality in Grand Teton National Park has remained stable or improved relative to FY 1998 conditions.
		Water Quality: by September 30, 2005, Grand Teton National Park and Parkway continue to have unimpaired water quality.
		Wildlife Research and Monitoring: by September 30, 2005, 9 of 9 (100%) of Grand Teton National Park and Parkway species of concern will continue to be monitored to provide sufficient information to assist in management decisions.
		Resource Inventories: by September 30, 2005, 50% of the available natural resource data sets for Grand Teton National Park will be collected and evaluated.
		Vital Signs: by September 30, 2005, Grand Teton National Park has identified its vital signs for natural resource monitoring.

Key to GPRA Goal Codes:

Ia1A. Restoration of disturbed lands
Ia1B. Invasive Plant Management
Ia2. Threatened and Endangered Species
Ia2X. Native Species of Special Concern
Ia3. Air Quality
Ia4. Water Quality
Ia9. Geological and Paleontological Resources
Ib3. Vital Signs Identification
Ib5. Aquatic Resource Assessment

Legislation (Executive Orders)	Summary content
E.O. 11987—Exotic Organisms	This Order states that government agencies will restrict the introduction of exotic species into natural areas. *"Executive agencies shall, to the extent permitted by law, restrict the introduction of exotic species into the natural ecosystems on lands and waters which they own, lease, or hold for purposes of administration; and, shall encourage the States, local governments, and private citizens to prevent the introduction of exotic species into natural ecosystems of the United States."*
E.O. 11988—Floodplain Management	This Order mandates the management of floodplains such that their natural flood cycles are maintained, while decreasing the impacts of floods on human safety. *"Each agency shall provide leadership and shall take action to reduce the risk of flood loss, to minimize the impact of floods on human safety, health and welfare, and to restore and preserve the natural and beneficial values served by floodplains in carrying out its responsibilities for (1) acquiring, managing, and disposing of Federal lands, and facilities; (2) providing Federally undertaken, financed, or assisted construction and improvements; and (3) conducting Federal activities and programs affecting land use, including but not limited to water and related land resources planning, regulating, and licensing activities."*
E.O. 11990—Protection of Wetlands	This Order provides for the preservation of wetlands in their natural state without modifications by humans. *"Each agency shall provide leadership and shall take action to minimize the destruction, loss or degradation of wetlands, and to preserve and enhance the natural and beneficial values of wetlands in carrying out the agency's responsibilities for (1) acquiring, managing, and disposing of Federal lands and facilities; and (2) providing Federally undertaken, financed, or assisted construction and improvements; and (3) conducting Federal activities and programs affecting land use, including but not limited to water and related land resources planning, regulating, and licensing activities."*
E.O. 13186—Protection of Migratory Birds	This Order provides additional protection for migratory birds, such that Federal agencies should *"design migratory bird habitat and population conservation principles, measures, and practices, into agency plans and planning processes (natural resource, land management, and environmental quality planning, including, but not limited to, forest and rangeland planning, coastal management planning, watershed planning, etc.) as practicable, and coordinate with other agencies and nonfederal partners in planning efforts."*



REPORT OF

THE NATIONAL PARK SERVICE
GREATER YELLOWSTONE INVENTORY AND MONITORING NETWORK:
VITAL SIGNS MONITORING WORKSHOP

MAY 6-8, 2003

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EXECUTIVE SUMMARY

This report summarizes the events of the *Vital Signs Monitoring Workshop* hosted by the Greater Yellowstone Inventory and Monitoring Network (GRYN) May 6-8, 2003 at the Strand Union Building on the campus of Montana State University, Bozeman, Montana. This workshop is part of the extensive process used to select vital signs to be included in the GRYN Vital Signs Monitoring Plan. The overall goal of the meeting was to apply priority setting to a list of proposed candidate vital signs to be monitored as a means for determining the long-term ecosystem health of the parks of the GRYN. Throughout the workshop, participants also undertook the task of peer review of the ecosystem conceptual models and the decision support system created by the GRYN workshop planning team. (Please see Appendix A for the complete workshop agenda.)

The first day of the workshop was designed to create a shared knowledge and understanding of the National Inventory and Monitoring (I&M) Program, the GRYN and the process by which the workshop planning team developed the list of proposed candidate vital signs used throughout the *Vital Signs Monitoring Workshop*. The goals of the National I&M Program were explained to the participants, as was the need to create a comprehensive and integrative program. Because of time and budgetary constraints, prioritization of vital signs is fundamental, and the primary objective of this workshop was to use experts' knowledge to undertake one step of the prioritization process. Participants were informed that choices they made during this workshop did not constitute a final list of vital signs to be monitored by the GRYN, but that their decisions would be used by the GRYN staff and Technical Planning Committee to make recommendations to the Board of Directors for final approval in August 2003.

During the second day of the workshop, participants were divided into resource-based breakout groups as follows: air quality and climate (joint group), geology and geothermal (joint group), aquatics and water quality (joint group), human use, invertebrates, terrestrial vegetation, terrestrial vertebrates. Using a list of proposed candidate vital signs and information such as the justification given through the conceptual model process or the Delphi survey process and proposed metrics, the breakout groups used a worksheet to evaluate each candidate vital sign using a predetermined set of desirable characteristics. The completion of these worksheets required current knowledge about the ecological relevance, response variability, management relevance, feasibility of implementation, interpretation and utility of the proposed vital sign. (Please see Appendix B for the complete set of selection criteria.) These data were given to the workshop data manager and entered into the decision support system Access database in real time to produce a ranked list of candidate vital signs. (Please see Appendix I for the ranked list of candidate vital signs.)

On the third day of the workshop, participants were given the opportunity to evaluate the ranked list of candidate vital signs and give overall comments. Comments are given in more detail in the body of this report. Participants then engaged in an exercise to determine the spatial and temporal scales within which data about each candidate vital sign could be collected or evaluated. The results of this exercise will be used to evaluate the utility of the vital signs throughout various spatial and temporal scales. This information will be used to summarize the spatial sampling design for the parks.

OVERVIEW OF THE GRYN

GRYN BACKGROUND INFORMATION

The Mission of the National Park Service (NPS) is "to conserve unimpaired the natural and cultural resources and values of the national park system for the enjoyment of this and future generations". To uphold this goal, the NPS created the Natural Resource Challenge in 2000 to encourage National Parks to focus on the preservation of the nation's natural heritage through science, natural resource inventories and expanded resource monitoring and management. This Challenge was legally guided by the *National Parks Omnibus Management Act of 1998*. Through the Natural Resource Challenge, the 265 parks of the NPS were placed into seven regions and, subsequently, organized into thirty-two Inventory and Monitoring Networks, based on geographic and ecological similarities. The overarching goal of the Networks can be summarized by the following quote from the NPS Advisory Board in July 2001: "A sophisticated knowledge of resources and their condition is essential. The Service must gain this knowledge through extensive collaboration with other agencies and academia, and its findings must be communicated to the public. For it is the broader public that will decide the fate of these resources". The goals of the Networks are:

- To inventory the natural resources and park ecosystems under NPS stewardship;
- To determine their nature and status;
- To monitor park ecosystems to better understand their dynamic nature and condition;
- To provide reference points for comparisons with other altered environments;
- To integrate natural resources inventory and monitoring information into NPS planning, management and decision-making.

The Greater Yellowstone Area (GYA) encompasses 18 million acres in three states—Montana, Wyoming and Idaho. Six National Forests and three National Wildlife Refuges lie within this area. Known as one of the largest intact natural areas in the contiguous United States, it has an enormous variety of vegetative communities that boast stable grizzly bear populations, trumpeter swan wintering grounds, free-ranging bison and the largest elk herd in North America. However, because of its wild nature, the GYA is attracting widespread development, in turn creating new disturbances to flora and fauna. The GRYN encompasses the GYA, which consists of four National Park Service protected areas: Bighorn Canyon National Recreation Area (BICA), Grand Teton National Park (GRTE), John D. Rockefeller Memorial Parkway (JODR) and Yellowstone National Park (YELL).

The GRYN was approved by a charter in 2001 and consists of a Board of Directors, Technical Planning Committee, Science Committee and GRYN staff. The Board of Directors (BOD) is comprised of the park superintendents (or his/her appointee) from each of the three GRYN parks and the Research Coordinator for the Rocky Mountains-Cooperative Ecosystems Studies Unit. The BOD directs the GRYN and provides oversight, as well as approving budgets, work plans and the final monitoring plan. The Technical Planning Committee (TPC) is responsible for strategic decisions, such as writing work plans, identifying subject experts as scientific advisors and providing the GRYN with current data and methodologies being used by the parks. A representative from each park sits on the TPC, as well as the Inventory and Monitoring (I&M) Program Manager and the Research Coordinator for the Rocky Mountains-Cooperative Ecosystems Studies Unit. Members of the Science Committee (SC) are chosen from regional universities and other scientific agencies. The role of the SC is to provide scientific

background, suggestions and review that will be used to choose vital signs and to assist in the creation of sampling designs and protocols. The GRYN staff consists of a Program Manager, Cartographic Technician, Communications Director and Writer/Editor, all of whom are based at the Forestry Sciences Lab at Montana State University in Bozeman, Montana and are hosted by the USGS-Northern Rocky Mountain Science Center. In addition, Bighorn Canyon National Recreation Area houses a GRYN ecologist and Grand Teton National Park hosts a GRYN hydrologist. The positions of Data Manager and Quantitative Ecologist, both to be based in Bozeman, will be filled in 2003.

The GRYN is focusing its efforts in three primary areas: data management, inventories and long-term monitoring. Because monitoring vital signs is one of the primary goals of the GRYN, the selection of these vital signs and how best to measure them is an integral part of the success of the program. In order to assure a secure scientific backing, the GRYN formed partnerships with universities, non-profits and park personnel. In 2001 the GRYN joined with the University of Idaho-College of Natural Resources to conduct an internet-based survey of park personnel, university faculty, environmental groups and other agencies. This "Delphi" survey process consisted of three rounds of questioning meant to identify and rank the most important ecosystem components, conditions and processes. Over 100 individuals responded to this survey.

In addition to the Delphi surveys, the GRYN took on the task of developing conceptual ecosystem models to understand the complex nature of the interactions between ecosystem components. These conceptual models are being used to better understand the ecosystems under study and provide solid scientific information based in literature as well as to help guide those who will choose the vital signs for monitoring. The models show drivers, stressors, ecological responses, outcomes and indicators that will warn managers of ecosystem changes.

Along with the Delphi survey and conceptual models, the GRYN has completed a literature review and park-specific workshops. The literature review allows the GRYN quick access to a variety of pertinent scientific studies that have been performed in the GYA and, specifically, in the GRYN parks. The GRYN also hosted park-specific workshops, preceding the *Vital Signs Monitoring Workshop*, where park managers were given the opportunity to peer review the conceptual models and selection criteria used by the GRYN during the *Vital Signs Monitoring Workshop*. (Workshop reports from the park-specific workshops are available upon request.)

PURPOSE OF THE VITAL SIGNS MONITORING WORKSHOP

The list of vital signs to be monitored by the GRYN will be approved by the Board of Directors in August 2003. In order to narrow down an extensive list of possible indicators to a manageable few that will become the final list, the GRYN, under guidance from the National I&M Program, hosted the *Vital Signs Monitoring Workshop*. The goal of this workshop was to assemble subject-area experts to give guidance on which proposed candidate vital signs they believed were most beneficial to the GRYN in keeping with the Service-wide Network goals set forth by the NPS. In order to complete these tasks, the workshop planning team created a list of thirteen selection criteria—a set of yes/no questions to be answered by workshop participants, with space provided for helpful comments corresponding to the criteria. (Please see Appendix H for the complete table of comments.) The selection criteria were developed to determine which of the candidate vital signs contained those desirable characteristics that were deemed important through a literature review and peer review during the park-specific workshops prior to the *Vital Signs Monitoring Workshop*. The selection criteria worksheets were completed by the participants and then

entered into the decision support system Access database the afternoon and evening of the second day of the workshop. This allowed the workshop planning team to present the results to the participants during the third day of the workshop, allowing for comment by the participants on both the process and results.

Approximately 150 individuals were invited from a variety of government, non-government, academic and non-profit organizations, with fifty-six attending. Organizations represented include: Yellowstone National Park, Grand Teton National Park, Bighorn Canyon National Recreation Area, Rocky Mountains-Cooperative Ecosystems Studies Unit, National Park Service-Air Resources Division, U.S. Geological Survey-Water Resources Division, U.S. Geological Survey-Northern Rocky Mountain Science Center, Environmental Protection Agency, Greater Yellowstone Coordinating Committee, U.S. Forest Service, Wyoming Game and Fish, Snowcap Hydrology, Yellowstone Ecological Research Center, Montana Natural Heritage Program, Montana State University, Montana State University-Big Sky Institute, Idaho State University, Iowa State University, University of Oregon, University of Montana, University of Wyoming and the Wyoming Natural Diversity Database. For a complete list of participants and contact information, please see Appendix C.

WORKSHOP PLANNING TEAM

The workshop planning team consisted of a group of individuals who helped create the concept behind the *Vital Signs Monitoring Workshop*, establish workshop goals, generate useful selection criteria and produce a decision support system database. Cathie Jean, Program Manager for the GRYN, was the leader of workshop planning and implementation. Tom Olliff, Chief of Resources at Yellowstone National Park and a member of the TPC, was an integral part of the vital signs selection process and provided helpful critique. Glenn Plumb, Supervisory Wildlife Biologist at Yellowstone National Park, was the author of the selection criteria, ranking process and development of narrative and schematic conceptual models. Ann Rodman, Supervisory GIS Specialist at Yellowstone National Park and a member of the TPC, created the version of the decision support system Access database used during the workshop and provided oversight during data entry and analysis. Duncan Patten, Research Professor at Montana State University, was instrumental in the conceptual model design, as well as author of many individual models and narratives. Bob Hall, Assistant Professor at the University of Wyoming, was the aquatics conceptual model author. Dan Tinker, Assistant Professor at the University of Wyoming, authored many of the terrestrial vegetation conceptual models. Anne Schrag, Communications Director for the GRYN, provided logistical support during the workshop and prepared this workshop report.

THE FUTURE: WHERE DO WE GO FROM HERE?

After completion of the *Vital Signs Monitoring Workshop*, the GRYN will work closely with the TPC to choose and recommend vital signs for BOD approval. The GRYN will begin this process by hosting the Technical Planning Committee Vital Signs Selection Meeting at Mammoth Hot Springs, Yellowstone National Park, in June 2003. During this meeting, the GRYN staff and Technical Planning Committee members will choose candidate vital signs to submit to the Board of Directors for approval. In order to select the appropriate vital signs for monitoring, they will have at their disposal a conceptual framework for the proposed vital signs, the ranked list of vital signs from the *Vital Signs Monitoring Workshop* and technical notes on highly ranked vital signs from all resource areas. After the vital signs selection has occurred, the Board of Directors will have final approval during an August 2003 meeting at Lake, Yellowstone National Park. Following this meeting, the GRYN will submit its Phase II Report in September 2003, outlining the process it took to choose the selected vital signs, including literature

review, the Delphi survey, conceptual models and the workshop series. During the following year, 2004, the GRYN will undertake extensive research efforts to develop monitoring objectives and protocols that will be included in the Phase III Report, to be submitted in December 2004, along with the Draft Vital Signs Monitoring Plan for peer review. The final Vital Signs Monitoring Plan will be submitted in December 2005.

VITAL SIGNS MONITORING WORKSHOP-DAY 1

OBJECTIVES

The objectives of the first day of the *Vital Signs Monitoring Workshop* were as follows:

- To create a shared understanding of the NPS I&M Program and the Greater Yellowstone Network
- To inform participants of the process used to identify candidate vital signs
- To create an informal, open-forum discussion of the posted conceptual models as part of an evening social hour

PRESENTATIONS

In order to accomplish these objectives, several presenters were asked to share information about the part of the workshop planning process with which they were involved. To open the meeting, Tom Olliff, Chief of Resources at Yellowstone National Park, shared the sentiment that this is a historic time in the life of the NPS with respect to a shift in focus from scenery management to natural resources management.

Introduction to the National Park Service Inventory & Monitoring Program

Steve Fancy, National I&M Program Coordinator

This introduction was followed by a presentation by Steve Fancy, National I&M Coordinator, about the national program perspective. He referred to the Natural Resource Challenge, which provides the funding for the I&M Program, as a "wave of change", giving true meaning to the phrase "science for parks, parks for science". The Challenge doubles the natural resource staff in the NPS. According to Fancy, goals of long-term monitoring include providing an early warning of change in order to eliminate non-action due to a lack of knowledge and resources. In addition, the I&M Networks are tasked with identifying what kinds of changes are acceptable, meanwhile focusing on the most significant ecological indicators because of time and money constraints. Fancy also focused on the need for partnerships between Networks and universities and other agencies, all the while keeping the information obtained through inventories and monitoring useful for many different divisions within the parks. The creation of Networks will allow for professional staff to design, implement and communicate the results of the I&M program throughout the Network parks.

GRYN Vital Signs Monitoring Plan

Cathie Jean, GRYN Program Manager

Cathie Jean, Program Manager for the GRYN, gave an overview of the GRYN, including the GRYN parks, operating procedures and budget estimates. Jean gave an overview of the process leading to the list of proposed candidate vital signs. The Delphi Internet survey consisted of three rounds of questions, with the third round including a ranking of indicator importance. One value of such a survey was the independent thinking that took place because participants were dispersed through time and space. However, this process also lacks statistical power. Ecosystem conceptual models were then created to show the most important components and linkages in key ecosystems throughout the parks of the GRYN and are backed by scientific literature. Jean then emphasized the importance of the process the participants would undergo during day two, and encouraged recording any comments that classify or justify answers given on the selection criteria worksheets.

Variability in Natural Systems and Monitoring Considerations

Duncan Patten, Research Professor, Montana State University

The focus of Duncan Patten's presentation was the application of historic range of variability to ecosystem management and monitoring. This presentation was requested, in part, to give participants a frame of reference for some of the selection criteria that dealt with the natural range of variability of certain proposed candidate vital signs. According to Patten, the historic range of variability helps in understanding the dynamic nature of ecosystems. In order to consider past conditions, one must include both natural and human-induced impacts, such as climate change, invasive species, etc. One method of evaluating the historic range of variability is through repeat photography, which gives a good representation of historic changes, as well as showing temporal and spatial variability, but also requires interpretation. Patten left participants with the question of whether the historic range of variability is a useful tool for monitoring at a variety of scales, as well as the question of "what do we do?" when the desired future condition does not match the historic range of variability or the present condition does match the historic range of variability.

The Role of Conceptual Models in Choosing Vital Signs

Glenn Plumb, Supervisory Wildlife Biologist, Yellowstone National Park
Duncan Patten, Research Professor, Montana State University
Dan Tinker, Assistant Professor, University of Wyoming
Bob Hall, Assistant Professor, University of Wyoming

Glenn Plumb, Supervisory Wildlife Biologist at Yellowstone National Park, was on detail with the GRYN during the winter of 2002-2003 with the specific task of helping to create a defensible vital signs selection process. Plumb went about this task by using graphic conceptual models as "problem solving vehicles" that illustrate the linkages among key environmental drivers, stressors, ecological effects, outcomes and measurable parameters that serve as ecological response signals. According to Plumb, the GRYN conceptual model formula was based off of work done in the Everglades, wherein eight steps were taken to create useful conceptual models that lead the GRYN to a list of vital signs to monitor. These steps include: 1) considering the spatial, temporal and ecological scales and boundaries; 2) identifying important elements of ecosystem structure and function; 3) identifying sources of anthropogenic or natural stressors of concern; 4) describing stressor mechanisms and routes of exposure or linkage; 5) identifying ecological receptors and at-risk components; 6) identifying ecological endpoints; 7) developing stress-effects causal pathways; and 8) identifying a particular structural framework for the graphics. Plumb stressed that the conceptual models designed for the GRYN were not meant to be complete ecosystems, rather to identify components of the systems that are often not considered, but are more informative than many other parts of the system that are easily recognized and used.

Following this presentation, Duncan Patten, Dan Tinker and Bob Hall, three of the five conceptual model authors for the GRYN, gave brief presentations on chosen models, in order to guide participants through this part of the process used to identify proposed candidate vital signs. A complete set of draft conceptual models presented at the workshop can be found in Appendix D.

EVENING CONCEPTUAL MODEL SOCIAL HOUR

On the evening of day one of the workshop, participants were invited to a social in which the draft conceptual models were displayed for peer review. Conceptual model authors contributed fifteen total models focusing on the following systems: lake, river, dry woodland, lodgepole pine, ponderosa pine, whitebark pine, mixed conifer, aspen, alpine and timberline (joint), riparian, wetland, shrubland, grassland, geothermal and Yellowstone National Park. These models were reproduced in 36"x 42" poster size at the social and participants were encouraged to discuss questions, concerns and comments with the authors and to "mark up" the posters with changes they believed would make the posters more informative or inclusive of important ecosystem processes. Dan Tinker, terrestrial systems model author, received many excellent and helpful comments during this time and thought that the social atmosphere was helpful. According to Bob Hall, aquatics conceptual model author, the peer review received during this social hour was very helpful, especially since the social occurred almost directly after the presentation of the models. Therefore, many participants came with questions or ideas already formulated and ready for discussion.

VITAL SIGNS MONITORING WORKSHOP-DAY 2

OBJECTIVES

The objectives for the second day of the *Vital Signs Monitoring Workshop* were as follows:

- To apply the selection criteria from the decision support system to each candidate vital sign in the topic area and provide results to the decision support system manager by 5:00 pm
- To document comments related to the scoring decisions that will be incorporated into a report for the Technical Committee and Science Committee

BREAKOUT GROUP SESSIONS

Participants were directed to breakout rooms (one group per room, except for very small groups) and given the task of completing the selection criteria worksheet(s) for each vital sign assigned to that group. The number of assigned candidate vital signs ranged widely, from fifty-four in the terrestrial vegetation group to seven in the invertebrate group. However, the number of experts in each group also varied, from thirteen in the terrestrial vegetation group to three in both the invertebrate and human-use groups. In fact, the terrestrial vegetation group proved to be too large and, thus, was split into two groups after the lunch break in order to facilitate the scoring process. Although the terrestrial vertebrate group was also quite large, the group members had fewer candidate vital signs to score than the vegetation group. In addition, the vertebrate group found it helpful to designate threshold values from the beginning of the process in order to answer the criteria as efficiently as possible. The complete list of breakout group members can be found in Appendix E.

Each group was assigned a group moderator—usually the author of the conceptual model(s) that best applied to that breakout group. In addition, two professional facilitators were on hand throughout the three-day conference to answer questions about the consensus process and to guide groups whose assignments proved difficult. The groups were to use the following process to complete the selection criteria worksheets (please see Appendix F for a complete list of proposed candidate vital signs and Appendix B as a reference for the selection criteria worksheets):

- Decide on the appropriate name for the proposed candidate vital sign. The group could choose to:
    - keep the current candidate vital sign name
    - change the candidate vital sign name to be more informative
    - lump the candidate vital sign with another vital sign
    - split the candidate vital sign into multiple (two or more) new vital signs
- Choose the parks in which the candidate vital sign occurs or applies
- Answer each selection criteria by filling in the “yes” or “no” bubble on the worksheet
- Add comments that refer to one of the following:
    - the specific selection criteria statements
    - the broad topic group of selection criteria (i.e. “management relevance”)
    - the vital sign as a whole

To aid the groups in using the selection criteria, the workshop planning team composed a short, descriptive phrase to better explain each of the statements. These explanations, along with the vital signs information, the schematic conceptual models, the narrative conceptual models and some appendices offering information specific to the selection criteria were included in breakout group notebooks. One notebook was given to each group. The vital signs information contained in this notebook was extremely lengthy and, therefore, is not included in full in this report. An example follows and the entire report is available upon request:

Channel dimensions Unique ID: AqHa_123

Primary Resource: Aquatic Habitats Secondary: Rivers and Streams

Why is this an important Vital Sign?

Riparian vegetation not only responds to changing channel geomorphology but plays a role in its formation. Any change in channel geomorphology will consequently alter the amount and distribution of the riparian community. Thus, channel geomorphological metrics may be a useful indicator of the condition of riverine and riparian systems. Altered hydrological conditions and concomitant degraded riparian systems play a role in channel changes. For example, changing regional hydrology or influences of upstream flow regulators, e.g., dams, will cause channels to adjust to new conditions and offer less or more habitat for riparian plant communities. The ratio of channel width to depth and channel sinuosity in relation to floodplain type can be combined to develop a channel index that would indicate whether the channel is being altered from expected geomorphic conditions. Decreasing width/depth ratios tend to indicate a degraded, incised channel; however, a greatly increasing width/depth ratio may result from excessive bank destabilization by ungulate use.

Metrics:

Variability and changes in channel cross section geometry and river length to floodplain length relationships.

The expanded explanations of the selection criteria and the appendices can be found in Appendix G of this report.

In order to decide on an appropriate name for the proposed candidate vital sign, the group generally went through much discussion. Many of the original candidate vital sign names did not seem as informative as possible to group members. This process occurred simultaneously with the lumping and splitting of vital signs. Obviously, the freedom to create new vital signs from those given was important for participants. This liberty also allowed the participants to feel more comfortable with the candidate vital sign name than if they had been limited to using those provided through the Delphi survey and conceptual models. However, one overall problem with the candidate vital sign names occurred when participants noted that some candidate vital signs were very specific (i.e. specific taxa), while others were broad (i.e. group of taxa, such as small-bodied mammals). Many times a potential vital sign would be a better indicator if its name were more descriptive (i.e. specific butterfly species instead of overall insect biodiversity). As was seen in earlier park-specific workshops, vital signs about which people know little or are perplexed tend to rank in the middle, whereas those vital signs about which people know a lot (possibly because they are more specific) tend to rank either very high or very low, depending on the circumstance.

The next step in the worksheet process was to choose in which parks the candidate vital sign occurs or applies. Many times the candidate vital sign applied to all three parks. However, occasionally the candidate vital sign would not apply in one or two parks. This occurred more often with Bighorn Canyon in the area of geothermal features and terrestrial vegetation. However, often Bighorn Canyon had

candidate vital signs in which it was the only park that a species or community occurs or specific measurement applies. This outcome was expected by the workshop planning team.

The workshop planning team put much thought into the structure of the selection criteria and the possible ways of quantifying a response that is, in actuality, qualitative by nature. Originally designed as a coarse and fine filter criteria wherein participants would choose how many statements they agreed with (thus giving a specific "score" such as low, medium or high that corresponded with a number), the selection criteria evolved to become a set of thirteen "yes/no" questions based upon extensive literature review and National I&M Program guidance as to what makes a "good" ecological indicator. These thirteen questions were placed into five broader categories, including ecological relevance, response variability, management relevance, feasibility of implementation and interpretation and utility. By making the answers to these questions binary in nature, the workshop planning team believed that they would provide a way in which participants could complete the task on time and eliminate debates about semantics. As the "yes/no" answers were entered into the Access database, the database was programmed to convert and calculate the scores as follows:

For those broad topic areas that contained only two questions (i.e. ecological relevance):

- two "yes" answers=1.0 score
- one "yes" answer and one "no" answer=0.5 score
- two "no" answers=0 score

For those broad topic areas that contained three questions (i.e. response variability):

- three "yes" answers=1.0 score
- two "yes" answers and one "no" answer=0.6 score
- one "yes" answer and two "no" answers=0.3 score
- three "no" answers=0 score

In addition to this scoring method, the workshop planning team decided on a weighting scheme for the broad topic areas. The scheme was decided upon after input from the park-specific workshops on which broad topic areas participants felt were most important in creating a useful indicator of ecosystem health. These weights were then multiplied by the broad topic area scores (explained above) to create the final score. The weights chosen were as follows:

- Ecological relevance=25%
- Response variability=25%
- Management relevance=20%
- Feasibility of implementation=15%
- Interpretation and utility=15%

Another aspect of the decision of which candidate vital signs to monitor includes the responsibility of National Parks to monitor those resources whose protection is required by law. Therefore, information on the legal relevance is included in the Access database in the form of which piece of legislation requires the protection of specific resources. After much debate throughout the park-specific workshops, the workshop planning team decided to omit this criteria as a decision to be made by the expert participants who attended the workshop.

Although the workshop planning team made every effort to insure that sufficient explanations of the selection criteria and background information were provided to the participants, the process of ranking the candidate vital signs still produced questions and concerns. Because many comments were shared between group members and not formally recorded, what follows is a rough summary of major topic areas of discussion.

Overall comments about the process and/or selection criteria

- Many individuals felt that there was a need to separate the drivers and stressors from the response variables in order to fairly evaluate them as candidate vital signs. Also, there was much discussion about incorporating both types of candidate vital signs to create a comprehensive monitoring plan.
- One conceptual model author noted that, while lumping and splitting certainly was helpful in some circumstances, occasionally, when a vital sign was split, it lost its relevance with respect to why it was originally nominated. For example, when "riparian associated animal species" is split into specific taxa vital signs, the importance of the community structure that made it a good indicator of riparian ecosystem health is lost.
- One participant felt that narratives accompanying the conceptual models would have proven helpful. Although the narratives contributed by the conceptual model authors were provided in the notebooks, along with the vital signs justification statements, the workshop planning team did not set aside specific time to review them or notify the participants of their existence. Sending these materials ahead of time would have allowed participants to review their contents and come with any prepared questions.
- Many participants felt it would have been helpful to do a "trial run" of a few vital signs in order to alert them of potential difficulties with the selection criteria. This did occur, to some extent, at the park-specific workshops, wherein participants were given the opportunity to progress step-wise through the selection criteria, alerting the workshop planning team of potential difficulties. These suggestions were then incorporated into the final selection criteria presented to the *Vital Signs Monitoring Workshop* participants.
- One participant observed that a particular candidate vital sign could be both affected by some driver or stressor and also be a driver or stressor for another vital sign.
- A moderator noted that the overall response to the list of proposed candidate vital signs was very positive.

Specific comments about the process and/or selection criteria

- The terrestrial vertebrates group mentioned that vertebrate and invertebrate monitoring should be stratified by habitat. In addition, this group added that the candidate vital sign "native species richness" caused more discussion and differences of opinion than any other candidate vital sign and, therefore, they feel it should be re-evaluated.
- One individual felt that the sagebrush community that constitutes an important part of Grand Teton National Park was overlooked.

Concerns with the interpretation of the selection criteria

- Many groups created a "threshold level" for agreement with a specific selection criterion. In some cases, this threshold level was inconsistent among candidate vital signs.

- Many of the groups felt that particular criteria were not specific enough in their original wording to be assigned a "yes" or "no" answer definitively. Therefore, groups had to go through a decision process in order to define what "yes" or "no" meant in these cases. Hopefully, in addition, the groups also recorded this reasoning in the comment section of the worksheet.
- Although the workshop planning team made a best effort to include park managers in each of the breakout groups, many groups still did not feel comfortable answering the management relevance criteria without further assistance. Many groups felt that someone with complete knowledge of the business plan standards, enabling legislation, GPRA goals, etc. should go through their answers and check them against these management standards.
- There was much disagreement about how long a "long-term dataset" had to be. Groups obviously defined "long-term" differently depending upon what types of data they were evaluating.
- Although participants were asked not to take into account whether or not another agency is currently monitoring a specific proposed candidate vital sign, one group chose to rank highly those candidate vital signs that are already being monitored. This group also had the task of evaluating many stressors to the environment; thus, changing the application of the selection criteria. The effects of this ranking method are not yet fully understood, but will certainly be taken into account by those making the final decisions about which vital signs should be monitored. This also brings up the fact that this ranking is not the sole determinant of which vital signs will be monitored by the GRYN. Many other factors will be evaluated.
- Some groups also mentioned that whether or not a candidate vital sign was "cost prohibitive" was not specific and, therefore, required the use of intuition in the ranking process.
- The air quality/climate group moderator noted that it is virtually impossible to distinguish between natural variation and human-induced variation, which was one of the selection criteria.
- The natural versus human-induced criterion also raised questions because of the circular relationship between human and natural drivers.

Concerns with the wording of the selection criteria

- The aquatics group moderator felt that the criterion concerning the candidate vital sign's helpfulness in identifying the causal mechanism of an ecological response was difficult to interpret. In addition, he noted that the criterion concerning low statistical power and variability was complicated because these two things were not thought to be the same and that it overlapped with the question concerning natural versus human-induced variation.
- There was some confusion as to the meaning of scales with respect to ecological organization. One participant felt that the use of levels would have been more clear.
- Adjectives used in the selection criteria to qualify statements (such as "helpful") were often difficult for participants to interpret.
- Some groups had difficulty with the definition of "high" and "low" with respect to natural variability and, therefore, this definition was generally used inconsistently within and among breakout groups.

Comments recorded by breakout groups regarding the selection criteria

The breakout groups were asked to record any comments that qualified their answer to a specific statement and/or a set of statements, such as "management relevance". These comments usually concerned why a certain park was not included in the applicable parks section or why the candidate vital sign was difficult to evaluate, given the selection criteria. Because many comments were recorded,

resulting in a multiple-page report, a complete list of these comments is contained in Appendix H instead of in the body of this report.

VITAL SIGNS MONITORING WORKSHOP-DAY 3

OBJECTIVES

The objectives of the third day of the *Vital Signs Monitoring Workshop* were as follows:

- To present the results of the breakout groups' decisions on ranked list of vital signs
- To discuss options for organizing, into logical groups, vital signs whose data are generally collected simultaneously or, when combined, are more useful for interpreting results.
- Using a full suite of vital signs, to build a conceptual framework that integrates the diversity of spatial and temporal scales across the GRYN

PRESENTATIONS, BREAKOUT GROUP EXERCISES AND COMMENTS

Each participant was given a copy of the entire ranked list of candidate vital signs by score. Although many different kinds of reports could be produced and were discussed by the workshop planning team beforehand, an executive decision was made to distribute the ranked list by overall score. Many participants immediately voiced frustration with those candidate vital signs that ranked high and wanted to see the ranked list by resource area. This outcome was somewhat expected by the workshop planning team. A report listing the candidate vital signs by park and then by resource area was quickly produced and distributed. The distribution of this list was followed by a short presentation and comment section before participants were asked to participate in a breakout group exercise.

Presentation of the ranked list of vital signs

Cathie Jean, GRYN Program Manager

Cathie Jean congratulated the group on a job well done and commented on how nice it would have been to have one person contribute that one indicator that could tell us everything. Jean mentioned that the group did an excellent job of "cleaning up" the original list of proposed candidate vital signs by subsuming ninety candidate vital signs and adding twenty-one. Jean pointed out that nineteen vital signs received a "perfect" score, meaning that they met all of the selection criteria. She also pointed out that some groups interpreted the selection criteria differently and that this would be taken into consideration when choosing the final vital signs list. She reminded the participants that this ranked list was not the final list of vital signs to be monitored by the GRYN, but rather a tool to use in choosing the final vital signs. A complete ranked list of the candidate vital signs can be found in Appendix I of this report.

Comments

Many participants felt the need to share comments about the ranked list with the group as a whole. These comments were valuable in understanding the limitations of this exercise. The comments are summarized below:

- Participants felt that the candidate vital signs needed to be ranked relative to the other candidate vital signs in their resource areas. Participants were concerned that the GRYN would choose to monitor only those highly ranked vital signs without consideration of choosing a broad suite from many different resource areas.
- Participants felt it may be useful to have time to reconsider the candidate vital signs from their breakout group, as some believed that the scoring changed throughout the day and, thus, affected

the overall result. Many groups who were rushed to finish by 5pm believed that those candidate vital signs scored later in the day could possibly have received better scores than they normally would have and believed that time for recalibration could have helped.

- Participants once again recognized the unevenness in specificity of the candidate vital signs. According to many experts, this caused an unevenness in scoring as well.
- Some participants included comments of papers that could be important and helpful in choosing vital signs. These included papers by Tom Hoeskstra of the Inventory and Monitoring Institute and the EPA's EMAP website.
- Concerns arose about the difference between vital signs that are drivers and those that are response variables.
- A comment was made that the vertebrate group did not look at specific habitat types, while the vegetation group did. This comment also follows that statement given by the vertebrate group on day two that vertebrate monitoring should be stratified by habitat.
- A participant brought up the fact that many of the highly ranked vital signs overlap, while also impacting other candidate vital signs.
- Someone also mentioned that there are many long-term datasets available, and a monitoring program should focus on what data can be used from these long-term datasets, even though they were not originally created to monitor the chosen candidate vital signs.
- Integration was a key component of many comments. Most participants felt that in order to have a comprehensive program, the GRYN must concentrate on integration both with other agencies as well as integrating the chosen vital signs into a coherent whole, including knowledge of the basic drivers of the systems.

Breakout group exercise

Options for organizing highly ranked vital signs into a coherent monitoring program

In order to bring some closure to the meeting, the workshop planning team devised a short exercise focusing on the creation of a conceptual framework that explains the spatial and temporal scales on which the candidate vital signs operate. To do this, the participants were asked to form into the same breakout groups that they had used during day two and were given overheads with a blank template of spatial and temporal scales. Participants were given the opportunity to draw the spatial and temporal scale of the candidate vital signs that they had ranked highly during day two on the overhead and to watch for aggregations of candidate vital signs along these given scales. Reproductions of the results of this exercise are contained in Appendix J of this report. Overall comments about the exercise follow.

Comments

While some candidate vital signs may be sampled at a small scale, the effects of the results of this sampling can be amplified; thus, the candidate vital sign will have a wider applicability.

- The geology/geothermal group had to rescale the axes, as they were given a template made for ecological processes.
- The aquatics group also rescaled the axes to make the template more useful. A question was posed to the aquatics group about whether or not yearly changes in algal production is a reasonable way to assess nitrogen inputs. The answer given was that changes in diatom populations can be detected in time scales even shorter than one year.

- The air quality/climate group qualified the answers given by commenting that they focused on the measurement period and that the effects would be seen throughout the range of spatial and temporal scales given.
- One comment was made that the U.S. Forest Service starts monitoring with aerial detection and then "fills in" with groundwork.
- A participant commented that some vital signs will be good at detecting small-scale changes rather quickly, while others will be better at detecting changes across multiple scales. A mixture of these types of vital signs could produce the desired result of a comprehensive monitoring program.
- Someone also commented on the difficulty in integrating human-caused change with the vast array of natural variation one finds within ecosystems. The question was posed as to whether the monitoring program should be looking at human impacts or having the ecosystems unimpaired for future generations. In order to accomplish this, goals and objectives need to be set; then, the monitoring objectives that the GRYN establishes can define a meaningful level of change and how best to detect such a change.

CONCLUSIONS

In conclusion, the *Vital Signs Monitoring Workshop* hosted by the GRYN was a success. Although participants had concerns with the wording and interpretation of the selection criteria, as well as the ranked list of candidate vital signs, the workshop planning team agreed that creating a framework that allowed a large group of experts to come together and offer knowledge and insight into the proposed list of vital signs was extremely useful and productive. The participants successfully applied an objective set of criteria to a long list of proposed candidate vital signs. The criteria used were a balance of complex ideas and a simplified ranking system. Because of among-group variations in interpretation of the criteria, the results are best reviewed within groups.

In order to aid future Networks with their vital signs scoping workshops, the GRYN has developed a short list of lessons learned from the *Vital Signs Monitoring Workshop*:

- Doing a "trial run" of the selection criteria and a proposed candidate vital sign will help everyone involved to understand the depth of knowledge and consideration that is needed to answer the given questions
- Sending out information that will be used during the workshop would be helpful to those who have time for preparatory work
- Spending time deciding on the level of specificity for the candidate vital signs names and tailoring the names to this level before the workshop could eliminate some of the confusion seen at the GRYN workshop
- Making sure that participants are given a chance to review the schematic and narrative conceptual models beforehand would allow for a greater understanding of the process as well as give participants a chance to express concerns with the results of these processes with the model authors
- The first and second weeks of May are generally poor times to invite academic and agency scientists to travel for a meeting
- Given more time, many of these concerns would probably have been addressed by the GRYN.

Despite the set-backs, the GRYN now has a defensible list of candidate vital signs based on sound scientific advise from experts in many different fields from which it can take on the task of creating a comprehensive and integrative monitoring program. By all accounts, the participants who took part in this process, although frustrated at times, were always forthcoming with helpful comments about the process and the specific candidate vital signs, as well as having a high level of respect and praise for their colleagues in this exercise. The outcome of this meeting will be of particular interest to those Networks that are just beginning this process. The workshop planning team and the staff of the GRYN expresses a wealth of gratitude toward all who participated and hopes that everyone will stay tuned for our next steps!

ACKNOWLEDGEMENTS

The Greater Yellowstone Inventory and Monitoring Network wishes to extend a sincere thank you to those who made this workshop possible. The USGS-Northern Rocky Mountain Science Center is the campus host for the GRYN and, therefore, serves a central role in the GRYN's ability to use campus resources. A partnership through the Big Sky Institute at Montana State University allowed us to provide refreshments for guests through MSU Catering. We would like to thank the MSU Foundation for allowing us the use of their Great Room for our evening social. We would like to express our gratitude for the facilitation services provided by Michele Tae (throughout the workshop series) and Nancy Budge (for this workshop). Peggy Herzog was the scribe for the workshop series. A big thanks goes out to Chad Jacobson, Cartographic Technician for the GRYN, who became the interim data manager for the duration of the conference. Finally, many thanks to the GRYN's student employee, Sarah Stehn, who was extremely helpful in the days before the workshop, as well as aiding Chad with the data entry during the evening on day two of the workshop.

APPENDIX II.A-WORKSHOP AGENDA

Greater Yellowstone Network Vital Signs Monitoring Workshop

Agenda
May 6-8, 2003
Ballroom C, Strand Union Building
Montana State University

OVERALL WORKSHOP OBJECTIVE:

To apply priority setting to a list of vital signs to be monitored as a means for determining the long-term ecosystem health of the parks of the Greater Yellowstone Network

May 6

Day 1 Objectives:

1. To create a shared understanding of the NPS I&M Program and the Greater Yellowstone Network
2. To inform participants of the process used to identify candidate vital signs
3. To create an informal, open-forum discussion of the posted conceptual models as part of an evening social hour

12:30 **Participants Arrive, Joseph May Ballroom C, Strand Union Building**
Sign-in/registration

1:00 **Welcome, Opening Comments**
Tom Olliff, Chief of Resources, Yellowstone National Park

1:10 **Statement of Meeting Goals and Agenda Review**
Cathie Jean, Program Manager, Greater Yellowstone Network

1:25 **Introduction to the National Park Service Inventory & Monitoring Program**
Steve Fancy, National I&M Program Coordinator

Greater Yellowstone Network Vital Signs Monitoring Plan
Cathie Jean, Program Manager, Greater Yellowstone I&M Network

2:00 **Variability in Natural Systems and Monitoring Considerations**
Duncan Patten, Research Professor, Montana State University

2:30 **Break**

2:45 **The Role of Conceptual Models in Choosing Vital Signs**

- Overview of Conceptual Models, Glenn Plumb, Supervisory Wildlife Biologist, Yellowstone National Park
- Riparian and Wetland Ecosystem Model, Duncan Patten, Research Professor, Montana State University
- Terrestrial Ecosystem Model, Dan Tinker, Assistant Professor, University of Wyoming
- Aquatic Ecosystem Model, Bob Hall, Assistant Professor, University of Wyoming

3:45 **Workshop Objectives and Instructions**

Michele Tae, facilitator

- Breakout group objectives
- Explanation of Selection Criteria
- Roles of Moderators, Facilitators and Participants
- Participant Assignments and Meeting Locations

5:00 **Adjourn**

6:30 ****Social Hour**, MSU Alumni Foundation, 1501 S. 11th Ave.**

******Participants are encouraged to critique the conceptual models and discuss candidate vital signs with the authors of the conceptual models.

May 7

Day 2 Objectives:

1. To apply the selection criteria from the decision support system to each candidate vital sign in the topic area and provide results to the decision support system manager by 5:00 pm
2. To document comments related to the scoring decisions that will be incorporated into a report for the Technical Committee and Science Committee

8:00 **Groups Convene**

*Please use the attached map of the Strand Union Building and breakout group room assignments to find your breakout room for the day.

12:00 **Luncheon, Joseph May Ballroom C, Strand Union Building**

5:00 **Adjourn**

May 8

Day 3 Objectives:

1. To present the results of the breakout groups' decisions on ranked list of vital signs
2. To discuss options for organizing, into logical groups, vital signs whose data are generally collected simultaneously or, when combined, are more useful for interpreting results.
3. Using a full suite of vital signs, to build a conceptual framework that integrates the diversity of spatial and temporal scales across the network.

8:00 **Groups Convene, Joseph May Ballroom C, Strand Union Building**
Welcome and Comments
Michele Tae, facilitator

8:15 **Presentation of the Ranked List of Vital Signs**
Cathie Jean, Program Manager

8:30 **Part 1 Integration Exercise: Options for Organizing Highly Ranked Vital Signs into Logical Groups**
Michele Tae, facilitator
Glenn Plumb, Supervisory Wildlife Biologist, Yellowstone National Park

9:45 **Break**
** For those participants whose flights depart around noon or 1pm, a shuttle will be leaving from the Strand Union Building to take you to the airport following break.

10:00 **Part 2 Integration Exercise: Building a Conceptual Framework that Integrates a Full Suite of Vital Signs**

11:15 **Results of Conceptual Framework Exercise:**
Michele Tae, facilitator
Glenn Plumb, Supervisory Wildlife Biologist, Yellowstone National Park

11:45 **Wrap-up and adjournment**
** For those participants with flights later in the afternoon, a shuttle will be leaving from the Strand Union Building to take you to the airport at noon.

APPENDIX II.B-SELECTION CRITERIA WORKSHEET

Vital Sign:

Primary Resource:

Secondary Resource:

VITAL SIGN CRITERIA	Yes	No	Comments
Ecological Relevance			
• The candidate vital sign has high ecological importance with a demonstrated linkage between the vital sign and the ecological structure or function that it is supposed to represent, based on a conceptual model and/or supporting ecological literature	❍	❍	
• The candidate vital sign provides relevant information that is applicable to multiple scales of ecological organization	❍	❍	
Response Variability			
• The candidate vital sign responds to ecosystem stressors in a predictable manner with known statistical power	❍	❍	
• The candidate vital sign is anticipatory and is sensitive enough to stressors to provide an early warning of change	❍	❍	
• The candidate vital sign has low natural variability and has high signal-to-noise ratio (e.g. low error)	❍	❍	
Management Relevance			
▪ The candidate vital sign is stated in specific park management goals, GPRA goals, or Business Plan standards.	❍	❍	
▪ There is a demonstrated, direct application of candidate vital sign measurement data to current key management decisions or for evaluating past management decisions	❍	❍	
Feasibility of Implementation			
• The candidate vital sign's cost of measurement is not prohibitive	❍	❍	
• Impacts of measuring the candidate vital sign meet NPS standards	❍	❍	
• The candidate vital sign is relatively easy to measure and has measurable results that are repeatable with different personnel	❍	❍	
Interpretation and Utility			
• The response of the candidate vital sign can be distinguished between natural variation and anthropogenic impact-induced variation	❍	❍	
• The candidate vital sign is helpful in identifying the causal mechanism of an ecological response	❍	❍	
• Historic databases and baseline conditions for the candidate vital sign are already known	❍	❍	

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APPENDIX II.D-SCHEMATIC CONCEPTUAL MODELS

In order to eliminate redundancy, the schematic conceptual models, for the purposes of Phase II Report Appendices, can be found in Appendix VI. Also included in Appendix VI are the narrative conceptual models that accompany these schematics.

APPENDIX II.E-BREAKOUT GROUP MEMBERS

**Please note: this list reflects those participants who were part of the decision-making process in the resource-area breakout groups.

Air Quality/Climate

Kathy Tonnessen-Moderator	Rocky Mountains-CESU
Ellen Porter	NPS-Air Resources Division
Leora Nanus	USGS
Phil Farnes	Snowcap Hydrology
Cathy Whitlock	University of Oregon

Aquatic/Water Quality

Bob Hall-Moderator	University of Wyoming
Alisa Mast	USGS
Myron Brooks	USGS
Jeff Arnold	Yellowstone National Park
Scott Woods	University of Montana
Sue O'Ney	Grand Teton National Park
Tina Laidlaw	EPA
Alexander Zale	Montana State University
Brian McGlynn	Montana State University

Geotherml/Geology

Duncan Patten-Moderator (morning)	Montana State University
Ann Rodman-Moderator (afternoon)	Yellowstone National Park
Hank Heasler	Yellowstone National Park
Bill Inskeep	Thermal Biology Institute
Kirk Nordstrom	USGS
Ken Pierce	USGS

Terrestrial Vegetation

Dan Tinker-Moderator	University of Wyoming
Duncan Patten-Moderator (afternoon)	
Steve Haynes	Grand Teton National Park
Mary Hektner	Yellowstone National Park
Don Despain	USGS
Jennifer Whipple	Yellowstone National Park
Lisa Rew	Montana State University
Bruce Maxwell	Montana State University
Mary Manning	U.S. Forest Service
Elizabeth Crowe	MT Natural Heritage Program
Roy Renkin	Yellowstone National Park

Terrestrial Vertebrates

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Stephen Corn	USGS
Doug Keniath	WY Natural Diversity Database
Susan Wolff	Grand Teton National Park

Invertebrates

Steve Fancy-Moderator	National I&M Coordinator
Diane Debinski	Iowa State University
John Varley	Yellowstone National Park
Michael Ivie	Montana State University

Human Use

Tom Olliff-Moderator	Yellowstone National Park
Dan Burgette	Grand Teton National Park
Laura Gianakos	Bighorn Canyon NRA

APPENDIX II.F-COMPLETE LIST OF PROPOSED CANDIDATE VITAL SIGNS

**Please note: this list reflects the proposed candidate vital signs given to the participants at the beginning of day two. For the ranked list of candidate vital signs, please refer to Appendix I. The code to the right of the proposed candidate vital sign represents its unique ID for database purposes.

All Proposed Candidate Vital Signs

Grouped by Primary and Secondary Resource

Resource	Candidate Vital Sign	
Air Quality		
	Air, Biotic and Abiotic	
	Atmospheric deposition and response in sensitive headwater catchments	AiQu_003
	Atmospheric deposition of nitrogen, sulfur and all major anions and cations	AiQu_006
	Atmospheric deposition of sulfur	AiQu_002
	Change in visibility deciviews	AiQu_005
	Deposition and accumulation of mercury in biota	AiQu_004
	Deposition of trace organics and metals	AiQu_010
	Loading chemical species in snowpacks	AiQu_001
	Loss of forest productivity	AiQu_007
	Nitrogen concentration in streams during spring snowmelt	AiQu_009
	Over-snow vehicles emissions and effects	AiQu_281
	Ozone exposure index--W126	AiQu_008
	Vegetation chemistry	AiQu_207
Aquatic Communities		
	Aquatic Exotic species	
	Exotic fish abundance	AqCo_130
	Exotic fish distribution patterns	AqCo_131
	Aquatic Pathogens/disease	
	Fish pathogens and disease	AqCo_133
	Aquatic Species at risk	
	Cutthroat trout responses to exotic predators	AqCo_276
	Native and exotic community structure, composition, stability	AqCo_127
	Native fish genetic integrity	AqCo_126
	Native fish spawning population vital rates	AqCo_128
Aquatic Habitats		
	Rivers and Streams	
	Channel dimensions	AqHa_123
	In-stream habitat complexity and cover	AqHa_125
	Stream reach geomorphology	AqHa_124
Climate		
	Climate, Biotic and Abiotic	
	Alpine/subalpine climatic conditions and micro-environment	Clim_019

Basic climatological measurements	Clim_020
Date of "spring green-up"	Clim_018
Date of ice on/off on major lakes	Clim_023
Date of lake overturn	Clim_026
Extent of frozen ground	Clim_024
Extreme Climatological Events	Clim_028
Extreme hydrologic events	Clim_014
Glaciers retreat or increase	Clim_021
Maximum air temperature	Clim_017
Number of cloudy days	Clim_031
Number of rain-on-snow events	Clim_030
Photosynthetically active radiation (PAR)	Clim_029
Plant phenology	Clim_013
Snow cover	Clim_016
Snow-water equivalence of snowpack	Clim_015
Soil climate	Clim_022
Soil temperature	Clim_027
Stream gauging	Clim_012
Surface UV	Clim_025
Total precipitation	Clim_011

Geology and Geothermal

Geothermal Ecosystem

Geothermal plant community composition and exotic species	GeGe_287

Geologic Processes

Earthquake activity	GeGe_051
Volcanic unrest	GeGe_055

Geothermal Microbiology

Contamination of thermal microbial populations	GeGe_056
Geothermal microbial diversity	GeGe_060

Geomorphic Processes

Landslide and debris flows	GeGe_057
Stream channel change	GeGe_290
Stream sediment transport	GeGe_282

Geothermal Processes

Chloride flux in thermal features	GeGe_068
Geothermal feature abundance & distribution	GeGe_054
Geothermal gaseous emissions in the atmosphere over Yellowstone National Park	GeGe_073
Geothermal water chemistry	GeGe_052
Geothermal water flow rate	GeGe_053
Geyser eruption volume and rate	GeGe_059
Heat flow	GeGe_069
Hydro-thermal soil chemistry	GeGe_062
Level and temperature of groundwater associated with thermal features	GeGe_071
Spatial extent of thermal features	GeGe_072
Temperature of ground water associated with thermal features	GeGe_070
Thermal heat transfer	GeGe_058

Soils

Below-ground biomass	GeGe_061
Cryptobiotic crust integrity	GeGe_066
Soil and sediment erosion	GeGe_067
Soil biodiversity	GeGe_065
Soil chemistry	GeGe_063
Soil moisture/temperature/structure	GeGe_293
Soil structure and stability	GeGe_064

Human Activities

Park Visitation

Levels of backcountry day use	HuAc_277
Levels of backcountry overnight use	HuAc_085
Park infrastructure	HuAc_089
Resource consumptive use and hydrologic modification	HuAc_090
Resource violations	HuAc_088
Visitor experience and satisfaction	HuAc_082
Visitor use levels	HuAc_087

Surrounding Environments

Land use and land cover	HuAc_081
Landscape and habitat fragmentation	HuAc_080
Night sky pollution	HuAc_083
Population census by area	HuAc_086
Soundscapes	HuAc_084

Invertebrates - Terrestrial and

Native and Exotic Insects

Critical habitat abundance, distribution and stability	TeIn_074
Exotic insects	TeIn_078
Forest/grassland/shrubland defoliators and consumers	TeIn_250
Insect biomass	TeIn_077
Insect herbivory	TeIn_076
Insect species distribution	TeIn_079
Native insect biodiversity and distribution	TeIn_075
Selected insect species of concern	TeIn_288

Terrestrial Vegetation

Alpine Meadow and Timberline Ecosystems

Alpine plant community characteristics	TeVeg_208
Timberline elevation boundaries	TeVeg_210
Timberline forest density and health	TeVeg_209

Aspen Forest Ecosystems

Aspen community composition and structure	TeVeg_263
Aspen stand extent and distribution in landscape	TeVeg_266
Browsing effects within aspen stands	TeVeg_265

Dry Woodland Ecosystems

Dry woodland community structure and composition	TeVeg_268
Extent and distribution of woodlands	TeVeg_269

Herbaceous Meadow and Grassland

Grassland annual net primary productivity	TeVeg_226

Grassland insect and vertebrate community structure	TeVeg_229
Grassland nitrogen	TeVeg_228
Grassland vegetation annual offtake	TeVeg_227
Grassland vegetation community composition and structure	TeVeg_218
Lodgepole Pine Forest Ecosystem	
Lodgepole pine forest floor litter and coarse woody debris	TeVeg_239
Lodgepole pine plant community composition and exotic species	TeVeg_237
Lodgepole pine snag density	TeVeg_297
Plant species diversity	TeVeg_238
Mixed Conifer Forest Ecosystems	
Age structure of forest	TeVeg_255
Landscape structure and heterogeneity	TeVeg_254
Mixed conifer forest floor litter and coarse woody debris	TeVeg_253
Mixed conifer plant community composition and exotic species	TeVeg_249
Mixed conifer snag density	TeVeg_252
Understory plant species diversity	TeVeg_251
Montane Shrubland Ecosystems	
Shrubland community composition and structure	TeVeg_223
Shrubland exotic species	TeVeg_274
Shrubland growth form diversity	TeVeg_270
Shrubland insect and small vertebrate community structure	TeVeg_271
Shrubland nitrogen	TeVeg_272
Shrubland soil erosion	TeVeg_273
Ponderosa Pine Ecosystems	
Ponderosa pine plant community composition and exotic species	TeVeg_258
Ponderosa pine stand density of live and dead trees	TeVeg_257
Proportion of standing dead trees	TeVeg_259
Soil moisture	TeVeg_256
Riparian and Riverine Wetland Ecosystems	
Browse effects on riparian woody vegetation	TeVeg_225
Exotic plants in riparian zone	TeVeg_211
Riparian condition	TeVeg_212
Riparian vegetation community structure and composition	TeVeg_219
Terrestrial Ecosystems	
Aboveground net primary productivity	TeVeg_241
Area occupied by rare or declining plant community types	TeVeg_236
Bighorn basin plant community composition and exotic species	TeVeg_231
Distribution and trends of exotic plant diseases	TeVeg_233
Exotic terrestrial plant species diversity and/or richness	TeVeg_214
Fire and fuel loading	TeVeg_222
Landscape structure and heterogeneity	TeVeg_240
Lichen distribution, abundance and chemical composition	TeVeg_235
Native terrestrial plant species diversity and/or richness	TeVeg_215
Shrub-steppe community structure and composition	TeVeg_217
Taxonomy and distribution of aquatic vegetation	TeVeg_224
Wet Meadow, Spring, and Depressional	
Wetland extent	TeVeg_291
Wetland plant cover and composition	TeVeg_213

Whitebark Pine Woodland and Forest

Abundance of replacement tree species	TeVeg_246
Blister rust abundance and spread	TeVeg_248
Burned forest seedbed availability	TeVeg_243
Stand density of high-elevation live and dead whitebark pine trees	TeVeg_245
Whitebark pine cone production	TeVeg_247
Whitebark pine plant community composition and exotic species	TeVeg_286
Whitebark pine snag density	TeVeg_292

Terrestrial Vertebrates

Amphibian and Reptiles

Amphibian and reptile critical food abundance, distribution and stability	TeVer_033
Amphibian habitat quality, abundance, distribution and population vital rates	TeVer_032

Birds

Clark's Nutcracker abundance	TeVer_242
Colony nesting bird population abundance, distribution, vital rates and productivity	TeVer_037
Neotropical bird population abundance, distribution and vital rates	TeVer_035
Raptor population abundance, distribution and productivity	TeVer_038
Riparian wildlife species	TeVer_260
Selected sensitive bird species abundance, distribution and productivity	TeVer_034
Song bird population abundance and distribution	TeVer_036

Mammals

Bat occurrence, distribution and abundance	TeVer_045
Beaver presence and population estimates	TeVer_261
Bighorn sheep vital rates	TeVer_267
Human-carnivore interactions	TeVer_044
Large carnivore population abundance and distribution	TeVer_039
Low-elevation foraging by grizzly bears in autumn	TeVer_244
Meso-carnivore population abundance and distribution	TeVer_285
Native ungulate behavior and migration dynamics	TeVer_042
Predator-prey dynamics	TeVer_041
Rodents and insectivores (<250g) population, abundance and distribution	TeVer_283
Rodents and Lagomorphs (>250g) population, abundance and distribution	TeVer_284
Small-mammal population abundance, distribution and vital rates	TeVer_043
Ungulate population abundance, distribution and productivity	TeVer_040

Terrestrial Vertebrates

Amphibian occurrence	TeVer_279
Associated animal populations	TeVer_264
Emerging pathogens on vertebrate species	TeVer_050
Invasive vertebrate species richness and distribution	TeVer_048
Native species richness	TeVer_047
Pattern of non-park land-use changes	TeVer_289
Reptile occurrence	TeVer_278
Vertebrate diseases	TeVer_049

	Wetland associated wildlife species	TeVer_262
	Wildlife habitat loss and degradation	TeVer_046

Water Quality

Ground Water

Ground water chemistry	WaQu_299
Ground water hydrology	WaQu_300
Groundwater level and aquifer volume	WaQu_195

Lakes and Reservoirs

Algal species composition and biomass	WaQu_275
Alkalinity	WaQu_105
Bed sediment chemistry (adsorbed)	WaQu_119
Chlorophyll a	WaQu_101
Continuous water temperature	WaQu_295
Core parameters	WaQu_094
Dissolved organic carbon	WaQu_106
E. coli	WaQu_097
Major ion chemistry	WaQu_091
Metals	WaQu_098
Phosphorus concentrations in aquatic ecosystems	WaQu_093
Phytoplankton community structure	WaQu_103
Reservoir elevation	WaQu_121
Secchi transparency	WaQu_099
Zooplankton community structure	WaQu_104

Rivers and Streams

Alkalinity	WaQu_118
Bed sediment chemistry (adsorbed)	WaQu_298
Chlorophyll a	WaQu_116
Continuous water temperature	WaQu_096
Core parameters	WaQu_112
E. coli	WaQu_113
Major ion chemistry	WaQu_107
Metals	WaQu_114
Nitrogen concentrations in aquatic ecosystems	WaQu_110
Periphyton community structure, chlorophyll a	WaQu_117
Phosphorus concentrations in aquatic ecosystems	WaQu_111
River invertebrate assemblages	WaQu_109
Streamflow	WaQu_120
Total suspended solids	WaQu_115

Watershed

Watersheds

Watershed budgets	Wate_301

APPENDIX II.G-SELECTION CRITERIA EXPLANATIONS AND APPENDICES

ECOLOGICAL RELEVANCE

Criterion #1 - **The candidate vital sign has high ecological importance with a demonstrated linkage between the vital sign and the ecological structure or function that it is supposed to represent, based on a conceptual model and/or supporting ecological literature.**

Often, the selection of a relevant indicator is obvious from the assessment question and from professional judgement. However, a conceptual model can be helpful to demonstrate and ensure an indicator's ecological relevance, particularly if the indicator measurement is a surrogate for measurement of the valued resource. It must be demonstrated that the proposed indicator is conceptually linked to the ecological function of concern. A straightforward link may require only a brief explanation. If the link is indirect or if the indicator itself is particularly complex, ecological relevance should be clarified with a description, or conceptual model. *(*Adapted from *Jackson, L.E., J.C. Kurt and W.S. Fisher, eds. 2000. Evaluation guidelines for ecological indicators. EPA/620/R-99/05. U.S. E.P.A, Office of Research and Development, Research Triangle Park, NC. 107pp.)*

Criterion #2 - **The candidate vital sign provides relevant information that is applicable to multiple scales of ecological organization.**

The term "multiple scales of ecological organization" refers to the hierarchical ecological structure including individuals, populations, communities, landscapes and ecosystems. Accordingly, information from one scale can sometimes provide insight relevant to other scales, thus increasing the applicability of the candidate vital sign if the information gathered from monitoring it can be useful at multiple scales of ecological organization. *(*Adapted from *Dale, V.H. and S.C. Beyeler. Challenges in the development and use of ecological indicators. 2001. Ecological Indicators 1:3-10.)*

RESPONSE VARIABILITY

Criterion #3 - **The candidate vital sign responds to ecosystem stressors in a predictable manner with known statistical power.**

Predictable manner refers to the lack of ambiguity in the response of the candidate vital sign to ecosystem stressors. The response should be clear and predictable even given gradual change in the stressor. In a best-case scenario, the candidate vital sign's response is observable before the system is actually threatened. *(Adapted from Dale, V.H. and S.C. Beyeler. Challenges in the development and use of ecological indicators. 2001. Ecological Indicators 1:3-10.)* **Statistical power** refers to the ability of a candidate vital sign to have a low chance of Type I and II errors. If a change has occurred in an ecosystem, a vital sign will either detect the change or detect no change. If the vital sign detects a change when a real change has occurred, then no error has occurred. However, if the vital sign detects a change when no real change has occurred, then a

false-positive, or Type I, error has been made. Making a false positive error is costly, monetarily speaking, because usually unnecessary action ensues. If change has occurred and the vital sign does not detect this change, then a missed-change, or Type II, error has occurred. Therefore, although action should be taken, most likely the change will go unnoticed. *(*Adapted from *Booth, G.D. Monitoring data and the risks of management decisions. USDA Forest Service publication.)*

	No change has taken place	There has been a real change
Vital sign detects change	**False-positive Error (Type I)**	**No Error**
Vital sign detects no change	**No Error**	**Missed-change Error (Type II)**

Criterion #4 - **The candidate vital sign is anticipatory and sensitive enough to stressors to provide an early warning of change.**

In this case, **sensitivity** does not necessarily refer to a candidate vital sign that is responsive to any and all dramatic changes in the system; but, rather, those that react to subtle stressors in the system, giving early warning of potentially reduced system integrity. (Adapted from *Dale, V.H. and S.C. Beyeler. Challenges in the development and use of ecological indicators. 2001. Ecological Indicators 1:3-10.*)

Criterion #5 - **The candidate vital sign has low natural variability and has high signal-to-noise ratio.**

Signal-to-noise ratio refers to the measure of how the signal from the candidate vital sign compares with background noise. Noise is defined as the uncommon variance of the data. The strength of the signal is positively correlated with the quality of the candidate vital sign as an indicator of ecosystem health. Therefore, the higher the signal-to-noise ratio, the better the candidate vital sign is at predicting ecosystem changes. If the signal and noise are of equal strength, the signal borders on unreadable because the noise strongly competes with it. (Adapted from *Cook, E.R. and L.A. Kairiukstis. Methods of dendrochronology: applications in the environmental sciences. 1990. Dordrecht, The Netherlands.*)

MANAGEMENT RELEVANCE

Criterion #6 - **The candidate vital sign is stated in specific park management goals, GPRA goals or Business Plan Standards.**

Park Management Goals - The overall natural resource management goal of the National Park Service is as follows: *The National Park Service will preserve the natural resources, processes, systems and values of units of the national park system in an unimpaired condition, to perpetuate their inherent integrity and to provide present and future generations with the opportunity to enjoy them.* (Adapted from *Management Policies 2001. National Park Service publication.*)

The key management-related provision stated in the National Park Service Organic Act of 1916 is: *[The National Park Service] shall promote and regulate the use of the Federal areas known as national parks, monuments, and reservations hereinafter specified...by such means and measures as conform to the fundamental purpose of the said parks, monuments, and reservations, which purpose is to conserve the scenery and the natural and historic objects and the wild life therein and to provide for the enjoyment of the same in such manner and by such means as will leave them unimpaired for the enjoyment of future generations.* (Adapted from *Management Policies 2001. National Park Service publication.*) **Please refer to specific park management goals for Grand Teton and Bighorn Canyon in Appendix A.

GPRA Goals - The Government Performance and Results Act (GPRA) goals can be divided into four focal areas: 1) preserve park resources, 2) provide for the public enjoyment and visitor experience of parks, 3) strengthen and preserve natural and cultural resources and enhance recreational opportunities managed by partners and 4) ensure organizational effectiveness. (Adapted from *Yellowstone National Park Business Plan Fiscal Year 2002*.) **Please refer to specific GPRA goals in the appendix.

Business Plan Standards - According to Yellowstone National Park's Business Plan (Fiscal Year 2002), resource protection encompasses all activities related to the management, preservation and protection of the park's cultural and natural resources. Activities include research, restoration efforts, species-specific management programs, wildland fire management, archives and collections management, and historic site protection and information integration activities. (Adapted from *Yellowstone National Park Business Plan Fiscal Year 2002*.) **Please refer to specific business plan standards for Yellowstone National Park in Appendix A.

Criterion #7 - **There is a demonstrated, direct application of candidate vital sign measurement data to current key management decisions, or for evaluating past management decisions.**

Ultimately, an indicator is useful only if it can provide information to support a management decision or to quantify the success of past decisions. Policy makers and resource managers must be able to recognize the implications of indicator results for stewardship, regulation, or research. An indicator with practical application should display one or more of the following

characteristics: responsiveness to a specific stressor, linkage to policy indicators, utility in cost-benefit assessments, limitations and boundaries of application, and public understanding and acceptance. Detailed consideration of an indicator's management utility may lead to a re-examination of its conceptual relevance and to a refinement of the original assessment question. *(*Adapted from *Jackson, L.E., J.C. Kurt and W.S. Fisher, eds. 2000. Evaluation guidelines for ecological indicators. EPA/620/R-99/05. U.S. E.P.A, Office of Research and Development, Research Triangle Park, NC. 107pp. and Dale, V.H. and S.C. Beyeler. Challenges in the development and use of ecological indicators. 2001. Ecological Indicators 1:3-10.) **Please refer to the Threats and Management Issues table in Appendix A.*

FEASIBILITY OF IMPLEMENTATION

Criterion #8 - **The candidate vital sign's cost of measurement is not prohibitive.**

Cost is often the limiting factor in considering to implement an indicator. Estimates of all implementation costs should be evaluated. Cost evaluation should incorporate economy of scale, since cost per indicator or cost per sample may be considerably reduced when data are collected for multiple indicators at a given site. Costs of a pilot study or any other indicator development needs should be included if appropriate. The vital sign not only has to be relevant to monitoring but implementation also has to be feasible, practical and affordable. Sampling methods may include simple, low-tech or low-cost data collection methods, or more complex or expensive collection methods may be cost-effective, e.g. data collection every five years results in low annual costs. Consideration should be given to data collection methods, logistical requirements, data processing and information management, data quality, and costs in terms of time, money and personnel *(*Adapted from *Jackson, L.E., J.C. Kurt and W.S. Fisher, eds. 2000. Evaluation guidelines for ecological indicators. EPA/620/R-99/05. U.S. E.P.A, Office of Research and Development, Research Triangle Park, NC. 107pp.*).

Criterion #9 - **Impacts of the candidate vital sign's measurement meet NPS standards.**

Sampling activities for indicator measurements should not significantly disturb a site. Evidence should be provided to ensure that measurements made during a single visit do not affect the same measurement at subsequent visits or, in the case of integrated sampling regimes, simultaneous measurements at the site. Also, sampling should not create an adverse impact on protected species, species of special concern, or protected habitats. Any impact due to data collection of a specific park resource on that resource or on the surrounding environment can be considered impairment of a National Park Service natural resource or value if it impacts a resource or value whose conservation is:

- Necessary to fulfill specific purposes identified in the enabling legislation or proclamation of the park
- Key to the natural or cultural integrity of the park or to opportunities for enjoyment of the park
- Identified as a goal in the park's general management plan or other relevant NPS planning documents.

However, an impact is less likely to be considered impairment if it is the unavoidable result of an action necessary to restore or conserve the integrity of a park natural resource or value. All proposals for natural resource use and measurement within a National Park are evaluated against the following four points:

- Consistency with applicable laws, Executive Orders, regulations and policies
- Consistency with existing plans for public use and resource management
- Actual and potential effects on park resources and values
- Total costs to the Service, and whether the public interest will be served.

(Adapted from *Yellowstone National Park Business Plan Fiscal Year 2002*.) **Please refer to specific NPS standards in Appendix B.

Criterion #10 - **The candidate vital sign is relatively easy to measure and has measurable results that are repeatable with different personnel.**

A vital sign should be straightforward with methodology that is relatively easy to understand, and simple to apply. Measurement of the vital sign should not be dependent on a single expert, but rather should incorporate expert systems that can be implemented by adequately trained field staff. The logistical requirements should warrant practical implementation and the length of time required to collect, analyze and report the data of a vital sign should not be prohibitive. *(*Adapted from *Jackson, L.E., J.C. Kurt and W.S. Fisher, eds. 2000. Evaluation guidelines for ecological indicators. EPA/620/R-99/05. U.S. E.P.A, Office of Research and Development, Research Triangle Park, NC. 107pp. and Dale, V.H. and S.C. Beyeler. Challenges in the development and use of ecological indicators. 2001. Ecological Indicators 1:3-10.)*

INTERPRETATION AND UTILITY

Criterion #11 - **The candidate vital sign's response can be distinguished between natural variation and anthropogenic impact-induced variation.**

The vital sign should have a well-documented reaction to both natural disturbances and anthropogenic stresses in the system. This criterion would then apply to metrics that have been extensively studied and have well-developed models and clearly established patterns of response. (Adapted from *Dale, V.H. and S.C. Beyeler. Challenges in the development and use of ecological indicators. 2001. Ecological Indicators 1:3-10 and Angermeier, P.L. 1997. Conceptual roles of biological integrity and diversity. Pp: 49-65. In: Williams, J.E., C.A. Wood, and M.P. Dombeck, eds. Watershed Restoration Principles and Practicies, American Fisheries Society, Bethesda, MD. 559 pp.)*

Criterion #12 - **The candidate vital sign is helpful in identifying the causal mechanism of an ecological response.**

Although overlooked in the emerging literature on ecological vital signs (also indicators), the ability for one or more integrative vital signs to provide insight into the causal mechanisms of an

observed ecosystem response will be crucial to NPS needs. In order for vital sign information to be translated into management responses, park managers will need to be able to utilize the vital sign information to assess what processes are causing the measured ecosystem response and then translate this understanding into deliberate management decisions to intervene and attempt mitigation or accept that the observed departure from the range of natural variability cannot be mitigated. (Adapted from *Green, R.H. 1979. Sampling design and statistical methods for environmental biologists. Wiley, NY and Angermeier, P.L. 1997. Conceptual roles of biological integrity and diversity. Pp: 49-65. In: Williams, J.E., C.A. Wood, and M.P. Dombeck, eds. Watershed Restoration Principles and Practices, American Fisheries Society, Bethesda, MD. 559 pp.)*

Criterion #13 - **Historic databases and baseline conditions for the candidate vital sign are already known**.

Threshold values or ranges of values are often established to facilitate the ability to interpret whether vital sign information suggests an important departure from the range of natural variability. This is because there can be important natural spatial and temporal variation in measurable ecosystem responses with and across years. The ability for a vital sign to permit discrimination of natural variability along known condition gradient(s) from unacceptable ecological conditions will need to be based upon documented baseline conditions, known thresholds, historical records or observed responses at reference sites along an important condition gradient. (Adapted from *Environment Canada. 2000. Selecting core variables for tracking ecosystem change at EMAN sites. Final Report to Environment Canada. Geomatics International, Inc., Guelph, Ontario. http:/www.eman-rese.ca and Angermeier, P.L. 1997. Conceptual roles of biological integrity and diversity. Pp: 49-65. In: Williams, J.E., C.A. Wood, and M.P. Dombeck, eds. Watershed Restoration Principles and Practices, American Fisheries Society, Bethesda, MD. 559 pp.)*

APPENDIX II.G.A

**This information appends the expanded selection criteria information.

MANAGEMENT RELEVANCE

Park Management Goals

Specific park management goals are taken from each park's General Management Plan or Master Plan. The specific management goals of Bighorn Canyon National Recreation Area, according to its General Management Plan, are:

The preservation of the natural environment for the enjoyment of the recreation area visitors and for the integrity of the ecosystems...

According to the Master Plan of Grand Teton National Park states the following purpose:

To protect the scenic and geological values of the Teton Range and Jackson Hole, and to perpetuate the Park's indigenous plant and animal life. The Park will interpret these natural and scenic values, in association with the historical significance of the region, in a manner that preserves these resources for the benefit and d pleasure of present and future generations. (Adapted from *Greater Yellowstone Network Phase I Report.*)

GPRA Goals

Each of the four GPRA goal focal areas can be separated into specific mission goals, as follows: Preserve park resources: 1) natural and cultural resources and associated values are protected, restored and maintained in good condition and managed within their broader ecosystem and cultural context; and 2) the National Park Service contributes to knowledge about natural and cultural resources and associated valued; management decisions about resources and visitors are based on adequate scholarly and scientific information.

Provide for the public enjoyment and visitor experience of parks: 1) visitors safely enjoy and are satisfied with the availability, accessibility, diversity and quality of park facilities, services and appropriate recreational opportunities; and 2) park visitors and the general public understand and appreciate the preservation of parks and their resources for this and future generations.

Strengthen and preserve natural and cultural resources and enhance recreational opportunities managed by partners: 1) natural and cultural resources are conserved through formal partnership programs; 2) through partnerships with other federal, state and local agencies and non-profit organizations, a nationwide system of parks, open space, rivers and trails provides educational, recreational and conservation benefits for the American people; and 3) assisted through federal

funds and programs, the protection of recreational opportunities is achieved through formal mechanisms to ensure continued access for public recreational use.

Ensure organizational effectiveness: 1) the National Park Service uses current management practices, systems and technologies to accomplish its mission; and 2) the National Park Service increases its managerial resources through initiatives and support from other agencies, organizations and individuals. (Adapted from *Yellowstone National Park Business Plan Fiscal Year 2002*.)

Specific GPRA goals for the Network parks are included in the table below.

NPS GPRA GOALS	**Bighorn Canyon National Recreation Area**	Exotic Vegetation Species: by September 30, 2005, exotic vegetation on 70.25 (2.81%) acres of an estimated 2,500 targeted acres of Bighorn Canyon lands, as of FY 1999, is contained.
		Water Quality: by September 30, 2005, Bighorn Canyon has unimpaired water quality.
		Natural/Cultural Resource Inventories: by September 30, 2005, 4 (66.6%) of 6 Bighorn Canyon primary natural/cultural resource inventories are completed.
		Vital Signs: by September 30, 2005, Bighorn Canyon has identified its vital signs for natural resource monitoring.
	Yellowstone National Park	Natural Resources Fauna: by September 30, 2005, 356 (95%) of the 375 self-sustaining and free-ranging wildlife, native fish and birds identified in Yellowstone National Park as of 1999 are preserved and maintained.
		Geothermal Features: By September 30, 2005, 90 (90%) of the 100 indicator geothermal features identified in Yellowstone National Park as of 1999 are in good condition.
		Native Species of Special Concern: by September 30, 2005, four of Yellowstone National Park's native species of special concern (trumpeter swan, white pelican, pronghorn antelope and Yellowstone sand verbena), as of 1999, have an improved or stable status.
		Exotic Plant Species: by September 30, 2005, invasive exotic vegetation species on 20-22 (2.6%) of 822 targeted acres of Yellowstone National Park lands, as of FY 1999, are eradicated or contained.
		T&E Species Improved: by September 30, 2005, one (the gray wolf) (33%) of Yellowstone National Park's three identified populations of federally listed threatened and endangered species with critical habitat on park lands and/or requiring NPS recovery actions, as of 1999, has an improved status.
		T&E Species Stable: by September 30, 2005, two (the grizzly bear and bald eagle) (66%) of Yellowstone National Park's three identified populations of federally listed threatened and endangered species with critical habitat on park lands and/or requiring NPS recovery actions, as of 1999, have a stable status.

		Air Quality: by September 30, 2005, air quality in Yellowstone National Park has remained stable or improved relative to FY 1998 conditions.
		Water Quality: by September 30, 2005, Yellowstone National Park has unimpaired water quality.
		Vital Signs: by September 30, 2005, Yellowstone National Park has identified its vital signs for natural resource monitoring.
	Grand Teton National Park	Exotic Plant Species: by September 30, 2005, spotted knapweed and other alien vegetation species are contained on 20,000 (100%) of 20,000 acres targeted in Grand Teton National Park and the John D. Rockefeller Jr. Memorial Parkway.
		T&E Species: by September 30, 2005, 2 of the 4 federally listed threatened and endangered species NOT having critical habitat in Grand Teton and the Parkway and NOT requiring NPS recovery actions, as of 1997, have an improved status. Monitoring continues on the remaining 2 federally listed species.
		Native Species of Species Concern: by September 30, 2005, 1 of 2 (50%) of Grand Teton National Park and Parkway populations of plant and/or animal species of special concern (e.g. state-listed threatened and endangered species, endemic or indicator species, or native species classified as pests) are at scientifically acceptable levels.
		Air Quality: by September 30, 2005, air quality in Grand Teton National Park has remained stable or improved relative to FY 1998 conditions.
		Water Quality: by September 30, 2005, Grand Teton National Park and Parkway continue to have unimpaired water quality.
		Wildlife Research and Monitoring: by September 30, 2005, 9 of 9 (100%) of Grand Teton National Park and Parkway species of concern will continue to be monitored to provide sufficient information to assist in management decisions.
		Resource Inventories: by September 30, 2005, 50% of the available natural resource data sets for Grand Teton National Park will be collected and evaluated.
		Vital Signs: by September 30, 2005, Grand Teton National Park has identified its vital signs for natural resource monitoring.

(Table adapted from *Strategic Plan for Grand Teton National Park and John D. Rockefeller Jr. Memorial Parkway October 1, 2001- September 30, 2005. Strategic Plans. 2001.* <http://im.den.nps.gov/Documents/GpraPlans/GRTE%2Edoc> *(3 Apr. 2003); The Strategic Plan for Yellowstone National Park 2001-2005. Strategic Plans. 2000.* <http://im.den.nps.gov/Documents/GpraPlans/YELL%2Epdf> *(3 Apr. 2003)*; *The Strategic Plan for Bighorn Canyon National Recreation Area 2001-2005. Strategic Plans. 2001.* <http://im.den.nps.gov/Documents/GpraPlans/BICA%2Epdf> *(3 Apr. 2003)*)

Business Plan Standards

The following aspects of Yellowstone's natural resources are included in the Natural Resource Protection section of Yellowstone National Park's Business Plan:

- Air, Soils and Geology-including the monitoring of geothermal features, weather, air quality, river gauging stations and volcanic and earthquake unrest
- Backcountry and Wilderness Management-including 300 remote sites and 1,000 miles of trails
- Bear Management-including the reduction of bear-human conflicts and the monitoring of bear populations and ecology
- Bison Management-including the Interagency Bison Management Plan (a brucellosis transmission risk management strategy relying on strategic hazing and capture and removal techniques) and vaccination of bison calves and yearlings
- Elk and Other Ungulate Management-including monitoring of elk, pronghorn antelope, bighorn sheep, mountain goats, moose and whitetail and mule deer populations and ecology
- Fisheries and Aquatic Resources-including the control of invasive exotic species (e.g. lake trout, whirling disease, New Zealand mud snails) and the management of consumptive use through fishing permits and regulations
- Natural Resource Protection-including the protection of resources from human-caused threats and the protection of humans from wildlife, geothermal and other natural threats
- Natural Resource Research, Publications and Events-including the creation of a resource management-based research program that will benefit residential education programs and produce publications for various audiences
- Other Wildlife Management-including the management of birds, reptiles, amphibians, invertebrates, small mammals and mid-sized carnivores (e.g. Canada lynx, cougars, wolverines) and the Integrated Pest Management program
- Vegetation Management-including wetlands mapping and preservation, invasive exotic species control, rare vascular plant documentation, hazard tree removal and vegetation ecology studies
- Wildland Fire-including the encouragement of natural fires except when they threaten irreplaceable historic structures and sharing fire management resources with surrounding National Forest land
- Wolf Management-including monitoring wolves and their impacts on the ecosystem

Additionally, included in the Yellowstone Business Plan is the vision of the park, which encompasses the following areas:

- Public enjoyment and visitor experience
- Resource preservation
- Efficiency and effectiveness
- Safety

(Adapted from *Yellowstone National Park Business Plan Fiscal Year 2002*.)

APPENDIX II.G.B

Feasibility of Implementation

National Park Service Standards

For example, the following uses of National Park Service land are restricted and require special prior approval:

- Off-road vehicle use (Executive Order 11644)
- Aircraft over flights (Director's Order 47)
- Telecommunication antenna sites (Director's Order 53)
- Consumptive uses (i.e. collecting natural products) are only allowed when they are:
- Specifically authorized by federal law or treaty rights
- Specifically authorized pursuant to other existing rights
- Some pre-specified grazing activities
- Traditional visitor activities that are authorized in accordance with NPS general regulations.

(Adapted from *Management Policies 2001. National Park Service publication.*)

These additional conditions are placed on research permits obtained for Yellowstone National Park:

- All equipment left in the field including plot markers must be specifically authorized in advance. If you are authorized to place plot markers in Yellowstone, they must be eight-penny nails with an optional washer
- All VHF and GPS collars on wildlife must be camouflaged to blend in with the animal. The antennas on the collars must also be as invisible as possible. All collars must be removed at the completion of the study by either blow-off capabilities or cotton (rot-away) spacers
- Specific authorization must be obtained in advance before using chemicals or hazardous materials
- A research permit does not authorize you to enter closed or restricted areas in Yellowstone. Examples of restricted areas include most service roads, bear management areas, some thermal areas, some bird nesting areas, and wolf den sites, and trout spawning areas
- Cultural resources must not be adversely impacted by your research activities. Any ground disturbances must be specifically authorized in advance
- If your research requires flying in the park, you must request authorization in advance. You must also comply with FAA and Yellowstone National Park flight regulations
- The Permittee agrees to notify the Superintendent of Yellowstone National Park of every subject discovery or invention that relates in any respect to research results derived from use of any research specimens or other materials collected from Yellowstone National

Park, or that may be patentable or otherwise protected under the intellectual property (IP) laws of the United States or other jurisdiction
- Travel within the park is restricted to only those methods that are available to the general public unless otherwise specified in additional stipulations associated with this permit.

(Adapted from *Yellowstone National Park Permit Conditions 2003*.)

The following conditions apply to specimen collection in Yellowstone National Park:

- Collection of archeological materials without a valid Federal Archeology Permit is prohibited.
- Collection of federally listed threatened or endangered species without a valid U.S. Fish and Wildlife Service endangered species permit is prohibited.
- Collection methods shall not attract undue attention or cause unapproved damage, depletion, or disturbance to the environment and other park resources, such as historic sites.
- New specimens must be reported to the NPS annually or more frequently if required by the park issuing the permit. Minimum information for annual reporting includes specimen classification, number of specimens collected, location collected, specimen status (e.g., herbarium sheet, preserved in alcohol/formalin, tanned and mounted, dried and boxed, etc.), and current location.
- Collected specimens that are not consumed in analysis or discarded after scientific analysis remain federal property. The NPS reserves the right to designate the repositories of all specimens removed from the park and to approve or restrict reassignment of specimens from one repository to another. Because specimens are Federal property, they shall not be destroyed or discarded without prior NPS authorization.
- Each specimen (or groups of specimens labeled as a group) that is retained permanently must bear NPS labels and must be accessioned and cataloged in the NPS National Catalog. Unless exempted by additional park-specific stipulations, the permittee will complete the labels and catalog records and will provide accession information. It is the permittee's responsibility to contact the park for cataloging instructions and specimen labels as well as instructions on repository designation for the specimens.
- Collected specimens may be used for scientific or educational purposes only, and shall be dedicated to public benefit and be accessible to the public in accordance with NPS policies and procedures.
- Any specimens collected under this permit, any components of any specimens (including but not limited to natural organisms, enzymes or other bioactive molecules, genetic materials, or seeds), and research results derived from collected specimens are to be used for scientific or educational purposes only, and may not be used for commercial or other revenue-generating purposes unless the permittee has entered into a Cooperative Research And Development Agreement (CRADA) or other approved benefit-sharing agreement with the NPS. The sale of collected research specimens or other unauthorized transfers to third parties is prohibited. Furthermore, if the permittee sells or otherwise transfers collected specimens, any components thereof, or any products or research results developed from such specimens or their components without a CRADA or other approved benefit-sharing

agreement with NPS, permittee will pay the NPS a royalty rate of twenty percent (20%) of gross revenue from such sales or other revenues. In addition to such royalty, the NPS may seek other damages to which the NPS may be entitled including but not limited to injunctive relief against the permittee.

(Adapted from *General Conditions for Scientific Research and Collection Permit. Department of the Interior.*)

APPENDIX II.H-CANDIDATE VITAL SIGNS SCORING COMMENTS

**Please note: not all candidate vital signs are represented in the following table. Only those candidate vital signs that had recorded comments from day two of the workshop are found in this table.

Candidate Vital Sign	Applicable Park (GRYN=all three)	Secondary Resource Category	Comment (Ecological Relevance)	Comment (Response Variability)	Comment (Management Relevance)	Comment (Feasibility of Implementation)	Comment (Interpretation and Utility)
Deposition and accumulation of mercury in biota	GRYN	Air, Biotic and Abiotic	(q1)-n/a; mercury is an important toxic air contaminant that affects human health; needs further study to assess ecological impact and addresses linkages between deposition and accumulation in biota	(q2,3,4)-not enough information on this important vital sign to assess variability			(q11)-this is an important issue (q13)-some information from ice and sediment cores
Change in visibility deciviews	GRYN	Air, Biotic and Abiotic	We are mandated to do this. Already underway in YELL, need to do GRTE and BICA because it is difficult to extract information from YELL to other parks.				
Atmospheric deposition of nitrogen, sulfur and all major anions and cations	GRYN	Air, Biotic and Abiotic	This is a stressor variable; needed in all parks; comprehensive, continuous coverage is essential.				

Candidate Vital Sign	Applicable Park (GRYN=all three)	Secondary Resource Category	Comment (Ecological Relevance)	Comment (Response Variability)	Comment (Management Relevance)	Comment (Feasibility of Implementation)	Comment (Interpretation and Utility)
Over-snow vehicles emissions and effects	GRTE	Air, Biotic and Abiotic		(q3) N/A variable is a stressor (q4) N/A (q5) N/A			
Fish pathogens and disease	GRYN	Aquatic Pathogens/disease					(q12) whirling disease is an exception
Stream reach geomorphology	GRYN	Rivers and Streams		(q3)-only change is predictable, not the direction of change			
Stream gauging	GRYN	Climate, Biotic and Abiotic	(q1)-comprehensive coverage of stream gauging in all parks and networks; need cooperation of USGS	(q3)-variable is critical stressor and response variable; needs to be long-term continuous monitoring.			
Snow cover	GRYN	Climate, Biotic and Abiotic	(q1)-easy to measure with remote sensing				

Candidate Vital Sign	Applicable Park (GRYN=all three)	Secondary Resource Category	Comment (Ecological Relevance)	Comment (Response Variability)	Comment (Management Relevance)	Comment (Feasibility of Implementation)	Comment (Interpretation and Utility)
Date of "spring green-up"	GRYN	Climate, Biotic and Abiotic	One opinion in group is that we can estimate this parameter with weather data. We want to correlate weather data with spring green-up. Spring green-up is a remotely sensed variable. Need comprehensive coverage.	This is one of many variables that could be remotely sensed. Needs to be long-term continuous monitoring.			
Basic climatological measurements	GRYN	Climate, Biotic and Abiotic	We feel that these measurements are critical to all parks and should have comprehensive coverage of all ecosystems. All measurements should be coordinated with NWS and NRCS and across NPS. Should be coordinated across all NPS networks and parks.	This is stressor variable, not response variable, so we've answered 'yes' to all. Needs to be long-term continuous monitoring.			
Date of ice on/off on major lakes	GRYN	Climate, Biotic and Abiotic	Observational data=should be used to verify remotely sensed information				

Candidate Vital Sign	Applicable Park (GRYN=all three)	Secondary Resource Category	Comment (Ecological Relevance)	Comment (Response Variability)	Comment (Management Relevance)	Comment (Feasibility of Implementation)	Comment (Interpretation and Utility)
Extreme Climatological Events	GRYN	Climate, Biotic and Abiotic	Snow crusting can also be important; extreme events are important variables to measure for climate change; important human safety variables	(q3)-not appropriate for variable			
Geyser eruption volume and rate	YELL	Geothermal Processes		(q4)-with some		(q8)-may make sense in some places; volume is a problem	(q13)-'yes' not for volume
Chloride flux in thermal features	YELL	Geothermal Processes	(q1)-measurement of heat flux to surface	(q3)-disagreement on stressor		(q8)-technique relies upon river gauging stations	
Level and temperature of groundwater associated with thermal features	YELL	Geothermal Processes	activity of geothermal systems			(q8)-assumes use at existing wells (q9)-assumes use at existing wells	
Geothermal gaseous emissions in the atmosphere over Yellowstone National Park	YELL	Geothermal Processes	part of geothermal system				(q13)-spotty
Stream sediment transport	GRYN	Geomorphic Processes	(q1)-landscape stability	(q5)-over many years of measurements	(q6)-required by NAQWA	(q8)-suspended sediment easier to measure than bedload	(q13)-yes in some areas; no in others

Candidate Vital Sign	Applicable Park (GRYN=all three)	Secondary Resource Category	Comment (Ecological Relevance)	Comment (Response Variability)	Comment (Management Relevance)	Comment (Feasibility of Implementation)	Comment (Interpretation and Utility)
Landscape and habitat fragmentation	GRYN	Surrounding Environments		(q3) vital sign is a stressor	(q6) In park-driven by mgmt plans, outside-driven by counties, therefore, varies by county.	(q8,q10) Remotely sensed data can be used to classify land use and fragmentation. Cover is more difficult and costly.	
Levels of backcountry overnight use	GRTE	Park Visitation	(q1) Concern about on-site impacts and impacts that migrate off-site. (q2) Concern about pristine areas that will become less pristine through use - this is not ecologically important until you get off-site impacts	(q3)This vital sign is an ecosystem stressor. (q4)Based on Cole and others, this vital sign is predictable.		(q8) Measuring levels of use is very cheap. Measuring impact of use is more costly, but not prohibitive.	
Levels of backcountry overnight use	YELL	Park Visitation	(q1) Concern about on-site impacts and impacts that migrate off-site. (q2) Concern about pristine areas that will become less pristine through use - this is not ecologically important until you get off-site impacts	(q3)This vital sign is an ecosystem stressor. (q4)Based on Cole and others, this vital sign is predictable.		(q8) Measuring levels of use is very cheap. Measuring impact of use is more costly, but not prohibitive.	

Candidate Vital Sign	Applicable Park (GRYN=all three)	Secondary Resource Category	Comment (Ecological Relevance)	Comment (Response Variability)	Comment (Management Relevance)	Comment (Feasibility of Implementation)	Comment (Interpretation and Utility)
Visitor use levels	GRYN	Park Visitation	(q1)Visitor use and associated infrastructure is the biggest ecological impact in parks.	(q3)vital sign is a stressor.		(q8)Visitor use levels are easy to measure, impacts are difficult. visitor use levels are easy to measure, impacts are difficult.	
Resource violations	GRYN	Park Visitation	(q1) Yes for BICA (cattle trailing) No for YELL, GRTE. (q2) Yes for BICA with cattle trailing.	(q1) vital sign is a stressor			
Park infrastructure	GRYN	Park Visitation	(q1) This vital sign is a stressor	(q3) Depends on species, individual, habitat type. (q4) Anticipating in that one can predict roads will bring exotics and increased roadkill. (q5) Some things (roadkill) are well known, some are not known at all.		(q8) But depends on which metric one chooses (q10) Again, depends on metric	(q12) depends on metric (q13) yes-vegetation, roadkill, etc.
Resource consumptive use and hydrologic modification	GRYN	Park Visitation	(q1) Hunting has possible ecological impact to muledeer and raccoons (BICA) and small mammals	(q3) vital sign is an ecosystem stressor			

Candidate Vital Sign	Applicable Park (GRYN=all three)	Secondary Resource Category	Comment (Ecological Relevance)	Comment (Response Variability)	Comment (Management Relevance)	Comment (Feasibility of Implementation)	Comment (Interpretation and Utility)
Levels of backcountry day use	GRTE	Park Visitation	(q1) Some impacts, but this is more of a social impact issue	(q3)vital sign is a stressor.		(q8) Cost of monitoring this sign can be very high (e.g.. GRTE has a proposal to monitor day use for around 150,000) but it is not prohibitive.	(q11) This VS is a social issue primarily. (q12) YELL has numbers of day users measured in 1992-93, GRTE has numbers from 1986-87.
Levels of backcountry day use	YELL	Park Visitation	(q1) Some impacts, but this is more of a social impact issue than a (unfinished	(q3)vital sign is a stressor.		(q8) Cost of monitoring this sign can be very high (e.g.. GRTE has a proposal to monitor day use for around 150,000) but it is not prohibitive.	(q11) This VS is a social issue primarily. (q12) YELL has numbers of day users measured in 1992-93, GRTE has numbers from 1986-87.
Native insect biodiversity and distribution	GRYN	Native and Exotic Insects			(q6) need to check	(q8) quite in expensive per species, but more costly by indicator (q10) collection easy, but identification is difficult and expensive	(q13) some data available, but not adequate

Candidate Vital Sign	Applicable Park (GRYN=all three)	Secondary Resource Category	Comment (Ecological Relevance)	Comment (Response Variability)	Comment (Management Relevance)	Comment (Feasibility of Implementation)	Comment (Interpretation and Utility)
Exotic insects	GRYN	Native and Exotic Insects		(q3) Presence of insects are an ecosystem stressor		(q8) high cost for one species, but low considering number of species involved.	(q13) Some species
Forest/grassland/shrubland defoliators and consumers	GRYN	Native and Exotic Insects	(q1) combined 3 previous vital signs: Beetle and budworm pop., Insect herbivory and Insect biomass				(q13) Yes for forest-related species but not for grasshoppers
Selected insect species of concern	GRYN	Native and Exotic Insects			(q7) Maybe lady bird beetles ephidrid flies and geothermal		(q11) depends on the species
Alpine plant community characteristics	GRTE	Alpine Meadow and Timberline Ecosystems		(q4) for mountain goats			
Fire and fuel loading	GRYN	Terrestrial Ecosystems				(q8) could be restricted to small areas	
Shrubland community composition and structure	GRYN	Montane Shrubland Ecosystems					(q12) could be combination of causes
Browse effects on riparian woody vegetation	GRYN	Riparian and Riverine Wetland Ecosystems					(q13) limited in extent

Candidate Vital Sign	Applicable Park (GRYN=all three)	Secondary Resource Category	Comment (Ecological Relevance)	Comment (Response Variability)	Comment (Management Relevance)	Comment (Feasibility of Implementation)	Comment (Interpretation and Utility)
Grassland annual net primary productivity	GRYN	Herbaceous Meadow and Grassland Ecosystems		(q3) However, there are models addressing certain stressors			(q13) selected park areas access to remote sensing
Grassland vegetation annual offtake	GRYN	Herbaceous Meadow and Grassland Ecosystems			(q6) but maybe in BICA	(q8) n/a - need to develop metric (q9) N/a (both scored no)	
Grassland nitrogen	GRYN	Herbaceous Meadow and Grassland Ecosystems		(q3) models in development, (q4) Need to consult N-expert	(q6) could be good mgmt tool.	(q9,10) N/A	
Bighorn basin plant community composition and exotic species	BICA	Terrestrial Ecosystems		(q5) beyond our expertise			
Lichen distribution, abundance and chemical composition	GRYN	Terrestrial Ecosystems		(q3) particularly in regard to growth and climate variables			(q13) yes in YELL, no in GRTE and BICA
Lodgepole pine plant community composition and exotic species	GRTE	Lodgepole Pine Forest Ecosystem		(q3) dependent upon resolution of data			(q13) for limited areas

Candidate Vital Sign	Applicable Park (GRYN=all three)	Secondary Resource Category	Comment (Ecological Relevance)	Comment (Response Variability)	Comment (Management Relevance)	Comment (Feasibility of Implementation)	Comment (Interpretation and Utility)
Lodgepole pine forest floor litter and coarse woody debris	GRTE	Lodgepole Pine Forest Ecosystem			(q7) indirect for YELL		
Landscape structure and heterogeneity	BICA	Terrestrial Ecosystems		(q3) This VS has high value, despite this issue			(q13) yes, but only for limited areas
Aboveground net primary productivity	GRYN	Terrestrial Ecosystems					(q12) this is ecosystem specific
Stand density of high-elevation live and dead whitebark pine trees	GRTE	Whitebark Pine Woodland and Forest Ecosystems					(q13) if low density stands, can use old photos
Mixed conifer plant community composition and exotic species	YELL	Mixed Conifer Forest Ecosystems					(q13) for limited areas
Mixed conifer snag density	GRTE	Mixed Conifer Forest Ecosystems					(q13) possibly some surveys

Candidate Vital Sign	Applicable Park (GRYN=all three)	Secondary Resource Category	Comment (Ecological Relevance)	Comment (Response Variability)	Comment (Management Relevance)	Comment (Feasibility of Implementation)	Comment (Interpretation and Utility)
Ponderosa pine plant community composition and exotic species	BICA	Ponderosa Pine Ecosystems					(q12) more useful for vegetation. responses than animal responses
Aspen community composition and structure	GRTE	Aspen Forest Ecosystems		(q5) variable often high			
Aspen stand extent and distribution in landscape	GRTE	Aspen Forest Ecosystems					(q13) Based upon estimates
Shrubland nitrogen	GRYN	Montane Shrubland Ecosystems		(q3) models in development	(q6) could be good management tool (q7) need to contact N-expert		
Shrubland exotic species	GRYN	Montane Shrubland Ecosystems					(q11) cannot be causal in interpretation (12) specific to different species (13) mostly anecdotal.

Candidate Vital Sign	Applicable Park (GRYN=all three)	Secondary Resource Category	Comment (Ecological Relevance)	Comment (Response Variability)	Comment (Management Relevance)	Comment (Feasibility of Implementation)	Comment (Interpretation and Utility)
Selected sensitive bird species abundance, distribution and productivity	GRYN	Birds		(q3)unknown cause of trumpeter decline (q5) Harlequins: yes, swan? Loons? Occupancy (PAO) is less variable, so yes			current, ongoing debate
Song bird population abundance and distribution	GRYN	Birds	(Q1) Many species which effect many levels of food web (q2) migratory, many habitats	(q3) relative to abiotic factors (q4) e.g.. DDT. (q5) perhaps use a PAO methodology, but not from a territorial male perspective	(q6) neotropical migrants (q7) e.g.. Cavity nesters in burns, people get exited about bird watching	(q8) point sampling methods are relatively straightforward (q9) point counts non-invasive (q10) requires use of highly trained personnel	(q11) esp. because of migration & wintering sites (q13) much historic data, but in different formats. Monitoring must be correlated with other methods
Colony nesting bird population abundance, distribution, vital rates and productivity	GRYN	Birds		(q3)"reasons for declines are uncertain" (q5) site occupancy is not variable, but abundance is more so.	(q7) colony nesting birds specifically noted in state of park reports	(q8) easy (q10) low-training	(q11) seeq 3 above. (q12) see q3 above. (q13) good historic data
Raptor population abundance, distribution and productivity	GRYN	Birds		(q5) using to site fidelity			

Candidate Vital Sign	Applicable Park (GRYN=all three)	Secondary Resource Category	Comment (Ecological Relevance)	Comment (Response Variability)	Comment (Management Relevance)	Comment (Feasibility of Implementation)	Comment (Interpretation and Utility)
Large carnivore population abundance and distribution	GRYN	Mammals	(q1) food web = top predators	(q4) food switching, functional response		(q8) very expensive due to life history. (q10) not easy, collaring animals is labor intensive	(q13) good for grizzlies. Short term for wolves. Questionable for mountain lions
Ungulate population abundance, distribution and productivity	GRYN	Mammals		(q4) long-lived so low sensitivity. (q5) high variability			(q11) don't know enough about compensatory mechanisms in the absence of hunting
Bat occurrence, distribution and abundance	GRYN	Mammals	(q2) trophic factors. Dispersed forager, roosts, foraging areas, and commuting zones	(q3,4) known responses but qable statistical power.	(q6) never mentioned, often conflicting with park maintenance issues. (q7) cave use, building and historic sites, mine use, forest roost structures.	(q8) abundance of non-colony roosters potentially labor-intensive	(q11) In many cases, yes (especially for roosts.) However, population fluctuations may require additional research to determine causation. (q13) Inventory is currently occurring, but virtually no older data.

Candidate Vital Sign	Applicable Park (GRYN=all three)	Secondary Resource Category	Comment (Ecological Relevance)	Comment (Response Variability)	Comment (Management Relevance)	Comment (Feasibility of Implementation)	Comment (Interpretation and Utility)
Native species richness	GRYN	Terrestrial Vertebrates		(q4) does not provide early warning. (Q5) The SNR increases with the proportion of rare animals in the richness calculation. This rank assumes focus on the species with high to moderate detectibility	(q6) maintenance of diversity at national level is a goal of NPS. (q7) Management action very difficult to tie to a list of species, as opposed to particular species.	(q8) see note at bottom of page	(q13) Inventories are currently being done to establish baselines.
Invasive vertebrate species richness and distribution	GRYN	Terrestrial Vertebrates	(q1) Key taxa: bullfrogs, raccoons, English sparrows, starlings, pigeons, turkeys, pheasants, mute swans, feral cats. Species displacement, disease.	(q4) early warning of change. (q5) without 'natural' in wording of q. Its presence or absence, not abundance			(q11) It is an anthropogenic impact. (q13) Historic (or prehistoric) baseline is zero-they were not here before.

Candidate Vital Sign	Applicable Park (GRYN=all three)	Secondary Resource Category	Comment (Ecological Relevance)	Comment (Response Variability)	Comment (Management Relevance)	Comment (Feasibility of Implementation)	Comment (Interpretation and Utility)
Vertebrate diseases	GRYN	Terrestrial Vertebrates		(q3) much current research to uncover causes of spread			(q11) Anthropogenic causes can interact with diseases, making wildlife more susceptible. (q13) Many diseases are recently discovered or recently prevalent. With molecular techniques the history of diseases can often be traced back in time.

Candidate Vital Sign	Applicable Park (GRYN=all three)	Secondary Resource Category	Comment (Ecological Relevance)	Comment (Response Variability)	Comment (Management Relevance)	Comment (Feasibility of Implementation)	Comment (Interpretation and Utility)
Beaver presence and population estimates	GRYN	Mammals		(q3) Known response to predators and habitat structure.(q4) Responsive to multi-scale phenomena (floods, fire, drought, stressors, geomorphology). Sensitive at local scales, but anticipatory at larger scales.		(q8) East to identify and measure.	(q13) Beaver flights have been conducted for years in YNP. Some survey data for GRTE.
Reptile occurrence	BICA	Terrestrial Vertebrates	(q1) Function: Trophic relationships. (q3) Links to various spatial scales are more tenuous than other groups (e.g.. Amphibians.)	(q3,4) Relative to other groups. (q5) PAO doesn't work well with reptiles		(q8) drift fences /funnel traps labor intensive. (q9)) drift fences /funnel traps are invasive but feasible in BICA.	(q11) insufficient baseline data. (q12) relative to amphibians

Candidate Vital Sign	Applicable Park (GRYN=all three)	Secondary Resource Category	Comment (Ecological Relevance)	Comment (Response Variability)	Comment (Management Relevance)	Comment (Feasibility of Implementation)	Comment (Interpretation and Utility)
Amphibian occurrence	GRYN	Terrestrial Vertebrates	(q1) Predator and prey in aquatic systems . Nutrient transport. Larvae are important herbivores. Function: connected food web. (q2) contingent of noted change in description- ('scales' changed to 'levels' 'and spatial and temporal scale' added at end	(q3) Sometimes, depending on a stressor. Usually predictable although power is qable. Using PAO methods may be statistically feasible. (q4) Amphibians are sensitive relative to other vital signs. (q5) Low variability if PAO is used as metric.	(q6) Direct impacts on: road construction, fish stocking, water management, water diversion, fuels reduction and prescribed burns. Mgmt. goals, GRPA, Business plan: People understand, Applications, Resource is cared about.	(q9,10) Contingent upon using PAO to monitor.	(q11) Yes, given that we have baseline data. (q12) There is documented use of amphibians to identify contaminants, water issues, fish stocking, etc. (q13) Extensive monitoring via PAO has been done for 3 yrs. Other survey data collected for 20-30 yrs
Rodents and insectivores (<250g) population, abundance and distribution	GRYN	Mammals	(q1) Key taxa; Red-backed voles, Microtus spp.. Pocket gophers. Key reasons: prey base, burrows for amphibians.		(q3,4,5) high variability		(q13) except BICA
Rodents and Lagomorphs (>250g) population, abundance and distribution	GRYN	Mammals	(q1) prey base	(q3) responsive to some major stressors that restructure systems. (q4,5) high variability			(q11) see response above. (q13) variable by park unit. Selected data, but not across the board.

Candidate Vital Sign	Applicable Park (GRYN=all three)	Secondary Resource Category	Comment (Ecological Relevance)	Comment (Response Variability)	Comment (Management Relevance)	Comment (Feasibility of Implementation)	Comment (Interpretation and Utility)
Meso-carnivore population abundance and distribution	GRYN	Mammals	(q1) many populations are remnant or restricted. (e.g.. Fisher, lynx) . Wolverine tied to ungulates, marten to old forest, lynx to hares, others qable.		(q6) e.g.. Lynx, wolverine	(q10) Low abundance hard to detect, difficult to prove breeding, abundance hard to show	q11) poor knowledge on linkages. (q13) species and park specific
Pattern of non-park land-use changes	GRYN	Terrestrial Vertebrates		(q3) Stressors may be socio-economic trends and land-use change is the response.			
Major ion chemistry	GRYN	Lakes and Reservoirs	(q1)-includes alkalinity (q1)-especially in areas subject to atmospheric deposition and possible salinity changes	(q3)-acidification has highest sensitivity (q3)-may be 'no' for other uses	(q7)-assumes future management decisions as well as past	(q8)-assumes cost effective protocols; maintain this core set at sites-recommend	(q11)-for individual ions 'yes'; others 'no' (q13)-may be available on a case-by-case basis
E. coli	GRYN	Lakes and Reservoirs			(q6)-this is mainly an issue for BICA		(q11)-'no' unless typing methods are employed (q13)-GRTE has a recent baseline

Candidate Vital Sign	Applicable Park (GRYN=all three)	Secondary Resource Category	Comment (Ecological Relevance)	Comment (Response Variability)	Comment (Management Relevance)	Comment (Feasibility of Implementation)	Comment (Interpretation and Utility)
Metals	GRYN	Lakes and Reservoirs	(q2)-it may be more valuable to monitor biota (for bioaccumulation) in addition to monitoring water or sediment	(q3)-behavior of species is often coupled to episodic events (q5)-but YELL provides an extremely high level of spatial variability		(q8)-there may be exceptions, Hg is an example	(q13)-data are limited in some geographic areas
Zooplankton community structure	GRYN	Lakes and Reservoirs					(q12)-but could be useful for major (catastrophic) change
Core parameters	GRYN	Rivers and Streams	(q1)-not as important as major ion chemistry; 'yes' in some cases (q2)-unless under the context of a specific q, such as lake thermal structure	(q3)-'yes' in extreme situations			
Periphyton community structure, chlorophyll a	GRYN	Rivers and Streams	(q1)-linkage may not be as strong as that demonstrated in lakes	(q5)-further research needed in the area 'community structure and nutrient concentration relationships'		(q8)-however the identification costs for algae may be high	(q11)-unless there is a major change

Candidate Vital Sign	Applicable Park (GRYN=all three)	Secondary Resource Category	Comment (Ecological Relevance)	Comment (Response Variability)	Comment (Management Relevance)	Comment (Feasibility of Implementation)	Comment (Interpretation and Utility)
Continuous water temperature	GRYN	Lakes and Reservoirs					(q11)-depends on the magnitude of the change
Watershed budgets	GRYN	Watersheds	(q1)-integrates among ecosystems and among other ecological indicators (q2)-provides a foundation to integrate other measurements			(q8)-but many of these data are collected as part of other indicators; may be cheap	(q11)-but over decadal time scales

APPENDIX II.I-RANKED LIST OF CANDIDATE VITAL SIGNS BY RESOURCE AREA

**Please note: an overall ranked list of candidate vital signs is available upon request.

	Attribute	Secondary Resource	Score	GRTE	YELL	BICA
Air Quality						
	Atmospheric deposition of nitrogen, sulfur and all major anions and cations		1.00	X	X	X
	Atmospheric deposition and response in sensitive headwater catchments		1.00	X	X	
	Change in visibility deciviews		1.00	X	X	X
	Deposition and accumulation of mercury in biota		0.57	X	X	X
	Over-snow vehicles emissions and effects		0.40	X	X	
Aquatic Communities						
	Native and exotic community structure, composition, stability	Aquatic Species at risk	1.00	X	X	X
	Native fish genetic integrity	Aquatic Species at risk	1.00	X	X	
	Fish pathogens and disease	Aquatic Pathogens/disease	0.77	X	X	X
Aquatic Habitats						
	Stream reach geomorphology	Rivers and Streams	0.78	X	X	X
Climate						
	Basic climatological measurements	Climate, Biotic and Abiotic	1.00	X	X	X
	Date of "spring green-up"	Climate, Biotic and Abiotic	1.00	X	X	X
	Date of ice on/off on major lakes	Climate, Biotic and Abiotic	1.00	X	X	X
	Snow cover	Climate, Biotic and Abiotic	1.00	X	X	X
	Stream gauging	Climate, Biotic and Abiotic	1.00	X	X	X
	Glaciers retreat or increase	Climate, Biotic and Abiotic	0.80	X	X	
	Soil climate	Climate, Biotic and Abiotic	0.75	X	X	X
	Extreme Climatological Events	Climate, Biotic and Abiotic	0.53	X	X	X
Geology and Geothermal						
	Chloride flux in thermal features	Geothermal Processes	1.00		X	
	Geothermal water chemistry	Geothermal Processes	0.95	X	X	
	Heat flow	Geothermal Processes	0.95	X	X	
	Stream sediment transport	Geomorphic Processes	0.95	X	X	X

	Attribute	Secondary Resource	Score	GRTE	YELL	BICA
	Earthquake activity	Geologic Processes	0.87	x	x	x
	Emission rates of CO2, H2S, SO2, volatile Hg, and He to the atmosphere over Yellowstone NP	Geothermal Processes	0.87		x	
	Stream channel change	Geomorphic Processes	0.87	x		
	Landslide and debris flows	Geomorphic Processes	0.87		x	
	Landslide and debris flows	Geomorphic Processes	0.82	x		x
	Level and temperature of groundwater associated with thermal features	Geothermal Processes	0.82		x	
	Soil moisture/temperature/structure	Soils	0.82	x	x	
	Plant community composition and exotic species	Geothermal Ecosystem	0.78	x	x	
	Geothermal feature abundance & distribution	Geothermal Processes	0.73	x	x	
	Geothermal microbial diversity	Geothermal Microbiology	0.73	x		
	Geyser eruption volume and rate	Geothermal Processes	0.72		x	
	Stream channel change	Geomorphic Processes	0.67		x	x
	Soil chemistry	Soils	0.61	x	x	x
	Geothermal water flow rate	Geothermal Processes	0.51		x	
	Soil structure and stability	Soils	0.47	x	x	x
Human Activities						
	Landscape and habitat fragmentation	Surrounding Environments	1.00	x	x	x
	Park infrastructure	Park Visitation	0.83	x	x	x
	Levels of backcountry day use	Park Visitation	0.75	x	x	
	Levels of backcountry overnight use	Park Visitation	0.75	x	x	
	Resource consumptive use and hydrologic modification	Park Visitation	0.57	x	x	x
	Visitor use levels	Park Visitation	0.52	x	x	x
	Resource violations	Park Visitation	0.45	x	x	x
Invertebrates - Terrestrial and Aquatic						
	Forest/grassland/shrubland defoliators and consumers	Native and Exotic Insects	0.77	x	x	x
	Exotic insects	Native and Exotic Insects	0.70	x	x	x
	Native insect biodiversity and distribution	Native and Exotic Insects	0.56	x	x	x
	Selected insect species of concern	Native and Exotic Insects	0.42	x	x	x
Terrestrial Vegetation						
	Grassland vegetation community composition and structure	Herbaceous Meadow and Grassland Ecosystems	1.00	x	x	x

	Attribute	Secondary Resource	Score	GRTE	YELL	BICA
	Alpine plant community characteristics	Alpine Meadow and Timberline Ecosystems	0.95	X	X	
	Lichen distribution, abundance and chemical composition	Terrestrial Ecosystems	0.95	X	X	X
	Shrubland community composition and structure	Montane Shrubland Ecosystems	0.95	X	X	X
	Aspen community composition and structure	Aspen Forest Ecosystems	0.92	X	X	
	Browse effects on riparian woody vegetation	Riparian and Riverine Wetland Ecosystems	0.92	X	X	X
	Fire and fuel loading	Terrestrial Ecosystems	0.92	X	X	X
	Plant community composition and exotic species	Whitebark Pine Woodland and Forest Ecosystems	0.92		X	
	Plant community composition and exotic species	Mixed Conifer Forest Ecosystems	0.92		X	
	Plant community composition and exotic species	Lodgepole Pine Forest Ecosystem	0.92	X	X	
	Riparian vegetation community structure and composition	Riparian and Riverine Wetland Ecosystems	0.90	X	X	X
	Shrubland exotic species	Montane Shrubland Ecosystems	0.90	X	X	X
	Wetland extent	Wet Meadow, Spring, and Depressional Wetland Ecosystems	0.90	X	X	X
	Exotic plants in riparian zone	Riparian and Riverine Wetland Ecosystems	0.87	X	X	X
	Wetland plant cover and composition	Wet Meadow, Spring, and Depressional Wetland Ecosystems	0.85	X	X	X
	Blister Rust abundance and spread	Whitebark Pine Woodland and Forest Ecosystems	0.83	X	X	
	Browsing effects within aspen stands	Aspen Forest Ecosystems	0.83	X	X	
	Plant community composition and exotic species	Terrestrial Ecosystems	0.83			X
	Plant community composition and exotic species	Ponderosa Pine Ecosystems	0.83			X
	Timberline forest density and health	Alpine Meadow and Timberline Ecosystems	0.82	X	X	
	Whitebark pine cone production	Whitebark Pine Woodland and Forest Ecosystems	0.78	X	X	
	Landscape structure and heterogeneity	Terrestrial Ecosystems	0.75	X		
	Dry woodland community structure and composition	Dry Woodland Ecosystems	0.70			X
	Extent and distribution of woodlands	Dry Woodland Ecosystems	0.70			X

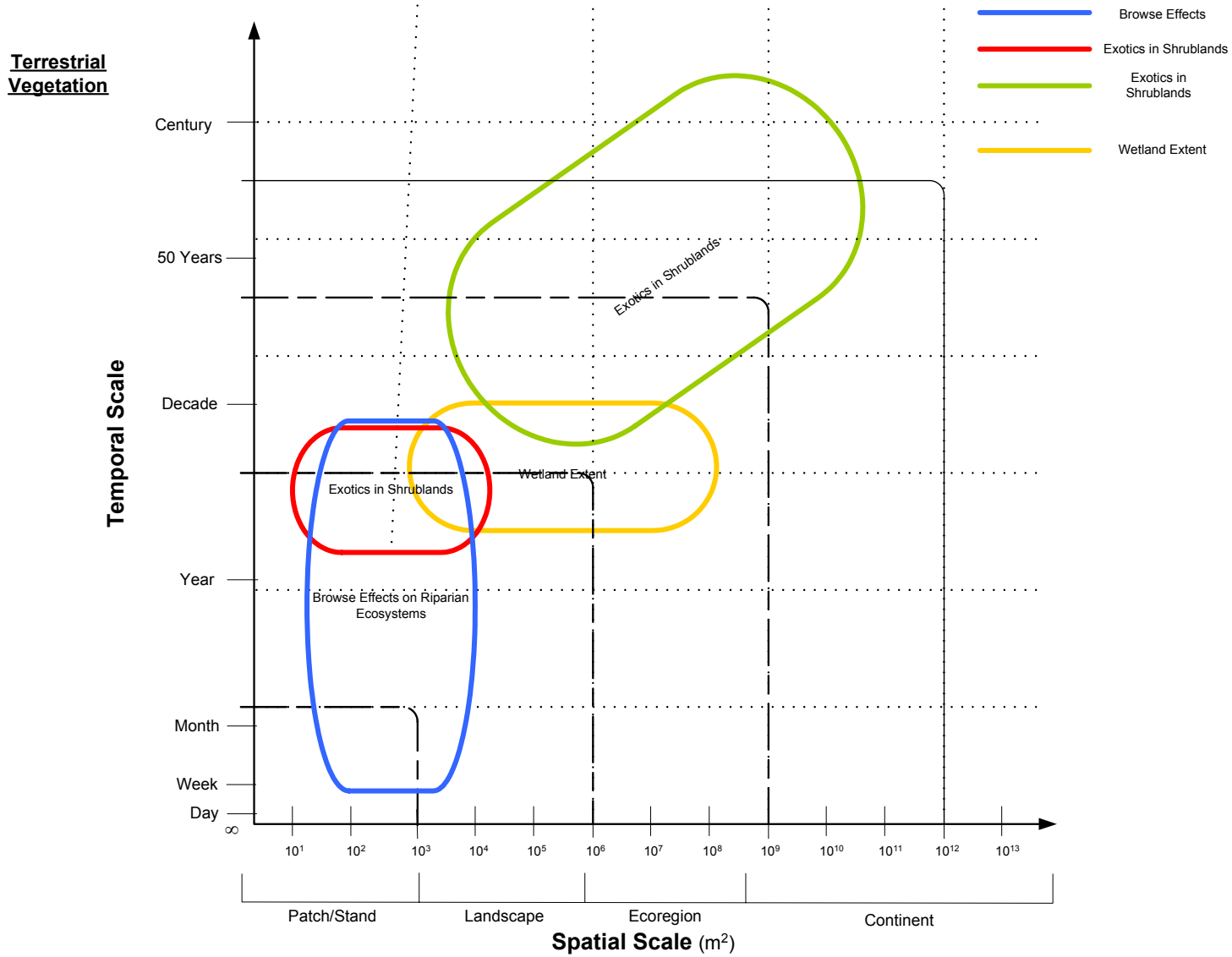
	Attribute	Secondary Resource	Score	GRTE	YELL	BICA
	Snag density	Whitebark Pine Woodland and Forest Ecosystems	0.68	X	X	
	Snag density	Mixed Conifer Forest Ecosystems	0.68	X	X	
	Snag density	Lodgepole Pine Forest Ecosystem	0.68	X	X	
	Timberline elevation boundaries	Alpine Meadow and Timberline Ecosystems	0.67	X	X	
	Landscape structure and heterogeneity	Terrestrial Ecosystems	0.65		X	
	Stand density of high-elevation live and dead whitebark pine trees	Whitebark Pine Woodland and Forest Ecosystems	0.63	X	X	
	Aspen stand extent and distribution in landscape	Aspen Forest Ecosystems	0.60	X	X	
	Forest floor litter and coarse woody debris	Mixed Conifer Forest Ecosystems	0.60	X	X	
	Forest floor litter and coarse woody debris	Lodgepole Pine Forest Ecosystem	0.55	X	X	
	Landscape structure and heterogeneity	Terrestrial Ecosystems	0.55			X
	Stand density of live and dead trees	Ponderosa Pine Ecosystems	0.53			X
	Aboveground net primary productivity	Terrestrial Ecosystems	0.50	X	X	X
	Grassland annual net primary productivity	Herbaceous Meadow and Grassland Ecosystems	0.45	X	X	X
	Grassland nitrogen	Herbaceous Meadow and Grassland Ecosystems	0.38	X	X	X
	Shrubland nitrogen	Montane Shrubland Ecosystems	0.38	X	X	X
	Grassland vegetation annual offtake	Herbaceous Meadow and Grassland Ecosystems	0.13	X	X	X
Terrestrial Vertebrates						
	Amphibian occurrence	Terrestrial Vertebrates	1.00	X	X	X
	Beaver presence and population estimates	Mammals	1.00	X	X	X
	Pattern of non-park land-use changes	Terrestrial Vertebrates	1.00	X	X	X
	Invasive vertebrate species richness and distribution	Terrestrial Vertebrates	0.92	X	X	X
	Vertebrate diseases	Terrestrial Vertebrates	0.92	X	X	X
	Raptor population abundance, distribution and productivity	Birds	0.87	X	X	X
	Selected sensitive bird species abundance, distribution and productivity	Birds	0.87	X	X	X
	Colony nesting bird population abundance, distribution, vital rates and productivity	Birds	0.82	X	X	X

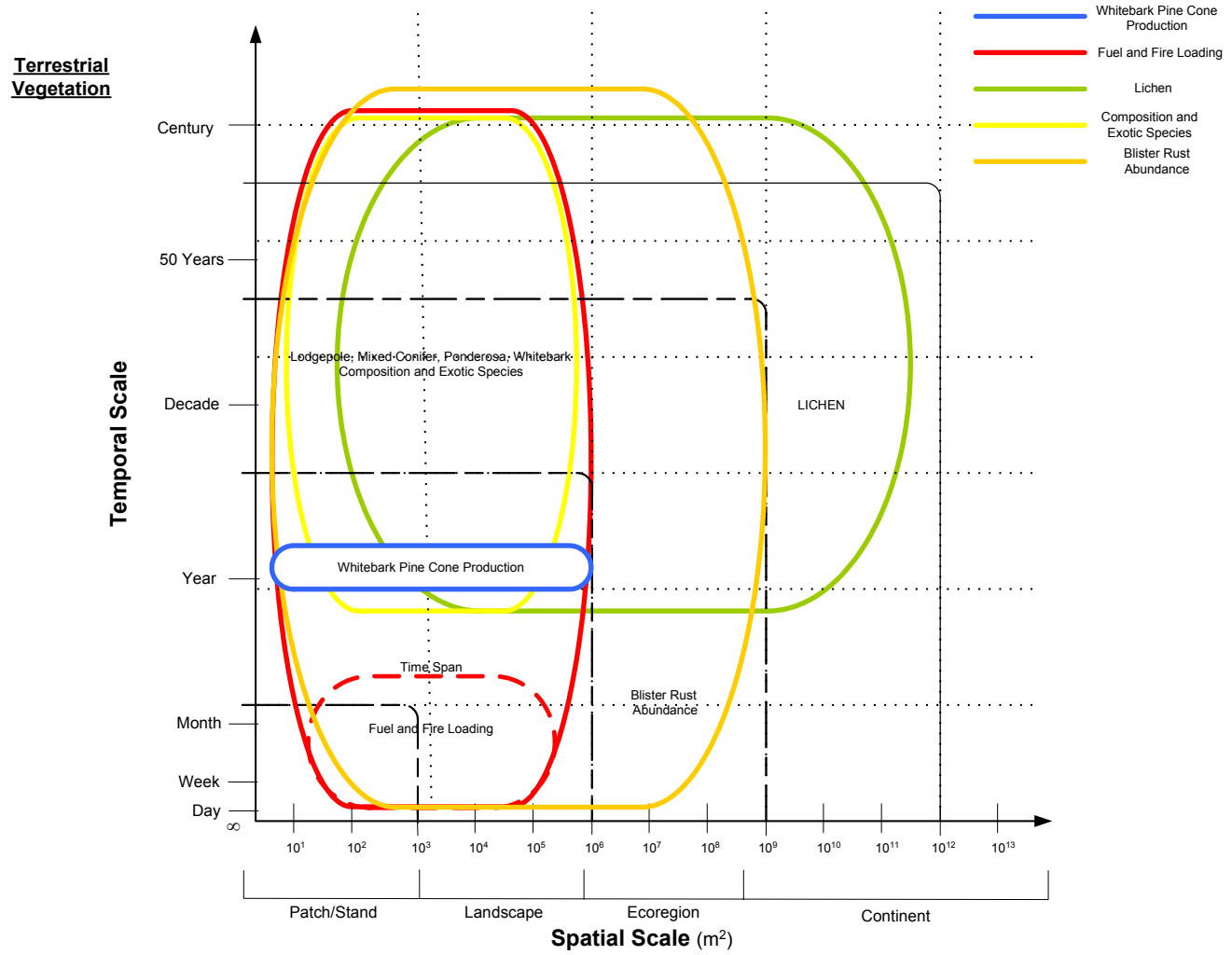
	Attribute	Secondary Resource	Score	GRTE	YELL	BICA
	Ungulate population abundance, distribution and productivity	Mammals	0.78	X	X	X
	Song bird population abundance and distribution	Birds	0.73	X	X	X
	Bat occurrence, distribution and abundance	Mammals	0.72	X	X	X
	Large carnivore population abundance and distribution	Mammals	0.60	X	X	X
	Meso-carnivore population abundance and distribution	Mammals	0.60	X	X	X
	Rodents and Lagomorphs (>250g) population, abundance and distribution	Mammals	0.58	X	X	X
	Native species richness	Terrestrial Vertebrates	0.53	X	X	X
	Rodents and insectivores (<250g) population, abundance and distribution	Mammals	0.50	X	X	X
	Reptile occurrence	Terrestrial Vertebrates	0.22			X
Water Quality						
	Ground water hydrology	Ground Water	1.00	X	X	X
	Reservoir elevation	Lakes and Reservoirs	1.00	X		X
	Streamflow	Rivers and Streams	1.00	X	X	X
	Algal species composition and biomass	Lakes and Reservoirs	0.95	X	X	X
	Continuous water temperature	Lakes and Reservoirs	0.95	X	X	X
	Continuous water temperature	Rivers and Streams	0.95	X	X	X
	Ground water chemistry	Ground Water	0.95	X	X	X
	Major ion chemistry	Rivers and Streams	0.95	X	X	X
	Major ion chemistry	Lakes and Reservoirs	0.95	X	X	X
	River invertebrate assemblages	Rivers and Streams	0.95	X	X	X
	Bed sediment chemistry (adsorbed)	Rivers and Streams	0.82	X	X	X
	Bed sediment shemistry (adsorbed)	Lakes and Reservoirs	0.82	X	X	X
	Metals	Rivers and Streams	0.69	X	X	X
	Metals	Lakes and Reservoirs	0.69	X	X	X
	Periphyton community structure, chlorophyll a	Rivers and Streams	0.58	X	X	X
	Zooplankton community structure	Lakes and Reservoirs	0.48	X	X	X
	E. coli	Rivers and Streams	0.38	X	X	X
	E. coli	Lakes and Reservoirs	0.38	X	X	X
	Field parameters	Rivers and Streams	0.38	X	X	X
Watershed						

	Attribute	Secondary Resource	Score	GRTE	YELL	BICA
	Watershed budgets	Watersheds	0.90	x	x	x

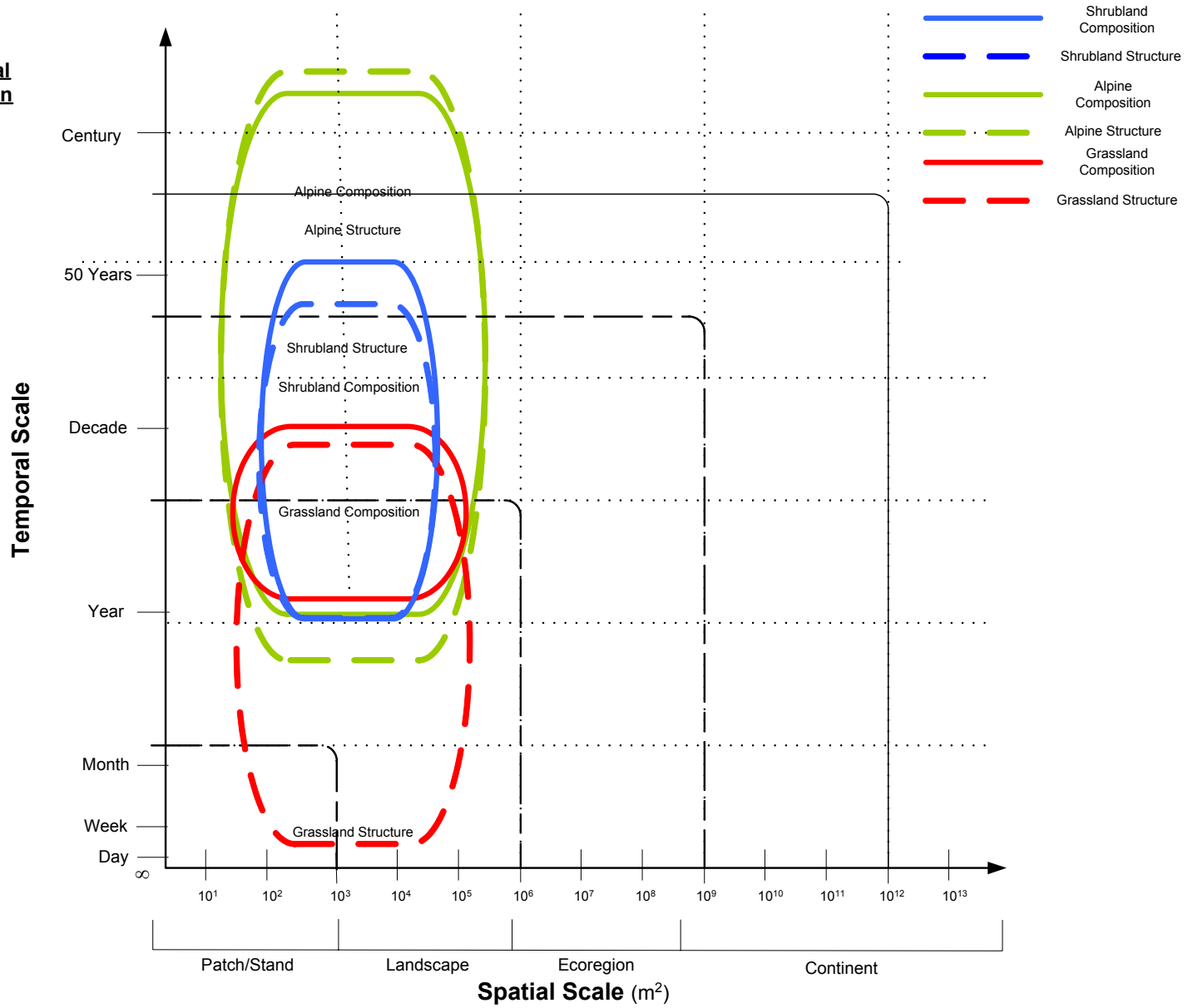
APPENDIX II.J-SPATIO-TEMPORAL MODELS

**Please note: these models are reproduction of those made by the breakout groups on day three of the workshop.

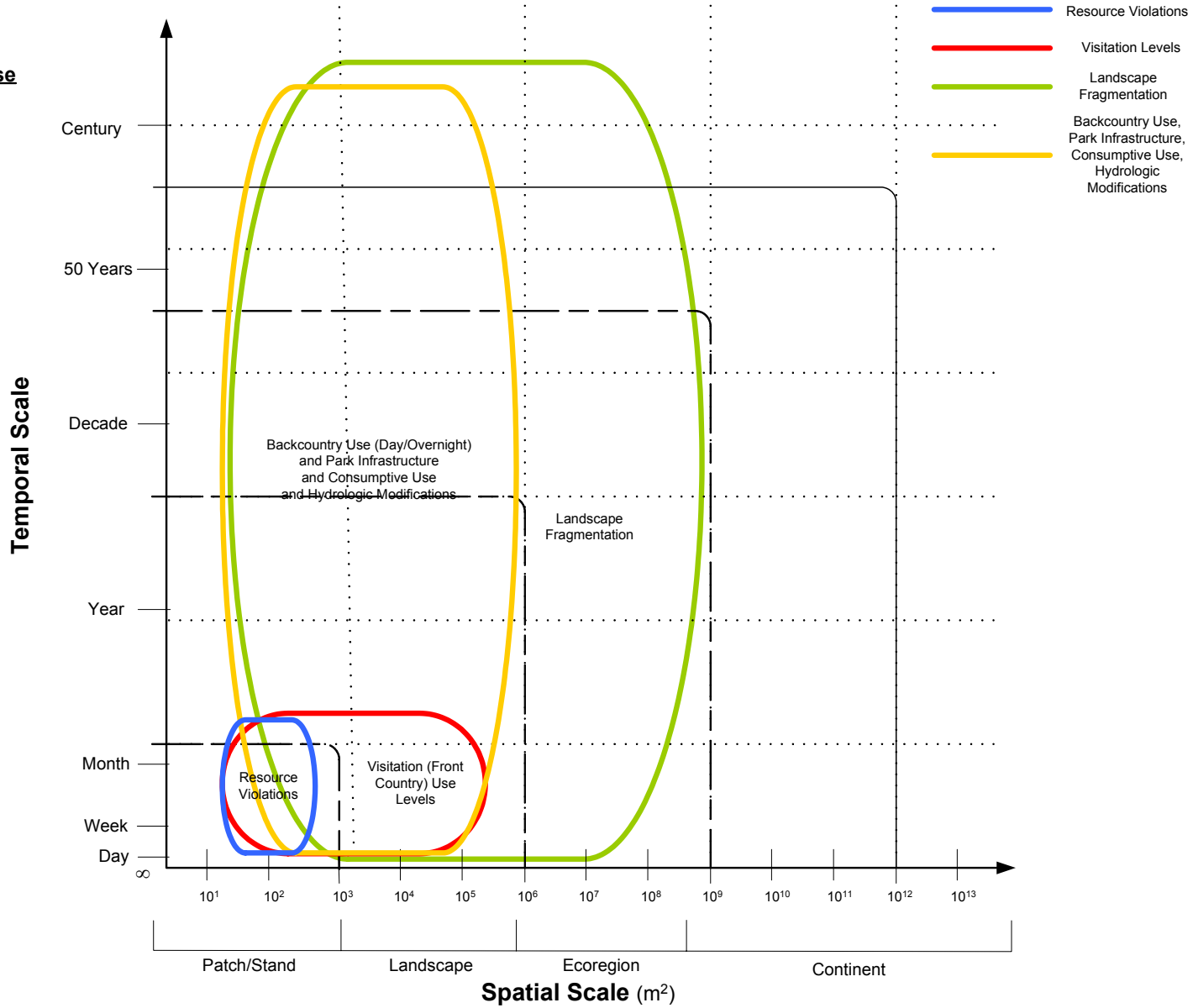



Terrestrial Vegetation
Whitebark Pine Cone Production
Fuel and Fire Loading
Lichen
Composition and Exotic Species
Blister Rust Abundance
Century
50 Years
Decade
Year
Month
Week
Day
Temporal Scale
Lodgepole, Mixed-Conifer, Ponderosa, Whitebark Composition and Exotic Species
LICHEN
Whitebark Pine Cone Production
Time Span
Blister Rust Abundance
Fuel and Fire Loading
10^1 10^2 10^3 10^4 10^5 10^6 10^7 10^8 10^9 10^{10} 10^{11} 10^{12} 10^{13}
Patch/Stand
Landscape
Ecoregion
Continent
Spatial Scale (m^2)

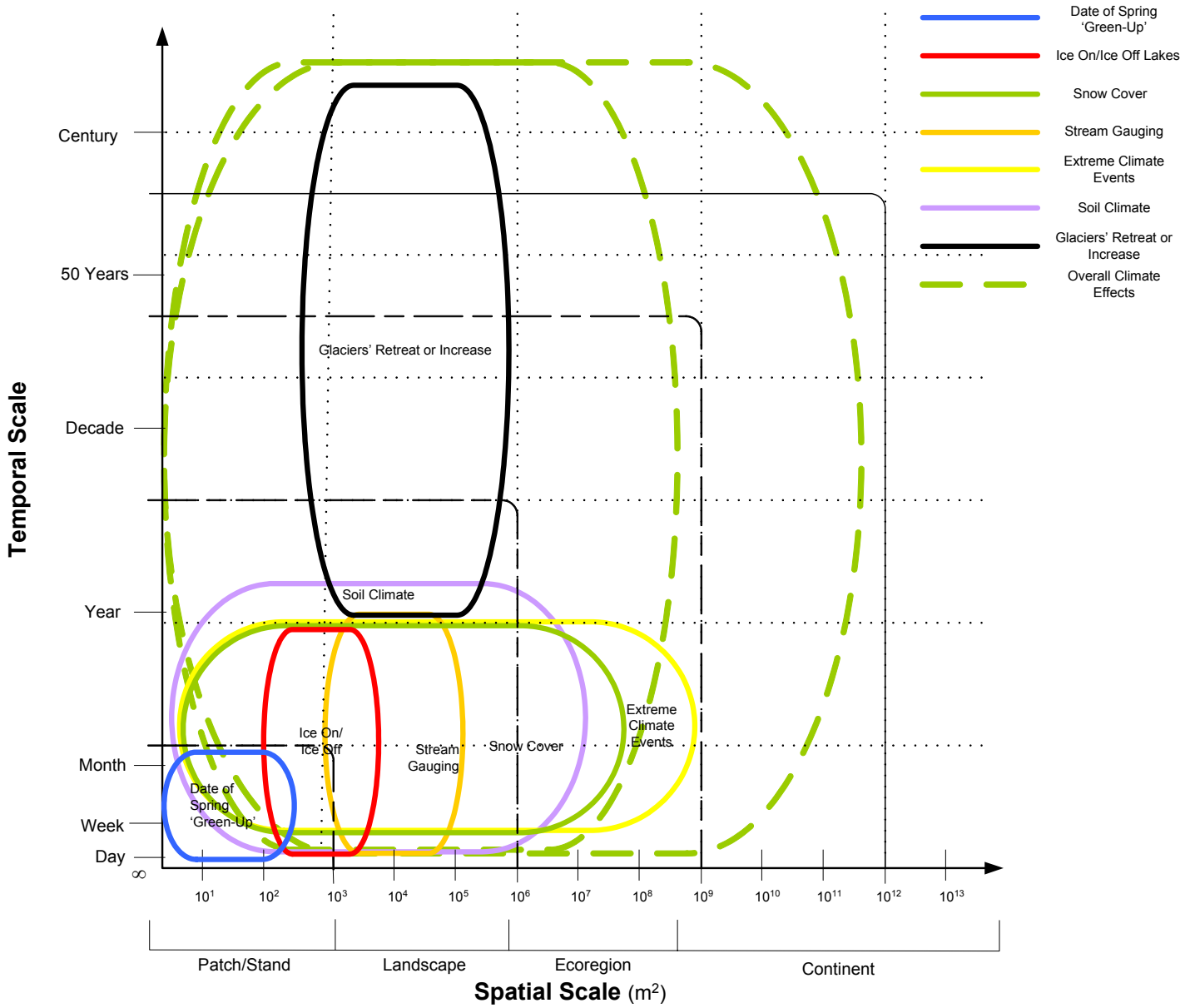
Terrestrial Vegetation



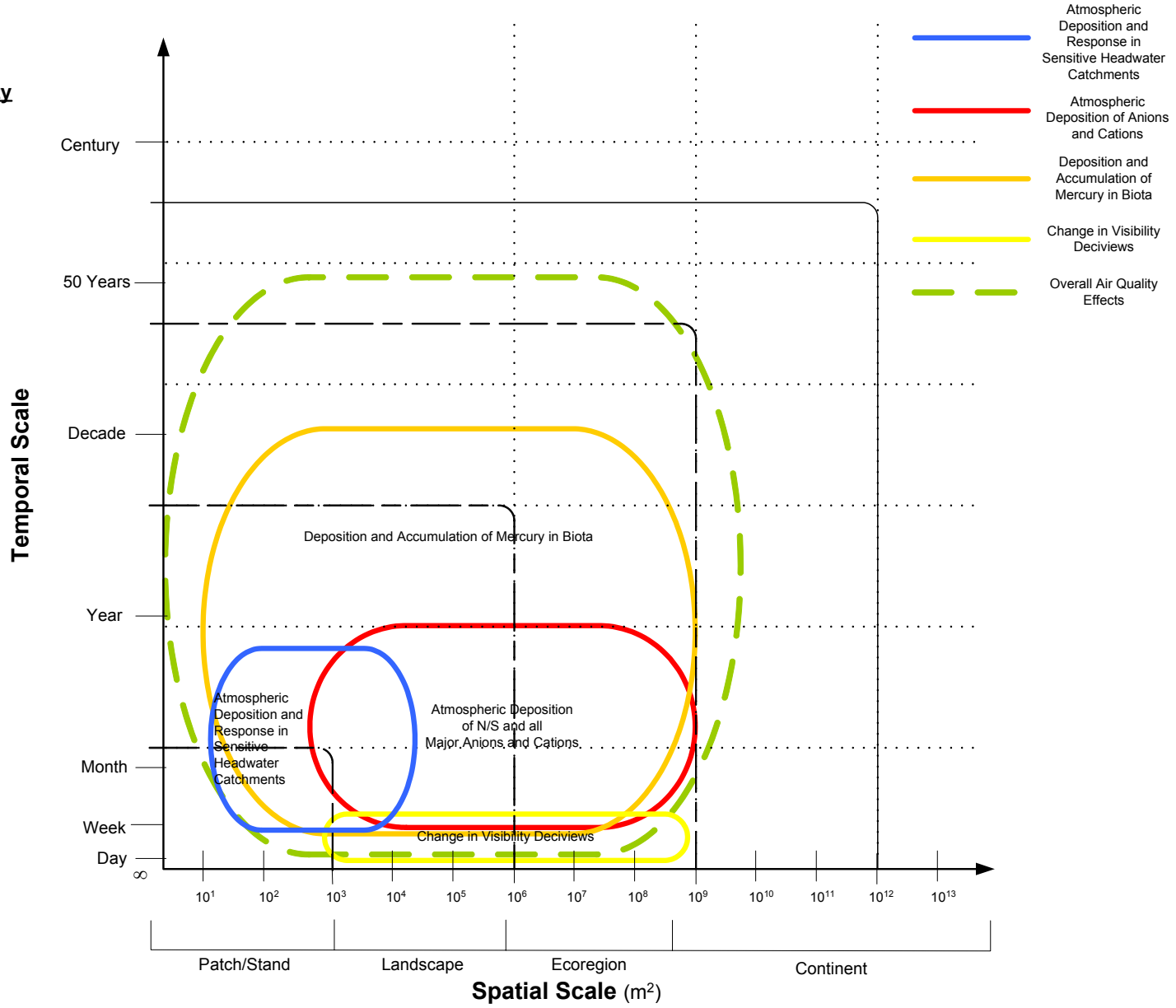
Human Use


Resource Violations
Visitation Levels
Landscape Fragmentation
Backcountry Use, Park Infrastructure, Consumptive Use, Hydrologic Modifications
Century
50 Years
Decade
Year
Month
Week
Day
Temporal Scale
Backcountry Use (Day/Overnight) and Park Infrastructure and Consumptive Use and Hydrologic Modifications
Landscape Fragmentation
Resource Violations
Visitation (Front Country) Use Levels
10^1 10^2 10^3 10^4 10^5 10^6 10^7 10^8 10^9 10^{10} 10^{11} 10^{12} 10^{13}
Patch/Stand
Landscape
Ecoregion
Continent
Spatial Scale (m^2)

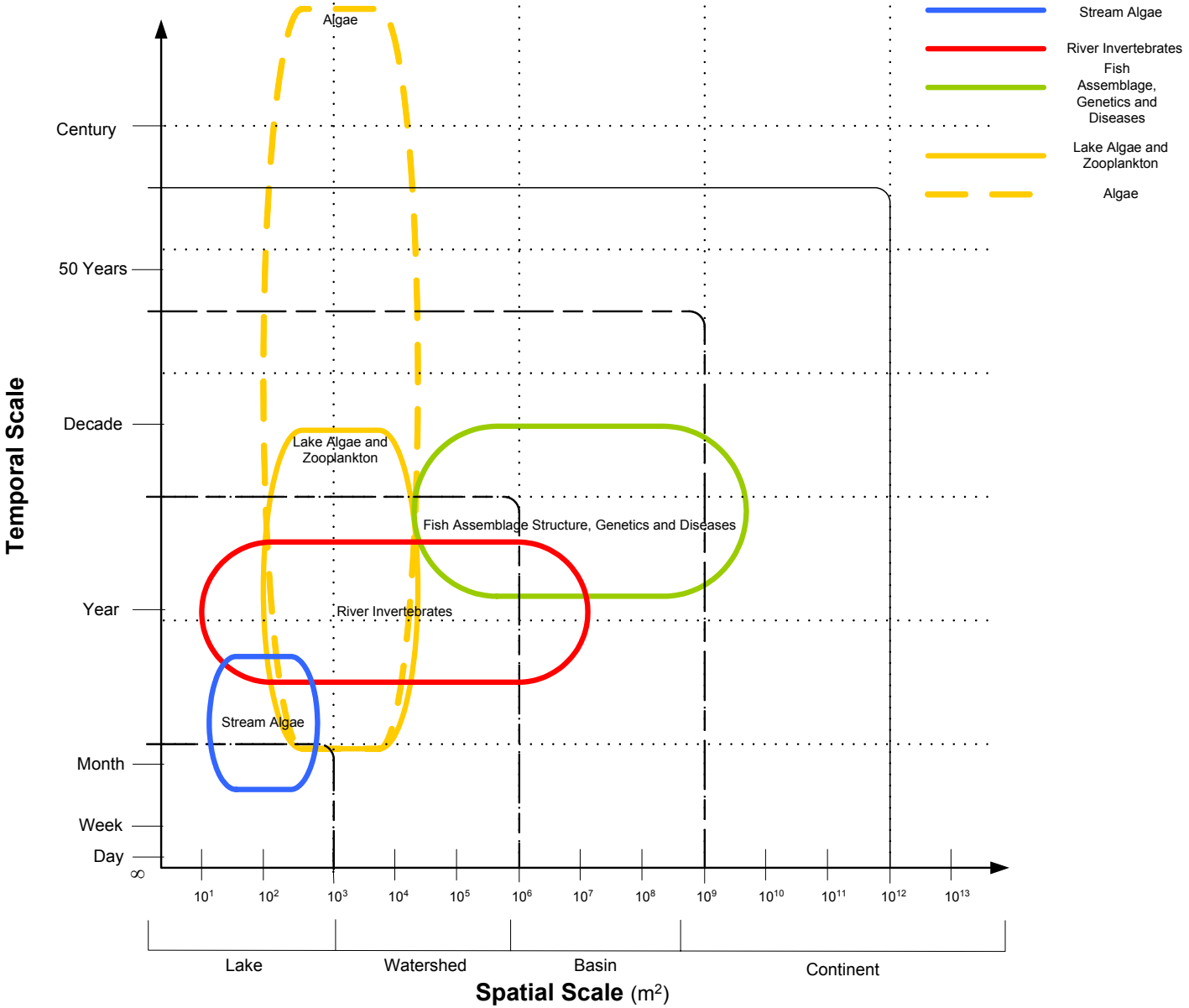
Climate


Date of Spring 'Green-Up'
Ice On/Ice Off Lakes
Snow Cover
Stream Gauging
Extreme Climate Events
Soil Climate
Glaciers' Retreat or Increase
Overall Climate Effects
Century
50 Years
Decade
Year
Month
Week
Day
∞
Temporal Scale
Glaciers' Retreat or Increase
Soil Climate
Ice On/ Ice Off
Stream Gauging
Snow Cover
Extreme Climate Events
Date of Spring 'Green-Up'
10^1 10^2 10^3 10^4 10^5 10^6 10^7 10^8 10^9 10^{10} 10^{11} 10^{12} 10^{13}
Patch/Stand
Landscape
Ecoregion
Continent
Spatial Scale (m^2)

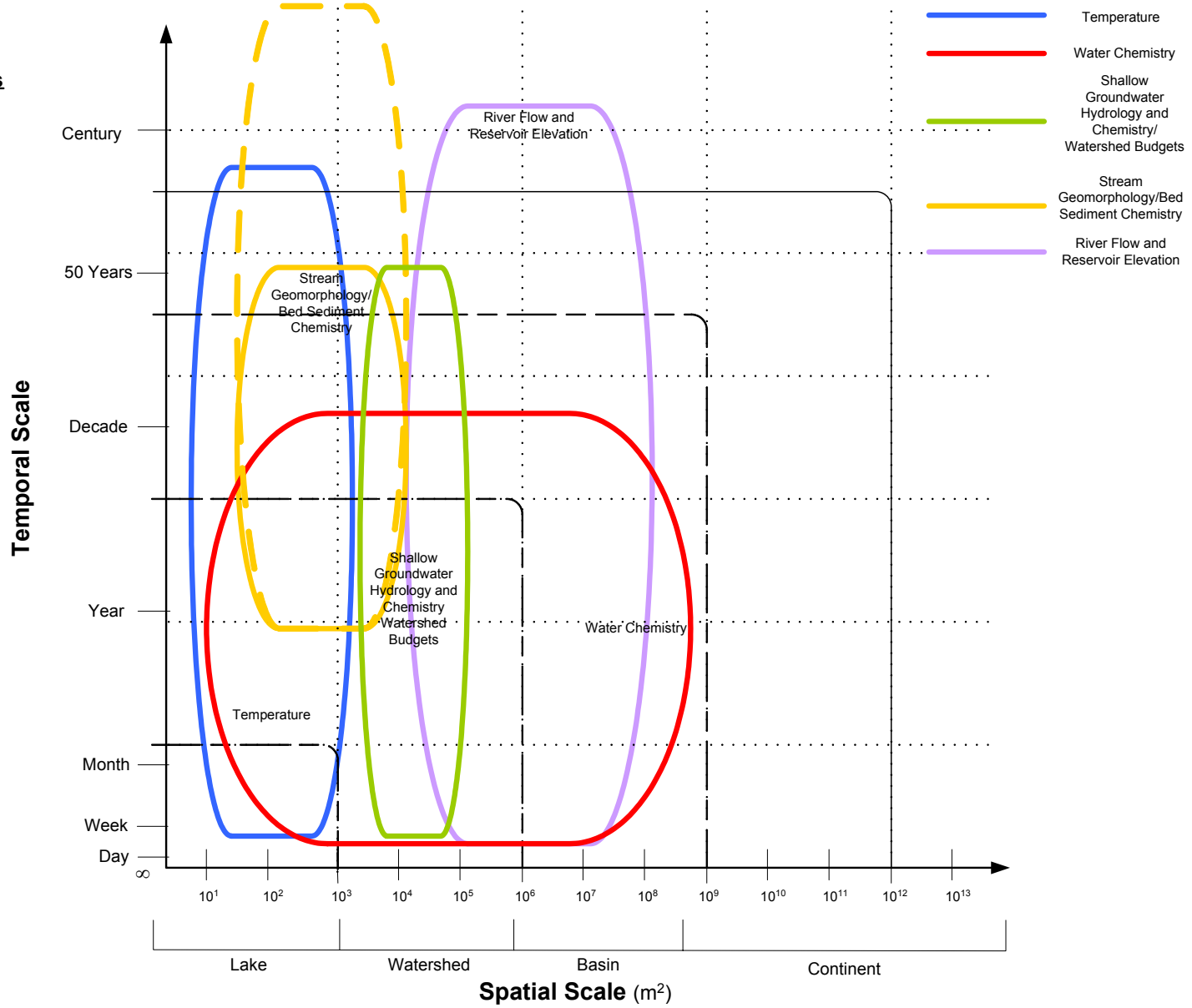
Air Quality


Atmospheric Deposition and Response in Sensitive Headwater Catchments
Atmospheric Deposition of Anions and Cations
Deposition and Accumulation of Mercury in Biota
Change in Visibility Deciviews
Overall Air Quality Effects
Temporal Scale
Century
50 Years
Decade
Year
Month
Week
Day
∞
Deposition and Accumulation of Mercury in Biota
Atmospheric Deposition and Response in Sensitive Headwater Catchments
Atmospheric Deposition of N/S and all Major Anions and Cations
Change in Visibility Deciviews
10^1 10^2 10^3 10^4 10^5 10^6 10^7 10^8 10^9 10^{10} 10^{11} 10^{12} 10^{13}
Patch/Stand
Landscape
Ecoregion
Continent
Spatial Scale (m^2)

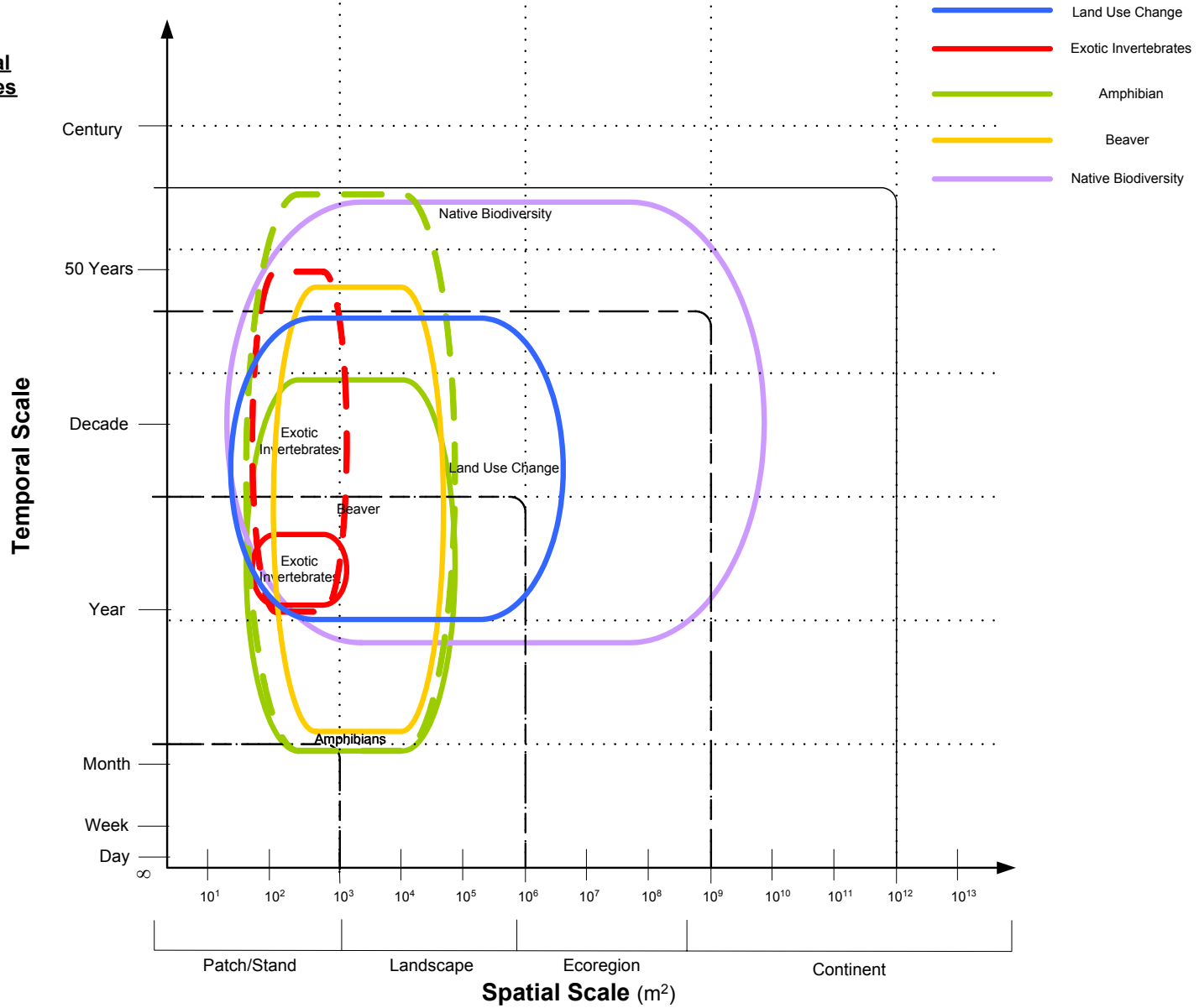
Aquatics

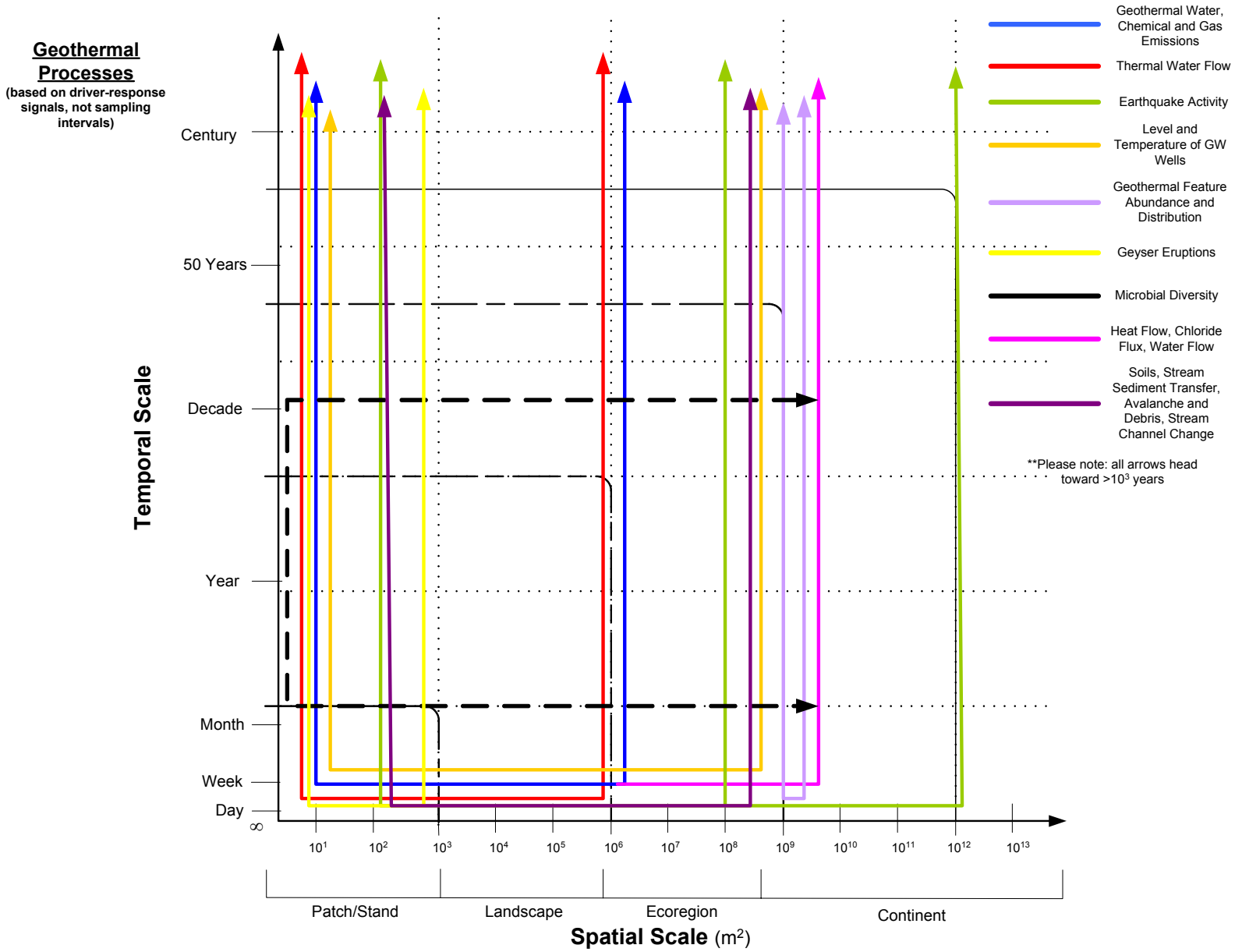

Stream Algae
River Invertebrates
Fish Assemblage, Genetics and Diseases
Lake Algae and Zooplankton
Algae
Century
50 Years
Decade
Year
Month
Week
Day
∞
Temporal Scale
Algae
Lake Algae and Zooplankton
Fish Assemblage Structure, Genetics and Diseases
River Invertebrates
Stream Algae
10^1 10^2 10^3 10^4 10^5 10^6 10^7 10^8 10^9 10^{10} 10^{11} 10^{12} 10^{13}
Lake
Watershed
Basin
Continent
Spatial Scale (m^2)

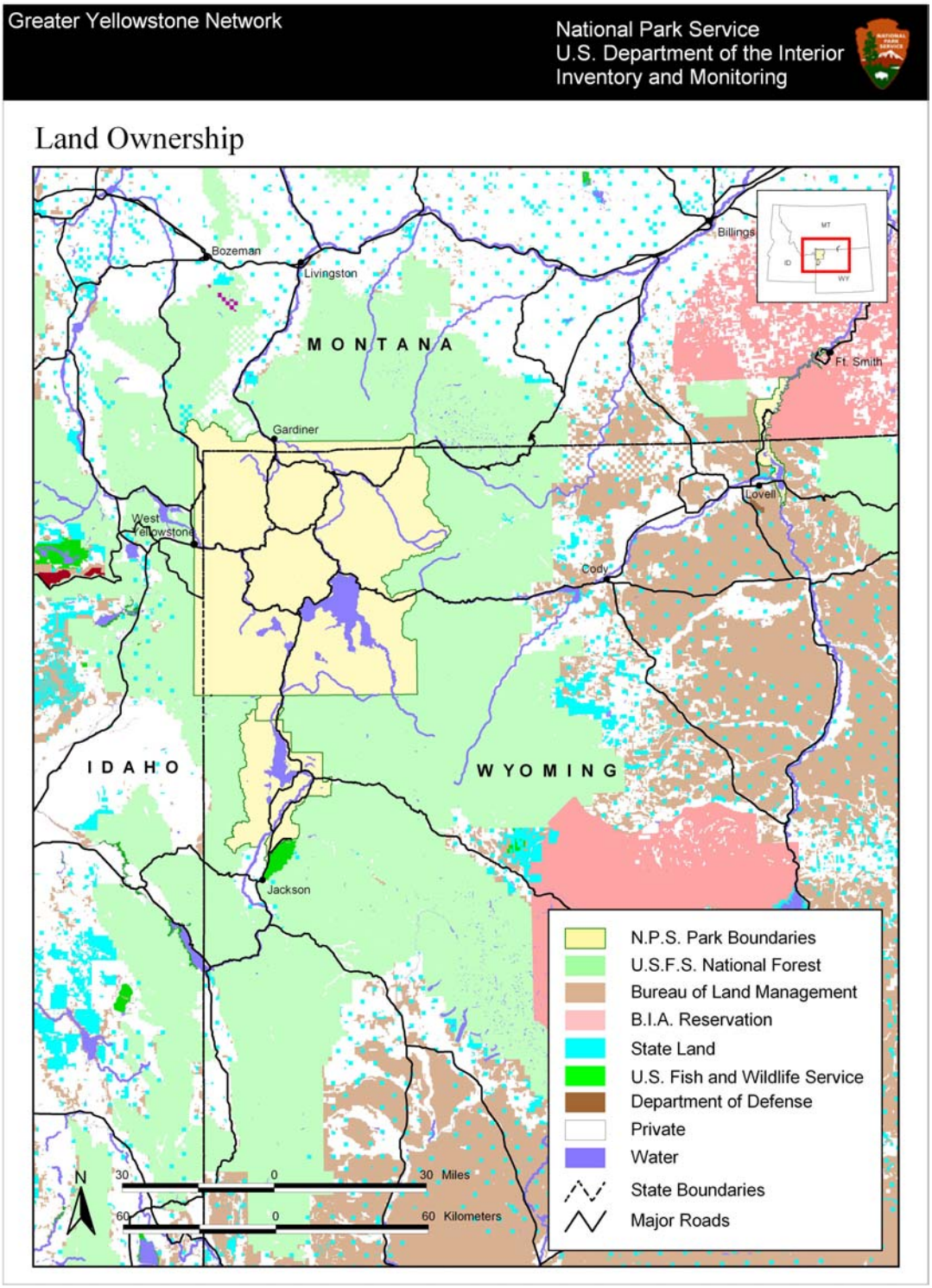
Aquatics


Temporal Scale
Century
50 Years
Decade
Year
Month
Week
Day
∞
River Flow and Reservoir Elevation
Stream Geomorphology/ Bed Sediment Chemistry
Shallow Groundwater Hydrology and Chemistry Watershed Budgets
Water Chemistry
Temperature
10^1 10^2 10^3 10^4 10^5 10^6 10^7 10^8 10^9 10^{10} 10^{11} 10^{12} 10^{13}
Lake
Watershed
Basin
Continent
Spatial Scale (m²)
Temperature
Water Chemistry
Shallow Groundwater Hydrology and Chemistry/ Watershed Budgets
Stream Geomorphology/Bed Sediment Chemistry
River Flow and Reservoir Elevation

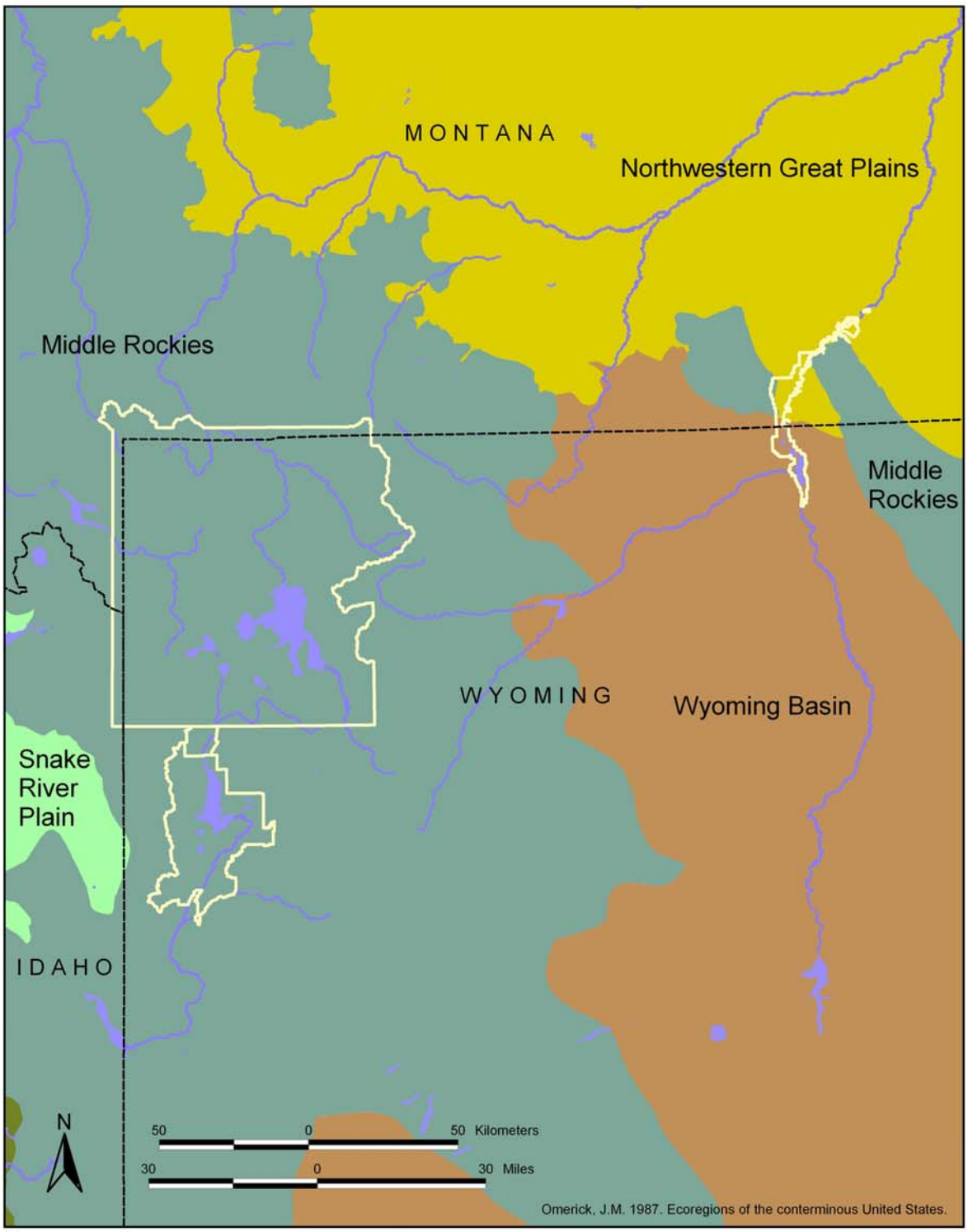
Terrestrial Vertebrates



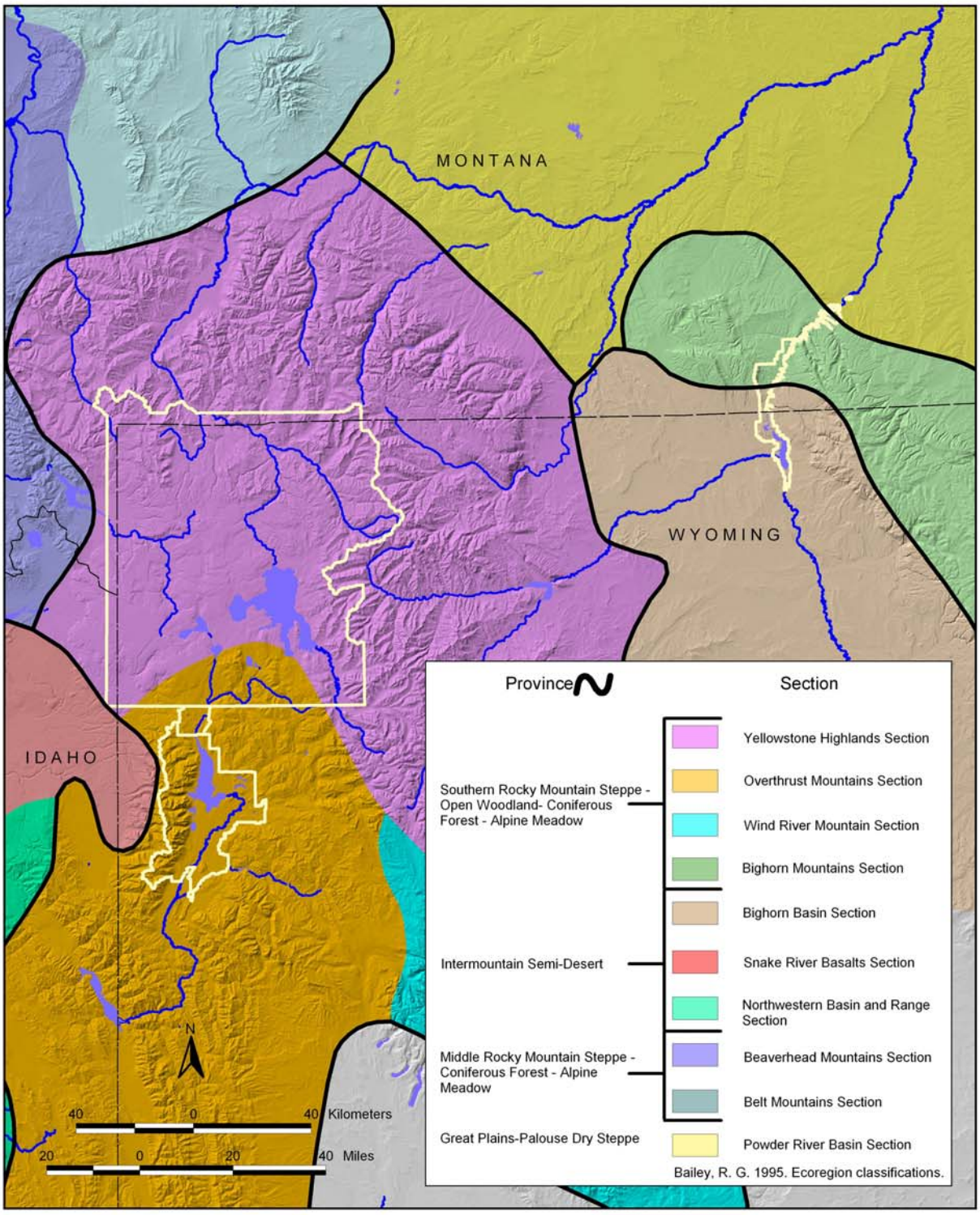

Geothermal Processes
(based on driver-response signals, not sampling intervals)
Century
50 Years
Decade
Year
Month
Week
Day
∞
Temporal Scale
Geothermal Water, Chemical and Gas Emissions
Thermal Water Flow
Earthquake Activity
Level and Temperature of GW Wells
Geothermal Feature Abundance and Distribution
Geyser Eruptions
Microbial Diversity
Heat Flow, Chloride Flux, Water Flow
Soils, Stream Sediment Transfer, Avalanche and Debris, Stream Channel Change
**Please note: all arrows head toward >10^3 years
10^1 10^2 10^3 10^4 10^5 10^6 10^7 10^8 10^9 10^10 10^11 10^12 10^13
Patch/Stand
Landscape
Ecoregion
Continent
Spatial Scale (m^2)


Greater Yellowstone Network
National Park Service
U.S. Department of the Interior
Inventory and Monitoring
Land Ownership
Bozeman
Livingston
Billings
MONTANA
Gardiner
Ft. Smith
Lovell
West Yellowstone
Cody
IDAHO
WYOMING
Jackson
N.P.S. Park Boundaries
U.S.F.S. National Forest
Bureau of Land Management
B.I.A. Reservation
State Land
U.S. Fish and Wildlife Service
Department of Defense
Private
Water
State Boundaries
Major Roads
N
30 0 30 Miles
60 0 60 Kilometers

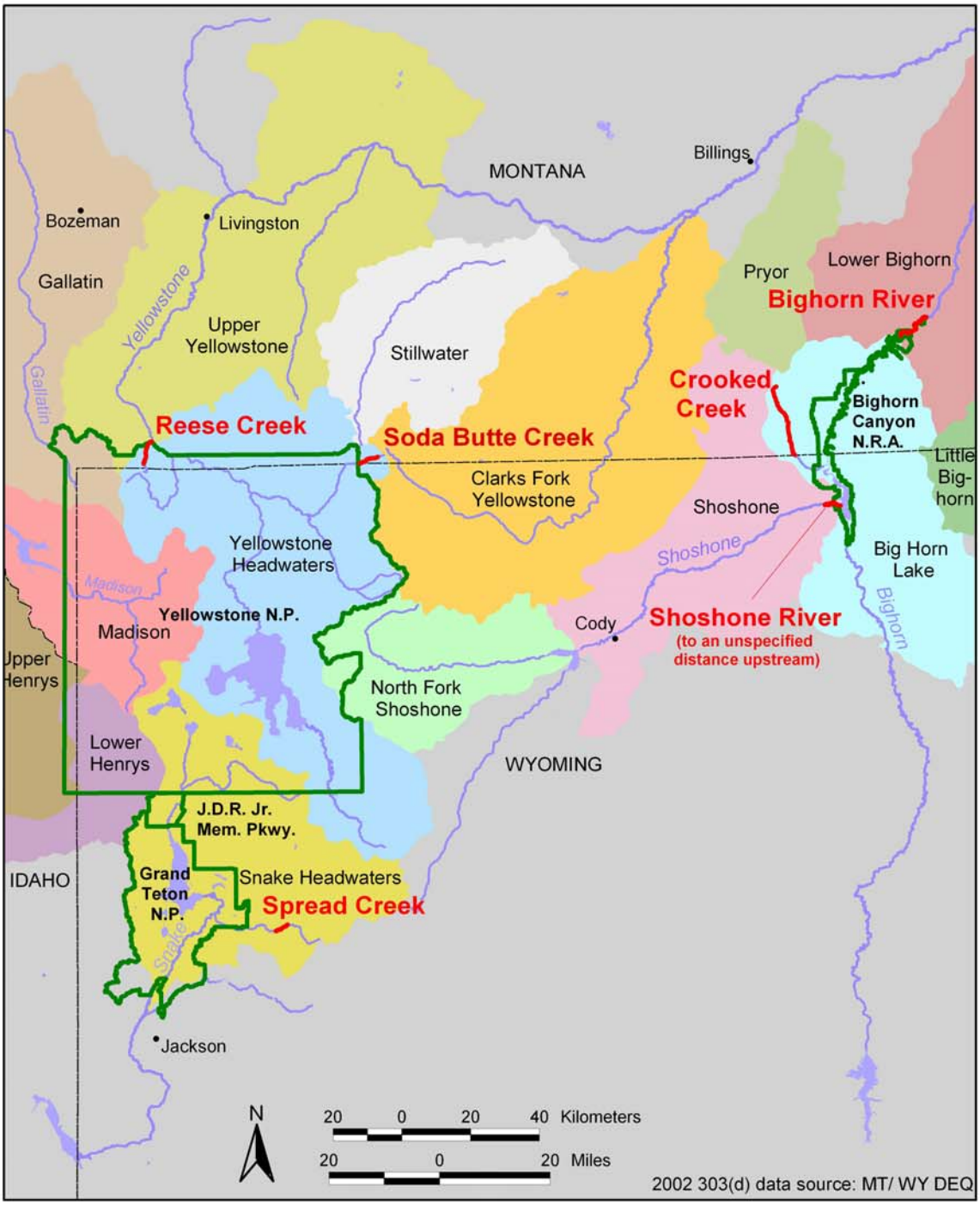
Omernick's Level III Ecoregions



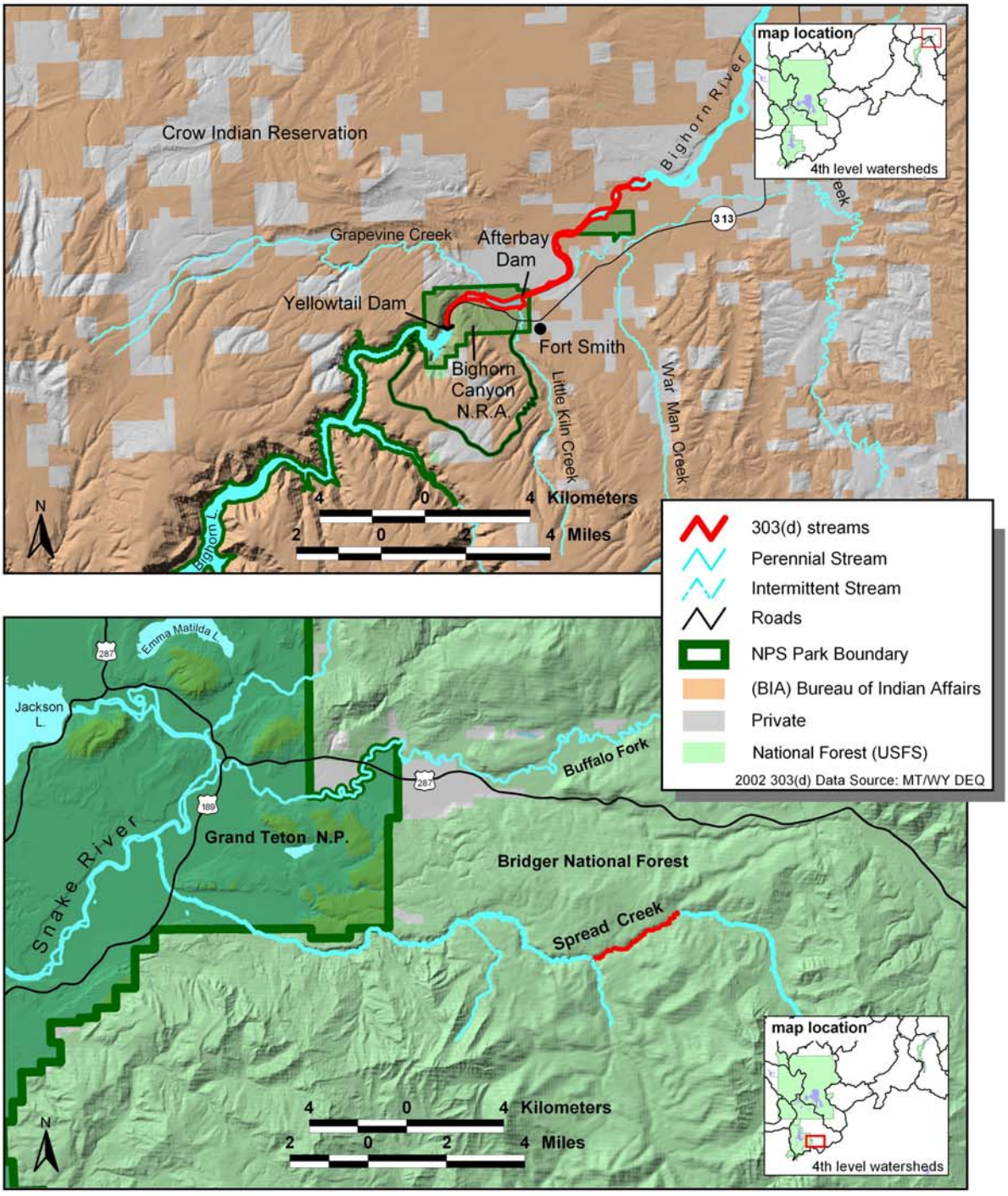
Ecological Units



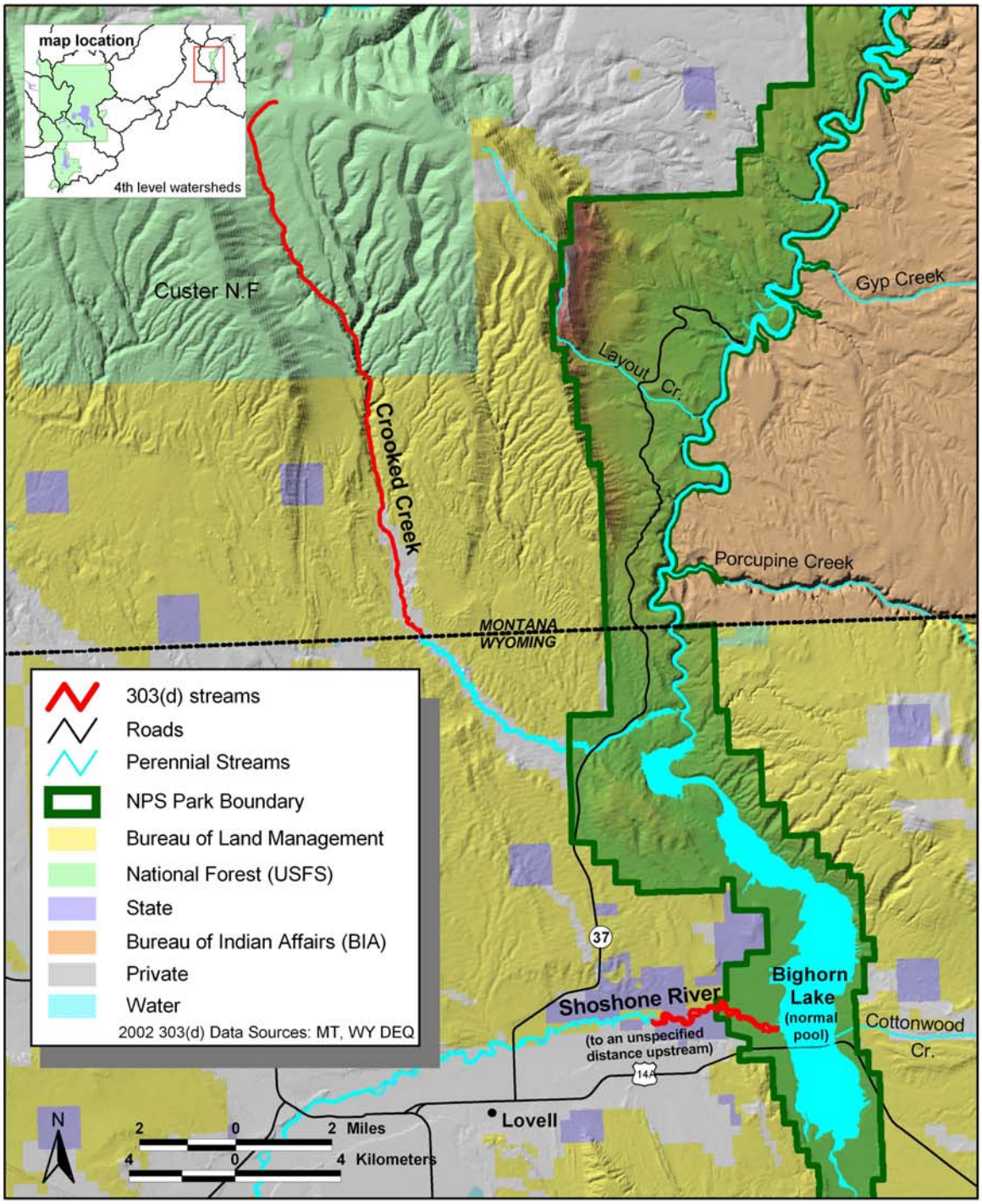
303(d) Impaired Waters and 4th Level Watersheds



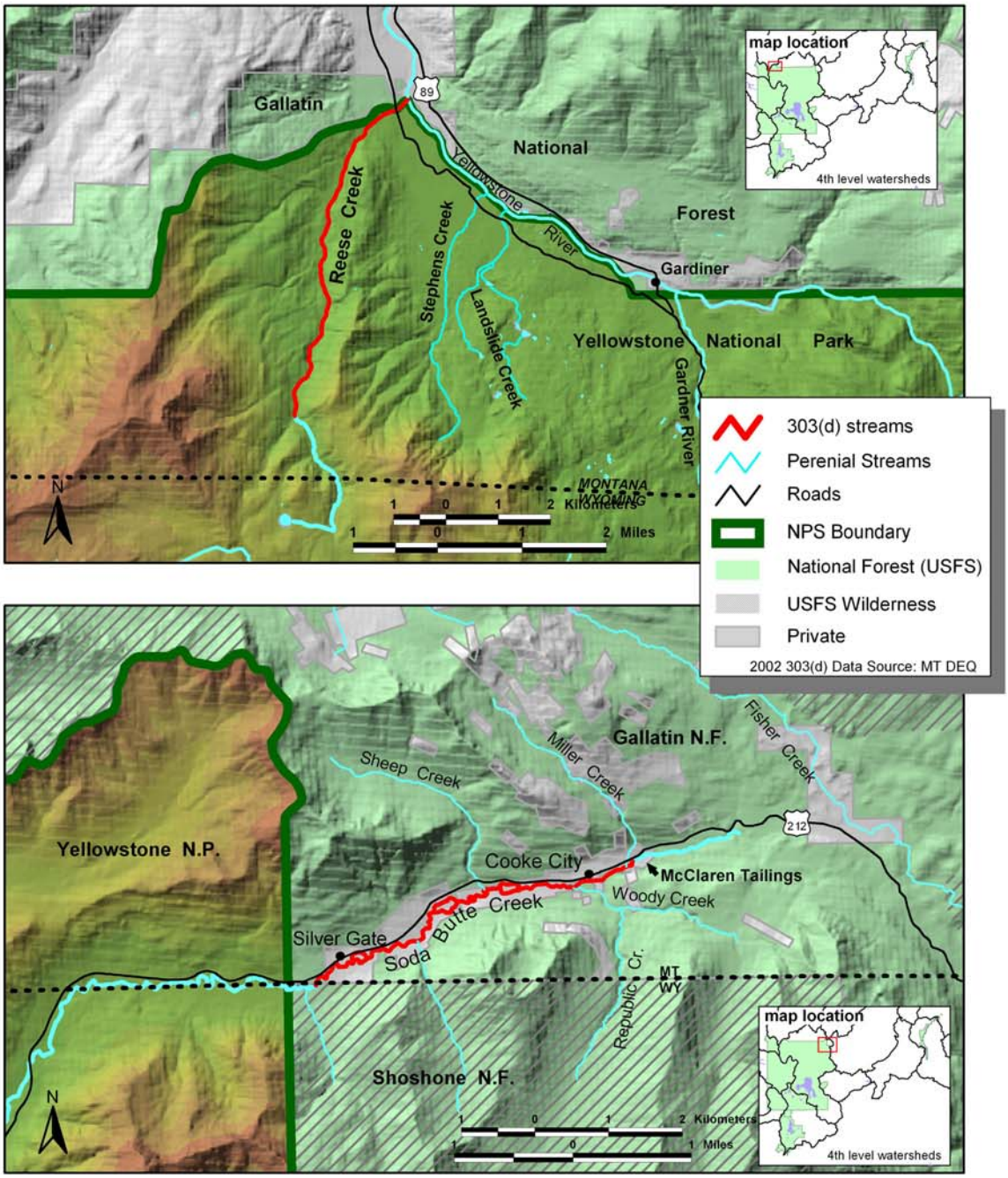
State of Montana and Wyoming 303(d) Impaired Waters
Bighorn Canyon N.R.A. and Grand Teton N.P.



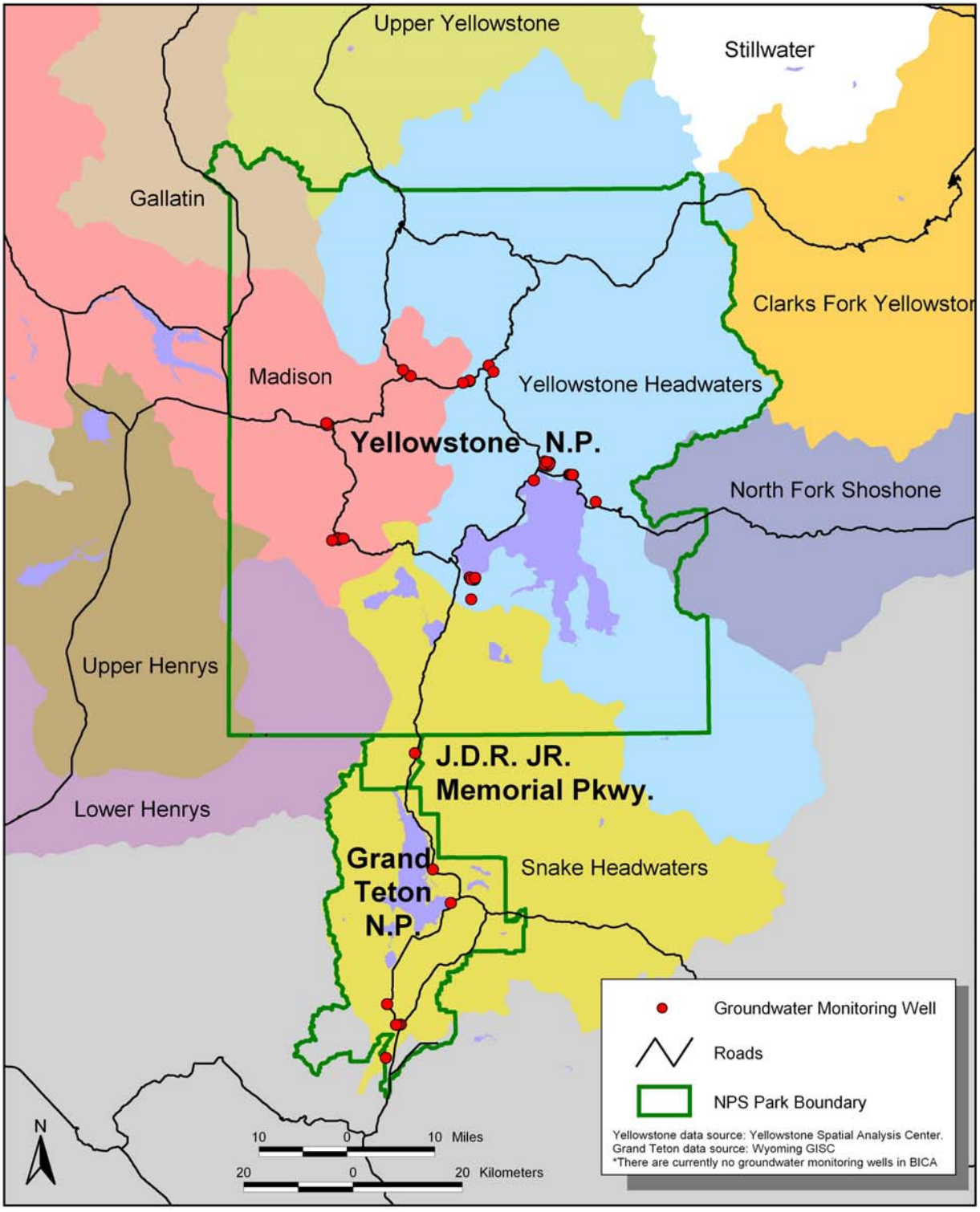
State of Montana and Wyoming 303(d) Impaired Waters
Bighorn Canyon N.R.A.



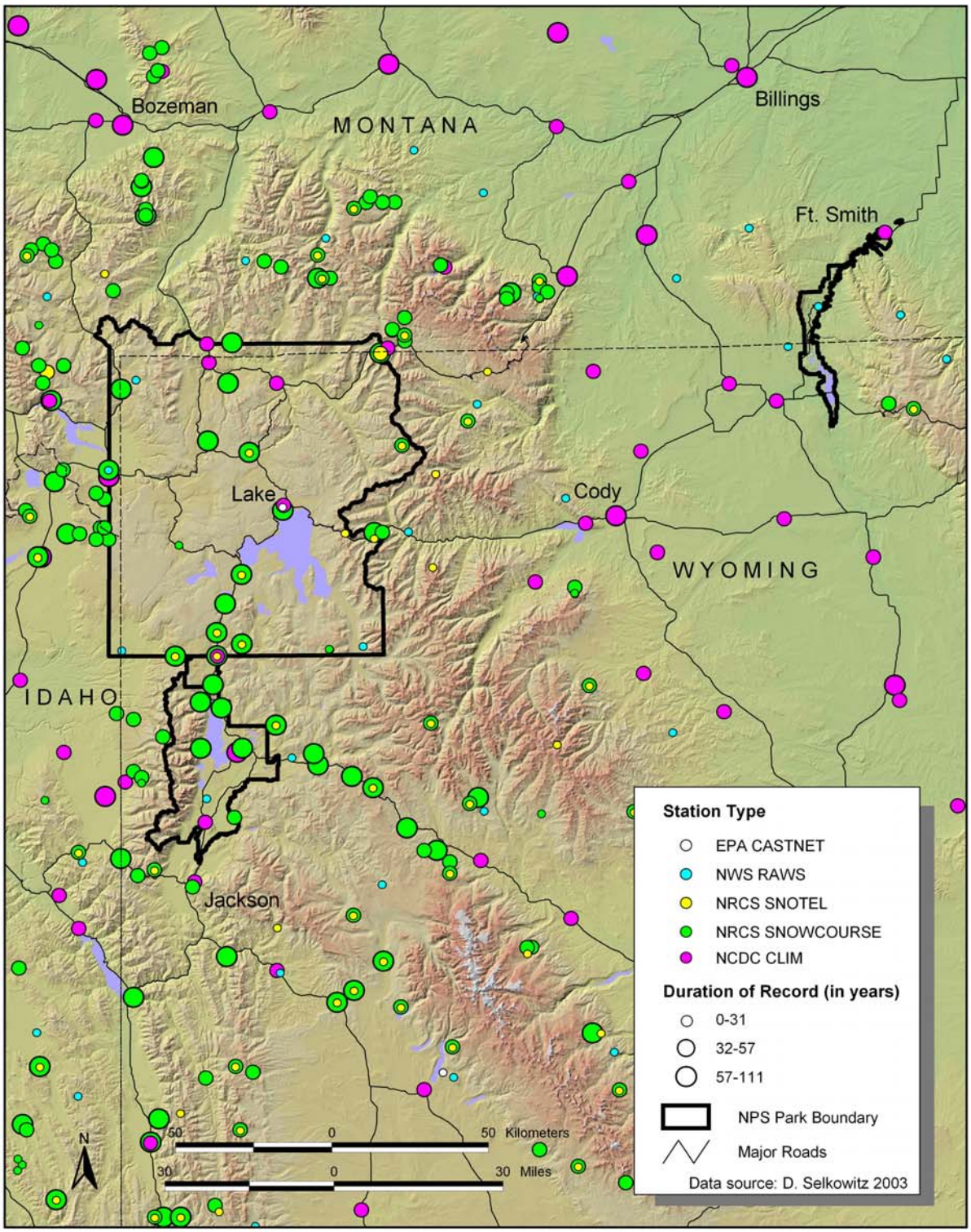
State of Montana 303(d) Impaired Waters
Yellowstone National Park



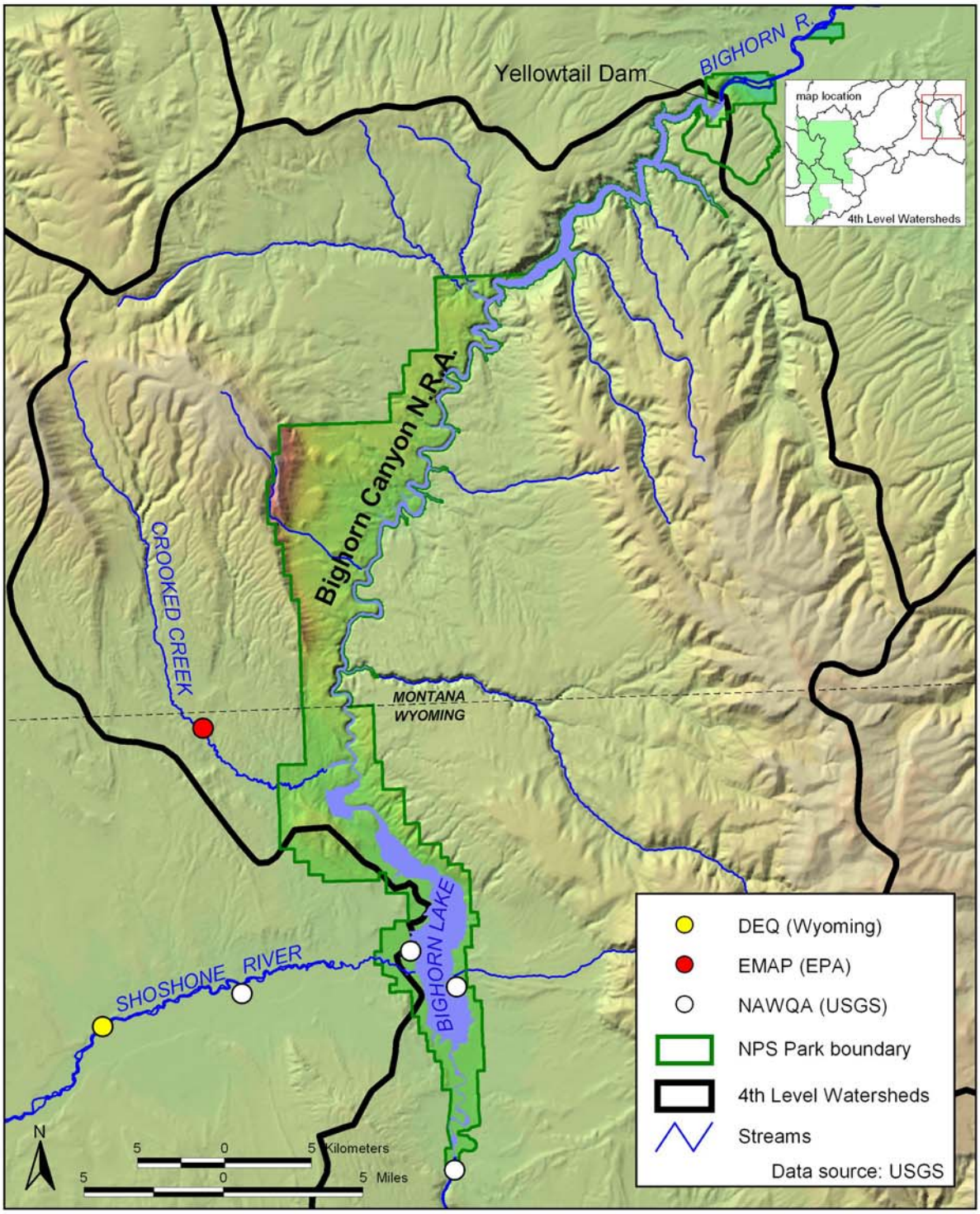
Groundwater Monitoring Locations and 4th Level Watersheds



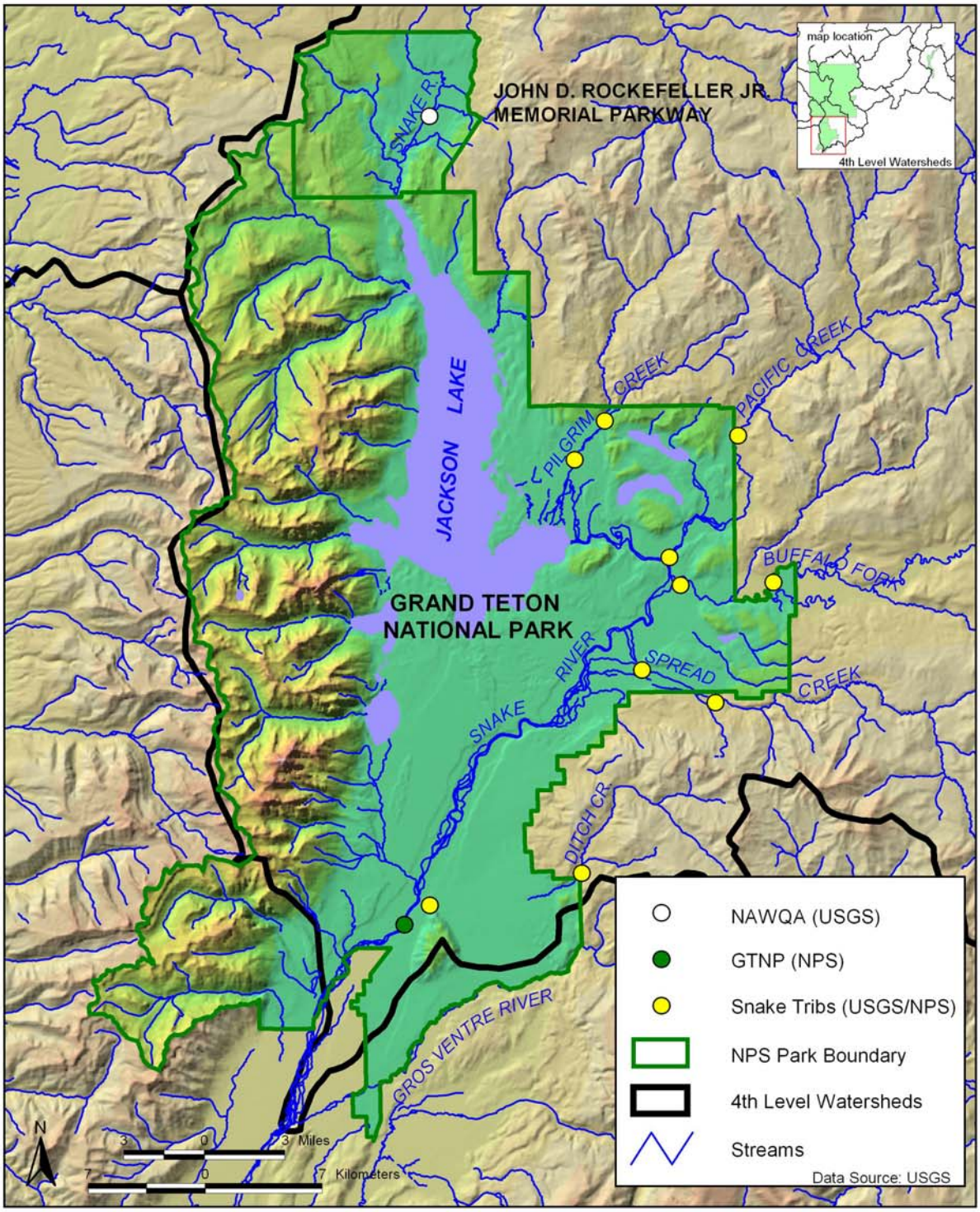
Climate Monitoring Stations



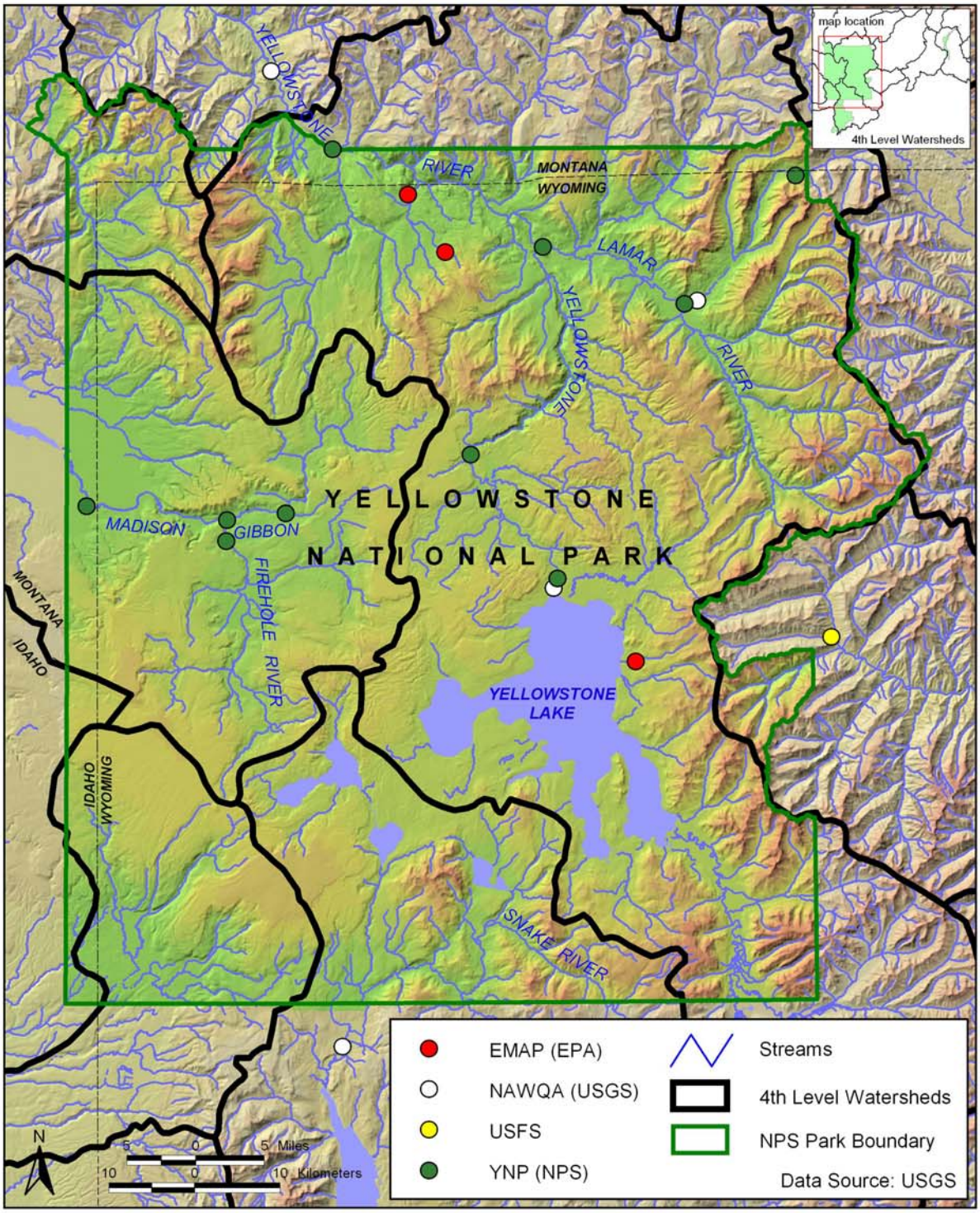
Current Water Quality Monitoring Locations and 4th Level Watersheds



Current Water Quality Monitoring Locations and 4th Level Watersheds



Current Water Quality Monitoring Locations and 4th Level Watersheds



IV. PAST AND CURRENT MONITORING IN THE GRYN PARK UNITS (INCLUDING DATASET CATALOG REFERENCES)

TOPIC	TITLE	DESCRIPTION	CATALOG #
YELLOWSTONE NATIONAL PARK			
Air Quality	Monitor Air Quality at Lake and Tower	NADP Stations	YELL-AQU-002, YELL-AQU-001,
Amphibians	Status and Trends of Amphibian Populations in the Greater Yellowstone Ecosystem	Assess amphibian status and distribution in YELL and GRTE based on: (1) surveys of all potential amphibian breeding sites in randomly selected hydrological units (7th level); (2) surveys for priority species (Northern Leopard Frog, Boreal Toad) and (3)population monitoring at sentinel sites. This project is part of the Dept. of Interior"s national Amphibian Research and Monitoring Initiative.'Assess amphibian status and distribution in YELL and GRTE based on: (1) surveys of all potential amphibian breeding sites in randomly selected hydrological units (7th level); (2) surveys for priority species (Northern Leopard Frog, Boreal Toad) and (3)population monitoring at sentinel sites. This project is part of the Dept. of Interior"s national Amphibian Research and Monitoring Initiative.	YELL-HER-014
Aquatic Resources	Gibbon River sediment study	Sediment deposition is being monitored on the Gibbon River during major road reconstruction	YELL-FM-007
Aquatic Resources	Monitoring the flow regimes of remote tributaries to Yellowstone Lake	Stream water elevation is being recorded digitally every hour at 13 remote tributaries to Yellowstone Lake	YELL-FM-006
Aquatic Resources	Monitoring the thermal regimes of Yellowstone's streams and rivers	Temperatures are monitored hourly by digital temperature loggers at sites on > 50 streams	YELL-GEO-001
Aquatic Resources	Macroinvertibrate Monitoring of Streams	Monitor macroinvertebrate and habitat parameters at fisheries sampling sites	YELL-FM-015
Aquatic Resources	Native Montana Grayling Monitoring	Inventory description, abundance, and movements of fluvial an adfluvial greyling, primarily in the Gibbon River drainage.	YELL-TEA-002
Aquatic Resources	Soda Butte stream flow, pH, and conductivity	Monitored at a gauging station near the Northeast Entrance under the Montana-NPS Reserved Water Compact	YELL-WQ-010 YELL-WQNT-002
Aquatic Resources	Yellowstone Cutthroat Trout Monitoring	Includes Fall Gillnetting, fish traps on Clear, Arnica, and Bridge Creeks, and dipnetting at LeHardy Rapids	YELL-FM-005
Aquatic Resources	Lake Trout in Yellowstone Lake Population Monitoring	Includes gillnetting, angler (separate from parkwide survey), and hydroacoustic surveys	YELL-FM-013,
Aquatic Resources	Backcountry lakes monitoring program	Monitor fish populations and habitat parameters on lakes other than Yellowstone Lake	YELL-FM-015
Aquatic Resources	Streams monitoring program	Monitor fish populations and habitat parameters in Yellowstone's streams	YELL-AQU-001
Aquatic Resources	Whirling disease monitoring	Efforts primarily focus on Yellowstone Lake. Disease samples have also been collected (database developed) in conjunction with recent stream studies.	YELL-WQ-015,
Aquatic Resources	New Zealand mudsnail monitoring	Monitor distribution, abundance, and spread of exotic mud snails. Public education about exotic invader through notices in angling regulations, park newspaper, and interpretive training.	YELL-ESA-002,
Aquatic Resources	Reese Creek Flow and YCT Population Monitoring	Monitor flow at Parshall flumes to ensure that irrigators leave legal in-stream flow; monitor fish populations	
Aquatic Resources	Westslope Cutthroat Trout Monitoring	Inventory distribution and abundance of genetically pure westslope cutthroat trout	YELL-ICH-003 YELL-FM-009, YELL-ICH-017,

TOPIC	TITLE	DESCRIPTION	CATALOG #
Aquatic Resources	Water quality monitoring near sewage treatment plants	Monitor groundwater quality near sewage treatment plants.	
Aquatic Resources	Long term monitoring of anglers and angler success	Monitor anlger effort and success in Yellowstone; includes volunteer angler report, tracking number of permits sold, Yell Lake creel surveys, volunteer cards returned and exit gate surveys	YELL-FM-010
Aquatic Resources	Developing effective ecological indicators for watershed analysis	This study is designed to develop improved indicators and innovative techniques for assisting and monitoring ecological integrity at the watershed level in the western United States. Its specific objectives are to develop practical, scientifically valid indicators that (1) span multiple resource categories, (2) are relatively scale independent, (3) address different levels of biological organization, (4) can be rapidly and cost-effectively monitored by remote sensing, and (5) are sensitive to a broad range of anthropogenic and natural environmental stressors.	
Aquatic Resources	Respiratiory physiology and habitat selection in thermophilic aquatic insects	Understand respiratory physiology and habitat selection decisions in thermophilic aquatic insects including water scavenger beetles (Coleoptera: Hydrophilidae) and both adult and nymphal stages of dragonflies and damselflies (Odonata). Correlate habitat selection decisions and thermal preference with respiratory physiology and development (Odonata).	
Aquatic Resources	Food web impacts of exotic New Zealand mud snails in Yellowstone national park	Estimate carbon flow in food webs of rivers with high (Firehole River) and low (Gibbon River) densities of exotic snails	
Aquatic Resources	Development of an empirical model for predicting the stream invertebrate fauna of the Greater Yellowstone Ecosystem: A pilot study	develop an empirical model that accurately predicts the expected invertebrate fauna in streams of the Greater Yellowstone Ecosystem. Models of this type can be used to assess the biological integrity of streams that may be impacted by anthropogenic activity.	
Aquatic Resources	Yellowstone River Basin Study Unit, National Water Quality Assessment	The overall goals of the NAWQA Program are to (1) describe current water-quality conditions for a large part of the Nation's freshwater streams and aquifers, (2) describe how water quality is changing over time, and (3) improve our understanding of the primary natural and human factors affecting the water quality.	
Aquatic Resources	Reference Stream Monitoring - Long-term Trend Sites	Collect long-term water quality, biological and stream habitat data at least-impacted streams in Yellowstone National Park. Reference stream data will be used as a benchmark for assessing water-quality, biological, and habitat conditions of test streams in the Middle Rockies ecoregion of Wyoming	YELL-WQ-004
Aquatic Resources	Biogeochemical Interactions at Environmental Interfaces (Mercury dynamics in aquatic ecosystems of Yellowstone National Park)	Total mercury and methyl mercury concentrations in Nymph Lake and nearby lakes, streams and ponds of YNP are the highest known natural concentrations in aquatic ecosystems anywhere. The objectives of this study are to understand the dynamics of mercury in these water bodies and the impacts (if any) of the high mercury concentrations on biota.	
Botany	Willow persistence	Going on in 2002	YELL-BOT-005 YELL-BOT-004, YELL-BOT-006,
Ecological processes	Food for the Masses	Wolf Predation Composition and Rate	YELL-WM-007
Ecological processes	Trophic Cascade	Elk-predator-herbivory interactions	YELL-ECO-005
Ecological processes	Predator Interactions	Wolf-lion-bear interactions	YELL-WM-008,
Ecological processes	Spawning stream surveys	Count spawners and associated bear activity in spawning tributaries to Yellowstone Lake. Summarized information used by Fisheries and Aquatic Resources to monitor cutthroat trout abundance at whirling disease test sites.	YELL-FM-001, YELL-WM-075

TOPIC	TITLE	DESCRIPTION	CATALOG #
Ecological processes	Whitebark Pine Transects	Count cones on 19 whitebark pine transects througout the ecosystem (10 located in YNP)	YELL-FOR-001
Ecological processes	Above- and belowground carbon allocation in developing and mature lodgepole pine forests in Yellowstone National Park	Determine the long-term effects of fire on carbon release and storage	
Ecological processes	A Remote Sensing and GIS-Based Model of Habitat as a Predictor of Biodiversity	objectives 1. Quantify the spatial and temporal variability in montane meadows.;2. Develop a spectrally-based spatially-explicit model for predicting plant and animal (butterflies and birds) species diversity patterns in montane meadows.;3. Test the spectrally-based spatially explicit model developed in Objective 2 for predicting plant and animal species diversity patterns in montane meadows	YELL-EM-004 YELL-EM-005, YELL-EM-006,
Ecological processes	Physiology and geochemical tracing of FeS/H2S micro-organisms in subsurface hydrothermal systems	To characterize the diversity of micro-organisms associated with sulfide-containing or acidic hot springs. The initial phases of the study concentrated on evidence for pyrite-forming anaerobic bacteria. Subsequent work has concentrated on recovery, preservation, and molecular analysis of thermoacidophilic archaea.	
Ecological processes	Phylogenetic Analysis of High-Temperature Ecosystems	On-going research in The Park continues to focus on the survey of microorganisms in Yellowstone microbial ecosystems with varying solution chemistries	
Ecological processes	Climatic Variation in the Greater Yellowstone Ecosystem: Evaluating the Evidence for Decade to Centennial Variability in Climate	The research proposed here is organized around the following questions and associated research strategies: Question 1: What is the nature of temperature variability over the past 1000 years	
Ecological processes	Postglacial fire frequency and its relation to long-term vegetational and climatic changes in Yellowstone Park	Postglacial fire frequency and its relation to long-term vegetational and climatic changes in Yellowstone Park	YELL-ECO-008,
Ecological processes	Aspen regeneration in northern Yellowstone National Park	Our objective was to measure aspen regenerative success inside and outside of established wolf pack territories on YNP"s northern range	YELL-ECO-006 YELL-FIR-010, YELL-FIR-009,
Ecological processes	Trace element content of cervid antlers	studying the strontium isotopic composition and the content of strontium and other trace elements in elk and deer antlers from selected national parks in the western U.S., including Yellowstone. The study will add to the general body of knowledge about the cycling of trace elements through the environment and increase our understanding of the biogeochemistry of strontium	
Ecological processes	Ungulate carrion impact on plant community composition and nutrient cycling	To determine whether wolf killed ungulate carcasses are having an impact on plant community composition and nutrient cycling	
Ecological processes	The Ecological Relationship Between a Rocky Mountain Threatened Species and A Great Plains Agricultural Pest	1.To determine where army cutworm moths (Euxoa auxiliaris) (ACMs) originate using microsatellite and mtDNA markers. 2. To determine if ACMs harbor agricultural pesticides in their tissues. 3. To determine whether ACMs from different Great Plains origins are interbreeding in high elevation sites prior to their return to agricultural areas.	
Ecological processes	Assesment of host races in the ovary-feeding beetle, Brachypterolus pulicarius (Coleoptera: Nitidulidae)	investigating the existence of host races in the beetle, Brachypterolus pulicarius, a natural enemy of yellow and Dalmation toadflax. Because this beetle exists on two separate host plants, researchers are investigating whether the species consists of two genetically distinct host races	

TOPIC	TITLE	DESCRIPTION	CATALOG #
Ecological processes	Winter wolf predation rates and prey selection in an elk-bison system in Yellowstone National Park	The goals of this study were to quantify wolf predation rates and prey selection, and assess wolf predation impacts on the ungulate populations in the Madison, Firehole, and Gibbon drainages of Yellowstone National Park. Specific objectives included: 1) estimate time ungulates were subjected to wolf predation, 2) estimated winter ungulate abundance and composition, 3) estimate temporal patterns in predation, within and between winters, 4) describe prey selection patterns, and 5) estimate total ungulate offtake by wolves according to species, sex, and age class.	YELL-WM-123
Ecological processes	Development of Algorithms to Use with Satellite Images to Assess Annual Snow Melt and Green-Up In Yellowstone National Park	methodology for use in conjunction with satellite imagery to determine snow cover and green up in Yellowstone National Park that can be used on a near-real-time basis	
Ecological processes	Fire: A Force for Change and Regeneration in Natural Ecosystems	To study the long-term changes in re-vegetation at sites affected by different fire intensities, with emphasis on lodgepole pine, aspen and whitebark pine	
Ecological processes	The sustainability of grazing ecosystems	To measure the effects of grazing ungulates on aboveground and belowground production at diverse grassland sites on winter, transitional, and summer ranges	
Ecological processes	Fungi from geothermal soils and thermotolerant plants	The proposed research will provide information to increase our understanding of fungal survival in unique environments, the roles of fungi in ecosystem dynamics, and the temporal and spatial scales of the micro-habitats that fungi occupy	YELL-BOT-010
Ecological processes	Fire Effects Monitoring in Yellowstone National Park	Monitor the effects of prescribed fire on Yellowstone"s ecosystems. Provide information to evaluate whether the objectives of the fire management office are met. Study the long-term effects of fire on the landscape	YELL-FIR-024
Exotics-Invetebrate	Gypsy Moth Detection Trapping	Detect spread of exotic gypsy moths	YELL-ESA-001
Geologic Resources	Quaternary geology and ecology of the Greater Yellowstone area	To determine the history of glaciation and distribution of glacial deposits; to determine the history of Yellowstone Lake and River level changes and related history of caldera inflation and deflation episodes; to determine the history of hydrothermal explosions, particularly in the Yellowstone Lake area; to determine geologic controls of plant ecology in the Greater Yellowstone area	
Geologic Resources	A Preliminary Investigation of the Eocene Palynoflora of the Yancey Creek Drainage Basin	,	
Geologic Resources	Aqueous-Solid Geochemical Process Model of Travertine Precipitation at Angel Terrace, Mammoth Hot Springs	develop a quantitative process model that will incrementally track the diagenesis of hot spring travertine depositional facies from the modern through the Recent, Holocene, and Pleistocene. Resulting constraints on the rates and products of water-rock reactions provide the template necessary to accurately interpret travertine deposits in the early Earth and perhaps other planets	YELL-GEO-005
Geologic Resources	Sulfur speciation and redox processes in mineral springs and their drainages	Water analyses are reported for samples collected at hot springs and their overflow drainages, geysers, and ambient-temperature acid streams. Research investigations focus on sulfur redox speciation in hot springs and microbially medicated sulfur oxidation in stream waters, to document chemical changes in overflows that affect major ions, redox species, and trace elements.	YELL-GEO-004

TOPIC	TITLE	DESCRIPTION	CATALOG #
Geologic Resources	Investigation of CO2 Emissions Related to the Yellowstone Volcanic / Hydrothermal System	1) estimate the CO2 emissions due to the Yellowstone volcanic/ hydrothermal system, ;2) monitor background temporal variability of CO2 emissions, and how variations are related to changes in hydothermal and seismic activity,;3) study the spatial distribution of CO2 emissions and investigate controls on spatial heterogeneity of gas emissions, and;4) monitor gas chemistry including carbon and helium isotopes to gain a broader understanding of the sources of gas emissions and interactions with the hydrothermal system.	
Geologic Resources	The biogeochemistry of sublacustrine geothermal vents in Yellowstone Lake, WY	These studies will continue to focus on the microbiology and biogeochemistry of the geothermal systems in Yellowstone Lake. At the Great Lakes WATER Institute of the Univ. of Wisconsin-Milwaukee we are currently analyzing a fragment of one of the Bridge Bay	
Geologic Resources	Volcano Emissions	Survey and characterize carbon dioxide emissions from Yellowstone soils and thermal areas in order to identify possible areas of anomalous degassing from depth and to provide a baseline with which to compare future surveys of carbon dioxide in the event of volcanic unrest.	
Geologic Resources	Arsenic Biogeochemitry in Yellowstone National Park	Our work will focus on geochemical and microbiological processes that influence the speciation and behavior of arsenic in thermal environments. Given the toxicity and potential negative impacts that As may have on biota in non-park environments, the thermal springs represent a potentially informative model system to begin to understand how microbiological life forms metabolize or detoxify As	
Geologic Resources	The search for microbial biomarkers in terrestrial deposits	The primary purpose of this investigation is to evaluate the fossilization process and the potential for a long term record of the microbial life that exists associated with hot springs and their carbonate (travertine) and siliceous (siliceous sinter) deposits.	
Geologic Resources	Operation And Development Of An Earthquake And Volcano Information System At Yellowstone (YSGN) And Ancillary Research on the Geodynamics of the Yellowstone Hotspot	The primary objectives of the Yellowstone earthquake and volcano information system is to operate seismic and GPS networks, the Yellowstone seismic and GPS networks (YSGN), necessary to monitor seismicity and ground deformation that may be related to volcanic, hydrothermal and tectonic earthquake activity	
Geologic Resources	Snow Pack on Northern Range	Evaluate variability of snow pack across YNP with empasis on northern range and determine sinking depths of different bearing pressures on different snow conditions	YELL-CLI-002
Geologic Resources	Geochemistry, biochemistry, and stable isotope systematics of sublacustrine hydrothermal vents in Yellowstone Lake	The objectives of this study are to understand hydrothermal processes in sublacustrine hydrothermal vents in the context of the Yellowstone ecosystem and subaerial hydrothermal systems in and around Yellowstone National Park. In particular, we are using chemical composition, especially minor and trace elements and stable isotopes (H, C, N, O, and S), to understand processes of hydrothermal mineralization and to track potentially toxic and nutrient elements from hydrothermal vents into the micro- and macro-fauna of Yellowstone Lake and the Greater Yellowstone ecosystem.	
Geologic Resources	Chloride Flux Monitoring	Monitor cloride levels in major drainages as they leave the park to measure heat loss from the hydrothermal system	YELL-VOL-005,
Geologic Resources	Monitor Old Faithful Geyser	Monitor eruptions and intervals	
Geologic Resources	Monitor Vandalism to Geothermal Features	Monitor and clean geothermal features in the Upper, Midway, and Lower basins	YELL-MAN-037

TOPIC	TITLE	DESCRIPTION	CATALOG #
Geologic Resources	Monitor selected features in the Upper, Midway, Lower Geyser Basins, Firehole Lake Drive, and the Norris Basin	Developing program under the auspices of the Geothermal Monitoring Plan	
Geologic Resources	Biogeochemistry of hydrothermal hot springs	Investigate geochemical variations in microbial mats, pore waters, siliceous sinters and geyserites at different hot springs and thermal drainages in the Park	
Geologic Resources	Geochemical and geophysical investigations of mine impacts and watersheds, Yellowstone National Park	The fundamental goals of this project are to contribute to the understanding of the complex geochemistry of the Soda Butte Creek watershed, and to investigate the impact of mining activities near the creek"s headwaters. This is accomplished through: 1) building a long-term database documenting seasonal variations in stream chemistry and metal concentrations in stream waters and sediments, and 2) delineation of shallow subsurface features in the Soda Butte Creek floodplain.	
Geologic Resources	Absolute gravity and crustal deformation in the Yellowstone Caldera	The primary objective to establish temporal absolute gravity and height changes in the Yellowstone caldera, and apply these measurements to constraining models for the sub-surface volcanic and magmatic sources of the caldera. Our gravity/GPS measurements will be integrated with regional GPS and/or SAR interferometric observations of deformation to model the sub-surface sources of the inflation/deflation of the resurgent domes (Sour Creek and Mallard Lake) within the caldera.	
Geothermal Resources	Thermal Feature Inventory	Field survey of feature location, temp. ph, conductivity, photos, description	YELL-VOL-006
Geothermal Resources	Thermophile Inventory		YELL-MAN-036
Microbiology	Determination of in situ growth rates of filamentous sulfur-oxidizing bacteria in a hydrothermal vent field in Yellowstone Lake	determine the specific growth rate of cells replicating within filaments of Thiothrix-like, sulfur-oxidizing bacteria that have attached to metal coupon surfaces positioned in a hydrogen sulfide gradient above a hydrothermal vent. Using published conversion factors, we will describe the chemosynthetic or mixotrophic biomass production of filamentous sulfur-oxidizing bacteria attached to coupons at different hydrogen sulfide concentrations and temperatures.	
Microbiology	Molecular and Functional Ecology of Hot Spring Photosynthetic Mats	The project combines modern microbiological, molecular biological, and ecophysiological methods for studying the microbial ecology of photosynthetic hot spring mats. The goal is to gain a better understanding of the structure and function of the photosynthetic community in hot spring microbial mats	
Microbiology	A Survey of Pilobolus in YNP	Objectives 1. To obtain isolates of Pilobolus to examine for differences in DNA sequences and cellular short chain fatty acid composition. 2. To compare isolates from various locations by contrasting morphological characters to DNA sequences and short chain fatty acids. 3. To analyze and compare nucleic acid sequences in the various isolates to compare and contrast taxa. 4. To analyze and compare cellular short chain fatty acids in the various isolates to compare and contrast taxa. 5. To study the characteristics that can be used to identify isolates.	
Microbiology	Bacterial Diversity of Thermophilic Photosynthetic Bacteria	The main objective of this research is to discover and isolate laboratory cultures of anoxygenic (non oxygen-evolving) photosynthetic bacteria from thermal environments. Photosynthetic bacteria are model organisms for the study of basic problems in photosynthesis and thermophilic phototrophs are very desirable because of their thermostable photosynthetic machinery.	YELL-VOL-010
Microbiology	Geochemical Constraints on the Ecology of the Deep Lineages within the Bacteria and Archaea	1. Determine the microbial diversity and geochemistry associated with high temperature thermal springs in YNP;2. Study the ecology of microbial communities inhabiting YNP thermal springs	

TOPIC	TITLE	DESCRIPTION	CATALOG #
Microbiology	Characterization of the microbial rhizosphere population of acid and thermotolerant grasses associated with hot springs and microbial diversity in thermal soils in YNP	To study the diversity and identification of the thermophilic and acidophilic organisms associated with thermophilic plants located in YNP. We are also very interested in examining the diversity of the microbial community that thrives in select thermal soil locations	
Microbiology	Isolation and chartization of thermophilic viruses from Yellowstone National Park	To isolate and characterize thermophilic viruses from the thermal features of Yellowstone National Park	
Microbiology	Survey Of Yellowstone Hot Springs for Green Sulfur Bacteria	(1) To survey selected hot springs in Yellowstone National Park for the presence of green sulfur bacteria (GSB). (2) To further characterize and possibly isolate organisms whose 16S ribosomal gene sequences indicate that they may be deeply branching relatives of green sulfur bacteria from selected Yellowstone hot springs.	
Microbiology	Bacteria living at low pH and high temperature	The main objective is to examine high temperature and low pH springs to find new (i.e. previously undescribed) hyperthermophiles and develop methods to isolate and culture them	
Microbiology	The search for thermophilic Protozoa in Yellowstone National Park	The goal of this research is to identify thermophilic Protozoa in Yellowstone National Park	
Recreational Use	Stocksite Monitoring	Monitor the level of graze utilization at about 40 popular stocksites	YELL-REC-001
Recreational Use	Overnight Backcountry Visits	Track the number of use nights and distribution of overnight backcountry campers	YELL-REC-003
Vegetation	Wetlands mapping	Map wetlands along the Grand Loop Road in conjunction with Federal Highways Projects	YELL-WET-001 YELL-GIS-069
Vegetation	Rare Plant Surveys	Primarily associated with construction, but some a priori work (e.g. Ross' bentgrass and Yellowstone Sand Verbena	
Vegetation	Monitor Exotic Plants	Done in conjunction with Exotic Plant Control; also as part of the Inventory Project	YELL-ESP-001
Vegetation	Assessment of Land cover changes in the upper snake river plain and greater yellowstone ecosystem	ground truthing remote sensing assessments	YELL-BOT-025
Vegetation	Non-Native Plant Monitoring	To complete several non-native monitoring projects initiated in Yellowstone since 1995. That included a re-survey of 60 sites established across the park in 1995 and 1996 which were used to assess native and non-native vegetation.	YELL-ESP-016
Vegetation	Cross-Boundary Plant Invasions in Protected Areas: The Case of West Yellowstone Area	1) Determine susceptibility of plant communities to invasion at the landscape scale in the interface between Gallatin NF and Yellowstone NP. 2) Determine both forest edge effects on alien plant invasions and biodiversity patterns, contrasting natural and human disturbances. 3) Determine the invasive strategy of Linaria vulgaris Mill. at multiple spatial scales in the study area and characterize its potential to invade areas in relation with disturbance types and regimes.	YELL-ESP-022
Widlife-predator	Cougar-wolf relationships	Document direct and indirect interactions between wolves and cougars in northern YNP	
Widlife-predator	Lynx Presence and Distribution	Document presence & distribution of Lynx in YNP	YELL-WM-106, YELL-TEA-002
Wildlife-birds	Bald Population and Recruitment Monitoring	Ground and aerial surveys(3) to monitor number of active nests and eaglets fledged	YELL-ORN-003, YELL-ORN-015

TOPIC	TITLE	DESCRIPTION	CATALOG #
Wildlife-birds	Peregrine Falcon Population and Recruitment Monitoring	Ground (require 3 visits) and aerial surveys to monitor number of active eyries and peregrines fledged	YELL-ORN-009 YELL-EM-003
Wildlife-birds	Osprey Population Monitoring	Ground and aerial surveys(3) to monitor number of nest attempts and production	YELL-ORN-003 YELL-ORN-005, YELL-ORN-011, YELL-ORN-012
Wildlife-birds	Trumpeter Swan Population and Recruitment Monitoring	Ground, weekly snowmobile and 1 aerial surveys to monitor number of swan nesting attempts and cygnet survival	YELL-ORN-006 YELL-ORN-004, YELL-ORN-008,
Wildlife-birds	Molly Islands colonial nesting bird surveys	Ground and aerial monthly surveys to monitor nesting attempts by white pelicans, double-crested cormorants, California gulls, and Caspian terns on the Molly Islands	
Wildlife-birds	Common Loon population monitoring	Three aerial surveys to monitor nest attempts and fledging	
Wildlife-birds	Breeding bird surveys	Three breeding bird surveys are conducted along established transects each year	YELL-ORN-001
Wildlife-birds	Glacier Boulder Route Survey	Documents birdlife found exclusively in lodgepole pine forests away from roads.	
Wildlife-birds	Christmas Bird Count	Local winter monitoring of birds as part of nationwide survey	
Wildlife-birds	International Migratory Bird Count	1 day count to monitor the pulse of spring bird migration.	
Wildlife-birds	Relating Avian Abundance and Diversity to Human Disturbance Regimes via Hyperspectral Imaging	1)Identify areas of significant avian abundance diversity within riparian zones on the Northern Range. 2)Identify areas supporting amphibian breeding, foraging, and dispersal activities within riparian zones on the Northern Range. 3)Relate hyperspectral imaging data to patterns of habitat, avian, and herptile abundances and distribution. 4) Relate diversity and abundance patterns to anthropogenic disturbance regimes within and between drainages	
Wildlife-general	Wildlife Disease Monitoring	Collection of animal parts to develop baseline levels of disease occurance	
Wildlife-general	Spring carcass surveys	Firehole, Norris, Heart Lake, Northern Range	YELL-WM-010,
Wildlife-general	Roadkill wildlife	Keep track of wildlife killed by vechicle strikes	YELL-WM-011
Wildlife-general	Rare Mammal Monitoring	Track rare mammal sightings	YELL-TEA-001,
Wildlife-Invertebrates	The Mosquitos of Yellowstone National Park, a Study of Their Species and Their Biology	An ongoing study of the mosquito species to determine species present and their biology	
Wildlife-mesocarnivores	Beaver Presence / Absence	Ground surveys by foot and horseback to search all riparian corridors and park lakes for old, recent and active beaver sign (lodges, caches, tracks, cut stumps, canals, and dams) and sightings.	YELL-WM-046,
Wildlife-mesocarnivores	The Dietary and Foraging Ecology of the Yellowstone River Otter: An Umbrella Species for Aquatic Systems	clarify the ecological role of native vs. non-native fish species on Yellowstone river otters by comparing otter populations on two lake systems in YNP	YELL-WM-118 YELL-WM-119
Wildlife-predator	Wolf Capture	Wolf Population and Distribution Monitoring	YELL-WM-023
Wildlife-predator	Genetic Study of Wolves		YELL-WM-126
Wildlife-predator	Grizzly Bear Population Monitoring	ecosystem-wide; includes bear sightings, counts of females with cubs, observation overflights, Home ranges, distribution, food habits, habitat use and mortality monitoring	YELL-WM-065 YELL-WM-024

TOPIC	TITLE	DESCRIPTION	CATALOG #
Wildlife-predator	Human-Bear Conflict Report	Track human-bear conflicts throughout the Greater Yellowstone area	YELL-WM-013
Wildlife-predator	Physiological stress responses, aggression and social dominance in Yellowstone wolves	1. Determine factors that affect stress hormone levels(glucocorticoids) in free-ranging wolves. This includes behavioral, ecological and anthropogenic influences.;2. Relate stress physiology to survival and reproduction.;3. Relate stress physiology to social status.	
Wildlife-predator	The Effect of Environmental Variability on Grizzly Bear Habitat Use	The overall design of this project is to utilize existing data, expertise and newly collected data from advanced technologies to evaluate the impact of anthropomorphic influences on grizzly bear (Ursus arctos horribilis) habitat selection. Initially, this study will have three areas of emphasis: 1) To evaluate potential relationships between habitat use and road density. 2) To evaluate potential relationships between habitat use intensity and types of human activity. 3) To evaluate potential relationships between habitat selection and land management status.	
Wildlife-predator	Grizzly & Black Bear Genetic Diversity	Monitor Grizzly and Black bear genetic diversity in GYE	YELL-WM-112
Wildlife-predator	Study of Grizzly Bear Behavior and Genetics	Continuation of a long term study of grizzly bear behavior and the use of nuclear DNA markers to determine genetic diversity and population estimates	
Wildlife-predator	Wolf Population Dynamics		YELL-WM-005 YELL-WM-022
Wildlife-ungulate	Bighorn Sheep Population Monitoring (too many)	Once-a-year aerial sheep count	YELL-WM-027 YELL-WM-036, YELL-WM-048, YELL-WM-049
Wildlife-ungulate	Mountain Goat Population Monitoring	Once-a-year aerial goat count	YELL-MAM-011,
Wildlife-ungulate	Northern Range Elk Population Monitoring	Once-a-year aerial elk count	YELL-WM-043 YELL-WM-042, YELL-WM-044, YELL-WM-108
Wildlife-ungulate	Elk classification	Once-a-year aerial survey to assess elk cow-calf ratios	YELL-WM-041
Wildlife-ungulate	Bison Population Monitoring	Monthly/quarterly aerial surveys to count bison	YELL-WM-035 YELL-WM-062, YELL-WM-068,
Wildlife-ungulate	Pronghorn Population Monitoring	Late-winter and late-summer one-day aerial counts/classifications and weekly ground monitoring during winter	YELL-WM-001 YELL-WM-045, YELL-WM-077, YELL-WM-069
Wildlife-ungulate	Mule deer Population Monitoring	One-day helicopter survey in spring and classification in winter	YELL-WM-124 YELL-WM-033, YELL-WM-034, YELL-WM-039
Wildlife-ungulate	Post-burn resource selection, physiological condition, and demographic performance of elk	The primary objective of this research is to evaluate the consequences of the 1988 fires on elk resource selection. Selection is being quantified for populations and individuals at multiple scales ranging from selection of patches within the landscape mosaic to selection of forages and plant parts within patches	YELL-WM-057 YELL-WM-037
Wildlife-ungulate	Winter recreation effects on wildlife in Yellowstone National Park	Our objective was to assess effects of winter recreation on wildlife populations in the Madison-Firehole-Gibbon drainages of Yellowstone National Park. We examined elk and bison distribution in relation to the winter road system, behavior, and stress hormone levels, along with winter season human activity types and levels	

TOPIC	TITLE	DESCRIPTION	CATALOG #
Wildlife-ungulate	Development of Aerial Survey Methodology for Bison Population Estimation in YNP	Objective is to develop aerial survey methodologies for statistically rigorous estimation of the bison population in the Yellowstone area that will that will have sufficient power and precision to detect demographic trends	YELL-WM-062
Wildlife-ungulate	Epidemiology and Pathogenesis of Brucellosis in Yellowstone National Park Bison	Determine the natural course of brucellosis in free-ranging bison. Determine modes of transmission. Provide information on the prevalence of infection and abortion.	
Wildlife-ungulate	Sagebrush ecology and ungulate relationships	1.) To determine the current status of the sagebrush-shrub community on the northern Yellowstone mule deer winter range; 2.) Determine the importance of the sagebrush community to wintering mule deer and elk	
Wildlife-ungulate	Bison Monitoring on Groomed winter roads	Snowmobile, groomer & camera surveys completed annually 1997-8 to present. Project asseses how bison use groomed winter roads.	YELL-WM-121
GRAND TETON NATIONAL PARK			
Bald Eagles	Bald Eagle Management	Monitor territorial occupancy and nest productivity at all nests annually. Territorial occupancy surveys should take place during late February. Breeding status surveys, to check for incubating adults, should take place in April. Additional nest status checks should take place during late May/early June to determine approximate age and number on nestlings, and to plan banding activities. Finally, the last nest status check should be conducted around mid-July to document productivity	GRTE-ORN-010
Birds	Breeding Bird Survey	Colter Bay Breeding Bird survey annually for contribution to the national database.	GRTE-ORN-011
Grizzly and Black Bears	Bear Management Plan Implementation	Collect visitor's and employees' observations of bear encounters on official observation report forms. Compile in a database to be maintained by the office of S&RM. Monitor any human/bear incidents that involve conflict resolution and take measures to solve the associated problem.	GRTE-WM-44, GRTE-WM-57
Grizzly and Black Bears	Bear Attractant Storage	Conduct bear attractant storage facilities inventory, on a Parkwide basis, at least every 3 years. Problems that are identified should be prioritized and resolved. Highest priority would be given to problems in the grizzly bear recovery area and those that may represent a significant threat to human safety.	GRTE-WM-48
Bison	Bison Status and Research	Monitor disease status, reproduction and seasonal movements of bison.	GRTE-WM-41
Elk	Elk Management	Continue to gather age distribution data from elk harvested during the annual reduction. Data will be compiled, added to the interagency Jackson elk database, and included in the Park's annual report to the Jackson Hole Cooperative Elk Studies Group.	GRTE-WM-54
Elk	Elk Monitoring	Conduct summer age and sex classifications, and expand classifications to include representative areas from throughout the Park.	GRTE-WM-58
Elk	Elk Monitoring	Conduct aerial surveys of elk on summer ranges throughout the Park every 3 years to arrive at annual population estimates..	GRTE-WM-36
Elk	Elk Reduction	Compile hunt statistics annually to include age class and sex of elk killed, time period, permit type, hunt area and nearest landmark to kill site. Enter all kill data into a digital database and periodically review harvest patterns and trends. Monitor hunter behavior, numbers and patterns to assure that hunting conditions remain within a reasonable margin of safety.	GRTE-WM-40
Elk	Elk Reduction	Cooperate and assist with USDA-APHIS, the State of Wyoming, and other agencies during animal disease monitoring programs, specifically as this relates to acquiring needed biological specimens that can be gathered from harvested elk.	GRTE-WM-38

TOPIC	TITLE	DESCRIPTION	CATALOG #
Bison	Bison Monitoring	Monitor the demography, movements, and distribution of the Jackson bison herd. Maintain a sample of radio-collared females to determine movements and distribution. Conduct weekly aerial surveys to document calving in time and space. Conduct ground and aerial winter distribution, sex and age classification, and population census surveys.	GRTE-WM-35
Grizzly Bear Management	Cumulative Effects Model	Monitor Park attributes documented contained within the CEM GIS data for significant changes (fire, landslides, etc.) that would effect CEM results. Modify the data base accordingly on an as-needed basis.	YELL-WM-106
Grizzly Bear	Grizzly Bear Management	Gather, record and store all grizzly bear sightings from the Park and Parkway, as well as any received from areas adjacent to the Park. Investigate and verify sightings as needed. Notify the IGBST immediately after any sow with cubs are verified.	GRTE-WM-44, GRTE-WM-57
Great Blue Heron	Great Blue Heron Management	Monitor all historical rookery sites and search for new ones on an annual basis. Nest occupancy and productivity of active rookeries should be determined in mid-June and early and mid-July. A second survey should be undertaken in July due to the difficulty in observing some of the nests and their disparate phenologies.	GRTE-ORN-007
Lynx	Lynx Management	Investigate all the reports of lynx or their sign and attempt to verify using trained staff. Verified observations will be recorded on Natural History Field Observation cards and stored in a wildlife observation database.	GRTE-WM-51
Mountain goat	Mountain Goat Management	Monitor status of mountain goats in conjunction with bighorn sheep surveys. Encourage the reporting of mountain goat observations by Park staff, particularly backcountry rangers. Reported observations of mountain goats would be investigated by S&RM staff for verification. Verified observations would be converted to a computerized database compatible with GIS.	GRTE-WM-55
Mountain Lion	Mountain Lion Management	Investigate all reports of mountain lions or their sign and attempt to verify using trained staff. Verified observations will be recorded on Natural History Field Observation cards and stored in a wildlife observation database.	GRTE-WM-52
Birds	Neotropical Migratory Bird Conservation Program	Perform point counts and mist netting activities to monitor trends in bird population abundance at the Beaver Creek hazard fuel reduction site. The control plots will provide information regarding neotropical bird status in old growth sub-alpine fir forest types.	GRTE-ORN-004
Osprey	Osprey Management	Conduct ground and/or boat surveys to gather more specific information such as hatching of fledging dates, causes of nest failures, and nest site characteristics. Survey data to be recorded on NPS Raptor Survey cards. Nest site characteristics would be recorded on NPS Raptor Nest/Eyrie Record cards. Nest locations would be mapped.	GRTE-ORN-005
Pronghorn	Pronghorn Management	Record and maintain pronghorn sightings in the Park's wildlife observation files. Record all known mortality.	GRTE-WM-42
Sage Grouse	Sage Grouse Status	Perform annual breeding ground surveys. Monitor all current and historical leks. Conduct aerial surveys of potential habitat.	GRTE-WM-46, GRTE-WM-49

TOPIC	TITLE	DESCRIPTION	CATALOG #
Trumpeter Swans	Trumpeter Swan Management	Monitor territorial occupancy and nesting success of trumpeter swans within the boundaries of GRTE and JODR. Visit all potential territories weekly through June to identify occupancy and nesting attempts. Determine when hatching should occur and monitor nest sites more frequently to determine when cygnets hatch, number of cygnets and number of unhatched eggs. During the course of monitoring cygnet survival, determine how many cygnets survive to fledging. Work with WGFD and Bridger Teton NF to insure all territories in the valley are monitored. Weekly surveys to quantify use of staging and molting area will be preformed at Two Ocean and Emma Matilda Lakes, Jackson Lake near Third Creek confluence, Cow Lake and Half Moon Lake. Prepare thematic maps of trumpeter swan wintering, nesting and security habitat for adding to the GIS database. Encourage employees and visitors to report swan observations and compile this information into the wildlife observation database. Identification of collared individuals will be verified and reported to appropriate agency officials. Cooperate with the USFWS in conducting Fall and mid-winter Tri-state population census.	GRTE-ORN-003
Whooping Crane	Whooping Crane Management	Reported observations of whooping cranes should be investigated by S&RM staff for verification. Verified observations would be recorded on Natural History Field Observation cards and stored in a wildlife observation database.	GRTE-ORN-008
Wolves	Wolf Monitoring	Monitor wolf presence, distribution, and fecundity for dens that occur in the Park, collaborating with FWS on movements (i.e. radio-tracking), document cattle depredations.	GRTE-WM-45
Wolverine	Wolverine Management	Investigate all reports of wolverine or their sign and attempt to verify using trained staff. Verified observations will be recorded on Natural History Field Observation cards and stored in a wildlife observation database.	GRTE-WM-53
BIGHORN CANYON NATIONAL RECREATION AREA			
Botany	Monitoring Vegetation in the Pryor Mountain Wild Horse Range	These data were collected during June, 1994, for a project designed to monitor vegetation conditions at selected sites in the Pryor Mountain Wild Horse Range (PMWHR). The overall objective of the research was to monitor vegetation conditions in a number of plant communities in the PMWHR.	BICA-BOT-007
Botany	Major Vegetation Types Found in the Bighorn River Floodplain Study Area in Bighorn Canyon NRA	Changes in riparian vegetation mosaic during the years of 1938 through 1988 were studied along the Bighorn River near Lovell, Wyoming. The results revealed a decline in Populus deltoides woodland area and an increase in shrubland area, particularly shrublands dominated by Tamarix chinensis and Rhus trilobata. Major causes for the changes are discussed and future changes are predicted. These data are descriptions of the individual vegetation types identified through this study.	BICA-BOT-014

TOPIC	TITLE	DESCRIPTION	CATALOG #
Botany	The Proportion of Land Area within the Bighorn Canyon National Recreation Area Covered by the Different Vegetation Types	The ecology of terrestrial vegetation in the Bighorn Canyon National Recreation Area (BCNRA) was studied during the period of 1984 - 1986. Seventy-five stands, distributed throughout the BCNRA, were sampled for plant species cover and various environmental characteristics. A vegetation classification and map were developed, the data were analyzed using gradient analysis techniques, and the results were synthesized with those from other relevant studies in the region. All types except marshes and agricultural land are discussed in this report, with the discussion focusing on adaptations of the dominant plant species, environmental factors affecting the distribution of each vegetation type, vegetation changes that have occurred and can be expected to occur in the future, certain aspects of weed ecology, and characteristics of the vegetation mosaic along the north-south axis of the Recreation Area. The riparian vegetation appears to be changing most rapidly, due in large part to flood control on the Shoshone and Bighorn Rivers. The suppression of fires and floods, combined with grazing and the creation of mudflats by fluctuating Bighorn Lake water levels, have produced ideal conditions in the riparian zone for the invasion of various exotic plants, saltcedar in particular.	BICA-BOT-003
Climatology	Yearly Precipitation data at Soreson Ranch between 1981-to-1994	Monthly Precipitation readings at Sorenson Ranch.	BICA-CLI-001
Climatology	Hillsboro RAWS Fire Weather Station	BICA maintains a NIFC sponsored RAWS Fire Weather Station located northwest of Barry's Landing. Data is collected hourly and includes precipitation, wind speed and direction, temperature and relative humidity, fuel temperature and moisture, and atmospheric conditions such as barometric pressure and solar radiation and is archived at several interagency fire dispatch centers and National Weather Service (NWS) regional climate centers.	
Fisheries Management	Angler Creel Reports	Data on fish numbers, size, species, hours fished in BICA. Water temperature and quanitity information.	BICA-FM-002
Ornithology	Christmas Count Lists for Kane, WY	Kane, WY Christmas Bird Count list of species.Members of the Audebon Society conduct thisbird count on Yellowtail every winter since 1990.	BICA-ORN-002
Ornithology	Breeding Bird Surveys and Other Wildlife Sightings	Data on breeding birds and bird observations	BICA-ORN-003
Water Quantity	Bighorn Lake Elevation Record	Water quantity in Bighorn Lake(1978-1989), Bighorn Canyon.	BICA-WQNT-001
Water Quantity	Water Temperature log for Barry's Landing	Water temperature and quanitity information.	BICA-WQNT-002
Wildlife Management	Interspecific Behavioral Interactions Among Bighorn Sheep, Mule Deer, and Feral Horses in BCNRA and Pryor Mountain Wild Horse Range	These data are one set of results from a study done from September of 1992 through February of 1996 on competitive interactions among bighorn sheep, feral horses, and mule deer in Bighorn Canyon National Recreation Area (BCNRA) and Pryor Mountain Wild Horse Range. These data were collected to determine if behavioral interactions among bighorn sheep, mule deer, and feral horses influence distribution or habitat patterns with a hypothesis that there is no difference in distribution given the presence or absence of another species.	BICA-WM-010
Wildlife Management	The Bighorn Sheep of Bighorn Canyon NRA and Pryor Mountain Wild Horse Range: Ecological Relationships and Management Recommendations	The Bighorn Sheep of Bighorn Canyon NRA and Pryor Mountain Wild Horse Range: Ecological Relationships and Management Recommendations	BICA-WM-022

TOPIC	TITLE	DESCRIPTION	CATALOG #
Wildlife Management	Summary of Vegetation Dynamics at the Pryor Mountain Wild Horse Range, 1992-1996.	Summary of vegetation dynamics at RMWHR, 1992-1996.	BICA-WM-031
Wildlife Management	Manager's Summary-Ecological Studies of the Pryor Mountain Wild Horse Range, 1992-1997	Collection of studies and papers that provide a synthesis of key findings of the landscape-scale, interdisciplinary studies of the effects of wild horses and native ungulates on a rugged, mountain ecosystem.	BICA-WM-030
Wildlife Management	Pheasant Crow Counts	This is the most effecive method of monitoringpheasant populations on Yellowtail. The WYG&F conducts the counts every spring to obtain a population index (as opposed to population numbers) in order to assess trend. They were started in 1969 and conducted every year through 1985, discontinued until 1994 and discontinued again until last spring (2003).	
Wildlife Management	Winter Bald Eagle Survey	The BLM conducts a survey for Bald Eagles on the Shoshone River each winter.	
Wildlife Management	Pryor Mountain Wild Horse Range Monitoring	The BLM oversees ongoing monitoring efforts of the Pryor Mountain Wild Horse Range and the herds.	

V. GRYN LITERATURE REVIEW

Greater Yellowstone Network Literature Review
Version 2
May 30, 2003

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AIR

Malm, W.C. 2002. Introduction to Visibility. Cooperative Institute for Research in the Atmosphere, Colorado State University, Fort Collins, 68pp.

Abstract in Progress (1)

National Atmospheric Deposition Program. 2002. National Atmospheric Deposition Program 2001 Annual Summary, NADP Data Report, 2002-01. Illinois State Water Survey. Champaign, Ill. Http://napd.sws.uiuc.edu/lib/

Abstract in Progress (334)

National Park Service, Air Resources Division, Air Quality in the National Parks, Monograph of the NPS-Air Resources Division, October 2002.

The report summarizes what has been learned from the NPS air quality research and monitoring program (1978-1987). The report provides information from the visibility, biological effects, and ambient air quality research and monitoring programs. Superintendents, resource managers, and interpreters can use the report as a reference for resource management planning and interpretive programs. The report helps individuals to have a better understanding of how air pollution is affecting park resources and values, on a service wide, regional and park specific basis. This report is currently in its Second Edition. (2)

Peterson, D.L., M.J. Arbaugh and L.J. Robinson. 1993. Effects of ozone and climate on ponderosa pine (Pinus ponderosa) growth in the Colorado Rocky Mountains. Can. J. For. Res. 23: 1750-1759.

Long-term radial growth trends of ponderosa pone (Pinus ponderosa var. scopulorum) were studied in second-growth stands in the Front Range of the Colorado Rocky Mountains to determine if there has been any impact from oxidant air pollution. Although ozone concentrations are relatively high at some locations, visible pollutant injury was not found in any trees. Time series of basal area increments are generally homogenous within stands. Concurrent periods of increasing and decreasing growth can be found in stands throughout the Front Range, which indicates that there are temporal growth trends at the regional level. Most of these trends appear to be related to the effects of stand dynamics and climate. Correlation analysis with climatic variables indicates that soil moisture supply is the dominant factor controlling interannual variation of basal area growth. Palmer hydrological drought index is highly correlated (positively) with growth during the simmer months; total precipitation in spring is positively correlated with growth, and mean temperature in spring is negatively correlates with growth. There are no recent changes in growth trends that might be associated with elevated levels of ambient ozone in the Front Range. (Abstract by Arbaugh and Robinson as printed in Canadian Journal of Forest Research). (3)

Peterson, D.L., T.J. Sullivan, J.M. Eilers, S. Brace, 1998. Assessement of Air Quality and Air Pollutant Impacts in National Parks of the Rocky Mountains and Northern Great Plains. Air Resources Division, Denver, CO,

For Yellowstone (pp. V1-V36), gives general description, monitoring and research activities, air quality related values, and research and monitoring needs. Includes lists of plant and lichen species useful as air quality indicators. (4)

Turk, J., H. Taylor, G. Ingersoll, K. Tonnessen, D. Clow, M. A. Mast, D.Campbell and J. Melack. "Major ion chemistry of the Rocky Mountain snowpack, USA", Atmospheric Environment 35 (2001): 3957-3966, 2001.

During 1993-97, samples of the full depth of the Rocky Mountain snowpack were collected at 52 sites from northern New Mexico to Montana and analyzed for major-ion concentrations. Concentrations of acidity, sulfate, nitrate, and calcium increased from north to south along the mountain range. In the northern part of the study area, acidity was most correlated (negatively) with calcium. Acidity was strongly correlated (positively) with nitrate and sulfate in the southern part and for the entire network. Acidity in the south exceeded the maximum acidity measured in snowpack of the Sierra Nevada and Cascade Mountains. Principal component analysis indicates three solute association were characterize as: (1) acid (acidity, sulfate, and nitrate), (2) soil (calcium, magnesium, and potassium), and (3) salt (sodium, chloride, ammonium). Concentrations of acid solutes in the snowpack are similar to concentrations in nearby wetfall collectors, whereas, concentrations of soil solutes are much higher in the snowpack than in wetfall. Thus, dryfall of acid solutes during the snow season in negligible, as is gypsum from soils. Snowpack sampling offers a cost-effective complement to sampling the wetfall in areas where wetfall is difficult to sample and where the snowpack accumulates throughout the winter. (Abstract by Turk et al as printed in Atmospheric Environment). (5)

BIODIVERSITY

Hansen, A.J., A. Gallant, J.J. Rotella, D. Brown. Natural and Human Drivers of Biodiversity in the Greater Yellowstone Ecosystem

Abstract in Progress (6)

Langner, L. L., and C. H. Flather. 1994. Biological diversity: status and trends in the United States. U.S. Forest Service General Technical Report RM-244. 21 pp.

The Nature Conservancy (1975) issued a report on natural diversity, almost 20 years ago, that indicated a rapid loss of ecosystems and communities in the United States. The report emphasized the reliance of society on ecological ecosystems, and the need to protect natural areas that support species and natural communities. Today the same concerns are being expressed in terms of biological diversity. This report summerizes information available that can provide evidence about the status and trends in biological diversity in the United States. A literature review of the topic has been handled elsewhere (Myers 1983, Wilson 1988a, Wilson 1992). (Introduction by Langner and Flather as printed in GTR RM-244) (8)

Whittaker, R.J., Willis, K.J., and Field, R. (2001) Scale and species richness : towards a general, hierarchical theory of species diversity. Journal of Biogeography, 28(4), pp. 453-470.

Aim: Current weaknesses of diversity theory include: a failure to distinguish different biogeographical response variables under the general heading of diversity; and a generalfailure of ecological theory to deal adequately with geographical scale. Our aim is toarticulate the case for a top-down approach to theory building, in which scale is addressed explicitly and in which different response variables are clearly distinguished. Location The article draws upon both theoretical contributions and empirical analyses from all latitudes, focusing on terrestrial ecosystems and with some bias towards (woody) plants. Methods: We review current diversity theory and terminology in relation to scale of applicability. As a starting point in developing a general theory, we take the issue of geographical gradients in species richness as a main theme and evaluate the extent to which commonly cited theories are likely to operate at scales from the macro down to the local. Results: A degree of confusion surrounds the use of the terms alpha, beta and gamma diversity, and the terms local, landscape and macro-scale are preferred here as a more intuitive framework. The distinction between inventory and differentiation diversity is highlighted as important as, in terms of scale of analysis, are the concepts of focus and extent. The importance of holding area constant in analysis is stressed, as is the notion that different environmental factors exhibit measurable heterogeneity at different scales. Evaluation of several of the most common diversity theories put forward for the grand clines in species richness, indicates that they can be collapsed to dynamic hypotheses based on climate or historical explanations. The importance of the many ecological/biological mechanisms that have been proposed is evident mainly at local scales of analysis, whilst at the macro-scale they are dependent largely upon climatic controls for their operation. Local communities have often been found not to be saturated, i.e. to be non-equilibrial. This is argued, perhaps counter-intuitively, to be entirely compatible with the persistence through time of macro-scale patterns of richness that are climatically determined. The review also incorporates recent developments in macroecology, Rapoport's rule, trade-offs, and the importance of isolation, landscape impedance and geometric constraints on richness (the mid-domain effect) in generating richness patterns; highlighting those phenomena that are contributory to the Ærst-order climatic pattern, and those, such as the geometric constraints, that may confound or obscure these patterns. Main conclusions: A general theory of diversity must necessarily cover many disparate phenomena, at various scales of analysis, and cannot therefore be expressed in a simple formula, but individual elements of this general theory may be. In particular, it appears possible to capture in a dynamic climate-based model and `capacity rule', the form of the grand cline in richness of woody plants at the macro-scale. This provides a starting point for a top-down, global-to-local, macro-to-micro scale approach to modelling richness variations in a variety of taxa. Patterns in differentiation/endemicity, on the other hand, require more immediate attention to historical events, and to features of geography such as isolation. Thus, whilst we argue that there are basic physical principles and laws underlying certain diversity phenomena (e.g. macro-scale richness gradients), a pluralistic body of theory is required that incorporates dynamic and historical explanation, and which bridges equilibrial and

nonequilibrial concepts and ideas. (Abstract by Whittaker as printed in the Journal of Biogeography). (9)

Wilson, E.O. 1988. Biodiversity. Harvard University, Editor; National Academy of Sciences/Smithsonian Institution

Abstract in Progress (10)

BIOLOGICAL INVENTORIES

Stohlgren, T. J., J. F. Quinn, M. Ruggiero, and G. Waggoner. 1995b. Status of biotic inventories in U.S. national parks. Biological Conservation 71:97-106.

It is the policy obligation of the National Park Service to conduct baseline inventories of natural resources preserved in its 32 million hectare National Park System. We evaluated the status of natural resources information in 252 national parks and monuments: those park units that contain significant natural resources. Results show that few parks contain relatively complete systematic inventories for any major plant or animal group. Better information on species occurrence is available for vascular plant, mammals and birds than for other taxa (reptiles, amphibians and fish). Although most parks have compiled species lists for at least some taxa, the majority (>80%) of the lists are reported to be less than 80% complete in their species, geographic, and ecological (community type) coverage. An earlier study of 40 parks in California, Arizona, Nevada, and Hawaii found that information on terrestrial invertebrates, aquatic invertebrates, and non-vascular plants was generally poor or non-existent. Thus, the National Park Service presently knows little about the biological diversity in national parks. Spatially explicit data on park resources are also limited. While 43.28 and 24% of the 252 parks surveyed had maps of vegetation, soils and geology, respectively, none of these maps appears to have been systematically checked for accuracy after their creation. If parks are to serve as baselines to measure environmental change, there is an urgent need (1) to develop strategic plans to rank inventory needs in the National Park System; and (2) to design and conduct biological inventory programs to bring all parks to an acceptable level of resource awareness. (Abstract by Stohlgren et al as printed in Biological Conservation). (11)

BIRD

Diem, K. L. , Pugesek, B. H. . 1994. American white pelicans at the Molly Islands, in Yellowstone National Park: Twenty-two years of boom-and-bust breeding, 1966-1987. Colonial Waterbirds. 17 2: 130-145.

Systematic monitoring of nesting and fledging of American white pelicans (Pelecanus erythrorhynchos) breeding on the Molly Islands of Yellowstone Lake was carried on for 20 years between 1966 and 1987. The mean number of pelicans fledged during those years was 214 (plus or minus 196 SD). In five of those years the number of pelicans fledged was at or near zero. In six other years, the number of young pelicans fledged ranged from 302-650, with four of those years producing record numbers of successfully fledged young. This paper chronicles the

dynamics of the Molly Island white pelican population and seeks to determine if a reliable status assessment of the white pelican population on the Molly Islands could be obtained. (13)

Diem, Kenneth L., Montopoli, George, Anderson, Donald A. 1991. Canada geese of Jackson Hole, some aspects of population and habitat changes. University of Wyoming, Jackson, WY.

This study addresses the population dynamics, factors influencing goose habitat and population productivity, as well as the maintenance of optimal levels of Canada geese in Jackson Hole, Wyoming during the period 1965-1989. Mean breeding pairs increased 54% from 117 pairs in 1965-1989. Mean clutch size in 1979-1980 was 5.0 compared to 5.2 for 1962-64 with mean brood sizes being 4.0 and 4.7, respectively. Thus maximum capacity for Canada goose production. Analysis of band recoveries indicated that the adjusted average annual mortality rate got geese banded in 1961-72 decreased by slightly more that 8% in comparison to those banded in 1956-60. Also, 1961-72 survival rates were higher in the 3rd years following banding and continued to be higher well beyond the 6th or 7th year than the survival rates of the 1956-1960 birds. Based on the 1977-78 data, the Canada goose breeding flock size in Jackson Hole was estimated to be 496 birds with a growth rate of 5-8% year. Ninety to 97% of hunter recoveries of banded geese are concentrated within Wyoming, Idaho, Utah, Arizona and California. Hunter harvests have not depressed the rate of population growth. Primary wintering areas for the geese are chiefly in southern California and Arizona. A 130% increase of private river float trips during the 10 years prior to 1989 presents a serious threat to the protective isolation historically provided the geese within Grand Teton National Park. A ceiling of 5000 commercial and 5000 private float trips per tear with trip permits required for all floaters would best serve all interests. A lottery drawing system for the allocation of private permits may be required. Snake River floater traffic is recommended to be lightest on the Flagg Ranch to Berry Creek sector, moderate on the Pacific Creek to Dead Man's Bar and heaviest on the Dead Man's Bar to Moos sector. Vegetated riverine island habitat provides some of the most desirable goose nesting and loafing habitat. Between 1949 and 1979, 19% (293 ha) of the vegetated island habitat of the Snake River of Jackson Hole was lost. The largest proportionate decrease (79.2 ha) was associated with the area of sectional flood control diking along the river below Wilson. At the same time there was a 37% (65.6 ha) increase in bare sand and grabble areas in the continuous flood control dike region. The prime Canada goose habitat in Jackson Hole extends laterally downstream from the Dime Creek-Upper Snake River junction to Jackson Lake, as well as along the western lake shore to the Berry Creek meadows. This habitat is particularly in need of management regulations which preserve their seasonal isolation from human activities. Long term aerial censusing of the goose breeding population should be continued on an annual basis with consistent procedures and experienced observers. Reliable flock composition and monitoring of population changes and the nature of the hunter harvest can only be determined through continued and consistent banding and color marking of geese in all seasons. (Abstract by Diem as printed in Canada Geese of Jackson Hole: Some Aspects of Population and Habitat Changes). (14)

Follett, D. Birds of Yellowstone and Grand Teton National Parks. Roberts Rinehart Publishing, Boulder, CO.

Abstract in Progress (15)

Hansen, A.J., and J.J. Rotella. 2000. Bird response to forest fragmentation. Pp. 201-219 in R. L. Knight, F.W. Smith, S.W. Buskirk, W.H. Romme, and W.L. Baker, eds. Forest Fragmentation in the Southern Rocky Mountains. University Press of Colorado, Boulder

Abstract in Progress (17)

Hayward, D. G., and J. Verner, editors. 1994. Flammulated, boreal, and great gray owls in the United States: a technical conservation assessment. U.S. Forest Service General Technical Report RM-253. 213 pp.

Flammulated (Otus flammeolus), boreal (Aegolius funereus), and great gray (Strix nebulosa) owls occur over a broad portion of North America and each is designated as a "sensitive species" in four or more USDA Forest Service regions. The insectivorous flammulated owl is a neotropical migrant requiring suitable wintering habitat in the extreme southwestern United State, Mexico, and Central America as well as breeding habitat in the mountains of the western United States. Flammulated owls breed predominately in yellow-pine Pinus ponderosa and Pinus jeffreyi) forest and are cavity nesters. The mature and older ponderosa pine forests used as breeding habitat by flammulated owls have changed during the past century due to fire management and timber harvest. In contrast, the boreal owl is a nomadic, small mammal specialist that occurs as an "island" species occupying subalpine and boreal forests. Movements among populations are probably important to boreal owl persistence, and coordinated management of disjunct populations in different Forest Service regions may be important. While the boreal owl's high altitude spruce-fir forest stands using existing raptor nests or tops of broken trees and snags for a nest platform. The species' requirement of a secure nesting platform leads to one potential ecological limitation on population size. Prey availability is the other factor thought to limit populations. Flammulated and boreal owls ma face significant conservation problems in the absence of conservation planning. Both owls are associated with older forest habitats. Limited research on the se species indicates that their demography and life history coupled with their fairly narrow habitat associations make them vulnerable to habitat change. Current forest management practices in many areas (i.e., stand replacement systems) remove quality habitat for these species. Therefore, on at least a local basis, persistence of these species could be in jeopardy, even in the short term. Long-term concerns are greater because the habitats that seem most important to these species require one to two centuries to regenerate. Furthermore, the population biology of both species necessitates across-region planning to facilitate effective conservation planning. Based on limited information, the persistence of great gray owl populations in the United States over both the short and long-term is more certain. Great gray owl foraging habitat use is more compatible with current forest management practices. Our understanding of the ecology and biology of these three species is not sufficient to produce a conclusive assessment of their conservation status. The enclosed assessments, however, give a sufficiently clear picture of each owl's status and the dynamics of important forest habitats to influence mangement and research decisions. It is clear that development of conservation strategies would aid management but current knowlegde of these species is insufficient to produce such a specific document. (Abstract by Hayward and Verner as printed in General Technical Report RM-253). (29)

Hutto, R.L. 1995. Composition of bird communities following stand-replacement fires in northern rocky Mountain U.S. A.) conifer forests. Conservation Biology 9(5):1041-1058.

During the two breeding seasons immediately following the numerous and widespread fires of 1988, I estimated bird community composition in each of the 34 burned-forest sites in western Montana and northern Wyoming. I detected an average of 45 species per site and a total of 87 species in the sites combined. A compilation of these data with bird-count data from more than 200 additional studies conducted across 15 major vegetation cover types in the northern Rocky Mountain region showed that 15 bird species are generally more abundant in early post-fire communities than in any other major cover type occurring in the northern Rockies. One bird species (Black-backed Woodpecker, Picoides arcticus) seems to be nearly restricted in its habitat distribution to standing dead forests created by stand-replacement fires. Bird communities in recently burned forests are different in composition from those that characterize other Rocky Mountain cover types (including early-succession clearcuts) primarily because members of three feeding guilds are especially abundant therein: woodpeckers, flycatchers, and seedeaters. Standing, fire-killed trees provided nest sites for nearly two-thirds of 31 species that were found nesting in the burned sites. Broken-top snags and standing dead aspens were used as nest sited for cavity-nesting species significantly more often than expected on the basis of their relative abundance. Moreover, because nearly all of the broken-top snags that were used were present before the fire, forest conditions prior to a fire (especially the presence of snags) may be important in determining the suitability of a site to cavity-nesting birds after a fire. For bird species that were relatively abundant in or relatively restricted to burned forests, stand-replacement fires may be necessary for longterm maintenance of their populations. Unfortunately, the current fire policy of public land management agencies does not encourage maintenance of stand-replacement fire regimes, which may be necessary for the creation of conditions needed by the most fire-dependant bird species. In addition, salvage cutting may reduce the suitability of burned-forest habitat for birds by removing the most important element-standing, fire-killed trees-needed for feeding, nesting, or both by the majority of bird species that used burned forests. (Abstract by Hutto as printed in Conservation Biology). (18)

McEneaney, T. et al. 1998. Greater Yellowstone Peregrine falcons: their trials, tribulations, and triumphs. Yellowstone Science, 6(2):16-21.

This article serves as an update on the “history, ecology and status” of the peregrine falcon (Falco peregrinus) in the Greater Yellowstone Ecosystem. A physical and biological description of the species including habitat, prey characteristics and breeding range is included. The article describes the history of abundance and of recovery efforts in the Greater Yellowstone that led to an encouraging 1997 report of 13 breeding pairs within the park who produced 25 young, with similar gains in Wyoming and Idaho. Authors state their consensus that the peregrine falcon is a recovered species that may be taken off the endangered species list but once de-listed will need to be monitored to ensure population security. (354)

McEneaney, T. M. . 1995. The common raven: an important Yellowstone predator. Pages 14 in No Editor/Author. Greater Yellowstone predators: Ecology and conservation in a changing landscape. Third Biennial Scientific Conference on the Greater Yellowstone Ecosystem. Agenda and abstracts. National Park Service.

The role of the common raven (Corvus corax) as a predator in Yellowstone has been largely overlooked. The information presented here is based on 9 years of field observations recorded by the author. Three points are discussed in detail, namely raven morphology, food habits, and anecdotal observations on behavior and predation. Morphology and behavior suggest that common ravens are quintessential Yellowstone predators that specialize in killing small- to medium-sized prey. Seasonal availability and abundance of food plays an important role in raven predation. Ravens merit systematic study to better understand their functional ecological role in the Yellowstone ecosystem. (Abstract by McEneaney as printed in the Third Biennial Scientific Conference on the Greater Yellowstone Ecosystem Agenda and Abstracts). (19)

McEneaney, T.M. 2000. 2000 Yellowstone Bird Report. YNP, YCR?
Abstract in Progress (20)

Rotella, J. . 1995. Ecology of cavity-nesting birds: influence of disturbance type on density, breeding success and dispersal. Investigator's Annual Report.
Abstract in Progress (21)

Saveraid, E.H., D.M. Debinski, K. Kindscher, and M.E. Jakubauskas. 2001. A comparison of satellite data and landscape variables in predicting bird species occurrences in the Greater Yellowstone Ecosystem. Landscape Ecology 16(1):71-83.

We compare the accuracy of predicting the occurrence of 11 bird species in montane meadows of the Greater Yellowstone National Park ecosystem, in the states of Montana and Wyoming, USA. We used remotely sensed, landscape, and habitat data. The meadow type, as determined from the remotely sensed data, was highly correlated with abundances of six of the 11 bird species. Landscape variables significant in predicting occurrence were selected using a stepwise multiple regression for each bird species. These variables were then used in a multiple regression with the variable meadow type. As expected, the abundances of the generalist species (American Robin, Dark-eyed Junco, White-crowned Sparrow, Brewer's Blackbird, and Chipping Sparrow) were not strongly correlated with landscape variables or meadow type. Conversely, abundances of the Common Snipe, Common Yellowthroat, Lincoln's Sparrow, Savannah Sparrow, Vesper Sparrow, and Yellow Warbler were highly correlated with meadow type and landscape variables such as percent cover of willow (Salix spp.), graminoid, woody vegetation, sagebrush (Artemisia spp.), and graminoid and shrub biomass. The results from our study indicate that remotely sensed data are applicable for estimating potential habitats for bird species in the different types of montane meadows. However, to improve predictions about species in specific sites or areas, we recommend the use of additional landscape metrics and habitat data collected in the field. (Abstract by Saveraid et al as printed in Landscape Ecology). (22)

Schieck, J., et al. (1995). Effects of patch size on birds in old-growth montane forests. Conservation Biology, 9(5): 1072-1083.

Following habitat alteration or fragmentation, competition, parasitism, and predation from species that live in the new habitats may reduce the survival and reproductive success of species living in the original habitats. Negative influences from species that live outside the

remnant patches are expected to be greater in small rather than in large remnant patches because more "external" species are expected to move through the centers of small remnant patches. We surveyed birds within remnant patches of old-growth montane forests on Vancouver Island, Canada, (1) to evaluate whether the richness and abundance of non-old-growth bird species were larger at the center of small rather than large patches and (2) to evaluate whether the opposite was true of old-growth bird species. More non-old-growth bird species were present at the center of small remnant patches of old growth than in large old-growth patches. We found no relationship, however, between patch size and richness or abundance of old-growth bird species at the center of remnant patches of old growth. This was true for old-growth species with open, cup-shaped nests and cavity nests. Old-growth birds may have been affected less in our study area than in other areas because they evolved within heterogeneous montane forests and interacted with non-old-growth species throughout their evolutionary histories or because the contrast between old-growth forests and logged areas was less than that between the forests and agricultural/urban areas that were surveyed in other studies. (Abstract by Schieck et al as printed in Conservation Biology). (23)

Sedgwick, J. A., and F.L. Knopf, 1990, Habitat Relationships and Nest Site Characteristics of Cavity-Nesting Birds in Cottonwood Floodplains: Journal of Wildlife Management, v. 54, p. 112-124.

We examined habitat relationships and nest site characteristics for 6 species of cavity-nesting birds--American kestrel (Falco sparverius), northern flicker (Colaptes auratus), red-headed woodpecker (Melanerpes erythrocephalus), black-capped chickadee (Parus atricapillus), house wren (Troglodytes aedon), and European starling (Sturnus vulgaris) -- in mature plains cottonwood (Populus sargentii) bottomland along the South Platte River in northeastern Colorado in 1985 and 1986. We examined characteristics of cavities, nest trees, and the habitat surrounding nest trees. Density of large trees (>69 cm dbh), total length of dead limbs ≥10 cm diameter (TDLL), and cavity density were the most important habitat variables; dead limb length (DLL), dbh, and species were the most important tree variables; and cavity height, cavity entrance diameter, and substrate condition at the cavity (live vs. dead) were the most important cavity variables in segregating cavity nesters along habitat, tree, and cavity dimensions, respectively. Random sites differed most from cavity-nesting bird sites on the basis of dbh, DLL, limb tree density (trees with ≥1 m dead limbs ≥ 10 cm diameter), and cavity density. Habitats of red-headed woodpeckers and American kestrels were the most unique, differing most from random sites. Based on current trends in cottonwood demography, densities of cavity-nesting birds will probably decline gradually along the South Platte River, paralleling a decline in DLL, limb tree density, snag density, and the concurrent lack of cottonwood regeneration. (Abstract by Sedgwick and Knopf as printed in the Journal of Wildlife Management). (655)
Swenson, J. E. , Alt, K. L. , Eng, R. L. . 1986. Ecology of bald eagles in the greater Yellowstone ecosystem. Wildlife Monographs. 95: 1-46.

The ecology of the bald eagle (Haliaeetus leucocephalus) was studied from 1972 to 1982 in the Greater Yellowstone Ecosystem in northwestern Wyoming and adjacent Idaho and Montana. This population consisted of 3 ecologically, but not genetically, distinct units: the Yellowstone Unit (YU), the Continental Unit (CU), and the Snake Unit (SU). The population probably was stable at 30-31 breeding pairs from 1960 to 1970, but increased exponentially to

50 known breeding pairs from 1971 to 1982. Breeding bald eagles were adaptable in selecting breeding areas. A stable food source, which was available from early spring, appeared to be the most important factor in breeding area selection. (24)

Taylor, D.L., Barmore, W.J.=, Jr. 1980. Post-fire succession of avifauna in coniferous forests of Yellowstone and Grand Teton National Parks, Wyoming. U-S-D-A-For-Serv-Gen-Tech-Rep-INT-U-S-Intermt-For-Range-Exp-Stn. 86: 130-145.

Yellowstone and Grand Teton National Parks have been zoned to allow certain natural fires to burn until they self-extinguish. The effect of these natural fires on avifauna in the two parks is reported in this paper.
Breeding birds populations in burned lodgepole or spruce-fir-lodgepole pine forest of the following post0fire ages are analyzed: MODERATE BURN 1, 2, 3 years; SEVERE BURN 1, 2, 3, 5, 7, 11, 13, 17, 25, 29, 43, 44, 45, 57, 61, 111, 115, 300, 304 years; UNBURNED SPRUCE-FIR WITH SOME LODGEPOLE PINE, and UNBURNED SPRUCE-FIR. Highest populations and greatest biomass occurred from 5-29 years post-fire. Bird density, species composition, and diversity on moderately burned spruce-fir-lodgepole were more like those on unburned spruce-fir than on other seral stages. Greatest biomass ground-seed feeding categories occurred where the forest canopy has not closed. Biomass of foliage-insect and timber-searching was greatest where the forest canopy had closed. Canopy closure affected avifuana more than fire did. (Abstract by Taylor and Barmore as printed in General Technical Report INT-86). (25)

USFS. Status and management of Neotropical migratory birds. U.S. Forest Service General Technical Report RM-229.

Abstract in Progress (12)

Wiens, J.A., and J.T. Rotenberry. 1981. Habitat associations and community structure of birds in shrubsteppe environments. Ecol. Monogr. 51(1)21-24.

Abstract in Progress (32)

Wolf, Carl E. 1990. Birding checklist for the Pryor Mountains and Bighorn Canyon.

Abstract in Progress (26)

CARNIVORE

Bangs, E. E. , Fritts, S. H. . 1996. Reintroducing the gray wolf to central Idaho and Yellowstone National Park [correction]. Wildlife Society Bulletin. 24(3): 402-413.

Plans to reintroduce the grey wolf to central Idaho and Yellowstone National Park attracted considerable controversy. Some people believed that the wolves would have a negative impact on agriculture in the region, while others felt that wolves were already in these areas or would soon return there, and that wolf habitat should be given greater protection. Nevertheless, the first wolves were released into central Idaho on Jan 14, 1995. Wolves reintroduced in the state travelled extensively, mostly going north, but most stayed on public land within the core reintroduction area. There were seven groups released in Yellowstone National Park, and all

expect one breeding pair remained together. (Abstract by Bangs as printed in Wildlife Society Bulletin). (33)

Berger, J. 1998. Future Prey: Some Consequences of Losing and Restoring Large Carnivores. Pp. 80-100. In: Behavioral Ecology and Conservation Biology. (Ed, T, Caro). Oxford University Press .

Abstract in Progress (34)

Blanchard, B. M., and R. R. Knight. 1996. Effects of wildfire on grizzly bear movements and foraging strategies. Pages 117-122 in J. M. Greenlee, editor. Proceedings of the second biennial scientific conference on the Greater Yellowstone Ecosystem. International Association of Wildland Fire, Fairfield, Washington.

Forty-four radio-telemetered grizzly bears (Ursus arctos horribilis) were located 867 times during 1989-92 within Yellowstone National Park following extensive wildfires in 1988. Pooled locations indicated avoidance of burned sites during 1989, especially by females with cubs-of-the-year, but not during subsequent years. On the average, individual grizzly bears were located in burned and unburned habitats in proportion to their availability within each bear's annual range. Rates of movement were lower than those recorded prior to the fires, indicating adequate native food supplies. Feeding habits at burned sites differed significantly from those recorded at unburned sites. Short-term effects of the fires were beneficial to grizzly bears largely because of increased production of diet items such as forb foliage and tuberous root crops in burned habitats. (Abstract by Blanchard and Knight as printed in the Proceedings of the Second Biennial Scientific Conference on the Greater Yellowstone Ecosystem). (35)

Browne-Nunez, C., and J.G. Taylor, 2002, Americans' Attitudes Toward Wolves and Wolf Reintroduction: an annotated bibliography: Information and Technology Report USGS/BRD/ITR-2002-0002, 15 p.

Abstract in Progress (36)

Buskirk, S. W. <Steven W. >. "Mesocarnivores of Yellowstone." In CarnivoresinEcosystems, ed. Tim W. Clark, p. 164-87. New Haven [Conn.]: Yale University Press,1999.

Abstract in Progress (37)

Cole, G.F. 1976. Management involving Grizzly and Black Bears in Yellowstone National Park. 1970-1975. Natural Resources Report No. 9. National Park Service, U.S. Department of the Interior, Washington, DC.

A management program to 1) maintain the grizzly bear (Ursus arctos) and black bear (U. americanus) populations in Yellowstone National Park under natural conditions and 2) reduce bear injuries to humans is evaluated by testing hypotheses that could be rejected by inconsistent data. Management involved eliminating sources of unnatural food that concentrated bears in and near developed areas, controlling bears that persisted in seeking food in such areas, regulating camping and hiking, and informing park visitors of appropriate precautions and the consequences of feeding bears. The author concluded that the management program was accomplishing its intended objectives. (38)

Copeland, J. 1996. Biology of the wolverine in central Idaho. M.S. Thesis, University of Idaho, Moscow. 138 pp.

I determined wolverine (Gulo gulo) presence, ecology, spatial characteristics, movement, demographics, social structure, and habitat use in central Idaho from 1992-1995. My study area encompassed approximately 8,000 km2 of primarily roadless and statutory wilderness habitats. The study area was characterized by montane coniferous forests at lower elevations, to high elevation subalpine habitats associated with talus scree and non-forested mountain tops. Nineteen wolverines were captured and instrumented with intraperitoneal implant transmitters. I monitored wolverines weekly, by ground and aerial telemetry, collecting 1,050 relocations. Annual home ranges of resident adults averaged 384 km2 for females and 1,582 km2 for males. Adult home ranges were segregated by sex, with female home ranges overlapping <10% and male home ranges overlapping <15%. Offspring of both sexes remained associated with the natal area for up to 2 years corresponding with sexual maturation. Juveniles and subadults interacted with resident kin, including their mother, the resident male, and siblings. Evidence of resident adult wolverine associating with subadult wolverine was previously undescribed. Periods of association lasted as long as 7 days with individuals traveling together or localizing at foraging sites. The extended association of subadults and adults may be related to the highly dispersed nature of food resources and may account for large home range sizes of resident females. Adult male home ranges encompassed up to 3 female home ranges. Snow-tracking sessions were conducted to document scent-marking and foraging behavior. Food resources were widely dispersed but consistent in timing and presence which may produce traditional foraging routes. Such sites were revisited within a season of use and between years and were shared within kinship groups. Urination was the primary method of scent-marking observed during this study. The reproductive rate for 4 adult females was less than 1 kit/female/year. Females used secluded high elevation cirque basins for natal den sites. Human disturbance at maternal dens resulted in den abandonment but not kit abandonment. Kits remained with the adult female for approximately 3 months subsequent to weaning at 9 to 10 weeks of age. Females commonly left dependent kits at rendezvous sites comprised of large boulder talus or riparian areas associated with mature overstory and dense timber deadfall. Boulder talus associated with subalpine habitats was also used for resting and foraging sites. Four male wolverines dispersed at sexual maturity, with 2 emigrating distances greater than 185 km. Two of these individuals appeared to establish at the new location while the other 2 returned to the study area. Seven wolverines died during the study, with predation accounting for 43% of the mortality. Distinct seasonal shifts in elevation use were recorded, with higher elevational talus/rock cover types preferred during summer months, and montane coniferous forest cover types preferred during winter. Wolverines avoided lowland grass/shrub and ponderosa pine (Pinus ponderosa) cover types. Movement to lower elevations during winter months may be correlated with increased presence of carrion attributable to the fall big game hunting seasons. Ungulate species including mule deer (Odocoileus hemionus), elk (Cervus elaphus), moose (Alces alces), and domestic cow (Bos bos) and horse (Equus sp.) were present at similar proportions in both summer and winter scat and foraging site collections. Other prey items included 5 species of carnivores: 12 rodent species, including 5 sciurids; and 1 lagomorph

species. Avian species constituted 4.9% of species occurrences while insects, primarily ants, occurred at 5.9%. (Abstract by J. Copeland. As printed in. M.S. Thesis) (39)

Crabtree, R.., and J.W. Sheldon. 1999. the ecological role of coyotes on Yellostone's northern range. Yellowstone Science 7(2): 15-23.

Discusses studies initiated in 1989, 6 years prior to wolf reintroduction. Covers social systems, reproduction, pup survival, population density and territory size, food habits, ecological relations between coyotes and prey species, fire impacts on coyotes, pack size and population regulation, and the return of the wolves. (40)

Craighead, John Johnson, Jay S. Sumner, and John A. Mitchell. The Grizzly Bears of Yellowstone: Their Ecology in the Yellowstone Ecosystem, 1959-1992. Washington DC:Island Press, 1995.

Abstract in Progress (41)

Gese, E.M., R.L. Ruff and R.L. Crabtree. 1996. Intrinsic and extrinsic factors influencing coyote predation of small mammals in Yellowstone National Park. Canadian Journal of Zoology. 74:784-97.

Examines factors influencing predation: age, sex, social status, snow depth and hardness, temperature, cloud cover, wind speed and habitat. Findings indicate young, inexperienced coyotes detected and attacked small mammals at a higher rate than did older animals. (396)

Gese, E.M., R.L. Russ, and R.L. Crabtree. 1996. Social and nutritional factors influencing the dispersal of resident coyotes. Anim. Behav., 52: 1025-1043.

Five resident packs were observed from January 1991 to June 1993 to determine what factors influence whether a coyote will remain in its natal pack or disperse. Lower ranking individuals were likelier to disperse and showed lower success at catching small mammals. (42)

Gunther, K., M. T. Bruscino, S. L. Cain, J. Copeland, K. Frey, M. A. Haroldson, and C. C. Schwartz. 2002. Grizzly bear-human conflicts in the Yellowstone Ecosystem. Ursus (in press).

Abstract in Progress (43)

Gunther, K.A. 1994. Bear Management in Yellowstone National Park, 1960-1993. Int. Conf. Bear Res. and Manage. 9(1):549-560

"From 1931 through 1959, an average of 48 people per year were injured by bears in Yellowstone National Park (YNP). In 1960, YNP implemented a bear management program designed to reduce the number of bear-caused human inures and property damages occurring with YNP and to re-establish bears in a natural state....After 10 years (1960-1969) of the program, 332 nuisance black bears (Ursus americanus) and 39 nuisance grizzly bears (Ursus arctos horribilis) had been removed from the population. ..In 1970, YNP initiated a new, more intensive bear management program with the objectives of restoring the grizzly and black bear populations to subsistence on natural forage and reducing the number of bear caused injuries to humans." (44)

Haroldson, M.A., M.A, Ternent, K.A. Gunther, and C.C. Schwartz. In Press. Grizzly bear denning chronology and movements in the Greater Yellowstone Ecosystem. Ursus 13:

Den entrance and emergence dates of grizzly bears (Ursus arctos) in the Greater Yellowstone Ecosystem are important to management agencies that wish to minimize impacts of human activities on bears. Current estimates for grizzly bear denning events use data that were collected from 1975-80. We update these estimates by including data obtained from 1981-99. We used aerial telemetry data to estimate week of den entry and emergence by determining the midpoint between the last known active date and the first known date denned, as well as the last known date denned and the first known active date. We also investigated post emergence movement patterns relative to den locations. Mean earliest and latest week of den entry and emergence were also determined. Den entry for females began during the fourth week in September, with 90% denned by the fourth week of November. Earliest den entry for males occurred during the second week of October, with 90% denned by the second week of December.

Mean week of den entry for known pregnant females was earlier than for males. Earliest week of den entry for known pregnant females was earlier than for other females and males. Earliest den emergence for males occurred during the first week of February, with 90% of males out of dens by the fourth week of April. Earliest den emergence for females occurred during the third week of March; by the first week of May, 90% of females had emerged. Male bears emerged from dens earlier than females. Denning period differed among classes and averaged 171 days for females that emerged from dens with cubs, 151 days for other females, and 131 days for males. Known pregnant females tended to den at higher elevations and following emergence remained at

higher elevations until late May. Females with cubs remained relatively close (<3 km) to den sites until the last 2 weeks in May. Timing of denning events was similar to previous estimates for this and other grizzly bear populations in the southern Rocky Mountains. (45)

Heinemeyer, Kimberly S., Aber, Bryan C., Doak, Daniel F. 2001. Aerial Surveys for Wolverine Presence and Potential Winter Recreation Impacts to Predicted Wolverine Denning Habitats in the Southwestern Yellowstone Ecosystem."
http://gis.ucsc.edu/Projects/gulo2000/wolverine_report2000.pdf

Abstract in Progress (377)

Johnson, K.A. and R.L. Crabtree. 1999. Small prey of carnivores in the Greater Yellowstone Ecosystem. Pp. 239-264 in Carnivores in Ecosystems: the Yellowstone Experience, T.W. Clark, A.P. Curlee, S.C. Minta, and P.M. Kareiva, eds. New Haven, CT: Yale University

"This chapter integrates information from a review of the literature and esults of a cooperative small mammal study on the Northern Range of Yellowstone National Park, hereafter called the Northern Range Small Mammal Study. This study was initiated in YNP in 1990 and has been continued since 1993 by Yellowstone Ecosystem Studies. We summarize small-mammal habitat relations, community structure, and landscape patterns (including the effects of disturbace) in the GYE, and we discuss relavant carnivore food habits studies as they pertain to

small mammals. We analyze the implications of current knowledge about small prey for carnivore conservation and make recommendations for small-mammal research." (Summary by Johnson and Crabtree as printed on first page of chapter) (46)

Keiter, R. B. . 1991. Observations on the future debate over "delisting" the grizzly bear in the Greater Yellowstone Ecosystem. Environmental Professional. 13 3: 248-253.

With grizzly bear population numbers now on the upswing in the Greater Yellowstone Ecosystem (USA), federal and state wildlife managers are suggesting tentatively that the bear might be "delisted" from the Endangered Species Act(ESA) in the not-too-distant future if current trends continue. Under the ESA, rigorous legal requirements must be met before a protected species is delisted. A Yellowstone delisting effort most likely would be based upon the grizzly bear delisting effort that currently is pending in the Northern Continental Divide Ecosystem in Montana. Biological and legal conditions in the Greater Yellowstone Ecosystem, however, differ quite significantly from those prevailing in the Northern Continental Divide Ecosystem. Indeed, agency officials have yet to answer several critical biological questions concerning the Yellowstone bear population and the security of its habitat, as well as important legal questions concerning how the bear and its habitat will be protected in the absence of state ESA or NEPA laws. Until these questions are answered, delisting discussions must be tempered with caution. (47)

Logan, K. A. and L. L. Irwin. 1985. Mountain lion habitats in the Big Horn Mountains, Wyoming. Wildl. Soc. Bull. 13:257-262.

Food habits of mountain lions (Felis concolor) have been quantified (Hornrocker 1970, Spalding and Lesowski 1971, Shaw 1977, Toweill and Meslow 1977, Ackerman et al. 1984), but relatively little is known about lion use of vegetation and topography. Seidensticker et al. (1973) and Hemker (1982) described habitat at scratch sites, and Berg et al. (1983) calculated density of lion sightings for 16 Kulchler (1964) potential vegetation types in Wyoming. This paper quantifies lion habitat use patterns by testing the hypothesis that lions use vegetation and terrain features in proportion to availability. (Abstract by Logan and Irwin as printed in Wildlife Society Bulletin). (48)

Logan, K. A. and L. L. Sweanor. 2001. Desert puma: evolutionary ecology and conservation of an enduring carnivore. Island Press, Washington, DC. 448pp.

Abstract in Progress (49)

Mattson, D. J. , Gillin, C. M. , Benson, S. G., Knight, R. R. . 1991. Bear feeding activity at alpine insect aggregation sites in the Yellowstone Ecosystem. Canadian Journal of Zoology. 69: 2430-2435.

"Bears (Ursus arctos horribilis and U. americanus) were observed from aircraft on or near alpine talus in Wyoming and Montana during 15 June-15 September 1981-89. Bears fed on insect aggregations at 6 known and 12 suspected alpine talus sites, disproportionately more at elevations above 3350 m, on slopes >30 degrees and on south- and west-facing aspects. While at these sites, bears almost exclusively ate invertebrates, typically Euxoa auxiliaris. Subadult

grizzly bears (U. a. horribilis) appeared to be underrepresented at the sites and proportionate representation of adult females with young decreased between 15 June and 15 September. Overall, observations of bears at these sites increased between 1981 and 1989. It is suggested that alpine insect aggregations are an important food source for bears, especially in the absence of high quality foraging alternatives in July and August of most years." (50)

Mattson, D. J., B. M. Blanchard, and R. R. Knight. 1991. Food habits of Yellowstone grizzly bears. Canadian Journal of Zoology 69:1619-1629.

Food habits of grizzly bears were studied for 11 years in the Yellowstone area of Wyoming, Montana, and Idaho by analyzing scats. Ungulate remains constituted a major portion of early-season scats, graminoids of May and Jun scats, and whitebark pine seeds of late-season scats. Berries composed a minor portion of scats during all months. The diet varied most among years during May, Sep, and Oct, and was most diverse during Aug. Defecation rates peaked in Jul and were low in Apr through Jun. Among-years differences in scat content were substantial; estimates of average scat composition took 4-6 years to stabilize. Major trends in diet were evident and reflected long-term variation. We suggest that long-term studies are necessary to adequately document bears' food habits in variable environments; the Yellowstone grizzly bears' diet varied with seasonal and yearly availability of high-quality foods, lack of berries and large fluctuations in the size of pine seed crops were major factors limiting bear density in the Yellowstone area. (51)

Mattson, D. J., S. Podruzny, and M. A. Haroldson. 2002. Consumption of fungal sporocarps by Yellowstone grizzly bears. Ursus 13:in press.

Abstract in Progress (52)

Murphy, K.M., P.I. Ross, and M.G. Hornocker. 1999. The ecology of anthropogenic influences on cougars. Pp. 77-102 in Carnivores in Ecosystems: the Yellowstone Experience, T.W. Clark, A.P. Curlee, S.C. Minta, and P.M. Kareiva, eds. New Have, CT: Yale University

Abstract in Progress (53)

Podruzny, S. R., D. P. Reinhart, and D. J. Mattson. 1999. Fire, red squirrels, whitebark pine, and Yellowstone grizzly bears. Ursus 11:131-138.

Whitebark pine (Pinus albicaulis) habitats are important to Yellowstone grizzly bears (Ursus arctos) as refugia and sources of food. Ecological relationships between whitebark pine, red squirrels (Tamiasciurus hudsonicus), and grizzly bear use of pine seeds on Mt. Washburn in Yellowstone National Park, Wyoming, were examined during 1984-86. Following large-scale fires in 1988, we repeated the study in 1995 –97 to examine the effects of fire on availability of whitebark pine seed in red squirrel middens and on bear use of middens. Half of the total length of the original line transects burned. We found no red squirrel middens in burned areas. Post-fire linear-abundance (no./km) of active squirrel middens that were pooled from burned and unburned areas decreased 27% compared to pre-fire abundance, but increased in unburned portions of some habitat types. Mean size of active middens decreased 54% post fire. Use of pine seeds by bears (linear abundance of excavated middens) in pooled burned and unburned

habitats decreased by 64%, likely due to the combined effects of reduced midden availability and smaller midden size. We discourage any further large-scale losses of seed producing trees from management-prescribed fires or timber harvesting until the effects of fire on ecological relationships in the whitebark pine zone are better understood. (54)

Renkin, R. A. , Gunther, K. A. . 1995. Predicting grizzly bear mortality in relation to frontcountry developed areas in Yellowstone National Park. Pages 17-18 in No Editor/Author. Greater Yellowstone predators: Ecology and conservation in a changing landscape. Third Biennial Scientific Conference on the Greater Yellowstone Ecosystem. Agenda and abstracts. National Park Service.

In 1986, a grizzly bear (Ursus arctos) mortality risk model was developed as part of the Environmental Impact Statement (EIS) for the Development Concept Plan (DCP) of the Fishing Bridge developed area. The model provided an estimate of the number of management transfers and, ultimately, bear mortalities that could be attributed to each of the 16 developed areas in the park for the subsequent 10-year period, 1987-96. Given that bear mortalities in relation to developed areas actually declined during the following decade, the model overestimated the number of transfers and mortalities that occurred across all developments from 1987-96. The model, however, accurately accounted for the 15 transfers and 3 mortalities that occurred at the 5 developments requiring bear management actions. Although restricted in utility to identifying point sources of continued mortality and the incremental risk associated with the placement of new facilities or the expansion of existing facilities within the park, the empirical model could supplement other efforts in quantifying mortality risk as part of a cumulative effects assessment for grizzly bears in the Greater Yellowstone Ecosystem (GYE). (Abstract by Renkin and Gunther as printed in Proceedings of the Third Biennial Conference on the Greater Yellowstone Ecosystem). (172)

Ripple, W. J., E.J. Larsen, R.A. Renkin, and D.W. Smith. 2001. Trophic cascades among wolves, elk and aspen on Yellowstone National Park's northern range. Biological Conservation. 102:227-234.

Quaking aspen (Populus tremuloides) biomass has declined in Yellowstone National Park (YNP) in the past century. We installed permanent belt transects (plots) for long-term monitoring of aspen stands both within and outside of established wolf pack territories on YNP's northern range to determine if reintroduced wolves are influencing elk browsing patterns and aspen regeneration through a trophic cascades interaction. Wolves may have an indirect effect on aspen regeneration by altering elk movements, browsing patterns, and foraging behavior (predation risk effects). Elk pellet groups, aspen sucker heights, and the percentage of browsed suckers were the variables used to measure differences in aspen stands in high and low wolf-use areas of the northern range. The aspen stands in the high wolf-use areas had significantly lower counts of elk pellet groups in the mesic upland steppe and the combined mesic upland steppe and riparian/wet meadow habitat types. Based on our pellet group results, it appears that elk foraging behaviors may have been altered by the increased risk of predation due to the reintroduction of the wolf. In the riparian/wet meadow habitat type, mean aspen sucker heights were significantly higher in the high wolf-use areas than in the low wolf-use areas. The percentage of browsed suckers in high and low wolf-use areas showed no significant differences in any of the habitat

types. Considering the high browsing pressure in YNP aspen stands, it is uncertain whether the taller aspen suckers measured in the wolf-use areas will eventually join the aspen overstory. These permanent plots represent a valuable baseline data set to assess any current and future aspen regeneration responses to the reintroduction of wolves in YNP. (Abstract by Ripple et al as printed in Biological Conservation). (55)

Ruggiero, L. F., K. B. Aubry, S. W. Buskirk [and others]. 2000. Ecology and conservation of lynx in the United States. University Press of Colorado, Boulder, CO. 480pp.

Abstract in Progress (56)

Ruggiero, L. F., K. B. Aubry, S. W. Buskirk, L. J. Lyon, and W. J. Zielinski, eds. The scientific basis for conserving forest carnivores. USDA Forest Service General Technical Report RM-254.184pp.

This cooperative effort by USDA Forest Service Research and the National Forest System assesses the state of knowledge related to the conservation status of four forest carnivores in the western United States: American marten, fisher, lynx, and wolverine. The conservation assessment reviews the biology and ecology of these species. It also discusses management considerations stemming from what is known and identifies information needed. Overall, we found huge knowledge gaps that make it difficult to evaluate the species' conservation status. In the western United States, the forest carnivores in this assessment are limited to boreal forest ecosystems. These forests are characterized by extensive landscapes with a component of structurally complex, mesic coniferous stands that are characteristic of late stages of forest development. The center of the distribution of this forest type, and of the forest carnivores, is the vast boreal forest of Canada and Alaska. In the western conterminous 48 states, the distribution of boreal forest is less continuous and more isolated so that forest carnivores and their habitats are more fragmented at the southern limits of their ranges. Forest carnivores tend to be wilderness species, are largely intolerant of human activities, and tend to have low reproductive rates and large spatial requirements by mammalian standards.
We must have information at the stand and landscape scales if we are to develop reliable conservation strategies for forest carnivores. Ecosystem management appears likely to be central to these conservation strategies. Complex physical structure associated with mesic late-successional forests will be important in forest carnivore conservation plans. Immediate conservation measures will be needed to conserve forest carnivore populations that are small and isolated. Additional forest fragmentation especially though clearcutting of contiguous forest may be detrimental to the conservation of forest carnivores, especially the fisher and marten. Specific effects will depend on the contest within which management actions occur. (Abstract by Ruggiero et al as printed in General Technical Report RM-254). (57)

Ruth, T.K. et al. 1999. Cougar-wolf interactions in Yellowstone National Park: competition, demographics, and spatial relationships. Annual technical rep., Hornocker Wildlife Institute, Yellowstone Cougars, Phas 11.

This article is a description of Phase II of Hornrocker Wildlife Institute's Yellowstone Cougar research to date. The purposes of this portion of the study were the quantification of cougar ecology with focus on relations between cougars and wolves and cougars and their prey

in the Greater Yellowstone Ecosystem. Specific objectives are detailed in the report, as are results of the first three years of data collection. The project documented 161 cougar kills, 144 of them ungulates, 33% of which were then scavenged or taken over by other carnivores. Ground and aerial locations were obtained and then investigated to collect habitat information. Two cougars and two wolves have been radio-collared to collect location data at simultaneous times during the day. A future report is expected. (58)

Schullery, P., and L.H. Whittlesey. 1999. Greater Yellowstone carnivores: a history of changing attitudes. Pp. 11-49 in Carnivores in Ecosystems.

Abstract in Progress (59)

Schwartz, C.C., M.A. Haroldson, K.A. Gunther, and D. Moody. In Press. Distribution of grizzly bears in the Greater Yellowstone Ecosystem, 1990-2000. Ursus 13:

The Yellowstone grizzly bear (Ursus arctos horribilis) has been expanding its range during the past 2 decades and now occupies historic habitats that had been vacant. A current understanding of the distribution of grizzly bears within the ecosystem is useful in the recovery process, and to provide guidance to the state and federal land management agencies and state wildlife agencies of Idaho, Montana, and Wyoming as they prepare management plans. We used kernel estimators to develop distribution maps of occupied habitats based on initial sightings of unduplicated females (n = 300) with cubs of the year, information from radio-marked bears (n = 105), and locations of conflicts, confrontations, and mortalities (n = 1,235). Although each data set was constrained by potential sampling bias, together they provide insight into areas within the Greater Yellowstone Ecosystem (GYE) currently occupied by grizzly bears. The current distribution (1990-2000) extends beyond the recovery zone identified in the U.S. Fish and Wildlife Service Recovery Plan. Range expansion is particularly evident in the southern portion of the ecosystem in Wyoming. A comparison of our results from the 1990s to previously published distribution maps show an approximate increase in occupied habitat of 48% and 34% from the 1970s and 1980s, respectively. We discuss data biases and problems implicit to the analysis. (Abstract by Schwartz et al as printed in Ursus). (60)

Varley, John D. ; Brewster, Wayne G. Wolves for Yellowstone? : a report to the United States Congress /[Yellowstone National Park : National Park Service?], 1990-1992v. 1. Executive summary -- v. 2. Research and analysis -- v. 3. Executive summary –v. 4.

Abstract in Progress (61)

CLIMATE

Arnold, W. Energetics of Social Hibernation. C. Carey, et al., Editors. 1993. Life in the Cold: Ecological, Physiological, and Molecular Mechanisms, Westview Press: Boulder, CO. p. 65-80.

Abstract in Progress (86)

Balling, R.C., Jr., G.A. Meyer, and S.G. Wells. 1992. Climate change in Yellowstone National Park: is the drought related risk of wildifres increasing? Climate Change 22(1):35-45.

The increased frequency of wildfires in the U. S. has become a common prediction associated with the build-up of greenhouse gases. In this investigation, variations in annual wildfire data in Yellowstone National Park are compared to variations in historical climate conditions for the area. Univariate and multivariate analytical techniques reveal that a) summer temperatures in the Park are increasing, b) January-June precipitation levels are decreasing, and c) variations in burn area within the Park are significantly related to the observed variations in climate. Outputs from four different general circulation model simulations for 2 x CO2 are included in the analyses; model predictions for increasing aridity in the Yellowstone Park area are generally in agreement with observed trends in the historical climate records. (62)

Barnosky, A. D. , Hadly, E. A. . 1998. Effects of global climate change on mammalian communities: a prehistoric perspective. Pages 26 in No Editor/Author. Making a place for nature, seeking our place in nature: 125th Anniversary Symposium; agenda and abstracts

We present data from four prehistoric climatic warming events in the Rocky Mountains to assess how ongoing global warming will affect mammalian communities. Responses to warming during Miocene (17 million years ago) are manifested as biogeographic range changes, adaptive radiations of new species, and extinction. Across middle Pleistocene glacial-interglacial transitions (about 800,000 years ago) the main responses are change in relative abundance and probably minor geographic range adjustments. Mammal communities spanning the late Pleistocene-Holocene transition (10,000 years ago) exhibit the same changes, with the added features of large-scale geographic range changes resulting in allopatry of previously sympatric species, and extinction of about 103 species. Limited evidence points to phenotypic change corresponding with climate change. On the short time scale exemplified by a late Holocene sequence, mammalian populations responded to the Medieval Warm Period (~1,200-650 years ago) by fluctuating in relative abundance (habitat specialist) and shifting biogeography margins of two species whose ranges barely reach into the area today. Pocket gophers (Thomomys talpoides) showed phenotypic, but not genetic, response to climate change. The data from these four warming events confirm that species respond individualistically to climatic change by (1) change or stasis in relative abundance, (2) altering geographic distribution, or (3) phenotypic response. These points of agreement transcend temporal scaling differences, and the same effects should be anticipated for future global warming. Extinction is evident in two of the four events and can also be expected in the current event. Speciation took place only in the event with the longest time scale (Miocene), and hence probably will not be important in maintaining diversity levels during the rapid climate change anticipated under current global warming scenarios. (Abstract by Barnosky and Hadly. As printed in Making a place for nature, seeking our place in nature: 125th Anniversary Symposium, May 11-23, 1998; agenda and abstracts.) (63)

Bartlein, P. J. ., Whitlock, C. , Shafer, S. L. . 1997. Future climate in the Yellowstone National Park region and its potential impact on vegetation. Conservation Biology. 11 3: 782-792.

The impact of global climate change in mountainous regions can't be predicted by simple upward displacements of existing vegetation zones. The output of a coarse-resolution climate model incorporating a doubling of carbon dioxide showed a combination of elevational and

directional range adjustments. New communities have no analogue in present day vegetation. (64)

Brooks, P.D., K. Tonnessen, S. Diamond, D. McKnight, P.S. Corn, E. Muths, and C. Ronca. Climate-mediated DOC concentrations control amphibian exposure to UV-B. Nature (Submitted)

Abstract in Progress (65)

Dirks, R. A. , Martner, B. E. . 1982. Climate of Yellowstone and Grand Teton National Parks. National Park Service, US Department of the Interior, National Park Service Occasional Paper Number 6, Washington, DC.

Climatological records were compiled and integrated to provide a summary of the climate of the Yellowstone and Grand Teton National Parks region. Semicontinuous records of daily maximum and minimum temperature and precipitation exist for several stations in the Parks, beginning as early as 1887. Wind, humidity, sunshine, and other data are very sparse. Tabulations of monthly means and extremes of temperature and precipitation are presented for several stations. Annual precipitation histories, wind velocity distributions, and other climate data are also provided. The complexity of the terrain and the wide range of elevations preclude the possibility that a single generalized description can accurately represent the climate at all localities in the region. However, the data presented typify most of the climatic regimes within the Parks. (67)

Engstrom, d.R., C. Whitlock, S.C. Fritz, and H.E. Wright, Jr. 1991. Recent environmental changes inferred from the sediments of small lakes in Yellowstone's northern range. J. Paleolimnology. 5:139-174.

Recent sediments of eight small lakes in the northern winter range of Yellowstone National Park were cored to examine stratigraphic records of past changes in limnology and local environment that might be attributed to grazing and other activities of elk, bison, and other large ungulates. Cores of undisturbed sediment were analyzed at close intervals to depths covering the last 100-150 years according to chronologies established by lead-210 dating. Pollen analyses were made to show change in regional vegetation, and diatom and geochemical analyses were made to reveal possible limnological changes resulting from soil erosion and nutrient input from the lake catchments. (68)

Fagre, D.B., D.L. Peterson, S.W. Running, P.E. Thornton, and C. Milesi. 2001. Climatic Variability, Ecosystem Dynamics, and Disturbance in Mountain Protected Areas. Global Change Open Science Conference: Challenges of a Changing Earth, July 10-13, 2001, Amsterdam, The Netherlands

Abstract in Progress (69)

Fastie, C.L., S.T. Gray, and J.L. Betancourt. In preparation. Late Holocene climate variation inferred from tree-rings in the Bighorn Mountains of Wyoming.

Abstract in Progress (70)

Graumlich, L.J. and M. Ingram. 2000. Drought in the context of the last 1000+ years: some surprising implications. In Drought: A Global Assessment, Vol 1, Ch 17:234-242. D. Wilhite, ed., Routledge Press, New York.

Abstract in Progress (71)

Hadly, E. A. . 1996. Influence of late-Holocene climate on northern Rocky Mountain mammals. Quaternary Research. 46 3: 298-310.

An exceptionally rich paleontological site containing thousands of mammalian fossils and well-dated with 18 radiocarbon samples provides evidence of late-Holocene ecological response to climatic change in northern Yellowstone National Park, Wyoming. The mammalian fauna, composed of 10,597 identified specimens, shows surprising affinity to the local habitat with little evidence of long-distance transport of faunal elements, thus revealing the faithfulness of a fossil site to the community from which it is derived. The mammals illustrate ecological sensitivity to a series of mesic to xeric climatic excursions in the sagebrush-grassland ecotone during the past 3200 yr. From 3200 cal yr B.P. to a maximum of 1100 cal yr B.P., the species composition of mammals indicates wetter conditions than today. Beginning about 1200 cal yr B.P., the fauna becomes more representative of xeric conditions with maxima in xeric-indicator taxa and minima in mesic-indicator taxa, concordant with the Medieval Warm Period (circa 1000 to 650 yr B.P.). Cooler, wetter conditions which prevailed for most of the Little Ice Age (700 to 100 yr B.P.) in general correspond to a return to a more mesic mammalian fauna. A warm period within the Little Ice Age is documented by a xeric fauna. These data show that mammalian ecological sensitivity to climatic change over this intermediate time scale holds promise for predictions about the impacts of future global warming. (Abstract by Hadly as printed in Quarternary Research). (72)

Hadly, E.A.. 1997. Evolutionary and ecological response of pocket gophers (Thomomys talpoides) to late-Holocene climatic change. Biological Journal of Linnean Society. 60:277-96.

Late-Holocene evolutionary and ecological response of pocket gophers and other species to climatic change is documented by fossils from Lamar Cave. Pocket gophers increase in abundance during mesic intervals and decline during xeric intervals. The same subspecies of pocket gopher (Thomomys talpoides tenellus) has occupied northern Yellowstone for at least 3200 years. (428)

Hall, M.H.P. and D.B. Fagre. 2001. Where Have All the Glaciers Gone? Modeling Climate-Induced Glacier Change in Glacier National Park, 1850 – 2100. BioScience (Accepted).

The glaciers in the Blackfoot–Jackson Glacier Basin of Glacier National Park, Montana, decreased in area from 21.6 square kilometers (km2) in 1850 to 7.4 km2 in 1979. Over this same period global temperatures increased by 0.45ºC (± 0.15ºC).We analyzed the climatic causes and ecological consequences of glacier retreat by creating spatially explicit models of the creation and ablation of glaciers and of the response of vegetation to climate change. We determined the melt rate and spatial distribution of glaciers under two possible future climate scenarios, one based on carbon dioxide–induced global warming and the other on a linear temperature extrapolation. Under the former scenario, all glaciers in the basin will disappear by the year 2030, despite predicted increases in precipitation; under the latter, melting is slower. Using a

second model, we analyzed vegetation responses to variations in soil moisture and increasing temperature in a complex alpine landscape and predicted where plant communities are likely to be located as conditions change. (73)

Kilham, S. S., Theriot, E. C. , Fritz, S. C. . 1996. Linking planktonic diatoms and climate change in the large lakes of the Yellowstone ecosystem using resource theory. Limnology and Oceanography. 41 5: 1052-1062.

The 8 important planktonic diatom species in the large lakes of the Yellowstone region are ranked along resource ratio gradients according to their relative abilities to grow under limitation by Si, N, P, and light. Hypotheses based on resource physiology can be used to test the causal factors proposed to explain diatom distributions over the Holocene. (74)

Kittel, T.G.F. and J.A. Royle. 100-year climate history of the U.S. Rocky Mountains. J. Climate, in preparation.

Abstract in Progress (75)

Lyford, M.E., J.L. Betancourt, S.T. Jackson. 2002. Holocene vegetation and climate history of the northern Bighorn Basin, southern Montana. Quaternary Research. 58(2):171-181.

Records of Holocene vegetation and climate change at low elevations (<2000 m) are rare in the central Rocky Mountain region.We developed a record of Holocene vegetation and climate change from 55 14C-dated woodrat middens at two low-elevation sites (1275 to 1590 m), currently vegetated by Juniperus osteosperma woodlands, in the northern Bighorn Basin. Macrofossil and pollen analyses show that the early Holocene was cooler than today, with warming and drying in the middle Holocene. During the Holocene, boreal (Juniperus communis, J. horizontalis) and montane species (J. scopulorum) were replaced by a Great Basin species (J. osteosperma). J. osteosperma colonized the east side of the Pryor Mountains 4700 14C yr B.P. Downward movement of lower treeline indicates wetter conditions between 4400 and 2700 14C yr B.P. Increased aridity after 2700 14C yr B.P. initiated expansion of J. osteosperma from the east to west side of the Pryor Mountains. (Abstract by Lyford et al as printed in Quarternary Research). (76)

Millar, C.I., and W.B. Woolfenden. 1999. The role of climate change in interpreting historical variability. Ecological Applications 9:1207-1216.

Significant climate anomalies have characterized the last 1000 yr in the Sierra Nevada, California, USA. Two warm, dry periods of 150- and 200-yr duration occurred during AD 900-1350, which were followed by anomalously cold climates, known as the Little Ice Age, that lasted from AD 1400 to 1900. Climate in the last century has been significantly warmer. Regional biotic and physical response to these climatic periods occurred. Climate variability presents challenges when interpreting historical variability, including the need to accommodate climate effects when comparing current ecosystems to historical conditions, especially if comparisons are done to evaluate causes (e.g., human impacts) of differences, or to develop models for restoration of current ecosystems. Many historical studies focus on "presettlement" periods, which usually fall within the Little Ice Age. Thus, it should be assumed that ecosystems inferred for these historical periods responded to different climates than those at present, and

management implications should be adjusted accordingly. The warmer centuries before the Little Ice Age may be a more appropriate analogue to the present, although no historic period is likely to be better as a model than an understanding of what conditions would be at present without intervention. Understanding the climate context of historical reconstruction studies, and adjusting implications to the present, should strengthen the value of historical variability research to management. (Abstract by Millar and Woolfenden as printed in Ecological Applications). (77)

Millspaugh, S. H. , Whitlock, C. , Bartlein, P. J. . 2000. Variations in fire frequency and climate over the last 17,000 years in central Yellowstone National Park. Geology. 28 3: 211-214. Yes- I have a copy

A 17 000 yr fire history from Yellowstone National Park demonstrates a strong link between changes in climate and variations in fire frequency on millennial time scales. The fire history reconstruction is based on a detailed charcoal stratigraphy from Cygnet Lake in the rhyolite plateau region. Macroscopic charcoal particles were tallied from contiguous 1 cm samples of a 6.69-m-long core, and the data were converted to charcoal-accumulation rates at evenly spaced time intervals. Intervals of high charcoal-accumulation rates were interpreted as local fire events on the basis of information obtained from modern charcoal-calibration studies in the Yellowstone region. The record indicates that fire frequency was moderate (4 fires/1000 yr) during the late glacial period, reached highest values in the early Holocene (>10 fires/1000 yr), and decreased after 7000 calendar yr B.P. The present fire regime (2-3 fires/1000 yr) was established in the past 2000 yr. The charcoal stratigraphy correlates well with variations in July insolation through time, which suggests that regional climate changes are responsible for the long-term variations in fire frequency. In the early Holocene, summer insolation was near its maximum, which resulted in warmer, effectively drier conditions throughout the northwestern United States. At this time, the fire frequency near Cygnet Lake was at its highest. After 7000 calendar yr B.P., summer insolation decreased to present values, the regional climate became cooler and wetter, and fires were less frequent. The Cygnet Lake record suggests that long-term fire frequencies have varied continuously with climate change, even when the vegetation has remained constant. (78)

Millspaugh, S.H. and Whitlock, C. in press. Postglacial fire, vegetation, and climate history of the Yellowstone-Lamar and Central Plateau provinces, Yellowstone National Park. In After the Fires: The Ecology of Change in Yellowstone National Park (L. Wallace, ed.). Yale University Press.

Abstract in Progress (79)

Romme, W. H. , Turner, M. G. . 1991. Implications of global climate change for biogeographic patterns on the Greater Yellowstone Ecosystem. Conservation Biology. 5 3: 373-386.

Projected changes in global climate have substantiated ramifications for biological diversity and the management of natural areas. We explored the potential implications of global climate change for biogeographic patterns in the Greater Yellowstone Ecosystem by using a conceptual model to compare three likely climate scenarios: 1) warmer and drier than the present; 2) warmer and drier, but with a compensating increase in plant water use efficiency; and 3) warmer and wetter than the present. The logical consequences of each scenario are projected

for several species and community types chosen to represent a range of local climate conditions and biotic responses in the Greater Yellowstone Ecosystem. The upper and lower timberline appear to be particularly sensitive to climate change. The upper timberline is likely to migrate upward in elevation in response to temperature changes, whereas the lower treeline may retreat under drier conditions or move down slope under wetter conditions. In all scenarios, the extent of alpine vegetation in the ecosystem is decreased. Climate-induced changes in the fire regime in the Greater Yellowstone Ecosystem would probably have substantial consequences for the extent and age-class distribution of forest communities. Alterations in the distribution and extent of grassland communities would affect the populations of large ungulates. Our analyses suggest directions for establishing long-term measurements for the early detection of response to climate change. (81)

Stohlgren, T.J., T.N. Chase, R.A. Pielke, Sr., T.G.F. Kittel, and J. Baron. 1998. Evidence that local land use practices influence regional climate, vegetation, and stream flow patterns in adjacent natural areas. Global Change Biology 4:495-504. [ISI citation index = 23]

We present evidence that land use practices in the plains of Colorado influence regional climate and vegetation in adjacent natural areas in the Rocky Mountains in predictable ways. Mesoscale climate model simulations using the Colorado State University Regional Atmospheric Modelling System (RAMS) projected that modifications to natural vegetation in the plains, primarily due to agriculture and urbanization, could produce lower summer temperatures in the mountains. We corroborate the RAMS simulations with three independent sets of data: (i) climate records from 16 weather stations, which showed significant trends of decreasing July temperatures in recent decades; (ii) the distribution of seedlings of five dominant conifer species in Rocky Mountain National Park, Colorado, which suggested that cooler, wetter conditions occurred over roughly the same time period; and (iii) increased stream flow, normalized for changes in precipitation, during the summer months in four river basins, which also indicates cooler summer temperatures and lower transpiration at landscape scales. Combined, the mesoscale atmospheric/land-surface model, short-term trends in regional temperatures, forest distribution changes, and hydrology data indicate that the effects of land use practices on regional climate may overshadow larger-scale temperature changes commonly associated with observed increases in CO2 and other greenhouse gases. (Abstract by Stohlgren et al as printed in Global Change Biology). (82)

Whitlock, C. . 1993. Postglacial vegetation and climate of Grand Teton and southern Yellowstone National Parks. Ecological Monographs. 63 2: 173-198.

Pollen records from northern Grand Teton National Park, the Pinyon Peak Highlands, and southern Yellowstone National Park were examined to study the pattern of reforestation and climatic change following late-Pinedale Glaciation. The vegetational reconstruction was aided by analyses of associated plant macrofossils and the modern pollen rain of the region. Radiocarbon-age determinations and tephrochronology provided a chronologic framework to help correlate pollen records among sites. The fossil records indicate that alpine meadow communities, with Betula and Juniperus, were present between ?14,000 and ?11,500 yr BP. This early assemblage implies a lowering of modern upper treeline by at least 600 m and a climate that was ?5-6 C colder than present. Between 11,500 and 10,500 yr BP, increased temperature

and winter precipitation allowed first Picea, and then Abies and Pinus cf. albicaulis to spread into areas underlain by andesite and nonvolcanic bedrock. By 10,500 yr BP, the fossil record in these areas resembled modern spectra from subalpine forest. In contrast, the Central Plateau of Yellowstone, which is underlain by infertile rhyolitic soils, was treeless prior to ?10,000 yr BP. The absence of late-glacial subalpine parkland in this area is attributed to the same edaphic factors that limit Picea, Abies, and Pinus albicaulis from the rhyolite plateau today. Between 10,000 and 9,500 yr BP, Pinus contorta forest developed throughout the region in response to further warming. Pseudotsuga and Populus were present between 9,500 and 5,000 yr BP, suggesting a warmer, drier climate than today and more frequent fires. In the last 5,000 yr BP mixed forests of Picea, Pinus, and Abies have developed on andesitic and nonvolcanic terrain, and closed forests of Pinus contorta have persisted on rhyolitic substrates. The vegetational patterns are attributed to a combination of climatic and nonclimatic controls operating on different spatial and temporal scales. Climatic changes brought about by the retreat of Laurentide ice and the amplification of the seasonal cycle of radiation explain the broad patterns of vegetational change on millennial time scales. On shorter time scales and smaller spatial scales, substrate differences and migration history shaped the vegetational variability. (Abstract by Whitlock as printed in Ecological Monographs). (83)

Young, J.A., G.F. Vance and R. Zhang. 2000. Climatic patterns in the Bighorn Basin, Wyoming. Agricultural Experiment Station Bulletin, University of Wyoming, Laramie, WY. (In review)

Abstract in Progress (84)

ECOSYSTEM

Betancourt, Julio L. 1990. Chapter 12: Late Quaternary Biogeography of the Colorado Plateau. Pages 259-292 in Betancourt, Julio L., Van Devender, Thomas R., Martin, Paul S. Packrat Middens: The Last 40,000 Years of Biotic Change. University of Arizona Press, Tucson, AZ.

Extensive book with several references to Chaco Canyon (primarily in this chapter - see p. 262-265). Plant remains from these middens provide information about the plant species found at earlier time periods. Suggests there were stands of Pinus edulis and Juniperus monsperma available to the Anasazi and may have been wiped out by overuse or climatic change. (165)

Billings, W. D. 1994. Effects of global and regional environmental changes on mountain ecosystems. Pages 1-29 in Despain, D. G. . Plants and their Environments: proceedings of the First Biennial Scientific Conference on the Greater Yellowstone ecosystem, Sept 16-17, 1991, Mammoth Hot Springs Hotel. U. S. Department of the Interior, Natural Resources Publication Office, Denver, Colorado.

Abstract in Progress (85)

Christensen, J.L., A.M. Bartuska, J.H. Brown, S. Carpenter, C. D'Antonia, R. Francis, J.F. Franklin, J.A. MacJahon, R.F. Noss, D.J. Parsons, CH. Peterson, M.G. Turner, and R.G. Woodmansee. 1996. the report of the Ecological Society of America on the scientific basis for ecosystem management. Ecological Applicatoins 6(3):665-691.

Ecosystem management is not a rejection of an anthropocentric for a totally biocentric worldview. Rather it is management that acknowledges the importance of human needs while at the same time confronting the reality that the capacity of our world to meet those needs in perpetuity has limits and depends on the functioning of ecosystems. (Abstract by Christensen et al. As published in Ecological Applications.) (167)

Coughenour, M.B. 1999. Ecosystem modeling of the Pryor Mountain Wild Horse Range. Report to USGS. Biological Resources Division, National Park Service, and Bureau of Land Management. 55pp + 100 Figs.

Abstract in Progress (87)

Debinski, D. M. , M. E. Jakubauskas, and K. Kindscher. 2000. Montane meadows as indicators of environmental change. Environmental Monitoring and Assessment. 64:213-225.

We used a time series of satellite multispectral imagery for mapping and monitoring six classes of montane meadows arrayed along a moisture gradient (from hydric to mesic to xeric).We hypothesized that mesic meadows would support the highest species diversity of plants, birds, and butterflies because they are more moderate environments. We also hypothesized that mesic meadows would exhibit the greatest seasonal and interannual variability in spectral response across years. Field sampling in each of the meadow types was conducted for plants, birds, and butterflies in 1997 and 1998. Mesic meadows supported the highest plant species diversity, but there was no significant difference in bird or butterfly species diversity among meadow types. These data show that it may be easier to detect significant differences in more species rich taxa (e.g., plants) than taxa that are represented by fewer species (e.g., butterflies and birds). Mesic meadows also showed the greatest seasonal and interannual variability in spectral response. Given the rich biodiversity of mesic montane meadows and their sensitivity to variations in temperature and moisture, they may be important to monitor in the context of environmental change. (Abstract by Debinski et al as printed in Environmental Monitoring and Assessment). (88)

Frank, D. A. , McNaughton, S. J. , Tracy, B. F. . 1998. The ecology of the earth's grazing ecosystems. Bioscience. 48 7: 513-521.

Studies of the Serengeti and Yellowstone ecosystems show many common properties. Yellowstone ungulates migrate seasonally, but for different environmental factors than Serengeti ungulates. The authors measured plant biomass concentration throughout the seasonal ranges of migrating animals. Just as eliminating processes such as fire that occur at large spatial scales, so eliminating migrating grazers by fragmenting grazing ecosystems alters the fundamental character of the habitat. (89)

Frank, D.A., and S.J. McNaughton. 1992. the ecology of plants, large mammalian herbivores, and drought in Yellowstone National Park. Ecology. 73(6):2043-2058.

The purpose of this study was to examine the effect of abundant native large herbivores on ecosystem function of a spatially and temporally heterogeneous temperate grassland. Net aboveground primary production (ANPP), large herbivore consumption (C), and dung deposition (D), an index of nutrient flow from herbivores to the soil, were measured in grassland and

shrub-grassland habitat on winter, transitional, and summer range used by herds of elk (Cervus elaphus) and bison (Bison bison) in northern Yellowstone National Park. Temporary exclosures (5-7 per site) were moved every 4 wk during the snow-free season to determine ANPP and C. Data were collected during 1988, a year of drought and unusually high elk and bison population levels, and 1989, a climatically near-average year, with dramatically fewer elk and bison. All three processes, ANPP, C, and D, varied widely among sites: ANPP range: 16-589 g/m super(2), C range: 0-306 g/m super(2), and D range: 0-68 g/m super(2). An average of 45% of ANPP was consumed by herbivores. Production and consumption, and consumption and dung deposition were positively correlated across all sites. In addition, sites were grazed when plants were growing. There was 19% reduction in ANPP from 1988 to 1989, likely caused by death or injury to plants during the 1988 drought. Drought also appeared to be partially responsible for reductions in elk and bison from 1988 to 1989, which were coincident with declines in C and D. Results indicate direct effects and suggest indirect effects of a single-season drought on grassland function that will persist for several years after the event. (90)

Greenlee, J. ed. 1996. The ecological implications of fire in Greater Yellowstone: Second biennial conference on the Greater Yllowstone Ecosystem. International Assoc. of Wildland Fire, Fairfield, Washington.

Thirty-three papers from the conference (91)

Holling, C.S. (1992). Cross-scale morphology, geometry, and dynamics of ecosystems. Ecol. Monogr., 62(4): 447-502.

This paper tests the proposition that a small set of plant, animal, and abiotic processes structure ecosystems across scales in time and space. Earlier studies have suggested that these key structuring processes establish a small number of dominant temporal frequencies that entrain other processes. These frequencies often differ from each other by at least an order of magnitude. If true, ecosystems therefore will have a few dominant frequencies that are endogenously driven and that are discontinuously distributed. This paper additionally tests the proposition that these structuring processes should also generate a discontinuous distribution of spatial structures coupled with the discontinuous frequencies. If that is the case, animals living in specific landscapes should demonstrate the existence of this lumpy architecture by showing gaps in the distribution of their sizes. This proved to be the case for birds and mammals of the boreal region forest and the short-grass prairie. Alternative hypotheses to explain the body mass clumps include architectural, developmental, historical, and trophic causes. These were all tested by comparing body-mass clump distributions (1) in ecosystems having different spatial structures (forest, grassland, and marine pelagic) and (2) in different animal groups having different body plans (birds and mammals) or feeding habits (carnivore, omnivore, and herbivore). The only hypothesis that could not be rejected in that the body-mass clumps are entrained by discontinuous hierarchical structures and textures of the landscape. There is evidence for at least eight distinct habitat "quanta," each defined by a distinct texture at a specific range of scales. These eight quanta together cover tens of centimeters to hundreds of kilometers in space and at least months to millennia in time.
There is a striking similarity, but not identity, between the clump structure of prairie and boreal animals. This indicates that many processes that form qualitative habitat structure are common

to both landscapes or ecosystems, but a few are landscape specific, particularly over larger scales. That conclusion is extended to all terrestrial ecosystems by an analysis of the body-mass clump structure of all North American birds.
In contrast, there are striking differences in clump structure between landscapes and "waterscapes," indicating that fundamentally different processes shape structure in terrestrial and open ocean systems. The discontinuous body-mass structure provides a bioassay of discontinuous ecosystem structure. Mammalian carnivores, omnivores, and herbivores all show the same number of body-mass clumps, and the gaps in these distributions occur at the same body masses. Mammals and birds show the same number of body-mass clumps, but the mass gaps for mammals occur at larger sizes than those for birds in such a way that the log-transformed body mass gaps for mammals are correlated linearly with those for birds. Hence there is a simple cross-calibration between the mammal and bird bioassays. I compiled and analyzed published data on home ranges in order to convert body masses into an absolute linear measure of geometric structures in the landscape. A new and general equation was developed relating home-range size to body mass, and was tested by reanalyzing published data for mammalian carnivores, omnivores and herbivores and for birds. I conclude: (1) Birds and mammals of all trophic levels utilize resources in their foraging areas in the same way by measuring the spatial grain of habitat patches with a resolution defined as a function of their size (i.e., the animal's step length or minimum unit of measurement). The step length is a morphological function of the size of animals and is not significantly affected by trophic status or taxonomy of the groups considered. That explains why all trophic levels and both birds and mammals show the same qualitative body-mass clump structure. (2) Home-range data can convert the body-mass data to a quantitative estimate of texture, i.e., of fractal dimension of the landscape. The landscape forms a hierarchy that contains breaks in object sizes, object proximities, and textures at particular scales. Animals also demonstrate a hierarchy of decisions whose target suddenly shifts at specific scales in space and time. The interaction between these two hierarchies produces the discontinuous body-mass clump structure. The breaks in geometry in the landscape occur because structuring processes exert their influence over defined ranges of scale. The temporal and architectural structure of habitat quanta are in general determined by three classes of processes, each dominating over three different ranges of scale. Vegetative processes that determine plant growth, plant form, and soil structure dominate the formation of texture at fine microscales of centimetres to tens of metres in space and days to decades in time. At the other, macroscale extreme, slow geomorphological processes dominate the formation of a topographic and edaphic structure at large scales of hundreds to thousands of kilometres and centuries to millennia. At the mesoscales in between, contagious disturbance processes such as fire, insect outbreak, plant disease, and water flow dominate the formation of patterns over spatial scales of hundreds of metres to hundreds of kilometres. In addition, the direct impacts of grazing by large herbivores and of human activities, and the indirect effects of large predators and animal disease, further transform spatial patterns over these meso-scales. These processes operate on time scales of years to decades, making them critically important in determining whether present local, regional, and global human influences will trigger a transition in vegetation types, and, if so, how rapidly. The paper provides a direction for the development of programs to evaluate, monitor, and predict ecosystem and community changes across scales. The necessary research elements include (1) models that incorporate a few scale-dependent

structuring processes to allow cross-scale analysis; (2) comparative studies of different disturbed and undisturbed landscapes using the animal body-mass bioassay technique to identify critical scales of ecosystem geometry; (3) analysis of remote imagery to identify spatial discontinuities and regions of scale invariance; and (4) behavioral studies of the hierarchy of animal decisions to identify species groups vulnerable to predicted (using models) or observed (using remote imagery) changes in vegetation geometry. (92)

Huff, D. E. , Varley, J. D. . 1999. Natural regulation in Yellowstone National Park's northern range. Ecological Applications. 9 1: 17-29.

"...It is the opinion of the authors that extensive published data support the position that current elk populations and sympatric herbivores do not exceed the ecological carrying capacity of the northern range: therefore, the range is not overgrazed by ecological standards..." (93)

Huntley, N. J. , Sirotnak, J. M. . 1998. The role of small mammals in the Greater Yellowstone ecosystem. Pages 37 in No Editor/Author. Making a place for nature, seeking our place in nature: 125th Anniversary Symposium, May 11-23, 1998; agenda and abstracts. Yellowstone Association, Yellowstone National Park.

The Greater Yellowstone Ecosystem harbors populations of many small mammals. Despite their small individual size, these animals can be locally abundant, and research shows that they can play important, though frequently overlooked, roles in ecosystem dynamics. For instance, voles (Microtus species) can change the patterns of nitrogen mineralization in riparian areas, which have been shown to have plant communities that are nitrogen-limited. Voles' effects are particularly interesting in that they change over the course of the population cycle that is typical of these small herbivores. The change through time in nitrogen mineralization is accompanied by, and we speculate is caused by, changes in the plant community that appear to result from voles' activities. The net outcome is the fluctuation of plant species abundance and nitrogen availability over a several year time-scale. Another small mammal that is common at high elevations in the Greater Yellowstone region is the pika (Ochotona princeps), a lagomorph. Pikas have been shown to alter vegetation in subalpine areas. Recent work on the Beartooth Plateau shows that they sometimes similarly alter the vegetation of high alpine areas. Additionally, they appear to cause development of spatially variable soils. Pocket gophers (Geomyidae) also are common in many meadow-types of the Greater Yellowstone Ecosystem. Work in Yellowstone Park and nearby regions shows that these animals frequently play an important role in generating heterogeneity in soil quality and behavior, and, through this, can change the productivity and species composition of plant communities. In addition to their direct effects on soils and plant, small mammals are an important link of the food webs that characterize montane and higher elevation areas of the Greater Yellowstone region, providing a significant food source for many carnivores. Although our studies are limited to distribution of small mammals and their effects on plant communities and soil dynamics, we also review literature that suggests the interactions of the small mammal community with the larger fauna of the park and the ways in which fire may influence the abundance, distribution, and ecological effects of small mammals. (Abstract by Huntley and Sirotnak. As printed in Making a place for

nature, seeking our place in nature: 125th Anniversary Symposium, May 11-23, 1998; agenda and abstracts.) (94)

Kay, C.E. 1998. Are ecosystems structured from the top-down or bottom-up: a new look at an old debate. Wildlife Society Bulletin. 26 3:484-498.

"Native Americans were the ultimate keystone predator...until the importance of aboriginal land management is recognized and modern management practices change accordingly, our ecosystems will continue to lose the biological diversity and ecological integrity they once had..." (95)

Keiter, R. B. , Boyce, M. S. 1991. The Greater Yellowstone ecosystem: redefining America's wilderness heritage. Yale University Press, New Haven.

Abstract in Progress (96)

Landres, P.B., P. Morgan, and F.J. Swanson. 1999. Overview of the use of natural variability concepts in managing ecological systems. Ecological Applications 9: 1179-1188.

Natural resource managers have used natural variability concepts since the early 1960 s and are increasingly relying on these concepts to maintain biological diversity, to restore ecosystems that have been severely altered, and as benchmarks for assessing anthropogenic change. &. We conclude that natural variability concepts provide a framework for improved understanding of ecological systems and the changes occurring in these systems, as well as for evaluating the consequences of proposed management actions. &. These concepts can also be misused. &. Natural variability concepts offer an opportunity and a challenge for ecologists to provide relevant information and to collaborate with managers to improve the management of ecological systems (97)

LaRoe, E. T., G. S. Farris, C. E. Puckett, P. D. Doran, and M. J. Mac, editors. 1995. Our living resources: a report to the nation on the distribution, abundance, and health of U.S. plants, animals, and ecosystems. U.S. Department of the Interior, National Biological Service

Abstract in Progress (98)

Leopold, A. S., S. A. Cain, C. M. Cottam, I. N. Gabrielson, and T. L. Kimball. 1963. Wildlife management in the national parks. Transactions of North American Wildlife and Natural Resources Conference 28:28-45.

This report emphasizes biological principles involved, defines the aesthetic, historical and scientific values of the parks, and sets forth the philosophy of management thus called for. (99)

Marshall, Kent G., Knight, Dennis H., Barmore, William J. , Jr. 1979. An indexed and annotated bibliography on the ecology of Grand Teton National Park : including unpublished literature. University of Wyoming, National Park Service Research Center, Laramie, WY.

Contains citation concerning the ecology of Grand Teton National Park (100)

Meagher, M.M., and D.B. Houston. 1998. Yellowstone and Biology of Time: Photographs Across a Cantury. Norman: University of Oklahoma Press.

Consists of an extensive series of pictures comparing various sites taken at 2 or 3 widely separated dates, with cogent explanations of possible reasons for differences in growth patterns and their implications. (101)

National Research Council. 2002. Ecological Dynamics on Yellowstone's Northern Range. National Academy Press, Washington, D.C. 144 pages.

Abstract in Progress (663)

Ojima, D.S., T.G.F. Kittel, T. Rosswall, and B.H. Walker. 1991. Critical issues for understanding global change effects on terrestrial ecosystems. Ecological Applications 1:316-325. [ISI citation index = 29]

Marked alterations in the Earth's environment have already been observed, and these presage even greater changes as the impact of human (i.e., land use and industrial) activities increases. Direct and indirect feedbacks link terrestrial ecosystems with global change, and include interactions affecting fluxes of water, energy, nutrients, and "greenhouse" gases and affecting ecosystem structure and composition. Community development can affect ecosystem dynamics by altering resource partitioning among biotic components and through changes in structural characteristics, thereby affecting feedbacks to global change. The response of terrestrial ecosystems to the climate-weather system is dependent on the spatial scale of the interactions between these systems and the temporal scale that links the various components. The International Geosphere-Biosphere Programme (IGBP), which was initiated by the International Council of Scientific Unions (ICSU) in 1986, has undertaken to develop a research plan to address a predictive understanding of how terrestrial ecosystems will be impacted by global changes in the environment and the potential feedbacks. The IGBP science plan, which incorporates established Core Projects and activities related to research on terrestrial ecosystem linkages to global change, includes the International Global Atmospheric Chemistry Project (IGAC); the Biospheric Aspects of the Hydrological Cycle (BAHC); the Global Change and Terrestrial Ecosystems (GCTE); Global Analysis, Integration, and Modelling (GAIM); IGBP Data and Information System (DIS); and IGBP Regional Research Centers (RRC). The coupling of research and policy communities for the purpose of developing mechanisms to adapt to these impending changes urgently needs to be established. (Abstract by Ojima et al. As published in Ecological Applications.) (102)

Parson, D.J., R.W. Swetnam, and N.L. Christensen. 1999. Uses and limitations of historical variability concepts in manageing ecosystems. Ecological Applications 9:4 p.1177-1178

"Despite the wide diversity of approaches and opinions regarding the best ways to utilize historical data, it is clear that there is great value in considering historical-ecological information in natural resource planning and management. Although the application of such information may vary widely, depending on the quality and resolution of the available data and the goals and constraints of those applying the information, the value of historical perspectives in understanding factors influencing the structure and function of ecological systems is critical to almost all resource management decisions. We hope, and expect, that the discussion generated

by these papers will stimulate increased dialogue between scientists and managers regarding the value and limitations of historical variability data in developing scientifically based land management programs." (103)

Schullery, P. 1995. The greater Yellowstone ecosystem. Pages 312-314 in E. T. LaRoe, G. S. Farris, C. E. Puckett, P. D. Doran, and M. J. Mac, editors. Our living resources: a report to the nation on the distribution, abundance, and health of U.S. plants, animals, and ecosystems. U.S. Department of the Interior, National Park Service

Status summary for the Greater Yellowstone ecosystem, the "last large, nearly intact ecosystem in the northern temperate zone of the earth," and the controversies over management. (104)

Sinclair, A. R. E. 1998. Natural regulation of ecosystems in protected areas as ecological baselines. Wildlife Society Bulletin. 26 3: 399-409.

Ecological baseline areas are necessary benchmarks to detect slow change and predict fast change in ecosystems that humans depend upon. National parks, by default, fulfill this role provided they are large enough to maintain natural processes. They should be used to understand natural regulatory ecosystem processes that are then compared with other human-dominated systems. Natural regulation operates through negative feedback mechanisms in reproduction or mortality caused by factors such as food shortage and predation. Protected areas are capable of self-regulation as evidenced by many studies of such ecosystems covering several decades. They exhibit natural change, often with periodicities of decades or centuries, and such change must be accommodated in management plans. Ecosystems exhibit >1 natural state, often as a result of top-down processes such as predation and herbivory. These multistates are identified by their irreversibility when the cause of perturbations is removed. They are characterized by >1 combination of population densities and species. Predators may or may not be present, and herbivores may or may not impinge on the vegetation. Therefore, there is no single combination of species or ecosystem stated for which management should strive. Naturalness, per se, is not the objective. Rather, the fundamental need is to compare ecosystems experiencing modern human impact with those in protected areas that are relatively free of such impacts so as to understand their consequences for mankind. The presence or absence of prehistoric humans is not relevant to these objectives. Management, however, should act to minimize disturbance, such as the presence of exotic species, within these ecological baselines. Monitoring of ecosystem change should be coordinated on a global basis, using simple and robust techniques. (Abstract by Sinclair as printed in Wildlife Society Bulletin). (105)

Whitlock, C., Reasoner, M.A., and Key, C.H. 2002. Paleoenviromental History of the Rocky Mountain region during the last 20,000 years. In Rocky Mountain Futures: An Ecological Perspective (J.A. Barron, ed) Ch 3: 41-59. Island Press.

Ecosystem management is management driven by explicit goals, executed by policies, protocols, and practices, and made adaptable by monitoring and research based on our best understanding of the ecological interactions and processes necessary to sustain ecosystem composition, structure, and function. In recent years, sustainability has become an explicitly stated, even legislatively mandated, goal of natural resource management agencies. In practice, however, management approaches have often focused on maximizing short-term yield and

economic gain rather than long-term sustainability. Several obstacles contribute to this disparity, including: (1) inadequate information on the biological diversity of environments; (2) widespread ignorance of the function and dynamics of ecosystems; (3) the openness and interconnectedness of ecosystems on scales that transcend management boundaries; (4) a prevailing public perception that the immediate economic and social value of supposedly renewable resources outweighs the risk of future ecosystems damage or the benefits of alternative management approaches. The goal of ecosystem management is to overcome these obstacles. Ecosystem management includes the following element: (1) Sustainability. Ecosystem management does not focus primarily on "deliverables" but rather regards intergenerational sustainability as a precondition. (2) Goal. Ecosystems management establishes measurable goals that specify future processes and outcomes necessary for sustainability. (3) Sound ecological models and understanding. Ecosystem management relies on research performed at all levels of ecological organization. (4) Complexity and connectedness. Ecosystem management recognizes that biological diversity and structural complexity strengthen ecosystems against disturbance and supply the genetic resources necessary to adapt to long-term change. (5) The dynamic character of ecosystems. Recognizing that change and evolution are inherent in ecosystem sustainability, ecosystem management avoids attempts to "freeze" ecosystems in a particular state or configuration. (6) Context and scale. Ecosystem processes operate over a wide range of spatial and temporal scales, and their behavior at any given location is greatly affected by surrounding systems. Thus, there is no single appropriate scale or time frame for management. (7) Humans as ecosystem components. Ecosystem management values the active role of humans in achieving sustainable management goals. (8) Adaptability and accountability. Ecosystem management acknowledges that current knowledge and paradigms of ecosystem function are provisional, incomplete, and subject to change. Management approaches must be viewed as hypotheses to be tested by research and monitoring programs. The following are fundamental scientific precepts for ecosystem management. (1) Spatial and temporal scale are critical. Ecosystem function includes inputs, outputs, cycling of materials and energy, and the interactions of organisms. Boundaries defined for the study or management of one process are often inappropriate for the study of others; thus, ecosystem management requires a broad view. (2) Ecosystem function depends on its structure, diversity, and integrity. Ecosystem management seeks to maintain biological diversity as a critical component in strengthening ecosystems against disturbance. Thus, management of biological diversity requires a broad perspective and recognition that the complexity and function of any particular location is influenced heavily by the surrounding system. (3) Ecosystem are dynamic in space and time. Ecosystem management is challenging in part because ecosystems are constantly changing. Over time scales of decades or centuries, many landscapes are altered by natural disturbances that lead to mosaics of successional patches of different ages. Such patches dynamics are critical to ecosystem structure and function. (4) Uncertainty, surprise, and limits to knowledge. Ecosystem management acknowledges that, given sufficient time and space, unlikely events are certain to occur. Adaptive management addresses this uncertainty by combining democratic principles, scientific analysis, education, and institutional learning to increase our understanding of ecosystem processes and the consequences of management interventions, and to improve the quality of data upon which decisions must be made. Ecosystem management requires applications of ecological science to natural resource actions. Moving from concepts to practice

is a daunting challenge and will require the following steps and actions. (1) Defining sustainable goals and objectives. Sustainable strategies for the provision of ecosystem goods and services cannot take as their starting points statements of need or want such as mandated timber supply, water demand, or arbitrarily set harvest of shrimp or fish. Rather, sustainability must be the primary objective, and levels of commodity and amenity provision must be adjusted to meet that goal. (2) Reconciling spatial scales. Implementation of ecosystem management would be greatly simplified if management jurisdictions were spatially congruent with the behavior of ecosystem processes. Given the variation in spatial domain among processes, one perfect fit for all processes is virtually impossible; rather, ecosystem management must seek consensus among the various stakeholders within each ecosystem. (3) Reconciling temporal scales. Whereas management agencies are often forced to make decisions on a fiscal-year basis, ecosystem management must deal with time scales that transcend human lifetimes. Ecosystem management requires long-term planning and commitment. (4) Making the system adaptable and accountable. Successful ecosystem management requires institutions that are adaptable to changes in ecosystem characteristics and in our knowledge base. Adaptive management by definition requires the scientist's ongoing interaction with managers and the public. Communication must flow in both directions, and scientists must be willing to prioritize their research with regard to critical management needs. Scientists have much to offer in the development of monitoring programs, particularly in creating sampling approaches, statistical analyses, and scientific models. As our knowledge base evolves, scientists must develop new mechanisms to communicate research and management results. More professionals with an understanding of scientific, management, and social tissues, and the ability to communicate with scientists, managers, and the public are needed. Ecosystem management is not a rejection of an anthropocentric for a totally biocentric worldview. Rather it is management that acknowledges the importance of human needs while at the same time confronting the reality that the capacity of our world to meet those needs in perpetuity has limits and depends on the functioning of ecosystems. (Abstract by Christensen et al. As published in Ecological Applications.) (166)

Yellowstone National Park. 1997. Yellowstone's Northern Range: complexity and change in a wild-land ecosystem. National Park Service, Mammoth Hot Springs, Wyoming.

Abstract in Progress (662)

Macdonald, I.A.E., L.L. Loope, M.B. Usher, and O. Hamann. 1989. Wildlife conservation and the invasion of nature reserves by alien species: a global perspective, p. 215-255. In J.A. Drake and others (eds.), Ecology of Biological Invasions: a Global Synthesis. John Wiley & Sons, Chichester, U.K.

Discusses the ways in which introduced species can affect nature conservation. Describes current invasions and provides examples, successes and failures, of management of these invasions. Section on island ecosystems. (108)

EXOTIC

Olliff, T. ,et. al. 2001. Managing a Complex Exotic Vegetation Program in Yellowstone National Park. Western North American Naturalist. 61 3: 347-358.

The number of documented exotic plants in Yellowstone National Park has increased from 85 known in 1986 to over 185 today. Exotic plants are substantially impacting the park's natural and cultural resources and are a high management priority. We have adopted an integrated weed management approach with regard to exotic vegetation, emphasizing prevention, education, early detection and eradication, control, and, to a lesser degree, monitoring. The program involves over 140 staff with program expenditures averaging approximately $190,000 annually. Prevention actions include requiring approved gravel on construction projects; banning hay in the backcountry and allowing transport of only certified weed-seed-free hay through Yellowstone; requiring construction equipment to be pressure-cleaned prior to entering the park; and native species revegetation after road, housing, and other construction projects have disturbed ground. Over 4500 acres, primarily along roadsides and in developed areas, are surveyed annually in early detection efforts with emphasis placed on eradicating small, new infestations of highly invasive species such as sulfur cinquefoil (Potentilla recta L.) and leafy spurge (Euohirbia esula L.) Control efforts focus on about 30 priority species, such as spotted knapweed (Centaurea maculosa Lam.), oxeye daisy (Chrysanthemum leucanthemum L.), and hoary cress (Cardaria draba [L.] Desv.) using chemical, mechanical, and cultural techniques. A total of 2027 acres were treated during 1998, whereas control efforts for 12 species occurred on 2596 acres during the precious 3-year period, 1995-1997. Strong and expanding partnerships with other federal, state, and local agencies and private companies contribute to management efforts within the park. Future program goals emphasize increases in base funding to ensure continued weed management efforts as well as expanding survey, monitoring, and reclamation efforts. Ultimately, a more rigorous assessment of program effectiveness is desired. (Abstract by Olliff et al as printed in Western North American Naturalist). (303)

Vitousek, P.M., C.M. D'Antonio, L.L. Loope, and R. Westbrooks. 1996. Biological invasions as global environmental change. American Scientist 84:468-478.

Argues that biological invasions have become so wide-spread that they constitute a significant component of global environmental change. Challenges two beliefs that help perpetuate this cycle: the idea that invasions are a natural process that has always been a part of evolutionary history; and the assumption that the ease of travel and the continued expansion of the global economy will make it impossible to prevent invasions. Identifies a need for improvements to legal frameworks that concern the control of exotic species; and suggests a need for greater public awareness of (and involvement in) this problem. (109)

FIRE

Bessie, W.C., and E.A. Johnson. 1995. the relative importance of fuels and weather on fire behavior in subalpine forests. Ecology 76: 747-762.

Surface fire intensity (kilowatts per metre) and crown fire initiation were predicted using Rothermel's 1972 and Van Wagner's 1977 fire models with fuel data from 47 upland subalpine conifer stands varying in age from 22-258 yr and 35 yr of daily weather data (fuel moisture and wind speeds). Rothermel's intensity model was divided into a fuel component variable and

weather component variable, which were then used to examine the relative roles of fuel and weather on surface fire intensity (kilowatts per metre). Similar variables were defined in the crown fire initiation were strongly related to the weather components and weakly related to the fuel components, due to much greater variability in weather than for fuel, and stronger relationship to the fire behavior mechanisms for weather than for fuel. Fire intensity was correlated to annual area burned; large area burned years had higher fire intensity predictions than smaller area burned years. The reason for this difference was attributed directly to the weather variable frequency distribution, which was shifted towards more extreme values in years in which large areas burned. During extreme weather conditions, the relative importance of fuels diminishes since all stands achieve the threshold required to permit crown fire development. This is important since most of the area burned in subalpine forests has historically occurred during very extreme weather (i.e., drought coupled to high winds). The fire behavior relationships predicted in the models support the concept that forest fire behavior is determined primarily by weather variation among years rather than fuel variation associated with stand age. (Abstract by Bessie and Johnson. As printed in Ecology) (110)

Boyce, M. S. , Merrill, E. H. . 1996. Predicting effects of 1988 fires on ungulates in Yellowstone National Park. Pages 361-368 in Singer, F. J. . Effects of grazing by wild ungulates in Yellowstone National Park. National Park Service, Natural Resource Information Division, Denver

We used computer simulation to forecast the effects of the 1988 fires on bison (Bos bison) and elk (Cervus elaphus) in Yellowstone National Park, based on our studies of these two species before the fires. Few ungulates died as a direct result of the 1988 fires in Yellowstone National Park. The greatest effects of the fires are expected to be changes in the forage base for these animals. Most of the area burned was summer range. Only 9% of the grasslands normally used by elk and bison on the northern range during winter burned. Before the 1988 fires, factors were studied that influenced population dynamics of elk and bison in Yellowstone. Three variables—summer herbaceous biomass, winter severity, and population size—accounted for most of the year-to-year variance in per capita population growth rates for both species. These three parameters were modeled into a stochastic difference equation for each species. According to the model, the population for both elk and bison at the beginning of winter 1988-89 was larger than average carrying capacity due to a series of mild winters. High overwinter mortality during spring 1989 was therefore largely a consequence of abnormally high populations and slightly more severe winter weather. According to other studies, drought during the summer of 1988 and the burned winter ranges further aggravated the situation. Vegetation succession was used to project consequences of the 1988 fires to elk and bison populations. Both elk and bison should have enhanced recruitment and population size for several years, gradually declining to long-term carrying capacities of approximately 3,000 bison and 20,000 elk overwintering in the park. (Abstract by Boyce and Merrill as printed in Effects of grazing by wild ungulates in Yellowstone National Park). (111)

Knight, D. H. , Wallace, L. L.. 1989. The Yellowstone fires: issues in landscape ecology. Bioscience. 39 10: 700-706.

Addresses fire-caused temporal and spatial variability in vegetation patterns, plant-animal relationships, and land-water interactions in Yellowstone National Park. (112)

Loope, L. L., and G. E. Gruell. 1973. The ecological role of fire in Jackson Hole, northwestern Wyoming. Quaternary Research 3:425-443.

Fire-history investigations in the Jackson Hole area of northwestern Wyoming reveal that most current stands of aspen and lodgepole pine regenerated following extensive fires between 1840 and 1890 and that widespread fires occurred in the 1600s and the 1700s. White man's major effect on the fire incidence has been the successful suppression during the past 30-80 yr. Successional changes in the absence of fire include the deterioration of aspen stands, massive invasions of subalpine fir in lodgepole pine stands, great increase in conifer cover, heavy fuel buildup in lodgepole pine and Douglas fir stands, and increase in sagebrush and other shrubs. Steps are being taken, starting in 1972, to allow fire to play a more natural role in Grand Teton and Yellowstone National Parks. Teton National Forest plans experimental prescribed burning to determine wheteer fire can stimulate successful aspen regeneration in the prescense of large numbers of wintering elk. (Abstract by Loope as printed in Quaternary Research). (113)

Meyer, G.A., Wells, S.G. and A.J.T. Jull. 1995. Fire and alluvial chronology in Yellowstone National Park: climatic and intrinsic controls on Holocene geomorphic processes. Geological Society of America Bulletin 107: 1211-1230.

Debris-flow and flood events following the 1988 fires provided facies models for interpreting the stratigraphic record of fire-related sedimentation within valley-side alluvial fans of Soda Butte Creek. .. Fire-related deposits make up ca. 30% of the late Holocene fan alluvium... A major pulse of fire-related debris-flow activity between 950 and 800 B.P. coincided with the Medieval Warm Period...Instrumental climate records over the last ~100yr in Yellowstone imply that the intensity and interannual variability of summer precipitation are greater during warmer periods, enhancing the potential for severe short-term drought, major forest fires, and storm-generated fan deposition. (114)

Romme, W. H. , Despain, D. G. . 1989. Historical perspective on the Yellowstone fires of 1988. Bioscience. 39 10: 695-699.

In this article, the authors compare the fires of 1988 with fires during the previous 350 years. The authors use both information contained in park files and results of our tree-ring research on the prehistoric fire history. (115)

Schullery, P. , Despain, D. G. . 1989. Prescribed burning in Yellowstone National Park: a doubtful proposition. 1989. Wildlands 15(2):30-34.

The fires of 1988 raised many questions about the use of human-set prescribed burns in Yellowstone. It has been proposed that an aggressive program of prescribed burns was either ecologically necessary before the fires, or could have prevented the fires from growing as large as they did. These suggestions are interesting, and should be addressed, even if to some extent such conjectural exercises may be inconclusive. Most of all, such suggestions lead to some fascinating insights into the ecological and philosophical challenges of managing large natural areas such as Yellowstone Park. (116)

Turner, M. G. , Romme, W. H. , Gardner, R. H. , Hargrove, W. W. . 1997. Effects of fire size and pattern on early succession in Yellowstone National Park. Ecological Monographs. 67 4: 411-433.

Study analyzed whether vegetation responses differed between small and large burned patches within the fire-created mosaic and evaluated the influence of spatial patterning on postfire vegetation. (117)

Turner, M. G. , Romme, W. H. . 1994. Landscape dynamics in crown fire ecosystems. Landscape Ecology. 9: 59-77.

Crown fires create broad-scale patterns in vegetation by producing a patch mosaic of stand age classes, but the spread and behavior of crown fires also may be constrained by spatial patterns in terrain and fuels across the landscape. In this review, we address the implications of landscape heterogeneity for crown fire behavior and the ecological effects of crown fires over large areas. We suggest that fine-scale mechanisms of fire spread can be extrapolated to make broad-scale predictions of landscape pattern by coupling the knowledge obtained from mechanistic and empirical fire behavior models with spatially-explicit probabilistic models of fire spread. Climatic conditions exert a dominant control over crown fire behavior and spread, but topographic and physiographic features in the landscape and the spatial arrangement and types of fuels have a strong influence on fire spread, especially when burning conditions (e.g. fuel moisture and wind) are not extreme. General trends in crown fire regimes and stand age class distributions can be observed across continental, latitudinal, and elevational gradients. Crown fires are more frequent in regions having more frequent and/or severe droughts, and younger stands tend to dominate these landscapes. Landscapes dominated by crown fires appear to be nonequilibrium systems. This nonequilibrium condition presents a significant challenge to land managers, particularly when the implications of potential changes in the global climate are considered. Potential changes in the global climate may alter not only the frequency of crown fires but also their severity. Crown fires rarely consume the entire forest, and the spatial heterogeneity of burn severity patterns creates a wide range of local effects and is likely to influence plant reestablishment as well as many other ecological processes. Increased knowledge of ecological processes at regional scales and the effects of landscape pattern on fire dynamics should provide insight into our understanding of the behavior and consequences of crown fires. (Abstract by Turner and Romme and printed in Landscape Ecology). (186)

Bozek, M. A., Young, M. K. . 1994. Fish mortality resulting from delayed effects of fire in the greater Yellowstone ecosystem. Great Basin Naturalist. 54 1: 91-95.

Often public concern focuses on the immediate, terrestrial impacts of wildfire. Such was the case during the summer and fall of 1988 when fires burned 562,000 ha in the Greater Yellowstone Ecosystem (Greater Yellowstone Ecosystem). Besides the obvious loss of vegetation, less apparent, short-term consequences of these fires to terrestrial ecosystems included greater nutrient availability, widespread soil modification, and direct and indirect mortality of wildlife. But as a result of the linkages between streams and their valleys, fires also may affect the hydrology, water chemistry, and geomorphology of aquatic ecosystems. During the 1988 in the Greater Yellowstone Ecosystem, Minshall et al. observed fish kills in streams,

but the extent and causes of mortality were not reported. While conducting other studies of watersheds in the Greater Yellowstone Ecosystem, we observed a fish kill in a burned watershed that occurred two years after the fires. In this paper we describe aspects of this fish kill and relate them to hydrologic conditions in this stream and those in a nearby stream with an unburned watershed. (471)

FISH

Gresswell, R. E. , Liss, W. J. 1995. Values associated with management of Yellowstone Cutthroat trout in Yellowstone National Park. Conservation Biology. 9 1: 159-165.

Recent emphasis on a holistic view of natural systems and their management is associated with a growing appreciation of the role of human values in these systems. In the past, resource management has been perceived as a dichotomy between extraction (harvest) and nonconsumptive use, but this appears to be an oversimplified view of natural-cultural systems. The recreational fishery for Yellowstone cutthroat trout (Oncorhynchus clarki bouvieri) in Yellowstone National Park is an example of the effects of management on a natural-cultural system Although angler harvest has been drastically reduced or prohibited the recreational value of Yellowstone cutthroat trout estimated by angling factors (such as landing rate or size) ranks above that of all other sport species in Yellowstone National Park. To maintain an indigenous fishery resource of this quality with hatchery propagation is not economically or technically feasible. Nonconsumptive uses of the Yellowstone cutthroat trout including fish-watching and intangible values, such as existence demand, provide additional support for protection of wild Yellowstone cutthroat trout populations. A management strategy that reduces resource extraction has provided a means to sustain a quality recreational fishery while enhancing values associated with the protection of natural systems. (118)

Gresswell, R. E. , Liss, W. J., Larson, G. L. , Bartlein, P. J. . 1997. Influence of basin-scale physical variables on life-history characteristics of cutthroat trout in Yellowstone Lake. North American Journal of Fisheries Management. 17: 1046-1064.

Examines basin-scale physical characteristics of tributary drainages and subbasins of Yellowstone Lake in relation to timing (peak and duration) of lacustrine-adfluvial Yellowstone cutthroat trout spawning migrations and mean length of cutthroat trout spawners in 27 tributaries to the lake; found evidence of distinct aggregations of cutthroat trout that are related to physical and limnological characteristics of the lake subbasins. (119)

Knapp, R.A., P.S. Corn, and D.E. Schindler. 2001. The introduction of nonnative fish into wilderness lakes: good intentions, conflicting mandates, and unintended consequences. Ecosystems 4: 275–278.

Abstract in Progress (120)

Schullery, P. , Varley, J. D. . 1994. Fires and fish: the fate of Yellowstone waters since 1988. Trout. V. 35 p. 16-23.

Six years after the 1988 Yellowstone fires, the authors examine research results of the influence of fire on watersheds and relate that to fish health. The ’88 fires effected over 100,000

acres in every major watershed in Yellowstone National Park without any major fish kills recorded. The influence of a fire on a watershed is a factor of many pre-fire conditions (i.e. slope, aspect, type of vegetation burned, elevation) and post-fire conditions (namely precipitation patterns). Changes in groundwater chemistry occurred, but not outside the norms. Foreseen species change of aquatic invertebrates was documented and will continue, but is not expected to endanger fish populations. The authors conclude with a discussion on the impact of the fires on park management including a brief history of fish management in the park. (121)

Varley, J.D.. and P. Shullery. 1998. Yellowstone fishes: Ecology, history, and angling in the park. Stackpole Books, Mechanicsburg, Penn. 154 pp.

Abstract in Progress (122)

FOREST

Allen, K.K. and J.L. Harris. 1999. Insects and diseases of the Bighorn National Forest. Internal report, Bighorn National Forest, Sheridan, Wyoming.

Abstract in Progress (123)

Anderson, Peter George. 1994. Conifer Forest Dynamics in Grand Teton National Park, Wyoming. University of Utah, Salt Lake City, UT.

The objective of this study is to determine past and present conifer forest patterns and processes, and to project future forest mosaics of the valley conifer forest in Grand Teton National Park, Wyoming. The hypothesis that the present forest mosaic of Grand Teton National Park has not been adversely affected by twentieth century forest fire suppression is examined. The forested moraine of the Bradley - Taggart Lakes area provides a case study of forest pattern and process. Historical aspects of vegetation development in Jackson Hole and Grand Teton National Park are discussed. Plant assemblages and the forest mosaic are analyzed using phytosociological methods. Forest community dynamics and historic tree distributions and growth influences are evaluated using dendroecological methods. Information derived from these methodologies forms the database for a landscape scale, vegetation simulation model. The model is utilized to simulate forest dynamics and project future forest mosaics. Vital attributes theory and forest composition, structure, and diversity are used to evaluate the successional pathways of the forest mosaics. I suggest that twentieth century forest fire suppression has not altered successional dynamics and pathways of the forest mosaic of Grand Teton National Park. However, if forest fire suppression is reinstituted, I suggest that successional dynamics will precede along multiple pathways that will alter the forest mosaic, changing energy, nutrient, and water cycles and balances, impacting the biotic habitat of the Grand Teton National Park - Jackson Hole area ecosystem. (124)

Arct, M. J. , Chadwick, A. V. . 1983. Dendrochronology in the Yellowstone fossil forest. Abstracts with Programs - Geological Society of America. 15 5: 408.

The ability to crossdate trees implies that they were sensitive to some aspect of their environment- usually temperature or precipitation. Since procedures used in traditional

dendrochronology are impractical when dealing with fossil assemblages with this method. The interpretation of growth features is based on modern analogues.
Thin sections of ring sequences were prepared from 37 coniferous stumps and logs from a 12 m thick section located near the base of the bands, false rings, bark rings, and climatic cycles (ring widths). Nine upright stumps (~40 years old) including pine, spruce and Douglas fir, sampled 1-3 m above their associated "soils" contained a series of 5 rings, 25-21 years before the final ring which displayed highly correlatable intra-annual bands corresponding to temporarily infavorable growth conditions. Ring 9 typically was small with a late season increase in water availability that caused a false ring feature in many trees. Although rings 8-4 were consistently large, bark rings show that several trees ceased growing in ring 4 while others indicated an instantaneous death before the end of the growing season in ring 1. Crumpled tracheids and insect galleries suggest a severe infestation was in progress to account for the early death of some trees.
Five older trees (~120 years) agree with the basic growth pattern of the younger trees. A period of reduced growth, probably related to drought and insect damage, occurs near ring 40. Subsequent rapid growth occurs coincident with the origin of younger trees.
Crossdated petrified trees thus promise a wealth of new paleoenvironmental information for the deposits in which they occur. (Abstract by Arct et al as printed in Agronomy Abstracts). (125)

Fahey, T.J. and D.H. Knight. 1986. Lodgepole pine ecosystems. BioScience 36:610-617.

The authors studied structurally contrasting stands of lodgepole pine in the Medicine Bow Mountains of Wyoming. Investigating the effect of water and nutrient flux in this relatively cool and dry ecosystem, they discussed related hydrology, low nitrogen content, and ion flow. These characteristics were found to contribute to biota and overall structure and function of the ecosystem. A consideration of the factors investigated is thought by the authors to be pertinent to management issues, although they suggest a more complete understanding is needed. They research the relatively simple lodgepole pine ecosystem in detail as an insight to the increasing complexity within which other forest types operate. (126)

Foster, D.R., D.H. Knight, and J.F. Franklin. 1998. Landscape patterns and legacies resulting from large infrequent forest disturbances. Ecosystems 1(6): 497-510.

Includes 1988 fires in a discussion of effects of large, infrequent disturbance. Resulting landscape patterns are strongly controlled by interactions between the specific disturbance, the abiotic environment, and the composition and structure of the vegetation at the time of disturbance. (127)

Hawksworth, F.G. and D.W. Johnson. 1989. Biology and management of dwarf mistletoe in lodgepole pine in the Rocky Mountains. USDA Forest Service General Technical Report RM-169.

This publication synthesizes the vast literature on lodgepole pine dwarf mistletoe (Arceuthobium americanum) and adds some new information on biology of the parasite. Although dwarf mistletoe has been recognized as a serious parasite of lodgepole pine for more than 75 years, its routine operational control through forest management has been primarily a development over the past two decades. This report discussed silvicultural control of dwarf mistletoe in various types of stands where fiber production is the primary goal, and also in

forests used mainly for recreation. (Abstract by Hawksworth and Johnson as printed in General Technical Report RM-169). (128)

Kendall, K.C. and R.E. Keane. 2001. Whitebark pine decline: Infection, mortality, and population trends. Pages 221-242 in Tomback, D.F., S.F. Arno, and R.E. Keane (eds.). Whitebark pine communities: Ecology and restoration. Island Press. Washington, DC. (Book Chapter)

The authors examine whitebark pine decline mechanisms including: white pine blister rust, mountain pine beetle and dwarf mistletoe, and fire exclusion. They also look at the temporal scale of decline and regional population trends. They conclude with a look at the future in whitebark pine communities. (129)

Knight, D.H. 1994. Dynamics of subalpine forests. Pages 128-138 in G.D. Hayward and J. Verner, editors. Flammulated, boreal, and great gray owls in the United States: a technical conservation assessment. USDA Forest Service General Technical Report RM-253

The boreal owl's fairly specific habitat requirements restrict its range in the conterminous U.S. to subalpine forests (see Chapter 9). These forests provide tree cavities, incrusted snow that facilitates preying on small mammals, and cool microclimates essential for summer roosting. Such forests also provide habitat for the owl's prey, which consists primarily of red-backed voles, mice, and other small mammals. Significantly, these prey animals often eat lichens and the sporocarps of fungi. Both are common at high elevations or along drainages in the middle and northern Rocky Mountains, the Blue Mountains, and the northern Cascade Range. This chapter focuses on the distribution, structure, and dynamics of subalpine forests in these areas, with emphasis on the Rocky Mountains. (Abstract by Knight as printed in General Technical Report RM-253). (131)

Loope, Lloyd L. 1971. Dynamics of forest communities in Grand Teton National Park. Naturalist. 22 1: 39-47.

Loope describes the ecology of the seven major tree types in Grand Teton National Park: lodgepole pine, whitebark pine, limber pine, Englemann spruce, subalpine fir, Douglas fir, and aspen. He proposed that the present (1971) forest composition and extent of species is due to a number of interactions between the tree species and climate, soils, and other living organisms. He describes in depth the ecology of the seven main species types in Grand Teton National Park including distribution, susceptibility to fire and disease, reproductive traits and age characteristics. He also examines the historical role of fire in the Teton Range, in the valley bottoms, and on the Yellowstone plateau and relates the effects these fires have had on the current forest composition and extent. Fire dates were determined from tree-ring record of fire scars and historical accounts. The impact of these fires is also explored in terms of forest health, namely, species susceptibility to disease. Loope concludes with a list of six consequences of continued fire exclusion in Grand Teton National Park and a recommendation for more research on fire suppression and primitive forest conditions. (132)

Lundquist, J.E. 1993. Large scale spatial patterns of conifer diseases in the Bighorn Mountains, Wyoming. Research Note RM-523. USDA forest Service, Rocky Mountain Forest and Range Experiment Station, Ft. Collins, Colorado.

A roadside reconnaissance for forest diseases in the Bighorn National Forest was conducted in 1991. The most common disorders were dwarf mistletoe, Comandra blister rust, western gall rust, and an undetermined needlecast of lodgepole pine; broom rusts, patch mortality, branch canker, and crown mortality of Engelmann spruce and subalpine fir; and white pine blister rust of limber pine. The most widespread disorders showed the creates diversity across the forest. Two or more disorders (average=4) occurred concurrently on all townships. (Abstract by Lundquist as printed in Research Note RM-523). (133)

Lynch, E.A. 1998. Origin of a park-forest vegetation mosaic in the Wind River Range, Wyoming. Ecology. 79(4):1320-1338.

Abstract in Progress (134)

Mattson, D.J., K.C. Kendall, D.P. Reinhart. 2001. Whitebark pine, grizzly bears, and red squirrels. In: Whitebark pine communities, ecology and restoration. Eds. D. Tomback, S.F. Arno, and R.E. Keane. Island Press, Washington DC.

Abstract in Progress (135)

McMillin, J.D. and K.K. Allen. 2000. Impacts of Douglas-fir beetle on overstory and understory conditions of Douglas-fir stands, Shoshone National Forest, Wyoming. USDA Forest Service Technical Report R2-64, Golden, Colorado.

Douglas-fir beetle (Dendroctonus pseudotsugae) infestations frequently result from disturbance events that create large volumes of weakened Douglas-fir (Pseudotsuga menziesii) trees. Although research has focused on measuring and predicting the amount of tree mortality caused by Douglas-fir beetle infestations following disturbance events, there has been an inadequate amount of work on the consequent changes in both the overstory and understory. In 1988, extensive wildfires occurred in Yellowstone National Park and the Shoshone National Forest. Populations of Douglas-fir beetle increased in firescorched trees caused by the wildfires. Subsequent generations of the beetles moved from these injured trees to undamaged trees in neighboring stands on the Shoshone National Forest, Wyoming. In 1999, Forest Health Management personnel quantified changes in forest stand conditions and subsequent responses in the understory caused by the Douglas-fir beetle infestation using transect sampling (20 miles) and 25 pairs of previously infested and uninfested plots. Significant effects of the Douglas-fir beetle infestation included: 1) Basal area was reduced by 40 - 70 percent, tree diameter decreased by 8 - 40 percent, and the Douglas-fir component of the overstory decreased by more than 15 percent. 2) Conifer seedling regeneration increased nearly four-fold in the infested plots and 90 percent of the regeneration was Douglas-fir. 3) The understory vegetation (forbs, grass, and shrubs) had a three-fold increase in the infested plots compared with uninfested plots. In addition, basal area of Douglas-fir killed by the Douglas-fir beetle was significantly correlated with initial Douglas-fir basal area and percent of Douglas-fir, but not tree diameter or trees per hectare. Significant inverse relationships were also found between post-infestation basal area and the abundance of forbs, grass, shrubs, and understory

height. Based on these results, Douglas-fir beetle infestations, although causing significant shortterm impacts in both the overstory and understory, probably are not changing the long-term successional patterns. Management alternatives are presented to control Douglas-fir beetle impacts for areas where the beetle is jeopardizing forest objectives. Information gathered from this study will be useful to the Shoshone National Forest, and other national forests both inside and outside the region, and the Yellowstone National Park. (136)

Merrill, E., J. Hak, and S. Beauchaine. 1993. Forest fragmentation and bird diversity in the Bighorn National Forest, Wyoming. EMAP-01-93, Project #R-82-1748. Report on file at the Wyoming Game and Fish Department, Sheridan, WY.

Abstract in Progress (137)

Meyer, C.B., and D.H. Knight. In review. Historic range of variability of upland vegetation in the Bighorn National Forest, Wyoming. U.S. Forest Service Report.

Abstract in Progress (138)

Miller, C. and D. L. Urban. 1999. Interactions between forest heterogeneity and surface fire regimes in the southern Sierra Nevada. Canadian Journal of Forest Research 29: 202-212.

Fire is a major agent of spatial pattern formation in forests, as it creates a mosaic of burned and unburned patches. While most research has focused on landscape-level patterns created by crown fires, millions of hectares of forests in North America are subject to surface fire regimes. A spatially explicit forest gap model developed for the Sierra Nevada was used to evaluate the influence of surface fire regimes on the heterogeneity of forest structure and composition within forest stands. Forest pattern was evaluated for a wide range of topographic position in Sequoia National Park. The spatial heterogeneity of some forest characteristics increased under a simulated fire regime relative to scenarios without fire. &. The interaction between surface fires and forest pattern may be qualitatively different from that which occurs in forests subject to crown fires. As such, what has been learned about forests dominated by crown fires may not apply to forests subject to surface fire regimes (139)

Murcia, C. 1995. Edge effects in fragmented forests: implications for conservation. Trends in Ecology and Evolution 10: 58-62.

Edges are presumed to have deleterious consequences for the organisms that remain in forest fragments. However, there is substantial discrepancy among recent studies about the existence and intensity of edge effects. Most studies have focused on seeking simplistic and static patterns. Very few have tested mechanistic hypotheses or explored the factors that modulate edge effects. Consequently, studies are very site-specific and their results cannot be generalized to produce a universal theory of edges. Although estimates of the intensity and impact of edge effects in fragmented forests are urgently required, little can be done to ameliorate edge effects unless their mechanics are better understood. (Abstract by Murcia as printed in TREE). (140)

Patten, D. T. . 1969. Forest succession in Yellowstone National Park. National Parks Magazine. 43 264: 21-22.

lodgepole pine forests in Yellowstone and forest succession. (141)

Renkin, R.A., and D.G. Despain. 1992. Fuel moisture, forest type and lightning-caused fire in Yellowstone National Park. Can. J. for. Res. 22(1)37-45.

The occurrence and behavior of lightning-caused fires in Yellowstone National Park were summarized for 17 years (1972-1988) during a prescribed natural fire program. Both ignition (occurrence) and spread (stand replacing fire activity) of fires were strongly influenced by fuel moisture and forest cover type. Fuel moisture estimates of 13% for large (gt 7.6 cm) dead and downed fuels indicated a threshold below which proportionately more fire starts and increased stand replacing fire activity were observed. During periods of suitable fuel moisture conditions, fire occurrence and activity were significantly greater than expected in old-growth, mixed-canopy lodgepole pine (Pinus contorta Dougl. var. latifolia) and Englemann spruce-subalpine fir (Picea engelmannii Parry-Abies lasiocarpa (Hook.) Nutt.) forest types, and significantly less than expected in the successional lodgepole pine forest types. During periods of extended low fuel moisture conditions (drought), sustained high winds significantly reduced the influence of forest cover type on stand replacing fire activity. These extreme weather conditions were observed during the later stages of the 1988 fire season, and to a lesser extent, for a short duration during the 1981 fire season. The Douglas-fir (Pseudotsuga menziesii (Mirb.) Franco) forest type typically supported little stand replacing fire activity, even though a preponderance of fire starts was observed. (142)

Rochefort, R.M., et al. (1994). Changes in sub-alpine tree distribution in western North America: a review of climatic and other causal factors. The Holocene, 4(1): 89-100.

Changes in the distribution of sub-alpine tree species in western North America have been attributed to climatic change and other environmental stresses. These changes include tree-line fluctuations throughout the Holocene and recent invasion of subalpine meadows by forest. Most paleoecological studies suggest that the tree-line was higher during a period of warmer climate advance. Recent advances in sub-alpine tree distribution can be compared with weather records, allowing and examination of relationships between tree advance and climate at a finer resolution. In general, recent sub-alpine forest advances in western North America, based on studies representing three climatic zones (maritime, Mediterranean and continental), have been associated with climatic periods favoring tree germination and growth, although factors such as fire and razing by domestic livestock have had an impact in some area. Limitations to tree establishment (e.g., winter snow accumulation, summer drought) vary in relative importance within each climate zone, as do predicted consequences of anthropogenic climate change. Recent increased in establishment of sub-alpine trees may continue if climatic change alleviates the limitations to tree establishment important in each climatic zone. However, factors such as topography and disturbance may modify tree establishment on a local scale. (Abstract by Rochefort et al as printed in The Holocene). (143)

Romme, W. H., and D. H. Knight. 1981. Fire frequency and subalpine forest succession along a topographic gradient in Wyoming. Ecology 62:319-326.

Differences in fire frequency and the rate of secondary succession following fire have had a major effect on the present composition of forest vegetation in a 4500-ha undisturbed

watershed in the subalpine zone of the Medicine Bow Mountains, southeastern Wyoming, USA. Periodic fire coupled with slow secondary succession has perpetuated lodgepole pine forest on the upland, while mature Engelmann spruce-subalpine fir forest have developed in sheltered ravines and valley bottoms where fire is less frequent and succession following fire is more rapid and/or more direct. A graphic model is presented showing the relationship between topographic position, fire-free interval, and the occurrence of mature forests dominated by spruce and fir. (Abstract by Romme and Knight as printed in Ecology). (144)

Schmidt, W. C. , McDonald, K. J. . Proceedings - Symposium on Whitebark Pine Ecosystems: Ecology and Management of a High Mountain Resource. Intermountain Research Station, US Department of Agriculture Forest Service, Ogden, UT.

Abstract in Progress (313)

Vance, G.F. and D.H. Knight. 1999. Coarse woody debris and soil organic matter in Rocky Mountain coniferous forests. Agronomy Abstracts, 91:365

Natural and human disturbances to forest ecosystems can alter above-and below-ground C pools that influence vegetation and soil energy and nutrient flows, wildlife habitats, and sequestration potentials. Large quantities of course woody debris (CWD) are produced by natural disturbances (e.g., fires, insect outbreaks, wind storms) whereas timber harvest (e.g., bolewood, whole tree) removes much of the CWD. The objectives of this study were to: 1) compare the volume and distribution of CWD that remains following disturbances and 2) evaluate the quality and quantity of soil organic matter (OM) under CWD and forest litter layers. For objective 1, CWD was measured in clearcut/uncut stands in the Medicine Bow Mountains and in burned/unburned stands in Yellowstone National Park. Results indicated a net loss (80 Mg/ha of >7.5 cm dia.) of CWD in clearcut stands and an average gain (95 Mg.ha) in stands that burn. Objective 2 results suggested soil OM under CWD sites was higher in N and 65% greater in phenolic products. Soil solutions from CWD sites were more acidic, had higher N, P, and S nutrients and greater percentages of acid DOC fractions. (Abstract by Vance and Knight as printed in Agronomy Abstracts). (145)

GEOLOGY

Antweiler, J.C., J.D. Love, H.J. Prostka, D.M.. Kulik, L.A. Anderson, F.e. Williams, J.E. Jinks, and T.D.. Light. 1989. Mineral resources of the Teton Wilderness and adjacent areas, Teton, Fremont, and Park counties, Wyoming: U.S. Geol. Surv. Bulletin 1781

Discusses a mineral survey of the Teton Wilderness and adjacent areas (146)

Baker, R.G. . 1986. Sangamonian and Wisconsin paleoenvironments in Yellowstone National Park: Geol. Soc. America Bulletin, vol. 97, p. 717-736, 13 figs, 1 table.

Pollen and plant macrofossil records from Yellowstone National Park, if combined with dated glacial events, provide a paleoenvironmental record of much of the last glacial-interglacial cycle. Bull Lake glaciation has been dated at ~140,000 yr B.P. Section EP-6 records a late-glacial to full interglacial sequence which is correlated with the Sangamonian interglacial and estimated to be 127,000 yr old at the peak warm period. A prevailing Pseudotsuga-Pinus

flexilis-Pinus ponderosa forest suggests that climate was considerably warmer than any in the Holocene. Section EP-5 is somewhat younger, probably late Sangamonian, and shows forest dominated by Picea, Abies, Pseudotsuga, and a haploxylon Pinus. Slightly cooler conditions than those of the present are indicated. The warmest phase of Grassy Lake Reservoir section is considered to be ~82,000 yr old and records a warm interstadial cycle beginning with tundra. The warming sequence is indicated by change to a Picea-Abies-Pinus albicaulis forest and then to a Pinus contorta forest. The cycle ends with forest destruction and a return to open (tundra?) and, presumably, cold conditions. Extremely low values of arboreal pollen indicate that tundra vegetation and cold conditions continued from ~70,000 to ~50,000 yr B.P. One cool and, apparently, short interstadial interrupted this extended period of tundra shortly after 68,000 B.P. when a very open parkland of Picea-Abies-Pinus albicaulis appeared. No records of environment are available between ~50,000 and 30,000 yr B.P. The Pinedale icecap apparently expanded ~30,000 yr B.P. and lasted until ~14,000 yr B.P. Late-glacial Picea-Abies-Pinus albicaulis parklands gave way to Pinus contorta forests that have prevailed with minor variation for ~10,000 yr. (Abstract by Baker as printed in Geological Society of America Bulletin). (147)

Barnosky, A. D. . 1998. A long term view of the Greater Yellowstone geoecosystem. Pages 26 in No Editor/Author. Making a place for nature, seeking our place in nature: 125th Anniversary Symposium; agenda and abstracts. Yellowstone Association, Yellowstone

Geology influences ecosystem structure and function at a variety of temporal and spatial scales, ranging from millions of years on a continental scale to tens of years on a local scale. The present ecosystem in and around Yellowstone Park therefore reflects a composite of interactions between geological and biological processes that have been ongoing since the northern Rocky Mountains first uplifted. This composite results from processes that take place on million-year scales (e.g., tectonism and long-term volcanic patterns), hundred-thousand year scales (e.g., long-term climate trends), ten-thousand to several hundred year scales (specific climate changes and volcanic events), and the decadal scale (e.g., weather-driven events, geologically-influenced human settlement patterns). Data from intermontane basins in and around the Greater Yellowstone area indicate that the geological processes included (1) widespread volcanism during the Eocene, and global circulation patterns that resulted in tropical to subtropical environments; (2) a period of regional uplift, block-faulting, and erosion during the Miocene that defined major aspects of the regional topography and was accompanied by global climate change that resulted in locally arid environments; (3) local volcanism during the Miocene; (4) late Miocene/early Pliocene uplift in and around Yellowstone Park, which regionally increased precipitation gradients and opened previously tectonically dammed valleys; (5) Pliocene and Pleistocene volcanism and overprinting of topographic and geophysical relationships related to the approach of the Yellowstone hotspot; (6) Pleistocene glaciation related to global cooling; and (7) retreat of glaciers during the Holocene, related to global warming. The overprints of these geological events on the modern biota include: (1) a pattern of biodiversity that relates to the fragmentation of the northern Rocky Mountain region into the basins and ranges; (2) a legacy of constituent taxa determined by evolutionary constraints, proximity of immigrants, and chance opening and closing of dispersal corridors; and (3) the activities of humans related to utilizing, recreating, and living in an area they are attracted to in part because of the geological setting. (Abstract by Barnosky. As printed in Making a place for

nature, seeking our place in nature: 125th Anniversary Symposium, May 11-23, 1998; agenda and abstracts.) (148)

Christiansen, R. L. . 1998. Geology of Yellowstone National Park and vicinity as the foundation of the Yellowstone geoecosystem. Pages 30 in No Editor/Author. Making a place for nature, seeking our place in nature: 125th Anniversary Symposium; agenda and abstracts

The unique character of the Yellowstone geoecosystem reflects a complex geologic evolution. Farther north much of the Continental Divide is a sharp mountainous backbone; through parts of Wyoming it is topographically inconspicuous. By contrast, a great plateau spans the Divide in Yellowstone at nearly 2500 m elevation. The specific trace of the Divide across this plateau is less significant than the broad high expanse at the headwaters of two great drainage systems. The Yellowstone Plateau is built upon mountains raised during the Laramide orogeny between about 70 and 55 million years (m.y.) ago. Before then, sedimentary rocks had been laid down over about 500 m.y. in a variety of environments, mainly but not entirely marine, upon a substructure of ancient crystalline rocks (~2600 m.y.). During the Laramide the continental crust was folded and thrust-faulted into numerous mountain ranges and intervening broad sedimentary basins. Postorogenic volcanism partly coalesced from northwestern Wyoming to the Pacific Coast. Much of the Rocky Mountain region still reflects a pattern inherited from the Laramide orogeny and early post-Laramide volcanism, as in the Gallatin, Snowy, and Absaroka Ranges of the Yellowstone region. Superimposed on the Laramide framework are younger basins and ranges formed by tectonic extension, mainly in the Great Basin region to the southwest but also in high ranges and adjacent valleys from central Idaho to northwestern Wyoming, dating mainly from the past 10 m.y. Slicing across these younger ranges, is the eastern Snake River Plain, the track of voluminous magmatism that, during the same time, propagated from southwest to northeast. Both extensional basin-range deformation and magmatism continue, as in the Teton Range and Jackson Hole and the Yellowstone Plateau volcanism of the past 2 m.y. Yellowstone Plateau volcanism differed significantly from that of many other areas. Rather then lofty stratocones or bulky volcanic shields, enormous volumes of rhyolitic magma erupted, partly as lavas but largely as explosively ejected pumice and volcanic ash that not only dispersed widely through the atmosphere but swept the landscape in searing density flows. Coming to rest, these hot ash flows welded to form broad lava-like sheets of rhyolite over thousands of square kilometers. The larges eruptions were three massive events 2.0, 1.3, and 0.6 m.y. ago, each ejecting hundreds to thousands of cubic kilometers of magma in a few hours or days, withdrawing crustal support to cause large areas to founder into gigantic craterlike calderas, subsequently filled with lavas and sediments to form the plateau. The outcrop pattern and the specific character of Yellowstone's rocks, especially the volcanic rocks and surficial deposits of streams, lakes, glaciers, and rock falls derived from them, determine much of the vegetation pattern of the plateau and its surrounding ranges. Heat from the still active magmatic system sustains Yellowstone's geysers, hot springs, and fumaroles, upon which the mega faunal population relies during winters, when they are often isolated from former grazing and hunting ranges. (Abstract by Christiansen, R. L.. As printed in Making a place for nature, seeking our place in nature: 125th Anniversary Symposium, May 11-23, 1998; agenda and abstracts.) (149)

Dorf, Erling, "The Petrified Forests of Yellowstone Park," Scientific American, 210 (4), 106 (April 1964).

Summary of the Yellowstone petrified forests and fossil plants. (150)

Doser, D.I. and R.B. Smith (1983). Seismicity of the Teton-Southern Yellowstone region: Bull. Seism. Soc. Am., vol. 73, p. 1369-1394, 12 figs, 3 tables.

Epicenter patterns, focal depths, and focal mechanisms for earthquakes occurring between 1973 and 1981 in the Teton-Jackson Hole-southern Yellowstone region are presented. Earthquake information recorded prior to 1980 was combined with two microearthquake surveys operated in 1980 and 1981. The majority of earthquakes do not appear to be associated with mapped traces of Quaternary faults. The Teton Fault appears active at the small earthquake level along some segments, although several segments appear to be quiescent. Seismicity in the Gros Ventre Range may be related to reactivation of older basement structures. Fault plane solutions show predominately normal faulting with extension in an east-west to northwest-southeast direction. Geologic seismic moment rates of 1.1 X 10(24) dyne-cm/yr for the Teton region and 4.0 X 10(23) dyne-cm/yr for the Teton Fault were estimated using available geologic information on mapped faults. From the limited available data, a return period of 130 to 155 yr for a magnitude 6.5 to 7.5 earthquake is predicted for the Teton region, while the Teton Fault has a predicted return period of 8000 to 1800 yr for a magnitude 7.5 earthquake. A regional strain rate of 6.9 X 10(-9)/yr is also obtained.--Modified journal abstract. (151)

Kharaka, Y.K. and A.S. Maest, eds. 1992. Proc. Of the 7th intern. Symp. On water-rock interaction-WRI-7. Park City, UT.

Abstract in Progress (152)

Love, J.D., J.C. Reed, and K.L. Pierce. 2001. Creation of the Teton Landscape, A geologic chronicle of Jackson Hole and The Teton Range. A 156-page manuscript plus 96 illustrations was completed in early 2001 and submitted to the Grand Teton National History Association for evaluation for publication.

Abstract in Progress (153)

Pierce, K.L. 1979. History and dynamics of glaciation in the Northern Yellowstone National Park Area. U.S. Geological Survey Professional Paper 729-F.

Yellowstone National Park, the oldest of the areas set aside as part of the national park system, lies amidst the Rocky Mountains in northwestern Wyoming and adjacent parts of Montana and Idaho. Embracing large, diverse, and complex geologic features, the park is in an area that is critical to the interpretation of many significant regional geologic problems. In order to provide basic data bearing on these problems, the U.S. Geological Survey in 1965 initiated a broad program of comprehensive geologic and geophysical investigations within the park. This program was carried out with the cooperation of the National Park Service, and was also aided by the National Aeronautics and Space Administration, which supported the gathering of geologic information needed in testing and in interpreting results from various remote sensing devices. This professional paper chapter is one of a series of technical geologic reports resulting from these investigations. (154)

Pierce, K.L. and L.A. Morgan. 1990. The track of the Yellowstone Hotspot: volcanism, faulting, and uplift: U.S. Geol Surv. Open File Rept 90-415, 68 pp., 24 gis, 3 tables.

The track of the Yellowstone hotspot is represented by a systematic NE-trending linear belt of silicic, caldera-forming volcanism that arrived at Yellowstone 2 Ma, was near American Falls, Idaho, about 10 Ma, and started about 16 Ma near the Nevada-Oregon-Idaho border. From 10-2 Ma, silicic volcanism migrated N 54 E towards Yellowstone at about 3 cm/yr, leaving in its wake the eastern Snake River Plain (SRP). The eastern SRP is a linear, mountain-bounded, 75-km-wide trench almost entirely floored by calderas that are thinly covered by basalt flows. From 16-10 Ma, particularly 16-14 Ma, volcanism was widely dispersed around the interred hotspot track in a region that now forms a moderately high volcanic plateau. The current hotspot position at Yellowstone is spatially related to active faulting and uplift. Basin-and-range faults in the Yellowstone-SRP region are classified into six types based on both recency of offset and height of the associated bedrock escarpment. The distribution of these fault types permits definition of three adjoining belts and a pattern of waxing, culminating, and waning activity. The central belt, Belt II, is the most active and is characterized by faults active since 15 ka on range fronts >700 m high. Belt II has two arms forming a "V" that joins at Yellowstone: one arm of Belt II trends south to the Wasatch front; the other arm trends west and includes the sites of the 1959 Hebgen Lake and 1983 Borah Peak earthquakes. Fault Belt I is farthest away from the SRP and contains relatively new and reactivated faults that have not produced new bedrock escarpments higher than 200 m during the present episode of faulting. Belt III is the innermost active belt near the SRP. It contains faults that have moved since 15-120 ka and which have been active long enough to produce range fronts more than 500 m high. A belt with inactive faults occurs only south of the SRP and contains late Tertiary range-front faults that experienced high rates of activity coincident with hotspot volcanism on the adjacent SRP. Comparison of activity based on these belts with that defined by modern seismicity is remarkably similar but differs in detail. Uplift migrating outward from the hotspot track is suggested by (1) the Yellowstone crescent of high terrain that is about 0.5 km higher than the surrounding terrain, is about 350 km across at Yellowstone, wraps around Yellowstone like a bow wave, and has arms that extend 400 km southerly and westerly from its apex, (2) readily erodible rocks forming young, high mountains in parts of this crescent, (3) geodetic surveys and paleotopographic reconstructions that indicate young uplift near the axis of the Yellowstone crescent, (4) on the outer slope of this crescent, glaciers during the last glaciation were anomalously long compared with those of the preceding glaciation, suggesting uplift during the intervening interglaciation, and (5) lateral migration of steams, apparent tilting of stream terraces away from Yellowstone, and , from increasingly younger terrace pairs, migration away from Yellowstone of their divergent-convergent inflection point. We conclude that the neotectonic fault belts and the Yellowstone crescent of high terrain reflect heating that has migrated to distances as much as 200 km from the eastern SRP in 10 m.y, and that the only mechanism for such heat transport is flow of hot material within the asthenosphere, most likely by a thermal mantle plume rising to the base of the lithosphere and flowing outward horizontally for at least such distances. The change in the volcanic track between 16-10 Ma and 10-2 Ma is readily explained by first the head (300 km diameter) and then the chimney (10-20 km across) phases of a thermal mantle plume rising to the base of the SW-moving North American plate. About 16 Ma, the bulbous

plume head intercepted and mushroomed out at the base of the lithosphere, resulting in widespread magmatism and tectonism centered near the common borders of Nevada, Oregon, and Idaho. Starting about 10 Ma near American Falls and progressing to Yellowstone, the chimney penetrated through its less active head and spread outward at the base of the lithosphere, adding basaltic magma and heat to the overriding SW-moving lithospheric plate, and leaving in its "wake" the eastern-SRP-Yellowstone track of calderas, and forming, ahead and outward from this track, the outward-moving belts of active faulting and uplift. We favor a mantle plume explanation for the hotspot track and associated tectonism and find problems with competing hypotheses that include the following: (1) for a rift origin, faulting and extension directions are at nearly right angles to that appropriate for a rift, (2) for a transform origin, geologic evidence requires neither a crustal flaw nor differential extension across the eastern SRP, and volcanic alignments on the SRP do not indicate a right-lateral shear across the SRP. The southern Oregon rhyolite zone is not analogous to the eastern SRP and therefore does not disprove formation of the Yellowstone hotspot track by a mantle plume. The postulated rise of a mantle-plume head into the mantle lithosphere about 16 Ma corresponds in both time and space with the following geologic changes: (1) the start of the present pattern of basin-range extension, (2) intrusion of basalt and rhyolite along the 1,100-km-long Nevada-Oregon rift zone, (3) the main phases of flood basalt volcanism of the Columbia River and Oregon plateaus, and (4) a change from calc-alkaline volcanism of intermediate to silicic composition to basaltic and bimodal rhyolite/basalt volcanism. (Abstract by Pierce and Morgan. As printed in U.S. Geol Surv. Open File Rept 90-415.) (155)

Richards, P.W. 1955. Geology of the Bighorn Canyon-Hardin Area, Montana and Wyoming. US Geological Survey Bulletin 1026

This report describes the geology of an area of about 1,300 square miles in south-central Montana extending from Hardin, Mont., southward across part of the Great Plains to the Bighorn Mountains and thence southwestward through the mountains along Bighorn Canyon to the Bighorn Basin. The area is mostly within the Crow Indian Reservation in southwestern Big Horn County, Mont., but it includes parts of Carbon County, Mont., and Big Horn County, Wyo., and less than 10 square miles of the southeast part of Yellowstone County, Mont. The only incorporated town within the area is Hardin, the county seat of Big Horn County, Mont., and the only other settlement is St. Xavier, Mont. The region is drained by the Bighorn River and its tributaries. The main valleys are cultivated. The proposed Yellowtail dam, in the canyon of the Bighorn River near the east edge of the Bighorn Mountains, would create a reservoir 70 miles long and provide irrigation water for extensive terrace lands along the Bighorn River. About 9,000 feet of sedimentary rocks, ranging in age from Cambrian to Late Cretaceous, are exposed in the area. Pre-Cambrian granites and metamorphic rocks, which form the central parts of the Bighorn Mountains and are separated from the overlying sedimentary rocks by an erosional unconformity, do not crop out in the area. In the deepest part of Bighorn Canyon approximately the upper 700 feet of about 1,000 feet of shale and thin-bedded limestone that make up the Cambrian Gros Ventre formation and Gallatin limestone is exposed. Resistant limestone and dolomite which overlie the Gallatin comprise 400 feet of Bighorn dolomite of Ordovician age, 200 feet of undivided Jefferson limestone and Three Forks shale of Late Devonian age, and 700 feet of Madison limestone and of Mississippian age. The overlying rocks belong to the Amsden

formation, which is intergradational from the Mississippian (?) to the Pennsylvanian and the Tensleep sandstone of Pennsylvanian age. The Amsden formation lies unconformably on the Madison limestone, consists of red shales and siltstones, gray limestones and sandstones, and ranges from 230 to 280 feet in thickness. The Tensleep sandstone, which is as much as 120 feet thick but is missing locally, consist of gray to yellowish-gray sandstone and a few thin beds of dolomite and chert. Overlying the Tensleep sandstone and separated from it by an erosional unconformity are the Permian Embar formation and the Triassic Chugwater formation. The Embar and Chugwater formations were mapped separately only in the southwestern part of the area where the Embar consists of 100 feet of dolomite, limestone, and red siltstone and sandstone. Elsewhere, a zone of redbeds, gypsum, and thin beds of limestone is seemingly the Embar equivalent, but the zone is too thin to map as a formation and was included in the base of the Chugwater formation. The Chugwater formation consists of 350 to 500 feet of red sandstone and siltstone and gypsum. About 150 feet of red siltstone and sandstone, limestone, and gypsum belonging to the Piper formation of Middle Jurassic age overlies the Chugwater formation. In central Montana the Piper is separated from rocks as old as Mississippian by an extensive unconformity, but in the area adjacent to the Bighorn Mountains the Piper is seemingly conformable above the Chugwater. About 300 feet of light olive-gray to olive-brown calcareous shale belonging to the Upper Jurassic Rierdon formation overlies the Piper, and nearly 200 feet of yellowish-gray to grayish-green sandstone and siltstone and light olive-gray shale of the Upper Jurassic Swift formation overlie the Rierdon. Glauconite-bearing marine beds of the Swift formation grade upward into continental sandstones and siltstones of the overlying upper Jurassic Morrison formation. The upper part of the Morrison is largely variegated shales which are commonly concealed, and the total thickness of the formation ranges from less than 100 feet to about 250 feet.

The Lower Crataceous Cloverly formation is 400 feet or less thick. It contains a basal lenticular member named the Pryor conglomerate member, a middle zone of variegated beds, and an upper zone of interbedded siltstones, shales, and sandstones. Where the Pryor member is missing, variegated beds in the upper part f the Morrison cannot be distinguished from beds of similar lithology in the Cloverly, and the two formations were mapped together. The Lower Crataceous Thermopolis shale, which is about 450 feet thick, consists of dark-gray shale and interbedded bentonite. A zone of gray sandstone dikes about 150 feet above the base is correlated with the Newcastle sandstone of the Powder River Basin and the Muddy sandstone in the Bighorn Basin. Overlying the Thermopolis shale is the Mowry shale which is characterized by abundant fish scales and numerous layers of siliceous shale and siltstone. The Mowry is 325 to 400 feet in thickness and contains several beds of bentonite. It is uppermost formation in the Lower Cretaceous series. A conformable sequence above the Mowry shale of about 4,000 feet of shales, siltstones, and sandstones underlies the Great Plains region. Included in this sequence are the Frontier formation, Cody shale, Parkman sandstone, and Bearpaw Shale, all of Late Cretaceous Age. These formations belong to the Colorado and Montana groups. The basal few feet of the nonmarine Hell Creek formation, which is equivalent to the Lance formation and younger than the Montana group, occurs in the northeast corner of the mapped area. The Frontier formation, about 250 feet thick, comprises dark-gray partly sandy shale and interbedded bentonite. Overlying the Frontier is the Cody shale which consists of 2,600 feet of dark-gray concretionary partly sandy shale and interbedded bentonite. It has been divided into 7 members,

the lower 4 belonging to the Colorado group and the upper 3 to the Montana group. From base to top, the members of the Cody shale are (a) an unnamed member 200 feet thick; (b) the Greenhorn calcareous member 60 to 100 feet thick; (c) the Carlile shale member about 280 feet thick; (d) the Niobrara shale member 400 feet thick; (e) the Telegraph Creek member 750 feet to 850 feet thick; (f) a shale member equivalent in age to the Eagle sandstone about 375 feet thick; and (g) the Claggett shale member about 350 feet thick. Above the Cody shale is the Parkman sandstone which comprises 100 feet of silty and sandy shale overlain by 150 feet of massive and thick-bedded yellowish-gray and greenish-gray sandstone. The Bearpaw shale, which is the uppermost formation of the Montana group, is exposed only in the northeastern corner of the area. It is composed of dark-gray shale 850 feet thick that has many beds of bentonite in the middle. A few feet of greenish sandstone, siltstone, and shale belonging to the Hell Creek formation overlie the Bearpaw in the northeastern corner of the area. Six well-developed stream terraces, the highest two of which may be late Tertiary in age, extend along the Bighorn River. These and correlative terraces in tributary stream valleys have a 25-foot thick veneer of limestone and volcanic rock gravel. Several surfaces, which were mapped as pediments, in the southwestern part of the area slope rather steeply away from the Pryor Mountains and are covered with limestone gravel and boulders washed from the Pryor Mountains. Several erosional surfaces in the Great Plains area have little covering other than reworked shale and gravel washed from nearby terraces, and these surfaces were mapped as undifferentiated Quaternary surfaces. The folding and main deformation of the mountains occurred during early Tertiary time after the deposition of all the sedimentary formations of the area. The domes and anticlines in the plains region may have formed during this same period of orogeny as they trend parallel to the northern end of the Bighorn Mountains which is itself the northward plunging end of a long anticline. Structural closure on the domes is small except for Soap Creek dome, and faults are simple and of relatively small displacement except for the Sykes Springs fault zone near the southern tip of the Pryor Mountains. Black oil has been produced from the Soap Creek oil field, which was first drilled in 1921, and gas for the town of Hardin is supplied from the Hardin gas field. Thick beds of bentonite in the Cretaceous formations and limestone in the Carboniferous strata may some day be of economic importance. (Abstract by USGS. As printed in US Geological Survey Bulletin 1026) (156)

HERPETOFAUNA

Baum, Ryan E., Peterson, Charles R. 2002. 2001 Progress report of occurrence, distribution, and habitat relationships of amphibians and reptiles in Bighorn Canyon. 89 pages (Unpublished).

Preliminary survey of amphibians and reptiles in Bighorn Canyon during the summer of 2001 (157)

Corn PS. 2000. Amphibian declines: review of some current hypotheses. In: Sparling DW, Bishop CA, Linder G, editors. Ecotoxicology of amphibians and reptiles. Pensacola FL: Society of Environmental Toxicology and Chemistry. p 639-672.

Abstract in Progress (158)

Koch, E. D. , Peterson, C. R. . 1995. Amphibians and reptiles of Yellowstone and Grand Teton National Parks. University of Utah Press, Salt Lake City.

Description, distribution, and natural habitat for each species, with color photos, simple identification key, range maps, (160)

Muths, E., P.S. Corn, A.P. Pessier, and D.E. Green. Evidence for disease-related amphibian decline in Colorado. Conservation Biology (Submitted).

The recent discovery of a pathogenic fungus (Batrachochytrium dendrobatidis) associated with declines of frogs in the American and Australian tropics, suggests that at least the proximate cause, may be known for many previously unexplained amphibian declines. We have monitored boreal toads in Colorado since 1991 at four sites using capture–recapture of adults and counts of egg masses to examine the dynamics of this metapopulation. Numbers of male toads declined in 1996 and 1999 with annual survival rate averaging 78% from 1991 to 1994, 45% in 1995 and 3% between 1998 and 1999. Numbers of egg masses also declined. An etiological diagnosis of chytridiomycosis consistent with infections by the genus Batrachochytrium was made in six wild adult toads. Characteristic histomorphological features (i.e. intracellular location, shape of thalli, presence of discharge tubes and rhizoids) of chytrid organisms, and host tissue response (acanthosis and hyperkeratosis) were observed in individual toads. These characteristics were indistinguishable from previously reported mortality events associated with chytrid fungus. We also observed epizootiological features consistent with mortality events associated with chytrid fungus: an increase in the ratio of female:male toads captured, an apparent spread of mortalities within the metapopulation and mortalities restricted to post metamorphic animals. Eleven years of population data suggest that this metapopulation of toads is in danger of extinction, pathological and epizootiological evidence. (Abstract by Muths et al as printed in Biological Conservation uncorrected proof). indicates that B. dendrobatidis has played a proximate role in this process. (161)

Patla, D. A. , Peterson, C. R. . 1999. Amphibians of Yellowstone: are amphibians declining in Yellowstone National Park?. Yellowstone Science. 7 1: 2-11.

The studies of amphibians and reptiles made by Frederick B. Turner in the mid 1950's provide baseline data for studying changes in the Park's populations and habitat. Lessons learned include the importance of viewing populations in the context of the local landscape; site fidelity may account for finding amphibians in disturbed areas; absence of historical information often makes judgments of species abundance difficult; development has costs beyond those usually considered; and above all, raw data should be retained in a safe place for the use of future investigators. Includes historical summaries, recommendations for future study. (162)

Peterson, C. R. , Koch, E. D. , Corn, P. S. 1993. Forty years of change in amphibian populations and habitats in Yellowstone and Grand Teton National Parks. Pages ? in No Editor/Author. Symposium on amphibian monitoring in western national parks; annual meeting of the Northwestern Veterbrate Biology, Astoria, Oregon, March 1993.

To determine long-term changes in amphibian populations in Yellowstone and Grand Teton National Parks, we revisited sites in 1991 that had been sampled in the 1950's. The most

striking result of these comparisons was the extent of human modification of several of the sites. The Soldier Creek area, where Turner studied the demography of spotted frogs (Rana pretiosa), has been fragmented by gravel and paved roads which apparently have separated one of the main breeding ponds from the creek. A mark/recapture study conducted in July and August indicated that the spotted frog population there has decreased by 75-85%. Similarly, the construction of buildings, roads, and changes to the Jackson Lake dam have so modified Carpenter's best studied sites that meaningful comparisons can not be made. Based on these experiences, we recommend that the National Park Service identify the locations of past studies and consider this information when making land use decisions. We also recommend that researchers carefully consider the probability of disturbance (vs. convenience) when selecting sites for future monitoring or research studies. (Abstract by Peterson et al as printed in Abstracts of the Annual Meeting of the Society of Northwestern Vertebrate biology). (163)

HUMAN

Bearss, E.C. 1970. Bighorn Canyon National Recreation Area, Montana-Wyoming: History basic data. Volumes 1 and 2. U.S. Dept. Int., Natl. Pk. Serv., Office of History and Historic Architecture, Eastern Serv. Ctr. 687 pp. and unnumb. Plates.

Abstract in Progress (164)

Hansen, A.J., R. Rasker, B. Maxwell, J.J. Rotella, J. Johnson, A. Wright, U. Langner, W.B. Cohen, R.L. Lawrence, and M.P.V. Kraska. 2002. Ecological causes and consequences of Demographic Change in the New West. BioScience 52:151-162.

Abstract in Progress (168)

Nelson, J. D. , et al. Tailings and Mine Waste '96; proceedings of the third International Conference on Tailings and Mine Waste, Fort Collins CO, 16-19 Jan 1996. Balkema, Rotterdam. The Yellowstone Research Library (YRL) has a couple papers pertaining

Abstract in Progress (204)

Patten, D. T. . 1991. Human impacts in the Greater Yellowstone Ecosystem: evaluating sustainability goals and eco-redevelopment. Conservation Biology. 5 3: 405-411.

The Greater Yellowstone Ecosystem is composed of a mosaic of national parks, forests, wildlife refuges, and private lands, each managed with different goals. Perturbations, both natural and anthropogenic, influence these areas. Maintaining naturalness and sustaining the systems within the Greater Yellowstone Ecosystem are desired assessment endpoints in determining the need for ecosystem redevelopment. Ecosystem degradation is a natural response to human impacts, and evaluation of degradation relative to management goals can be used to determine the acceptability of the goals and potential for eco-redevelopment. Goals may range from maintaining very natural sustainable ecosystems to developing sacrifice areas for heavy tourist use or oil development. To evaluate human impacts in the Greater Yellowstone Ecosystem, management goals for all systems should be reexamined to determine whether the original goals remain appropriate and whether some level of eco-redevelopment is necessary to

achieve these or newly established goals. Special attention should be given to impacts of interactive and cumulative human activities. (170)

Rasker, R. , Hackman, A. . 1996. Economic development and the conservation of large carnivores. Conservation Biology. 10 4: 991-1002.

"Employment and income trends in counties of NW Montana were also analyzed. It was found that protecting wildland
habitat for large carnivores is detrimental to a region's economy although enough counterevidence is presented to suggest an alternative hypothesis: the protection of wilderness habitat that sustains wild carnivores such as grizzly bears (Ursus arctos horribilis) and wolves (Canis lupus) does not have a detrimental effect on local or regional economies. Evidence presented suggests that economic growth is stimulated by environmental amenities. Further, use studies in southern British Columbia and Alberta in Canada and the Greater Yellowstone region, in the USA, where environmental protection has been explicitly recognized as an economic development strategy, suggest that environmental protection and economic development are complementary goals. " (171)

Watson, Alan E. 2000. Wilderness use in the year 2000: Societal changes that influence human relationships with wilderness. In: Cole, David N.; McCool, Stephen F.; Freimund, Wayne A.; O'Loughlin, Jennifer, comps. 2000. Wilderness science in a time of change conference – Volume 1: Changing perspectives and future directions; 1999 May 23-27; Missoula, MT. Proceedings RMRS-P-0-VOL-1. Ogden, UT: U.S. Department of Agriculture, Forest Service, RMRS.pg 53-60.

The purpose of this paper is to extend a synthesis of knowledge about wilderness visitors and their visits developed in 1985. At that time, visitor research was in decline, and there was very little ability to understand trends. Over the last 15 years, wilderness visitor research has been initiated at many places in the U.S. where no previous studies had been completed. There have also been several studies specifically aimed at providing comparisons over time. Although review of these studies has concluded that very little has changes about how we describe visitors, their visits or their preferences for management, limited data suggest that the way visitors relate to wilderness has changed and will continue to change well into the next century. (Abstract by Watson as printed in RMRS-P-15-VOL-4) (174)

INSECT

Christiansen, T. A. . 1996. Terrestrial litter invertebrate communities in Yellowstone National Park. Yellowstone Science. 4 2: 2-3.

Forest and sagebrush litter habitats were severely damaged during the 198 fires, and had not recovered 7 years later. The role of invertebrates in ecosystems is not yet well known. (176)

Ivie, M. A. . 1993. Biodiversity of insect fauna, pre and post burn: comparison between the 1970's and 1993-4. Investigator's Annual Report.

Abstract in Progress (177)

Lowrie, D. C. . 1989. A study of invertebrates of burned and unburned sagebrush grassland communities after the 1988 Yellowstone fires. Investigator's Annual Report.

A study of invertebrates of burned and unburned sagebrush grassland communities after the 1988 Yellowstone fires. (178)

Opler, P. A. 1995. Species richness and trends of western butterflies and moths. Pages 172-174 in E. T. LaRoe, G. S. Farris, C. E. Puckett, P. D. Doran, and M. J. Mac, editors. Our living resources: a report to the nation on the distribution, abundance, and health of U.S. plants, animals, and ecosystems. U.S. Department of the Interior, National Biological Service, Washington, D.C.

The authors have conducted a study of species richness in butterflies and three moth families covering 17 western states and 5 western subregions. Species richness of western moths and butterflies (Lepidoptera) is often closely related to plant diversity so these invertebrates are important indicators of environmental change. Opler identifies possible threats to western butterflies and moths including overgrazing, urbanization, and excessive controlled burns. He links management that produces high Lepidoptera species richness with management that also favors natural ecosystem processes. (179)

Swetnam, T.W., and A.M. Lynch. 1993. Multi-century, regional-scale patterns of western spruce budworm outbreaks. Ecological Monographs 63: 399-424.

Tree-ring chronologies from 24 mixed-conifer stands were used to reconstruct the long-term history of western spruce budworm (Choristoneura occidentalis) in northern New Mexico. Temporal and spatial patterns of budworm infestations (within-stand occurrences) and outbreaks (more-or-less synchronous infestations across many stands) were investigated to identify local-scale to regional-scale forest disturbance patterns. Nine regional-scale outbreaks were identified from 1690 to 1989. One ancient stand of Douglas-fir trees (Pseudotsuga menziessii) exceeding 700 yr in age revealed that budworms and overstory trees can coexist for extraordinary lengths of time. Using spectral analysis we found that the regional outbreak record contained important cyclical components with periods varying from ≈ 20 to 33 yr. The statistically significant ($P<.05$) but variable periodicity of regional outbreaks suggests the forest-budworm dynamic is pseudoperiodic (i.e., a stable limit cycle of damped oscillator perturbed by noise).
Duration of infestations within stands was ≈ 11 yr and has not obviously changed in the 20th century; however, infestations tended to be more synchronous among stands in this century than during earlier centuries. Regional budworm activity was low from the mid-1920s to late 1930s and mid-1960s to late 1970s, and the most recent outbreak, beginning in the late 1970s, was unusually severe. These results, and contrasting infestation patterns in mountain ranges with different land use histories, generally support a hypothesis that human-induced changes in Southwestern forest have led to more widespread and intense budworm outbreaks in the late 20th century.
Despite human-induced changes in the 20th century, climate variation also appears to have been important to budworm regimes in this century as well as in earlier times. Regional outbreaks in the 20th century tended to occur during years of increased spring precipitation, and decreased budworm activity coincided with decreased spring precipitation. No clear association with temperature was identified. Comparisons of regional outbreak history since AD 1600 with a

reconstruction of spring precipitation from limber pine (Pinus flexilis) ring width chronologies also shows that periods of increased and decreased budworm activity coincided with wetter and drier periods, respectively. This finding contrasts with results from shorter time-scale studies conducted in northwestern U.S. and Canada (western spruce budworm) and eastern Canada (spruce budworm C. fumiferana), where low precipitation and/or warmer temperatures were generally associated with outbreaks. Different patterns of budworm population response to changing moisture regimes might be due to differences in regional forest-budworm systems, or to differences in the spatial and temporal scales of observation. We conclude that changes in forest structure in the southwestern U.S. may have shifted the spatial and temporal pattern of budworm outbreaks. The dynamic behavior and statistically significant association between multicentury, regional budworm and climate time series also suggest that complex budworm dynamics are driven by a combination of internal and external factors. (Abstract by Swetnam and Lynch as printed in Ecological Monographs). (180)

LANDSCAPE

Good, John M. and Keneth L. Pierce. 1996. Interpreting the landscapes of Grand Teton and Yellowstone National Parks: Recent and Ongoing Geology. Grand Teton Natural History Association, Moose, WY.

Abstract in Progress (181)

Knight, D. H. 1994. Mountains and plains: the ecology of Wyoming landscapes. Yale University Press, New Haven, Conn. 338 pp.

Abstract in Progress (182)

Romme, W. H. , Knight, D. H. . 1982. Landscape diversity: the concept applied to Yellowstone Park. Bioscience. 32 8: 664-670.

Changes in landscape patterns may influence a variety of natural features including wildlife abundance, nutrient flow, and lake productivity. Data suggest that cyclic changes in landscape diversity occur on areas of 100 km² in Yellowstone National Park. When properly managed, large wilderness areas provide the best and probably the only locale for studying the kind of landscape changes that occurred for millenia in presettlement times. (183)

Shovic, H. F. , Maynard, C. L. , Nesser, J. A. . 1999. Greater Yellowstone area landscapes and soils: Project Description and Progress to date. Part One: the report. usfs, Natural Resources Conservation Service.

The Greater Yellowstone Area (GYA) Landscape Modeling Project is a cooperative effort between the Forest Service (Washington Office-ECOMAP, Region One, Two, Four, the Gallatin National Forest, and the Rocky Mountain Research Station), the Natural Resources Conservation Service, and the National Park Service (Yellowstone National Park.) Other supporting agencies include the Montana Natural Resources Information System-Montana State Library, and the Montana Natural Heritage Program. ...There is a critical need in the GYA to be able to study and manage changes and events that occur across administrative boundaries..There

is a need for consistently-compiled resource themes (based on ecological principles) for the entire area to provide a basis for cross-boundary analyses both for scientific and management purposes. .." (184)

Turner, M. G. , et al. 1993. A revised concept of landscape equilibrium: Disturbance and stability on scaled landscapes. Landscape Ecology. 8 3: 213-227. no luck yet

Temporal and spatial scales of disturbance and recovery are often confounded in discussions of landscape equilibrium. We developed a broad framework for the description of landscapes that separates the spatial and temporal scales of disturbance and recovery and predicts the resultant dynamics of a landscape. Two key parameters representing time and space are used to describe potential disturbance dynamics. The temporal parameter, T, is the ratio of the disturbance interval (i.e., time between successive disturbance events) to the time required for a disturbed site to recover to a mature stage. The spatial parameter, S, is the ratio of the size of the disturbance to the size of the landscape. The use of ratios in both parameters permits the comparison of landscapes across a range of spatial and temporal scales. A simple simulation model was developed to explore the implications of various combinations of S and T. For any single simulation, disturbances of a fixed size are imposed at random locations on a gridded landscape at specified intervals. Disturbed sites recover deterministically through succession. Where disturbance interval is long relative to recovery time and a small proportion of the landscape is affected, the system is stable and exhibits low variance over time (e.g., northeastern hardwood forests). These are traditional “equilibrium” systems. Where disturbance interval is comparable to recovery time and a large proportion of the landscape is affected, the system is stable but exhibits large variance (e.g., subalpine forests in Yellowstone Park). Where disturbance interval becomes much shorter than recovery time and a large proportion of the landscape is affected, the system may become unstable and shift into a different trajectory (e.g., arid ecosystems with altered fire regimes). This framework permits the prediction of disturbance conditions that lead to qualitatively different landscape dynamics and demonstrates the scale-dependant nature of concepts of landscape equilibrium. (Abstract by Turner et al as printed in Landscape Ecology). (185)

Anderson, Stanley H., Hubert, Wayne A., Patterson, Craig, Redder, Alan J., Duvall, David. 1987. Distribution of vertebrates of the Bighorn Canyon National Recreation Area. Great Basin Naturalist. 47 3: 512-521.

During a survey of the vertebrates in the Bighorn Canyon National Recreation Area, 46 mammal, 210 bird, 9 reptile, 5 amphibian, and 28 fish species were found. Habitat structure and moisture were two environmental variables associated with species numbers across this 1820-ha area. Eight distinct habitats were evaluated. In coniferous forests, 27% of the birds and 54% of the mammals were observed. Sagebrush/grasslands and upland shrublands were very arid and had relatively few vertebrates. Five introduced game birds occurred in sagebrush habitat. Riparian and wetland habitats had the largest number of unique vertebrates, 38 and 77 respectively. The establishment of Bighorn Lake in 1968 influenced the fisheries in streams and rivers as 10 introduced fish species are now there. (188)

MAMMAL

Beauvais, G.P. 1977. Mammals in fragmented forests in the Rocky Mountains: Community structure, habitat selection, and individual fitness. PhD. Diss. University of Wyoming, Laramie.

Chapter 1: We determined that species richness of mammal sin winter did not change along the major micro- and macrohabitatal gradients produced by clearcutting. However, habitat changes accompanying clearcutting allowed common habitat generalist to replace rarer, boreal adapted species. Distributions of small species were most affected by variations in microhabitat structure, whereas larger species responded to both micro- and macrohabitat variations. Persistent clearcutting of Rocky Mountain forests, especially on isolated mountain ranges, threatens to reduce mammal diversity at a regional scale. Chapter 2: Using data collected across a wide range of environmental variation, including a range of clearcut densities, we developed models predicting the probability of occurrence of each or 15 mammal species. For each species 1 model used microhabitat attributes and 4 models used macrohabitat attributes as predictors Macrohabitat models were developed at different spatial scales and compared on the basis of statistical significance and predictive success. Managers can use these models to estimate mammal distributions under current and predicted habitat conditions.
Chapter 3: We investigated the relationships between abundance, lipid content, litter size, and habitat structure for the southern red-backed vole (Clethrionomys gapperi). At small spatial scales, abundance and lipid content were weakly correlated; at larger scales, they were strongly correlated. Neither abundance nor lipid content were correlated with indices of litter size. Gradients of habitat structure did not predict abundance, lipid content, or litter size. Water content predicted lipid content in non-pregnant adults, and live mass predicted reproductive output in adult females. Chapter 4: Using artificially created mammal trails in snow, we found that trail visibility varies with track size, exposure to weather, and time since snowfall. We propose a new measure of trail detectability that controls for this variation and can produce more comparable indices of relative occurrence from snow-tracking data. Chapter 5: We tested the accuracy of estimates of trapping sampling effort from 2 different formulas. A simple correction for sprung traps improved estimated of sampling effort, and controlled for site-specific rates of trap-springing. Failure to use this correction can seriously bias comparisons of relative abundances estimated from trapping data. (Abstract by Beauvais as printed in Mammals in fragmented forests in the Rocky Mountains: Community structure, habitat selection, and individual fitness). (189)

Bogan, M.A., and P.M. Cryan, 2000, The Bats of Wyoming IN Choate, J. R., Reflections of a naturalist : papers honoring Professor Eugene D. Fleharty: Hays, KS, Fort Hays Studies, Special Issue 1, p. 71-94.

We examined 1280 bats of 12 species submitted to the Wyoming State Veterinary Laboratory (WSVL) for rabies testing between 1981 and 1992. The most abundant species in the sample was Myotis lucifugus, followed by Eptesicus fuscus, Lasionycterus noctivagans, M. ciliolabrum, and M. volans. Using the WSVL sample and additional museum specimens, we summarized available records and knowledge or 17 species of bats in Wyoming. Records of the WSVL show that, between 1981 and 1992, 113 bats actually tested positive for rabies. We examined 45 of those rabies-positive bats; E. fuscus had the highest incidence (60%) in the

sample, followed by L. noctivagans (11%) and L. cinereus (9%). (Abstract by Bogan and Cryan as printed in Reflections of a naturalist: papers honoring Professor Eugene D. Fleharty). (657)

Butts, T. W. . 1995. Bats of Yellowstone Park and vicinity. Investigator's Annual Report.
Abstract in Progress (190)

Clark, T.W. 1973b. Local distribution and interspecies interactions in microtines, Grand Teton National Park, Wyoming. Great Basin Naturalist 33:205-17.

Some ecological relationships and interspecies interactions (i.e. habitat, foods, and reproduction) between Microtus pennsylvanicus pullatus, M. montanus nanus, M. longicaudus mordex, and Clethrionomys gapperi galei were investigated in Grand Teton National Park, Wyoming. Trapping was conducted from June-July, 1968 and May-July, 1969 yielding 110 M.p.p., 171 M.m.n., 17 M.l.n. and 41 C.g.g. Six plant communities were defined structurally; all communities contained voles but varied considerably in number of species and individuals. Analyses of stomach contents showed similar diets. Embryo counts indicated that there was no significant interspecies differences in litter sizes. Females of all species were pregnant in about equal proportions. Almost all adult males showed descended testes and were reproductively active. Testicular and seminal vesicle weights and lengths fluctuated. M.p.p. mean body weights were largest: M44.7g (N=31). F38.1g (N=29); this was nearly twice the mean weights of C.g.g.: M20.4g (N=7). F23.3g (N=3). Weights for M.m.n. and M.l.m. fell between these extremes and were similar to each other. Trends in differential habitat use were clearly demonstrated and evidence suggests the four microtines are at least partially incompatible. (Abstract by Clark as printed in The Great Basin Naturalist). (191)

Clark, T.W. and M.R. Stromberg. 1987. Mammals in Wyoming. University of Kansas Museum of Natural History, Public Education Series no. 10. University Press of Kansas, Lawrence.
Abstract in Progress (526)

Craighead, Karen. 1991. Large mammals of Yellowstone and Grand Teton National Parks. Yellowstone Association for Natural Science, History, and Education, Yellowstone NP, WY.

Guidebook to Yellowstone and Grand Teton large mammals including reproductive biology, habitat, food habits, enemies, and tracks. (192)

Gompper, M., P. B. Stacey, and J. Berger. 1997. Conservation implications of the natural loss of Lineages in Wild Birds and Mammals. Conservation Biology 11:857-867.

Because populations in zoological parks and nature reserves often are derived from only a few individuals, conservationists have attempted to minimize founder effects by equalizing family group sizes and increasing the reproductive contributions of all individuals. Although such programs reduce potential losses of genetic diversity, information is rarely available about the actual persistence of family groups or genetic lineages in populations. In the abscesses of such data, it can be difficult to weigh the importance of human intervention in the conservation of small populations. Separate long-term studies of two mammals, North American bison (Bison bison) and the white-nosed coati (Nasua narica), and a bird, the Acorn Woodpecker (Melanerpes formicivorus), demonstrate differential extinction of genetic lineages. Irrespective of the

mechanisms affecting population structure, which may range from stochastic environmental events to such behavioral phenomena as poor intrasexual competitive abilities, our results show that lineages can be lost at rapid rates from natural populations. A survey of comparable studies from the literature indicates that the loss of matrilines over the course of the study varies from 3% to 87% in wild mammals and from 30% to 80% in birds, with several small mammals losing approximately 20% of matrilines per year of study. These lineage extinctions were not an artifact of the length of the study or the generation time of the species. Such rapid losses of lineages in less than 20-year periods in natural populations suggest that efforts to maintain maximal genetic diversity within populations may not always reflect processes that occur in the wild. Conservation biologists need to give further thought to the extent to which parity among genetic lines should be a primary goal of management of captive and small wild populations. (Abstract by Gompper et al as printed in Conservation Biology). (193)

Hadly, E.A. and Brian A. Maurer. 2001. Spatial and temporal patterns of species diversity in montane mammal communities of western North America. Evolutionary Ecology Research 3: 477-486.

We present the results of the first analysis of distributional patterns of the same taxa across thousands of kilometres and thousands of years, which demonstrate that the exponents for the power relationships in space and time are similar. In both space and time, the distribution of mammalian taxa of the Great Basin and Rocky Mountains follows a 'nested subset' pattern. We conclude that species identities and their relative abundances are non-random properties of communities that persist over long periods of ecological time and across geographic space. This is consistent with species abundance contributing heavily to evolutionary patterns, and allows predictions of how species within communities will respond to future global change. (Abstract by Hadley and Maurer as printed in Evolutionary Ecology Research). (194)

Jannett, FJ. 1982. Nesting patterns of adult voles, Microtus Montanus, in field populations. Journal of Mammalogy. 63 3: 495-498.

Jannett describes data collected from a field study of female/male relationships among montane voles (Microtus montanus) and a short review of a field study on the meadow vole (Microtus pennsylvanicus). Male and female relations are perhaps the least known aspects of small mammal behavior. He recites field methods involved in the project focusing on male territoriality and female birthing. It was found that cohabitation of adult female and male montane voles is rare in summer and fall with some explainable exceptions in spring. (532)

Kotliar, N. B., B. W. Baker, A. D. Whicker, and G. Plumb, 1999, A Critical Review of Assumptions About the Prairie Dog as a Keystone Species: Environmental Management, v. 24, p. 177-192.

Prairie dogs (Cynomysspp.) have been labeled as keystone species because of their influence on biological diversity and ecosystem function. However, the validity of several assumptions used to support keystone status is questionable. We review the strength of the evidence and the magnitude of the prairie dog's effects on ecosystem structure and function. We use this review to reevaluate the keystone role for prairie dogs. Our goal is to encourage sound management of the prairie dog ecosystem by improving the ecological foundation of their keystone status. Our review confirms that prairie dogs affect a number of ecosystem- level

functions but that their influence on prairie vertebrates may be less than previously suggested. Species richness and abundance patterns were variable among plants, mammals, and birds and were not consistently higher on prairie dog colonies compared to uncolonized areas. In addition, only nine of the 208 species listed in the literature as observed on or near prairie dogs colonies had quantitative evidence of dependence on prairie dogs. Abundance data indicated opportunistic use of colonies for an additional 20 species. A total of 117 species may have some relationship with prairie dogs, but we lacked sufficient data to evaluate the strength of this relationship. The remaining 62 species may be accidental or alien to the system. Despite our conclusion that some prairie dog functions may be smaller than previously assumed, collectively these functions are quite large compared to other herbivores in the system. We suggest that prairie dogs also provide some unique functions not duplicated by any other species and that continued decline of prairie dogs may lead to a substantial erosion of biological diversity and landscape heterogeneity across prairie and shrub-steppe landscapes. Thus, we concur that keystone status for prairie dogs is appropriate and may aid conservation efforts that help protect species dependent on prairie dogs and support other important ecosystem functions. (Abstract by Kotlier et al. as printed in Environmental Management). (654)

Maehr, D. editor. 2002. Large Mammal Restoration in North America: ecological and sociological considerations in the 21st century. Island Press, Washington, D.C.

Abstract in Progress (187)

Newmark, W. D. . 1986. Species-area relationship and its determinants for mammals in western North American national parks. Biological Journal of the Linnean Society of London. 28: 83-98.

Parks were evaluated for species richness, elevation, latitude, vegetative cover types, and species-area for area analysis. Study relevant to reserve design and preservation of biological diversity. Includes general data for Olympic National Park, WA. (195)

Patterson, Craig T. 1985. Bird and mammal inventory for the Bighorn Canyon National Recreational Area. Wyoming Cooperative Fishery and Wildlife Research Unit, Laramie, WY.

Abstract in Progress (196)

Pattie, D.L. and N.A.M. Verbeek. 1967. Alpine mammals of the Beartooth Mountains. Northwest Science 41:110-17.

A great expanse of alpine environment is included in six closely associated plateaus of the Beartooth Mountains in the Custer National Forest, Carbon County, Montana, and the Shoshone National Forest, Park County, Wyoming (Figure 1). McChesney (1879) first described a few of the mammals inhabiting the Beartooth Mountains, Bailey (1930) a few of the alpine forms in Yellowstone National Park to the west, and Hoffmann and Taber (1960) the dwarf shrew (Sorex nanus) taken in the Beartooth Mountains. Long (1965) indicated no one has described in detail the mammalian fauna of the extensive alpine areas in this part of Montana and Wyoming. This paper is a contribution on the mammals of this major biotic community, the alpine zone, defined as that area which is altitudinally above regions of normal tree growth and includes areas of krummholz-"the crooked wood"-making up part of the forest-tundra ecotone. (Abstract by Pattie and Verbeek as printed in Northwest Science). (653)

Pinter, A.J. 1988. Multiannual fluctuations in precipitation and population dynamics of the montane vole Microtus montanus. Canadian Journal of Zoology 66(4):2128-32.

The montane vole, Microtus montanus, exhibits multiannual fluctuations in population density in northwestern Wyoming. Multiannual fluctuations in precipitation during May were also observed in the area. For data from the past 19 years, there is a significant negative correlation between cycle phases of May precipitation and of population density. Peak precipitation in May (1970, 1974, 1977, 1980, 1984) was correlated in the same year with the decline phase in the population cycle. A trough in the May precipitation cycle (1969, 1973, `976, 1979, 1983, 1985) was correlated in the same year with a population peak. It is hypothesized that spring precipitation may contribute to the population dynamics of Microtus montanus in north-western Wyoming by influencing the survival and reproductive success of these rodents at a critical time, the onset of the breeding season. (Abstract by Pinter as printed in Canadian Journal of Zoology). (197)

Singer, F. J. , Schreier, W. , Oppenheim, J. , Garton, E. O. . 1989. Drought, fires, and large mammals. Bioscience. 39 10: 716-722.

Yellowstone National Park is renowned for its fauna of diverse and numerous large mammals. This article focuses on elk, because they are overwhelmingly the dominant park ungulate both in number and total mass. In early 1988 on the northern winter range, there were five times as many elk as all other types of ungulates combined. At the time of the 1988 drought and fires in Yellowstone, studies of the northern range were reevaluating the success of the natural regulation experiment. Extensive burning in 1988 occurred on five out of the seven elk summer ranges. All four of the elk winter ranges had from 2-50% of their areas burned. No previously published study has documented burning effects on such a large scale across the entire year-round ranges of several large elk herds. (198)

Smith, D.W. 1998. Beaver Survey in Yellowstone National Park. Mammoth, WY. YCR-NR-93-3.

The second parkwide aerial count of active beaver (Castor candensis) colonies was conducted in Yellowstone National Park in late October 1998. Flying time for the survey was 18.7 hours, slightly more than the 14.9 hours in 1996. Total number of colonies counted with a food cache was 51. Eighty percent of the beaver colonies were found at three locations: 1) the Madison-Grayling Creek-lower Gallatin River drainages; 2) the upper Yellowstone River from the Southeast Arm or Yellowstone Lake to Thorofare; and 3) the Bechler area. Average density of colonies per stream kilometer in these three areas was 0.23. The densest areas of beaver occupation in the park were found in the Yellowstone River delta and along a short section of the Madison River. Other locations where beaver colonies were found were Harlequin Lake, Shoshone Lake, Slide Lake, the Gallatin River, the Snake River, Outlet Creek, and Obsidian Creek. Beaver sign but no food cache was found at Heart Lake, the Lamar Valley, and Thorofare. Like the first survey in 1996, most observed beaver colonies were associated with willows (Salix spp.). (Abstract by Smith as printed in YCR-NR-99-3). (199)

Spildie, D.R. 1994. The density and distribution of small mammals in Grand Teton National Park, Wyoming. M.S. Thesis. University of Wyoming, Laramie, WY. 115 p.

I live-trapped small mammals in Grand Teton National Park during the summers of 1990 and 1991. In 1990, I sampled five burned and adjacent unburned sites of different ages to determine community response to post-fire succession. Of eight species captured, the deer mouse (Peromyscus maniculatus) and the southern red-backed vole (Clethrionomys gapperi) were most common: the deer mouse in open habitats and early successional seres; the red-backed vole in mature forests. Species diversity was higher in unburned forests, but density and diversity were related to the successional status of the sites, except for higher densities of deer mice in recent burns. In 1991, trapping was conducted in seven habitats along an elevational gradient and in the same sites at Huckleberry Mountain that were trapped in 1990. Nine small mammal species were captured in the elevational sites. Deer mice were the most numerous and were caught in all sites. The red-backed vole was also common but was only found in mature coniferous forest. Discriminant analysis of microhabitat variables allowed prediction of trap success at a significant level in the elevational sites. (Abstract by D.R Spilde, as printed in M.S. Thesis.) (200)

Streubel, D. P. . 1989. Small mammals of the Yellowstone ecosystem. Roberts Rinehart, Boulder CO.

Abstract in Progress (202)

Wood, M. A. . 1981. Small mammal communities after two recent fires in Yellowstone National Park. M.S. Thesis, Montana State University, Bozeman, MT.

The small mammals, their food habits, and their food resources were studied during the summers of 1978 and 1979 on two burns and two adjacent spruce-fir, lodgepole pine forest sites in Yellowstone National Park. The Divide site burned in 1976, and the Trail Creek site burned in 1974. A study plot was established in each burn and control site, and the small mammals were sampled by snap-trapping and pitfall traps twice each summer. Stomach contents were analyzed. Quantitative data were obtained on plant coverage, concealment cover (measured by a cover board), arthropod diversity and soil seed and fungal sclerotia numbers. (534)

Worthington, David J. 1991. Abundance and Distribution of Bats in the Pryor Mountains of South Central Montana and North Eastern Wyoming. University of Montana, Missoula, MT.

This report documents the results of a study on bat occurrence in the Pryor Mountains of south central Montana that was initiated in 1989. (203)

Youmans, C. C. . 1979. Characteristics of pocket gopher populations in relation to selected environmental factors in Pelican Valley, Yellowstone National Park. M.S. Thesis, Montana State University, Bozeman, MT.

Objectives of this study were to select specific representative sites in Pelican Valley on which pocket gopher numbers could be quantified, monitored, and compared with data gathered concurrently on vegetative composition, standing crop, soil moisture, soil texture, and snow melt phenology. Changes in pocket gopher numbers were analyzed by gathering data on pocket gopher natality, sex ratios, age structure, annual population turnover, recruitment, period of peak

parturition, and home range size. Frequency of infection with the parasitic nematode Capillaria hepatica, average weights, and composition of a pocket gopher cache were also determined. Field work was conducted from June to September in 1977 and from June to October in 1978. (535)

RIPARIAN

Akashi,Y. 1988. Riparian vegetation dynamics along the Bighorn River, Wyoming. M.S. Thesis, Univ. WY, Laramie. 245pp.

Changes in the riparian vegetation mosaic during the last 49 years were studied along the Big Horn River near Lovell, WY. The results revealed a decline in Populus deltoides woodland area and an increase in shrubland area, particularly shrublands dominated by Tamarix chinensis and Rhus trilobata. Major causes for the changes are discussed and future changes are predicted. (205)

Chadde, S.W., P.L. Hansen, and R.D. Pfister. 1988. Wetland plant communities of the northern range, Yellowstone Naional Park. School of Forestry, University of Montana, Missoula, Mont. Contract report for National Park Service on file at Mammoth Hot Springs.

Abstract in Progress (206)

Duffy, W. G. . 1999. Wetlands of Grand Teton and Yellowstone National Parks: Aquatic Invertebrate Diversity and Community Structure. Pages 733-756 in Batzer, D. P. , Rader, R. B. , Wissinger, S. A. . Invertebrates of Freshwater Wetlands of North America: Ecology and Management. Wiley, New York.

Aquatic invertebrates were sampled monthly from May through September in six wetlands in Yellowstone and Grand Teton National Parks during 1995. Wetlands sampled exhibited semipermanent, seasonal, and temporary hydrologic regimes. Physical and chemical characteristics of wetland water were similar, except for specific conductance, which was either low (<60 mS cm -1), intermediate (270-550 mS cm -1), or high (>900 mS cm -1). A total of 187 taxa of aquatic invertebrates were identified from all samples. Almost 70 percent of the taxa collected had not been reported previously in either park. Taxa richness was greatest in semipermanent wetlands and least in temporary wetlands. Among all wetlands, monthly mean abundance ranged from 18,041 m-2-335,975 m-2. Food webs of semipermanent wetlands were most complex, while those in temporary wetlands were most simple. (Abstract by Duffy as printed in Aquatic Invertebrate Diversity and Community Structure). (207)

Elliot, C.R. and M.M. Hektner. 2000. Wetland resources of Yellowstone National Park. Yellowstone National Park, WY. 32pp. (Online). Available: http://www.nps.gov/yell/publications/pdfs/wetlands/index.htm.

Abstract in Progress (208)

Girard, M., D.L. Wheeler, and S.B. Mills. 1997. Classification of riparian communities on the Bighorn National Forest, USDA Forest Service R2-RR-97-02.

Abstract in Progress (210)

Hupp, C. R. and W. R. Osterkamp. 1996. Riparian vegetation and fluvial geomorphic processes. Geomorphology 14: 277-295.

Riparian vegetation and fluvial-geomorphic processes and landforms are intimately connected parts of the bottomland landscape. Relations among vegetation, processes, and landforms are described here for representative streams of four areas of the United States: high-gradient streams of the humid east, coastal-plain streams, Great Plains streams, and stream channels of the southwestern United States. Vegetation patterns suggest that species distributions in the humid easy are largely controlled by variation in fluvial geomorphic processes (cycles of degradation and aggradation) in response to increases in channel gradient associated with channelization. Similarly, riparian vegetation of Great Plains streams may be controlled by fluxes in sediment deposition and erosion along braided streams. Patterns of riparian vegetation in semi-arid regions may be most closely related to patterns of water availability, unlike most other streams in more humid environments. Channel-equilibrium conditions control stability of the coincident fluvial landform and attendant vegetation pattern throughout the continent. In most situations, riparian-vegetation patterns are indicative of specific landforms and, thus, of ambient hydrogeomorphic conditions. (Abstract by Hupp and Osterkamp as printed in Geomorphology). (329)

Kay, C.E. 1994. The impact of native ungulates and beaver on riparian communities in the Intermountain West. Natural Resources and Environmental Issues 1:23-44.

This paper reviews the impact native ungulates, primarily elk and moose, and beaver can gave on riparian communities in the Western United States. In Yellowstone National Park and in other areas where ungulates are not managed, repeated browsing has reduced tall willow, aspen, and cottonwood communities by approximately 95 percent since the late 1800s. Native ungulates can also severely reduce or eliminate palatable grasses and forbs from herbaceous riparian communities. By eliminating woody vegetation and security cover and by altering plant-species composition, native ungulates can alter bird, mammal, and aquatic communities. They can even negatively affect endangered species like grizzly bears for which riparian areas provide critical habitat. In many respects, excessive use by native ungulates is similar to overgrazing by domestic livestock. Beaver is a keystone species that alters the hydrology, energy flow, and nutrient cycling of aquatic systems. Unlike ungulates, which tend to degrade riparian habitats, beaver actually, create and maintain riparian areas. Beaver dams not only impound water but they also trap sediments that raise the water table and allow the extension of riparian communities into former upland areas. By trapping silt over thousands of years, beaver have actually created many of the West's fertile valleys. Prior to the arrival of Europeans, Western streams supported large populations of beaver. During one five-day period in 1825, Peter Skene Ogden's fur brigade trapped 511 beaver. Today, state and federal land-management agencies are using beaver to restore damages riparian areas. Beaver, however, can become a nuisance when they dam irrigation facilities, plug highway culverts, or fell streamside trees valued by landowners. (Abstract by Kay as printed in Natural Resources and Environmental Issues). (211)

Keigley, R.B. 1998. Architecture of cottonwood as an index of browsing history in Yellowstone. Interm. J. Sci. 4(3/4):57-67.

I determined the history of browsing elk (Cervus elaphus) on narrowleaf cottonwood (Populus angustifolia) at a site in northern Yellowstone National Park (YNP). I aged cottonwoods in three stands by dendrochronology and classified them into four architectural categories that I postulated were produced of four browsing regimes: 1) uninterrupted-growth type (light-to-moderate browsing), 2) arrested-type (intense browsing), 3) retrogressed-type (a change from light-to-moderate browsing to intense browsing), and 4) release-type (a change from intense browsing to light-to-moderate browsing). Cottonwood trees established prior to 1947 were of uninterrupted-growth type architecture. Trees established between 1947 and 1968 were of uninterrupted- and release-type architectures. With the exception of individuals short enough to be protected from winter browsing by snowpack, all individuals established after 1968 were of arrested- and retrogressed-type architectures. Cottonwoods in the study area experienced the following browsing history: (1) light-to-moderate until 1951, (2) intense from 1952 to 1962, (3) light-to-moderate from 1963 to 1974, and (4) intense since 1975. Architecture-based methods can be used to determine the rank order sequence in which elk currently prefer different species of browse. Once determined, that rank order sequence can be used to test competing hypotheses about the declines in woody plants in YNP. (Abstract by Keigley as printed in the Intermountain Journal of Sciences). (212)

Knopf, F. L., and T. E. Olson. 1984. Naturalization of Russian-olive: implications to Rocky Mountain wildlife. Wildlife Society Bulletin. 12: 289-298

aturalization and spreading of exotic woody vegetation in riparian zones have received much attention in recent years. This attention has been directed primarily at salt-cedar tamarisk (Tamarix pentandra) in south-western states (e.g. Robinson 1965, Horton 1977). Tamarisk along the lower Colorado River does not compare favorably with native woody vegetation as avian habitats (Anderson et al. 1977) and, without control, will completely displace native riparian vegetation with time (Horton 1977). Russian-olive (Elaeagnus angustifolia) is a native of Europe and western Asia introduces into North American prior to 1900. The spreading, sometimes shrub-like, tree tolerates a wide range of soil and moisture conditions, adapting to local conditions throughout the western United Sates from Minnesota to Kansas to the Pacific Ocean (Borell 1976). The history of Russian-olive in western states was summarized by Christensen (1963). Briefly, the species was being planted extensively in residential areas by 1900. Russian-olives were first reported escaping cultivation in 1924 in Utah, 1925 in Nevada, 1942 in Arizona and California, 1952 in Idaho, 1954 in Colorado, and 1960 in New Mexico and Texas. Russian-olive has been promoted, especially by soil conservationists, as an excellent planting for windbreaks, erosion control, and wildlife enhancement (Van Dersal 1939, Wilson 1944, Billings 1945, Graham 1949, Borell 1976). Over 50 species of birds and mammals use Russian-olive as a source of food or cover (Borell 1976). Recently, we noticed that extensive, virtually monotypic stands of Russian-olive have invaded riparian zones of some western (Green, Missouri, Snake) river systems. These riparian zones provide critical, limited habitats for many vertebrate species in the West (Johnson and Jones 1977). This paper (1) alerts natural resource conservation personnel to naturalization of Russian-olive in the West, (2) reports on the avian and mammalian associations of monotypic stands of Russian-olive in 3 western states, (3) discussed similarities

of those associations to vertebrate communities occurring in nearby native riparian and upslope vegetation types using the analytical approach discussed by Samson and Knopf (1982), and (4) speculates on implications of the continued naturalization of Russian-olive to Rocky Mountain avian and mammalian communities. (Abstract by Knopf and Olson as printed in Wildlife Society Bulletin). (330)

Naiman, R.J. and H. Decamps. 1997. The ecology of interfaces: riparian zones. Annu. Rev. Ecol. Syst. 28(1):621-658.

Riparian zones possess an unusually diverse array of species and environmental processes. The ecological diversity is related to variable flood regimes, geographically unique channel processes, altitudinal climate shifts, and upland influences on the fluvial corridor. The resulting dynamic environment supports a variety of life-history strategies, biogeochemical cycles and rates, and organisms adapted to disturbance regimes over broad spatial and temporal scales. Innovations in riparian zone management have been effective in ameliorating many ecological issues related to land use and environmental quality. Riparian zones play essential roles in water and landscape planning, in restoration of aquatic systems, and in catalyzing institutional and societal cooperation for these efforts. (Abstract by Naiman and Decamps as printed in the Annual Review of Ecological Systems). (213)

Nilsson, C., R. Jansson, and U. Zinko. 1997. Long-term responses of river-margin vegetation to water level regulation. Science. 276. pp. 798-800.

The long-term effect of water-level regulation on riparian plant communities was assessed for storage reservoirs and run-of-river impoundments. Soon after the onset of regulations, there were few species and sparse vegetation cover, regardless of whether the new water level intersected former upland or riparian vegetation. IN the longer-term, an impoverished vegetation was maintained by storage reservoirs, whereas in run-of-river impoundments, some community characteristic deteriorated and others recovered compared to adjacent free-flowing rivers. (Abstract by Nilsson as printed in Science). (335)

Patten, D.T. 1998. Riparian ecosystems of semi-arid North America: diversity and human impacts. Wetlands 18(4):498-512.

Riparian ecosystems in the semi-arid West of North America are diverse but have many similarities. The mountainous landscape with wide range of latitude, longitude, and elevation offers diverse opportunities for streamside vegetation. All riparian ecosystems in the region are dependent on supplemental water, usually from the shallow, valley alluvial aquifer. Western riparian ecosystems provide several ecological services. They stabilize streambanks, trap sediment, improve water quality, and help control or modulate hydrologic processes. They function as habitat for many western animal species, serving as a small mesic island or strip within an arid landscape. They also serve as recreational sites for humans. Riparian systems are controlled by interacting hydrologic and geomorphic processes. Floods may alter river channel characteristics and the extent of riparian vegetation while enhancing recruitment of riparian species and recharging the alluvial water table. Geomorphic features, such as canyons and valleys, control the size of the riparian zone, as well as depth of the water table. Driving variables may differ from the north to south, especially hydrology. For example, northern

riparian zones are influenced by ice scour, while southern zones often have flash floods. Riparian systems occur along spatial and temporal gradients. Along elevational gradients, riparian vegetation may change from simple deciduous forests to mixed deciduous to coniferous and possibly alpine wetlands. Differences among channel, terrace, and upland plant communities decrease with increasing elevation as moisture stress decreases. Temporal gradients occur within a location in the riparian zone as early pioneer communities such as cottonwood/will give way to late successional communities such as mesquite or sagebrush, often a consequence of sediment accumulation. Many similarities among western riparian ecosystems exist because several dominant genera (e.g., Populus) are common throughout the West, and many geomorphic and hydrologic processes that influence riparian establishment are similar. Western riparian ecosystems have been greatly altered by human activity. Major factors include natural resource use, urbanization, alteration of stream flows through dam construction and ground-water withdrawal, modification of biotic conditions through grazing, agriculture, and introduction of non-native species, and alteration within watersheds. Better understanding of the ecology of western riparian ecosystems will increase potential for restoration and protection of remaining areas. (Abstract by Patten as printed in Wetlands).#237 We contrast the geochemistry of the Madison drainage, which has high concentrations of geothermal features, with the Lamar drainage of Yellowstone National Park, USA, and trace the consequences of geochemical differences through abiotic and biotic linkages in the ecosystem. Waters in the geothermal-dominated drainage contained anomalously high levels of fluoride (F) and silica (SiO2). Soils, stream sediments, and surface waters that interact or mix with geothermal waters, in turn, had elevated F and SiO2 concentrations compared to similar samples from the Lamar drainage. The geochemical differences were reflected in the chemistry of forage plants, with some plants from geothermally influenced areas containing four- to eightfold higher concentrations of F and SiO2 than similar plants in the Lamar drainage. Geothermal heat reduced snowpack, and we found that elk (Cervus elaphus) concentrated in these refugia as snowpack increased each winter. The consequent high dietary intake of F in animals associated with the geothermal areas was confirmed by the finding that bone samples from elk living in the Madison drainage contained sixfold higher concentrations of F than samples collected from animals wintering in the Lamar drainage. High F exposure resulted in compromised dentition due to fluoride toxicosis, which was undoubtedly exacerbated by the abrasive action of silica. The consequent accelerated and aberrant tooth wear resulted in early onset of senescence, reduced life span, and an abbreviated age structure. We speculate that these altered demographics, combined with spatial heterogeneity of snowpack, will result in increased vulnerability of this large herbivore population to wolf predation and less resiliency to compensate demographically for predation. (Abstract by Garrott et al as printed in Ecosystems). (214)

Rood, S. B. and J. M. Mahoney. 1993. River Damming and riparian cottonwoods: management opportunities and problems. In Riparian Management: common threads and shared interests. USDA Forest Service General Technical Report RM-226. pp 134-142.

Abstract in Progress (337)

Shafroth, P. B., J. M. Friedman, and L. S. Ischinger. 1995. Effects of salinity on establishment of Populus fremontii (cottonwood) and Tamarix ramosissima (saltcedar). Great Basin Naturalist. 55 (1): 58-65.

The exotic shrub Tamarix ramosissima (saltcedar) has replaced the native Populus fremontii (cottonwood) along many streams in southwestern United States. We used a controlled outdoor experiment to examine the influence of river salinity on germination and first-year survival of P. fremontii var. wislozenii (Rio Grande cottonwood) and T. ramosissima on freshly deposited alluvial bars. We grew both species from seed in planters of sand subjected to a declining water table and solutions containing 0, 1, 3, and 5 times the concentrations of major ions in the Rio Grande at San Marcial, NM (1.2, 10.0, 25.7, and 37.4 meq 1-1;0.11, 0.97, 2.37, and 3.45 dS m-1). Germination of P. fremontii declined by 35% with increasing salinity (P=.008). Germination of T. ramosissima was not affected. There were no significant effects of salinity on mortality or above- and belowground growth of either species. In laboratory tests the same salinities had no effect on P. fremontii germination. P. fremontii germination is more sensitive to salinity outdoors than in covered petri dishes, probably because water scarcity resulting from evaporation intensifies the low soil water potentials associated with high salinity. River salinity appears to plat only a minor role in determining relative numbers of P. fremontii and T. ramosissima seedlings on freshly deposited sandbars. However, over many years slat becomes concentrated on floodplains as a result of evaporation and salt extrusion from saltcedar leaves. T. ramosissima is known to be more tolerant of the resulting extreme salinities than P. fremontii. Therefore, increases in river salinities could indirectly contribute to the decline of P. fremontii forest by exacerbating salt accumulation of floodplains. (Abstract by Shafroth et al as printed in Great Basin Naturalist). (339)

Stettler, R.F., H.D. Bradshaw,Jr., P.E. Heilman, and T.M. Hinclley, eds. 1996. Biology of Populus and its implications for Management and Conservation. Ottawa: NRC Research Press, National Research Council of Canada.

Abstract in Progress (215)

Youngblood, Andrew P., Padgett, Wayne G., Winward, Alma H. 1985. Riparian community type classification of eastern Idaho-western Wyoming. Intermountain Forest and Range Experiment Station, R4-Ecol-85-01, Ogden, UT.

A community type classification is presented for the riparian ecosystems of eastern Idaho and western Wyoming. This hierarchical taxonomic system of vegetation classification is based on existing riparian vegetation, and uses data from 469 sample stands. (216)

SOIL

Marston. 1990. Runoff and Soil Loss Following the 1998 Yellowstone Fires. Great Plains-Rocky Mountain Geographical Journal. Vol. 18. No. 1. The Future University of Nebraska at Kearney. Kearney State College. 8pp.

Fires burned 570,000 hectares (1.41 million acres) in the Greater Yellowstone Area during 1988 with accelerated runoff and soil loss as an expected result. A rainfall simulator was used in the summer of 1989 to measure runoff and soil loss on plots representing a range in

geologic substrate, logging history, fire intensity, and geomorphic-pedologic conditions. Water repellent soils were common, producing high rates of runoff and soil loss for the experimental rainfall event. Rates of soil loss were highest on sites where litter cover was minimal, percent silt content in soils was high, and logging had occurred. Rated of runoff and soil loss did not exhibit statistically significant differences between glacial till and volcanic terrain, but the logging-fire history was associated with statistically significant differences in soil loss. Soil loss was highest on sites which had been logged before the 1988 fires and then burned, and this was attributed to the higher fuel load on the forest floor. (Abstract by Obia. As printed in Great-Plains Rocky Mountain Geographical Journal.) (219)

Miller, S. L. , Stanton, N. L. , Williams, S. E. . 1992. Effects of fire on ectomycorrhizal fungi, spore dispersal and dependent flora establishment in soils.

The objectives of this study were to determine spore dispersal agents and fungi present or introduced at the burned sites, determine the effect that mycorrhizal fungi have on conifer seedling recruitment after fire, and to determine vascular plant species dependent upon mycorrhizae for establishment. Hypothesis tested included: 1) Mycorrhizal fungi are primarily responsible for affecting conifer recruitment and secondary succession in the burns; 2) The mycorrhizal status of conifer seedlings affects their survivability, growth and development in the burns; 3) Mycorrhizal fungal spores and other propagules dispersed by small mammals into the burns affect the mycorrhizal status of conifer seedlings. The study area is located along the John D. Rockefeller Memorial Highway between Yellowstone and Grand Teton National Parks. (218)

Rodman, A. W. , Shovic, H. F. , Thoma, D. P. . 1996. Soils of Yellowstone National Park. Yellowstone Center for Resources, Yellowstone National Park.

Abstract in Progress (220)

Shovic, H. F. . 1996. Landforms and associated surficial materials of Yellowstone National Park. Yellowstone Center for Resources, Yellowstone National Park

This inventory describing "meso" level landforms(2.5 to 250 acres) and associated features for Yellowstone National Park, has possible application in many areas of natural resource management and analysis, from wetland mapping to fire-spread modeling, forest regeneration to wildlife habitat. (221)

West, N.E. 1990. Structure and function of soil microphytic crusts in wildland ecosystems of arid and semi-arid regions. Adv. Ecol. Res. 20:179-223.

Abstract in Progress (223)

Young, Jack F. 1982. Soil survey of Teton County, Wyoming, Grand Teton National Park Area. U.S. Department of Interior//Soil Conservation Service//National Park Service//Wyoming Agriculture Experiment Station, Washington, DC?.

This soil survey contains information that can be used in land-planning programs in Teton county, Grand Teton National Park Area, Wyoming. It contains predictions of soil behavior for selected land uses. The survey also highlights limitations and hazards inherent in the

soil, improvements needed to overcome the limitations, and the impact of selected land uses on the environment. (224)

THREATENED & ENDANGERED

Clark, T. W. , et al. 1989. Rare, sensitive, and threatened species of the greater Yellowstone ecosystem. Northern Rockies Conservation Cooperative, Jackson, Wyoming.

brief description, history and recommendations for the species listed (225)

Consolo Murphy, S. L. . 1999. Threatened and Endangered Species; brief summary of status in Yellowstone (rev.). ycr?, ynp?.

Brief status reports including population estimates. (226)

Dennis, B. , Munholland, P. L ., Scott, J. M. . 1991. Estimation of growth and extinction parameters for endangered species. Ecological Monographs. 61 2: 115-143.

"Survival or extinction of an endangered species is inherently stochastic. We develop statistical methods for estimating quantities related to growth rates and extinction probabilities from time series data on the abundance of a single population. The statistical methods are based on a stochastic model of exponential growth arising from the biological theory of age- or stage-structured populations. The model incorporates the so-called environmental type of stochastic fluctuations and yields a lognormal probability distribution of population abundance. We provide example analyses of data on the Whooping Crane (Grus americana), grizzly bear (Ursus arctos horribilis) in Yellowstone, Kirtland's Warbler (Dendroica kirtlandii), California Condor (Gymnogyps californianus), Puerto Rican Parrot (Amazona vittata), Palila (Loxioides balleui), and Laysan Finch (Telespyza cantans). The model results indicate a favorable outlook for the Whooping Crane, but long-term unfavorable prospects for the Yellowstone grizzly bear population and for Kirtland's Warbler." (227)

Heidel, Bonnie, Fertig, Walter. Rare Plants of Bighorn Canyon National Recreation Area. Montana Natural Heritage Program, Helena, Montana.

Abstract in Progress (228)

Marriof, Hollis. 1993. Rare plant of Grand Teton National Park, final report. Wyoming Natural Diversity Database, Wyoming.

In 1989, Grand Teton National Park began a project with the Wyoming Natural Diversity Database to identify plant species of concern and their locations within the Park. The project objectives are to: produce a list of plant species of concern for GRTE (i.e. species requiring attention and possibly special management for continued viability), begin collecting data on location, habitat, population size, trends, threats and management needs within GRTE for species identified. (229)

Reading, Richard and Brian Miller, eds. 2000. Endangered animals: a reference guide to conflicting issues. Greenwood Press, Westport, CT.

Abstract in Progress (230)

THERMAL

Ball, J. W. , Nordstrom, D. K. , Jenne, E. A. , Vivit, D. V. . 1998. Chemical analyses of hot springs, pools, geysers and surface waters from Yellowstone National Park, Wyoming and vicinity, 1974-75. U. S. Geological Survey, Boulder CO.#98574

Gives analytical determinations for samples collected 1974-75. Water temperature, pH, Eh and dissolved O2 were determined on-site. Flame atomic absorption spectrometry was used to determine concentrations of Li, Na, K, Ca and Mg. Ultraviolet/visible spectrophotometry was used to determine concentrations of Fe(II), Fe(III), As(III) and As(V). Direct current plasma-optical-emission spectrometry was used to determine the concentrations of B, Ba, Cd, Cu, Mn, Ni, Pb, Rb, Sr and Zn. (231)

Brock, T.D. 1994. Life at high temperatures. Yellowstone Association for Natural Science, History, and Education, Inc., Yellowstone National Park, Wyo. 31 pp.

Deals with the living organisms in Yellowstone National Park, and their great economic impact on society. There are microorganisms that live in the boiling waters and run-off channels of the geysers and hot springs. Although their color is visible to the naked eye, an individual microbial cell is so small as to be completely invisible. The microorganisms of the hot springs are mostly bacteria, but at the lower temperatures algae and protozoa are also present. (232)

Chester, C. C. . 1995. Biodiversity prospecting in Yellowstone National Park: management of Yellowstone microorganisms and the experience of the National Biodiversity Institute (INBio) of Costa Rico. Pages 16 in No Editor/Author. Biodiversity, ecology and evolution of thermophiles in Yellowstone National Park: overview and issues, Sept. 17-20, 1995 [abstracts of talks].

Microorganisms living in the thermal pools of Yellowstone National Park (YNP) represent a potential reservoir of scientific and economic value. One bacterium from the park, Thermus aquaticus, has already proven its commercial sales value in the range of over one hundred million dollars per year. None of the financial benefits from T. aquaticus, have gone back to YNP for the Park's mission of protecting biodiversity-including the microbial diversity of the Park. Some have criticized this, arguing that YNP should receive royalties for the commercial use of microorganisms found in the park. As of yet, however, YNP has not developed the institutional mechanisms to take fair advantage of its microbial resources. An institutional example for YNP lies in the National Biodiversity Institute (INBio) of Costa Rica, which has taken proactive steps to increase conservation through the sustainable use of Costa Rica's biological diversity. Partly because INBio conducts its "biodiversity prospecting" activities within Costa Rica's national parks and conservation areas, INBio's experience is directly relevant to the management challenges facing YNP. INBio's pilot projects in biodiversity prospecting focus on equitable benefits sharing arrangement that fulfill the needs of business, government, and conservation of biodiversity. INBio has already demonstrated that the commercial use of biodiversity can help support the protection of biodiversity. YNP should follow suit by developing policies and creating institutional capacity that enhance both industrial innovation and direct benefit to the national park system. (Abstract by Chester as printed in

Biodiversity, Ecology and Evolution of Thermophiles in Yellowstone National Park: Overview and Issues). (233)

Clifton, C. G., Walters, C. C., Simoneit, B. R. T. . 1990. Hydrothermal petroleums from Yellowstone National Park, Wyoming, USA. Pages 169-191 in No Editor/Author. Organic matter in hydrothermal systems - maturation, migration and biogeochemistry; selected papers from the 3rd Chemical Congress of North American and the 195th ACS national Meeting. Pergamon, Oxford.

"In Yellowstone National Park, oil is actively discharging with thermal waters at several widely separated thermal areas. Samples from two locations were studied. Petroleum from Calcite Springs occurs as vapor condensates in steam vents. Detailed geochemical analyses show a complex origin for the petroleum fluid. Deeply buried, hydrothermally altered sedimentary rocks are believed to have contributed a high temperature pyrolysate consisting largely of polynuclear aromatic hydrocarbons and heterocyclic compounds. Shallow sedimentary rocks, which are also hydrothermally altered, have contributed large amounts of aromatic and polar compounds, as well as minor amounts of hydrocarbons. The Permian Phosphoria Formation is suggested as a likely source rock for the bulk of the oils. Autochthonous pyrolysates and lipids from thermally altered surface and near surface bacterial and land plant debris have also been introduced to the vents by downward percolating meteoric water. The oil from Rainbow Springs is a highly paraffinic, low-S crude oil, depleted in light hydrocarbons. Unlike the Calcite Springs samples, the oil from Rainbow Springs is believed to have originated from a single sedimentary source rock with little or no hydrocarbon contributions from surface biota. " (234)

Des Marais, D. J. . 1996. Stable light isotope biogeochemistry of hydrothermal systems. Pages 83-98 in Bock, G. R. , Goode, J. A. . Evolution of hydrothermal ecosystems on earth (and Mars?). Wiley, New York.

Stable isotopic composition of the elements O, H, S and C in minerals can indicate the processes, including biological activity, of hydrothermal systems. Hydrothermal alteration of mineral values can be used to detect fossil systems. (235)

Fournier, R. O. 1989. Geochemistry and dynamics of the Yellowstone National Park hydrothermal system. Annn. Rev. Earth Planet. Sci. 17:13-53.

"Relatively dilute alkali-chloride waters at Norris Geyser Basin attain chemical equilibrium with reservoir rocks underground in a series of reservoirs at temperatures ranging from about 200 to 325 C. Reservoirs of acid-sulfate-chloride waters at >190-200 C also exist underground at Norris and there is episodic mixing (usually in the fall) of acid-sulfate-chloride and alkali-chloride waters. The rate of discharge of sulfate by the acid-sulfate-chloride water from deep in the system is large, and it is difficult to account for the generation of all of this type of water solely by present-day local oxidation of H2S that is carried in steam to the Earth's surface at Norris, followed by infiltration of acid-sulfate water back underground where it mixes with chloride-rich water. Additional sulfate may be generated by bacteria (sulfolobus) that consume native sulfur and liberate sulfuric acid in shallow underground environments. The source of native sulfur may be old solfataras in the Norris region, formed as a result of volcanic activity that produced silicic domes south of Norris, and that were subsequently covered either

by later volcanic flows, or by glacial material deposited on hot ground. Another possibility, supported by (superscript 3)He/(superscript 4)He data is that a component of magmatic gas containing SO2 is entering parts of the Norris system and reacting with water to form H2SO4 and H2S." (236)

Garrott, R.A., L.L. Eberhardt, J.K. Otton, P.J. White, and M.A. Chaffee. 2002b. A geochemical trophic cascade in Yellowstone's Geothermal Environments. Ecosystems. 5(7):659-666.

We contrast the geochemistry of the Madison drainage, which has high concentrations of geothermal features, with the Lamar drainage of Yellowstone National Park, USA, and trace the consequences of geochemical differences through abiotic and biotic linkages in the ecosystem. Waters in the geothermal-dominated drainage contained anomalously high levels of fluoride (F) and silica (SiO2). Soils, stream sediments, and surface waters that interact or mix with geothermal waters, in turn, had elevated F and SiO2 concentrations compared to similar samples from the Lamar drainage. The geochemical differences were reflected in the chemistry of forage plants, with some plants from geothermally influenced areas containing four- to eightfold higher concentrations of F and SiO2 than similar plants in the Lamar drainage. Geothermal heat reduced snowpack, and we found that elk (Cervus elaphus) concentrated in these refugia as snowpack increased each winter. The consequent high dietary intake of F in animals associated with the geothermal areas was confirmed by the finding that bone samples from elk living in the Madison drainage contained sixfold higher concentrations of F than samples collected from animals wintering in the Lamar drainage. High F exposure resulted in compromised dentition due to fluoride toxicosis, which was undoubtedly exacerbated by the abrasive action of silica. The consequent accelerated and aberrant tooth wear resulted in early onset of senescence, reduced life span, and an abbreviated age structure. We speculate that these altered demographics, combined with spatial heterogeneity of snowpack, will result in increased vulnerability of this large herbivore population to wolf predation and less resiliency to compensate demographically for predation. (Abstract by Garrott et al as printed in Ecosystems). (237)

Hinman, N. W. . 1995. Geochemistry of hot spring sinters and microbial mats. Investigator's Annual Report.

Abstract in Progress (238)

Hugenholtz, P., C. Pitulle, K.L. Hershberger and N.R. Pace. 1998. Novel division level bacterial diversity in a Yellowstone hot spring. Journal of Bacteriology 180(2):366-376.

A culture-independent molecular phylogenetic survey was done on Octopus Pool. A majority (70%) of the sequence types found were affiliated with 14 previously recognized bacterial divisions (main phyla; kingdoms); 30% were unaffiliated with recognized bacterial divisions. The unaffiliated sequence types (represented by 38 sequences) nominally comprise 12 novel, division level lineages termed candidate divisions. (239)

Redmann, R. E. 1984. Tolerance of plants to environmental stresses around thermal areas in Yellowstone National Park. Investigator's Annual Report.

Abstract in Progress (240)

Reysenbach, A. L. and S. Cady. 2001. Microbiology of ancient and modern hydrothermal systems. Trends in Microbiol. 9: 79-86.

Hydrothermal systems have prevailed throughout geological history on earth, and ancient Archeaen hydrothermal deposits could provide clues to understanding earth's earliest biosphere. Modern hydrothermal systems support a plethora of microorgansims and macroorganisms, and provide good comparisons for paleontological interpretation of ancient hydrothermal systems. However, all of the microfossils associated with ancient hydrothermal deposits reported to date are filamentous, and limited stable isotope analysis suggests that these microfossils were probably autotrophs. Therefore, the morphology and mode of carbon metabolism are attributes of microorganisms from modern hydrothermal systems that provide valuable information for interpreting the geological record using morphological and isotopic signatures. (Abstract by Reysenbach as printed in Trends in Microbiology). (241)

Reysenbach, A.-L., M.A. Ehringer, and K. Hershberger. 2000. Microbial diversity at 83 C in Calcite Springs Yellowstone National Park, reveals a novel deeply rooted bacterial lineage and another member of the Korarchaeota.Extremophiles 4: 61-67.

The use of molecular phylogenetic approaches in microbial ecology has revolutionized our view of microbial diversity at high temperatures and led to the proposal of a new kingdom within the Archaea, namely, the "Korarchaeota." We report here the occurrence of another member of this archaeal group and a deeply rooted bacterial sequence from a thermal spring in Yellowstone National Park (USA). The DNA of a mixed community growing at 83 C, pH 7.6, was extracted and the small subunit ribosomal RNA gene (16S rDNA) sequences were obtained using the polymerase chain reaction. The products were cloned and five different phylogenetic types ("phylotypes") were identified: four archaeal phylotypes, designated pBA1, pBA2, pBA3, and pBA5, and only one bacterial phylotype, designated pBB. pBA5 is very closely related to the korarchaeotal phylotype, pJP27, from Obsidian Pool in Yellowstone National Park. The pBB phylotype is a lineage within the Aquificales and, based on 16S rRNA sequence, is different enough from the members of the Aquificales to constitute a different genus. In situ hybridization with bacterial-specific and Aquificales-specific fluorescent oligonucleotide probes indicated the bacterial population dominated the community and most likely contributed significantly to biogeochemical cycling within the community. (Abstract by Reysenbach et al as printed in Extremophiles). (242)

Shanks, W. C. , et al. 1998. Geology and geochemistry of hydrothermal systems in Yellowstone Lake. Pages 50 in No Editor/Author. Making a place for nature, seeking our place in nature: 125th Anniversary Symposium; agenda and abstracts. Yellowstone Association, Yellowstone National Park.

The influence of sublacustrine vents on metal concentrations in Yellowstone Lake has been evaluated by collecting and analyzing water column profiles and hydrothermal vent samples. Metal analyses indicate that vents in West Thumb are enriched in As, Cs, Ga, Ge, Li, Mo, Na, Rb, Sb, and W whereas Mary Bay vents are enriched in Ba, Ce, Fe, La, Mn, and Y. The water column data indicate that these elements have higher concentrations in West Thumb and Mary Bay relative to those in Southeast Arm, outside the area of hydrothermal venting, and that

the differences in element enrichments between the West Thumb and Mary Bay vents are reflected in the respective water columns. Hydrogen (dD) and oxygen isotope (d18O) analyses indicate that Yellowstone Lake waters fall on an evaporation trend relative to the global meteoric water line, indicating the lake is 5-15% evaporated relative to Yellowstone River influx. Hydrothermal vent H S and d34S values averaging 2.0% Dissolved SO4 in lake waters has d34^2S values averaging 2.6%, indicating predominance of volcanic sulfur sources. In general, Yellowstone Lake water and Yellowstone River overflow are strongly influenced by geothermally supplied metals and sulfur.
Lake bottom hydrothermal deposits occur near active hydrothermal vents in West Thumb, Mary Bay, and off Stevenson Island. Two types of hydrothermal deposits have been recovered. Siliceous deposits from Mary bay consist of up to meter-length aggregates of tubular to irregularly-shaped cm-diameter filled fluid "conduits." The outer surface of the conduits comprises soft to friable sediment which is progressively recrystallized and cemented by hydrothermal amorphous silica toward the inner wall of the conduits. These observations indicate that the hydrothermal deposits formed via fluid flow within sediments, and that sediments have subsequently been winnowed away, probably by slumping. The second type of deposit occurs near Bridger Bay at a water depth of 15 m, where a group of hard irregular spires up to 7 m tall and 1-2 m diameter project above a relatively flat sediment surface in a hydrothermally inactive area. These spires are siliceous sinter that is texturally similar to many subaerial hot spring deposits in YNP. The spires have an outer zone of amorphuous iron oxyhydroxides that is enriched in As, Ba, Co, Cu, Ga, Li, Mo, Ni, Sr, Tl, V and W. Geochemical modeling indicates that the Bridge Bay spires have grown up from the sediment-water interface by mixing of hydrothermal fluids with lake water. (Abstract by Shanks et al. As printed in Making a place for nature, seeking our place in nature: 125th Anniversary Symposium; agenda and abstracts) (243)

Ward, D. M., M. J. Ferris, S. C. Nold, and M. M. Bateson. 1998. A Natural View of Microbial biodiversity within hot spring cyanobacterial mat communities: an evolutionary ecology view. Microbiol. Mol. Biol. Rev. 62:1353-1370.

Abstract in Progress (245)

Wiegert, R. G. . 1995. Long-term measurement of the ecology of thermal communities. Investigator's Annual Report.

Abstract in Progress (246)

Zeikus, J. G. , Brock, T. D. . 1972. Effects of thermal additions from the Yellowstone geyser basins on the bacteriology of the Firehole River. Ecology. 53 2: 283-290.

A series of stations was established on the Firehole River where it flows through the main geyser basins of Yellowstone Park, and temperature, pH, alkalinity, conductivity, and phosphate were measured. (247)

UNGULATES

Boyce, Mark S., Metzgar, Lee H., Peters, J. Terry. 1991. Bighorn Sheep and Horses on the BICA: Wilderness or Pasture?. University of Wyoming NPS Research Center, Laramie WY.

In this paper we review the ecology and management of feral horses and bighorn sheep on the BICA and Pryor Mountain Wild Horse Range, and to present information on competition between these species that could be relevant to the management of these species on wilderness areas. We develop a model of competition between horses and bighorns and use this model to make predictions of the probable future dynamics of the system under various management alternatives. Finally, we discuss management implications in the context of Park Service policy regarding the management of exotic species. (248)

Brownell, Joan. Horse Distribution in the Pryor Mountains Region Preceding the Creation of the Pryor Mountain Wild Horse Range, 1999

Abstract in Progress (345)

Caslick, J., and E. Caslick. 1999. Pronghorn distribution in winter 1998-1999. National Park Service, YCR, Mammoth Hot Springs, Wyo. YCR-NR-99-2.

Covers mortality, estimates of herd size, recommendations, predators, maps of weekly distribution. (249)

Coughenour, M.B., and F.J. Singer. 1996. Elk population processes in Yellowstone National Park under the policy of natural regulation. Ecological Applications 6:573-593.

The interrelations of weather, plant production and abundance, and elk population dynamics on Yellowstone's northern winter range were examined for a 23-yr period when there was minimal human offtake from the herd. Significant correlations between precipitation and plant production, between elk population responses and precipitation, and between elk population responses and elk population density strongly suggested that forage limited elk population growth. Although population responses to density have been documented previously in Yellowstone, responses to precipitation have not. Correlations between elk population responses and annual precipitation were presumably consequences of plant growth responses to precipitation and subsequent effects on elk nutritional status. Population regulation was most consistently achieved through the responses of juveniles rather than adults. Winter mortality of juveniles was primarily correlated with precipitation. Adult mortality rates were not significantly correlated with elk numbers, but were correlated with precipitation. Per capita rate of increase was negatively correlated with elk number, but 55% of the variance was density-independent. There was evidence that winter weather affected the elk, but season-long weather indices had poor predictive power. A stage-structured population model using regression equations of mortality and recruitment rate responses to precipitation and elk numbers, predicted that the population could vary within a range of ?16,400 ? 2,500 sighted elk (mean ? 1 SD). (Abstract by Coughenour and Singer as printed in Ecological Applications). (250)

Garrott, R.A., L.L. Eberhardt, P.J. White, and J. Rotella. 2002a. Climate-induced variation in vital rates of an unharvested large-herbivore population. Canadian Journal of Zoology, in review.

Variation in vital rates of an unharvested elk (Cervus elaphus) population was studied using telemetry for 7 consecutive years, 1991–1998. We found pronounced senescence in survival rates, but no evidence for reproductive senescence. Prime-age females (<10 years old) experienced very high annual survival rates (mean = 0.97, SE = 0.02), with lower survival rates for senescent animals (10 years old; mean = 0.79, SE = 0.06). There was evidence that the severity of snowpack conditions had little effect on survival of prime-age animals except during the most extreme winter, while survival of senescent animals was progressively depressed as the severity of snowpack conditions increased. Reproductive rates remained essentially constant, near their biological maxima (mean = 0.91, SE = 0.02). Annual re cruitment was highly variable. Snowpack had a pronounced effect on recruitment (r2 = 0.91), the most severe snowpack conditions resulting in the virtual elimination of a juvenile cohort. Population estimates and recruitment rates obtained during this investigation and historic data collected from 1965 to 1980 support the premise that the population has been maintained in a dynamic equilibrium for at least three decades despite the stochastic effects of climate variation on vital rates. We conclude that the population is resource-limited, with variation about the equilibrium caused primarily by variable recruitment driven by stochastic annual snowpack. Abstract (251)

Gogan, P.J. , E.M. Olexa, T.O. Lemke, and K. Podruzny. 1999. Population dynamic of northern Yellowstone Mule Deer. In abstract and presentation, Northwest Section, The Wildlife Society. Intermountain Journal of Science. Vol 5, p. 50March.

We report trends in numbers and age and sex structure of mule deer wintering in the Gardiner Basin area of the northern Yellowstone winter range between 1987 and 1998. The ratios of fawns: 100 adults in early spring are related to an index of winter severity and its component parts. Early winter fawn: 100 adult ratios are related significantly to the winter forage index as predicted by previous spring precipitation. Spring fawn: 100 adult ratios are related significantly to an index of snow water equivalent and the overall winter severity index. Survival of adult female mile deer from 1993 to 1997 as determined from radiotelemetry averages 0.80 per year. Models of survival constrained by the components of the index of winter severity are all more parsimonious than a tear-varying survival model. We conclude that variation in annual survival of adult females was a function of winter severity. (Abstract by Gogan et al as printed in the Intermountain Journal of Sciences). (252)

Gogan, P.J.P., J.A. Mack, W.G. Brewster, E.M. Olexa and W.E. Clark. 2001. Ecological studies of bison in the Greater Yellowstone Area: development and implementation. The George Wright Forum 18: 67–75.

Bison (Bison bison) of the Greater Yellowstone Area (GYA) are perhaps best known to the scientific community from the classic study of Meagher (1973) that reviewed their ecological status and management from the time of establishment of Yellowstone National Park in 1872 through the last National Park Service (NPS) removals of bison within the poark in 1966. Since the cessation of herd reductions in the park, bison numbers within Yellowstone increased (Dobson and Meagher 1996), as did range use (Meagher 1989b), including increased frequency and magnitude of movements beyond the park boundries in winter (Meagher 1989a; Pac and Frey 1991; Cheville et al. 1998). (Abstract by Gogan et al as printed in The George Wright Forum). (253)

Gogan, P.J.P., R.H. Barrett, W. Shook and T.E. Kucera. 2001. Control of ungulate numbers in protected areas. Wildlife Society Bulletin 29(4):1075-1088.

Successful long-term control of ungulate numbers within a protected area requires continuous review and refinement of management practices. Insight gained may have application to other sites. We evaluated management objectives and actions to control populations of exotic axis deer (Axis axis) and fallow deer (Dama dama) at Point Reyes National Seashore, California. Using records of numbers of each species culled from 1968 to 1996 and demographic data, we modeled each population's potential response to management actions and to the cessation of control in 1996. These simulations indicated that control measures hold numbers of both populations below ecological carrying capacity (K) and that populations of fallow and axis deer may have reached K within 5 to 13 years of ceasing control, respectively. We also simulated each population's response to removal of actual numbers of males killed but no females and actual numbers of females killed but no males from 1968 to 1996. Removing males only resulted in both populations reaching K. Removing females only lead to the extirpation of both populations. Cessation of control activities prior to removal of all females resulted in recovery of both populations. A team of personnel expended an average of 1.75 work-hours/deer to remove 1,182 exotic deer of both species from 1984 to 1994. The work effort required to remove ?2 deer/day reached as great as 20 hours/deer. Elimination of the axis deer population is feasible and likely a more cost-effective management alternative than continued population control. Elimination of fallow deer is potentially more difficult but may be more cost-effective than continuing control actions indefinitely. We recommend similar assessment s of management alternatives to those charged with controlling ungulate numbers in protected areas. (254)

Gudorf, Michelle, Sweanor, Patricia and singer, Francis, Bighorn Sheep Habitat Assessment of the Greater Bighorn Canyon National Recreation Area. 1996

Abstract in Progress (255)

Hobbs, N. T. 1996. Modification of ecosystems by ungulates. Journal of Wildlife Management. 60 4: 695-713.

Emerging evidence suggests that indirect interactions between species may be more important than direct ones in determining ecosystem patterns and processes. The author reviews the indirect effects of ungulates on nutrient cycling, net primary production, and disturbance regimes in terrestrial ecosystems. (256)

Hobbs, N.T. and R.A. Spowart. 1984. Effects of prescribed fire on nutrition of mountain sheep and mule deer during winter and spring. J. Wildlife Management 48: 551-560.

Prescribed burning elevated the concentration of protein and in vitro digestible organic matter (IVDOM) in winter diets of mountain sheep (Ovis canadensis) and mule deer (Odocoileus hemionus) feeding in grassland and mountain shrub communities. We observed no effect of burning on ungulate nutrition during spring. In both communities, the magnitude of treatment effects tended to depend on the month we observed diets. Effects of burning on diet crude protein persisted for 2 years in both communities. Treatment effects on diet IVDOM lasted for 2

years in mountain shrub, but were absent during the 2nd year in grassland. Effects of fire on diet quality resulted form changes in ungulate diet selection rather than improvements in the quality of individual forages. Differences in the amount of green grass in ungulate diets accounted for much of the enhancement in diet quality we observed. We conclude that prescribed fire can improve winter habitats for mule deer and mountain sheep. (Abstract by Hobbs as printed in Journal of Wildlife Management). (257)

Irby, L. and J. Knight, eds. 1998. International symposium on bison ecology and management in North America. Mont. State Univ., Bozeman, MT.

"This proceedings provides papers and abstracts on the broad array of interest related to bison in North America. Categories include: bison ecology, management perspectives, genetics, physiology, paleontology, history, and disease. Recognizing the array of opinions related to bison management, the symposium committee has also included a "Viewpoints on Management" section to allow opininon papers to reflect some non-scientific ideas." (258)

Irby, Lynn R., Mackie, Richard J., Kissell, Robert E.=, Jr. 1994. Competitive interactions between Bighorn Sheep, Wild Horses, and Mule Deer in BICA and Pryor Mountain Wild Horse Range. Montana State University, Bozeman, MT.

This report summarizes a study which attempted to differentiate ecological requirements of bighorn sheep, feral horses, and mule deer. The objectives were to determine population estimates for mule deer; ascertain species habitat associations; describe intra and interspecific behavior; and to examine commonalities of food habits of the species. (259)

Keigley, R.B., and F.H. Wagner. 2000. What is "Natural"?: Yellowstone Elk Population—A case study. Integrative Biology. 1:133-148.

Ecology analyzes the structure and function of ecosystems at all points along the continuum of human disturbance, from so-called pristine forests to urban backyards. Undisturbed systems provide reference points at one end of the spectrum, and nature reserves and parks are highly valued because they can provide unique examples of such ecosystems. Unfortunately the concept of "natural" or pristine is not that easy to define. Indeed, although ecologists have considered pre-Columbian, western-hemisphere ecosystems to have been largely unaltered by human action, and have termed their state "natural" or "pristine," evidence from archaeology challenges this view. U.S. and Canadian national parks are charged with preser5ving the "natural," and thus need to be able to understand and manage for the "natural." A pivotal "natural" question in Yellowstone National Park management is the size of the northern-range, wintering elk population at Park establishments in 1872, argued both to have been small and large. Integrating and quantifying several sources of evidence provides a consistent picture of a low population (ca. 5,000-6,000), largely migrating out of the northern range in winter, with little vegetation impact. If we accept this conclusion about what is natural for the Yellowstone ecosystem, then it dramatically alters how we view management alternatives for the Park, which currently supports a northern wintering herd of up to ~25,000 elk. (Abstract by Keigley and Wagner as printed in Integrative Biology). (260)

Laundre, J.W. 1994. Resource overlap between mountain goats and bighorn sheep. Great Basin Naturalist. 54(2):114-121.

Mountain goat (Oreanmnos americanus) and bighorn sheep (Ovis candanesis)ranges overlap substantially in northwestern United States and southwestern Canada. Resource overlap in food and habitat parameters is assumed, but the degree of overlap has not been estimated. Data from published separate and comparative studies on food and habitat use were used to calculate indices of resource overlap for goats and sheep. Indices of overlap for general forage classes (grasses, forbs, browse) were >0.90 in summer and winter for data based on pooled data from separate studies and in summer for data from comparative studies. In winter for comparative studies this overlap was 0.64. For studies where forage species were identified, estimates of resource overlap from separate studies were ~0.8 but were <0.5 for comparative studies. Indices of overlap for habitat variables were also low (<0.7) for comparative studies. It was concluded that possible overlap in food and habitat use by goats and sheep could be extensive; but in sympatric populations, resource overlap may be reduced substantially. (Abstract by Laundre as printed in Great Basin Naturalist). (261)

Meagher, M., and M. E. Meyer. 1994. On the origin of brucellosis in bison of Yellowstone National Park: a review. Conservation Biology 8:645-653.

"Brucellosis caused by Brucella abortus occurs in the free-ranging bison (Bison bison) of Yellowstone and Wood Buffalo National Parks and in elk (Cervus elaphus) of the Greater Yellowstone Area. As a result of nationwide bovine brucellosis eradication programs, states and provinces proximate to the national parks are considered free of bovine brucellosis. Thus, increased attention has been focused on the wildlife within these areas as potential reservoirs for transmission to cattle. Because the national parks are mandated as natural areas, the question has been raised as to whether Brucella abortus is endogenous or exogenous to bison, particularly for Yellowstone National Park. We synthesized diverse lines of inquiry, including the evolutionary history of both bison and Brucella, wild animals as Brucella hosts, biochemical and genetic information, behavioral characteristics of host and organism, and area history to develop an evaluation of the question for the National Park Service. All lines of inquiry indicated that the organism was introduced to North America with cattle, and that the introduction into the Yellowstone bison probably was directly from cattle shortly before 1917. Fistulous withers of horses was a less likely possibility. Elk on winter feedgrounds south of Yellowstone National Park apparently acquired the disease directly from cattle. Bison presently using Grand Teton National Park probably acquired brucellosis from feedground elk." (262)

Olexa, E.M., K.A. Keating, and P.J.P. Gogan. Bison habitat selection at the landscape level in Yellowstone National Park. In Conservation management of bison in northern landscapes: advances in ecology and epidemiology. (In prep.)

Abstract in Progress (263)

Ostovar, K. 1998. Impacts of human activity on bighorn sheep in Yellowstone National Park. M.S. Thesis, Mont. State. Univ., Bozeman, MT.

Seventeen years have passed since bighorn sheep (Ovis canadensis canadensis) in Yellowstone National Park (YNP) experienced massive Chlamydial-caused die-off. Currently

no sign of Chlamydia or pneumonia is evident, thus other factors are considered to be limiting the population. The proposed changes to the Gardiner-Mammoth highway and the highway through Dunraven Pass could increase or decrease human disturbances to the core of the population of bighorn sheep. Approximately 65% of all observations on the Everts winter range occurred on top of McMinn Bench (along the proposed road route). One ewe group currently must cross the Gardiner-Mammoth highway to reach spring lambing grounds. The placement of the road onto McMinn Bench would impact at least 2 other populations of ewe groups and 2-3 populations of ram groups, which seek shelter, security, water, and minerals in the cliffs. Use of the Dunraven Pass road corridor was low and potential displacement from road changes would be minor. Disturbance events were recorded during behavioral observations. Human presence was recorded for 26% of all observations, with 25% of these resulting in disturbances. The percentage of overall human disturbances for all observations in each group was: McMinn Bench ewes 7.5%, McMinn Bench rams 4.6%, Mount Washburn 4.3%, Deckard Flats 5.4%, Rattlesnake Butte 2.9%. The most disturbing human activity (based on overt reactions) was helicopter aircraft. To evaluate the effects of these human disturbances I used 3 non-invasive techniques that may be indicators of stress in bighorn sheep: behavioral activity levels, lungworm larvae shedding levels (LPG), and levels of hormone corticosterone. Most groups were not significantly different in degree of activity. Corticosterone levels did not correlate with LPG levels, suggesting that LPG may not be a good indicator of disturbances. Corticosterone differences in radio-collared and uncollared individuals were insignificant. Rams had significantly lower corticosterone levels than females (F=4.56, P=.0334). Levels dropped during winter and increased dramatically for both rams and ewes during the month of May, suggesting that measures of corticosterone may be more indicative of social stress than climatic or nutritional stress during the winter. McMinn Bench ewes had significantly higher levels of corticosterone than Rattlesnake Butte ewes (F=6.31, P=.0125) corresponding with distances to road, activity levels, human disturbance rates and possibly reproductive success. (Abstract by Ostovar as printed in his MSU Thesis). (264)

Schullery, Parul and Lee Whittlessey. In press. Mountain goats in the Greater Yellowstone Ecosystem: a prehistoric and historical context. Great Basin Naturalist.

Because the relatively recent colonization of portions of Yellowstone National Park by introduced mountain goats (Oreamnos americanus) from public game lands in Montana raises important policy and management questions for the park, it is necessary to understand the prehistoric and early historical record of mountain goats in the Greater Yellowstone Ecosystem. We reviewed previous paleontological, archeological, and historical studies of goat presence and examined a large body of historical material for evidence of goats. Native mountain goat range most closely approached the Greater Yellowstone Ecosystem to the west, but no modern authority claims goats were resident in the ecosystem in recent centuries. Historical accounts of goat presence in the region prior to 1882 (and thus prior to any known introduction of goats by Euro-Americans) are limited to one possible sighting by unreliable observers and a few casual mentions of goat presence by people of limited or unknown familiarity with the ecosystem. Other early observers in the region specifically stated that goats were not native. Between 1882 and 1926 other observers and residents agreed that mountain goats were not native to the park, or to the larger area around it. It is impossible to prove absolutely that there

were no goats in the ecosystem prior to modern introductions, but historical evidence demonstrates that if present, such goats must have been exceedingly rare and uncharacteristically unsightable. National Park Service policy relating to exotic species developed gradually after the creation of Yellowstone National Park in 1872, moving from a general receptivity to introduction of at least some favored nonnative species to a general prohibition on all such introductions. Current policy, while disapproving of all nonnative species, seems to reserve special efforts at removal of nonnatives for those species that pose the greatest threat to native species and ecosystems. Current policy is not helpful in defining the minimum amount of evidence needed to prove a species was present or absent, or whether or not an introduced nonnative species is causing sufficient harm to justify its removal. (265)

Scott, M. D. , Geisser, H. . 1996. Pronghorn migration and habitat use following the 1988 Yellowstone fires. Pages 123-132 in Greenlee, J. M. . Ecological implications of fire in Greater Yellowstone; proceedings, Second Biennial Conference on the Greater Yellowstone ecosystem, Yellowstone National Park, September 19-21, 1993. International Association of Wildland Fire, Fairfield WA.

Preburn known pronghorn range was compared to postburn habitat use as monitored through 73 radiotelemetered pronghorns. Forest burns on the summer range were probably beneficial due to the clearing of new feeding areas and/or corridors to isolated habitat. Pronghorn wintering on the unburned permanent range between Mammoth and Reese Creek depended on big sagebrush for food, but the sagebrush has been declining in this area. (667)

Singer, F. J. . Effects of grazing by wild ungulates in Yellowstone National Park. U. S. Department of the Interior, National Park Service, Denver CO.

Abstract in Progress (269)

Singer, F.J., and R.A. Renkin. 1995. Effects of browsing by native ungulates on the shrubs in big sagebrush communities in Yellowstone National Park. Great Basin Natu. 55(3):201-212.

The effects of elk (Cervus elaphus), pronghorn (Antilocapra americana), and mule deer (Odocoileus hemionus) browsing on shrubs in big sagebrush (Artemisia tridentata) communities were monitored over a 31-year period in Yellowstone National Park. Ungulates were restricting Wyoming big sagebrush (spp. Wyomingensis) heights, size, and recruitment on the lower-elevation stratum only, while no such suppression was observed on the high-elevation stratum. Parallel increases in mountain big sagebrush (spp. vaseyana) densities and cover occurred over the study period on both browsed and unbrowsed sites at the higher-elevation stratum, although big sagebrush, green rabbitbrush (Chrysothamnus viscidiflorus), and horsebrush (Tetradymia canescens) were slightly taller and crown sizes were slightly larger on unbrowsed than browsed sites. Wyomingoming big sagebrush utilization (percent leader rise) was eight times higher (hivin x = 87 +- 7.2% by pronghorns, mule deer, and elk) on the low-elevation winter range stratum (the Boundary Line Area (BLA) portion of the winter range), while mostly mountain big sagebrush with leader use averaged only 11 +- 4.1% (nearly all by elk) on the high-elevation range stratum. In addition, annual aboveground biomass production of big sagebrush did not differ between browsed and unbrowsed study sites on the high-elevation stratum of the winter range. Population turnover was higher on browsed big sagebrush at the high-elevation plots; seedling germination and survival rates were higher on browsed plots versus unbrowsed plots.

No difference was observed in percent dieback of big sagebrush adult plants between browsed and unbrowsed plots at the higher stratum. Browsing did not influence the Dumber of leaves or seedstalks per plant (P gt .05), but leaves averaged 45% longer and seedstalks 42% longer on browsed big sagebrush. Ungulate browsing, however, apparently suppressed production, germination, and survival of Wyoming big sagebrush on the low-elevation stratum. Numbers of Wyoming big sagebrush declined 43% and cover declined 29%, 1957-1990, on browsed sites on the BLA. Annual biomass production on browsed sites at the low-elevation stratum was only 6-35% that of unbrowsed sites, and big sagebrush recruitment was less on browsed sites. Percent leader use of big sagebrush did not differ between the period of ungulate reductions, 1962-1969, and the 1980s on the lower stratum (hivin x = 87% leader use), but utilization was less on higher portions of the winter range during the period of elk reductions (hivin x = 2%) than during the 1980s following cessation of elk controls (hivin x = 11%). (270)

Singer, Francis et al, Demographic Analysis, Group Dynamics and Genetic Effective Population Size in the Pryor Mountain Wild Horse Population, 1999

Data of Genetic Heterozygosity in the herd, reproductive success to conduct demographic analysis, estimate genetic effective size. (347)

Sloan, William, A Herd History of the Bighorn Sheep of Bighorn Canyon National Recreation Area, Montana and Wyoming, 1995

Abstract in Progress (266)

Taper, M.L., and P.J.P. Gogan. 2002. The northern Yellowstone elk: density dependence and climatic conditions. Journal of Wildlife Management 66:106-122.

We analyzed a time series of estimates of elk (Cervus elaphus) numbers on the northern Yellowstone winter range from 1964 to 1979 and 1986 to 1995 using a variety of discrete time stochastic population dynamic models. These models included adjustments for density, an increase in the are of winter range used by elk, lagged effects of the weather covariates of spring precipitation, snow depth and winter temperature, and the impacts of the 1988 drought and fires. An information-criteria-based model-selection process strongly supported evidence of density dependence. The best model, a Ricker model, distinguished between the 2 time periods. The bulk of the difference between the 2 periods is attributed to an increase in the amount of winter range used by elk. Inclusion of the covariates spring precipitation and spring precipitation squared greatly improved the model fit. We detected a short-lived increase in elk population growth rate following the 1988 drought and fires. Fertility and survivorship of adults appeared to have different density-dependant forms that together result in a biphasic relationship between population growth rate and density. This study confirms the presence of density-dependant regulation in the northern Yellowstone elk herd, and enhances our understanding of population dynamics of these ungulates. (Abstract by Taper as printed in Journal of Wildlife Management). (267)

Tyres, Dan. 1995. Winter ecology of moose on the Northern Yellowstone Winter Range. Yellowstone National Park, YCR.

Abstract in Progress (268)

VEGETATION

Bartos, D.L. and R.B. Campbell, Jr. 1998. Decline of quaking aspen in the Interior west: examples from Utah. Rangelands 20: 17-24.

The authors examine the aspen as a unique and vital tree to many interior-west ecosystems. They explore why aspen are in decline, namely suppression of fire and overgrazing, benefits of aspen stands, and what an ecosystem could experience after aspen decline. The authors' ideas are based largely on research done in Fishlake National Forest of southern Utah. This area historically held 75% aspen cover, but now holds only 20% aspen cover, 50% of that being currently endangered. Checking fire scars of ponderosa pine in the area, it was found that fires previously occurred on an average of every 19 years but have now been suppressed for over 150 years. Bartos and Campbell explore restoration efforts that have occurred in Fishlake National Forest and suggest them to other resources managers around the west along with details of which areas to consider priority and research topics to pursue. (272)

Bates, J., R.F. Miller, and T.J. Svejcar. 1998. Understory patterns in cut western juniper (Juniperus occidentalis spp. occidentalis Hook.) Woodlands. Great Basin Naturalist 58(4):363-374..

Western juniper (Juniperus occidentalis spp. Occidentalis) has rapidly expanded into shrub steppe communities in the Intermountain Northwest during the past 120 yr. Cutting juniper is a management tool used to restore shrub steppe communities. Response of the understory after cutting is strongly influenced by plant species composition existing prior to treatment. This study assessed distribution patterns of understory plants over 2 growing seasons after tree cutting in western juniper woodland. Cover, density, and diversity of understory species were compared among 3 locations: interspaces, duff zones (previously under tree canopies), and debris zones (beneath cut trees). Plant cover and density increased in all zones following tree cutting. Understory vegetation in cut woodlands exhibited strong zonal distribution. Cover and density of Poa sandbergii and Sitanion hystrix and canopy cover of annual forbs were greatest in duff zones ($P<0.05$). Density and cover of other perennial grasses and total densities of perennial forbs and annual forbs were greatest in interspaces ($P<0.05$). Debris zones tended to have the lowest overall understory cover and plant density values. Under juniper debris many species common to interspaces were reduced in density, although plants that survived or established beneath debris grew larger than their counterparts in interspaces. Species that increased in density and cover under debris were plants characteristic of duff zones and whose seeds are typically wind dispersed. (Abstract by Bates et al as printed in Great Basin Naturalist). (273)

Billings, W.D. (1989). Alpine Vegetation, in North American Terrestrial Vegetation, W.D. Billings and R.K. Peet, Editors. Paragon Books. p. 392-420.

Abstract in Progress (274)

Burke, I.C. W.A. Reiners, and R.K. Olson. 1989. topographic control of vegetation in a mountain big sagebrush steppe. Vegetation 84: 77-86.

Mountain big sagebrush steppes in Wyoming have strong spatial patterning associated with topography. We describe the spatial variability of vegetation in sagebrush steppe, and test that relationship between topography and vegetation using canonical correlation. Results of the analysis suggest that the main control over vegetation distribution in this system is wind exposure. Exposed sites are characterized by cushion plant communities and Artemisia nova, and less exposed sites by the taller sagebrush species Artemisia tridentata ssp. vaseyana. Topographic depressions and leeward slopes are characterized by aspen stands and nivation hollows. Measurements of soil microclimate suggest that a major influence of topographic position on vegetation is snow redistribution and its effect on soil moisture and temperature. (275)

Cook, J.G., T.J. Hershey, and L.L. Irwin. 1994. Vegetative response to burning on Wyoming mountain-shrub big game ranges. Journal of Range Management 47: 296-302.

Information on vegetative productivity and nutritive responses to burning in mesic, high elevation big sagebrush (Artemisia tridentata Nutt.) communities is limited. We investigated the effects of 2 wildfires and 3 prescribed fires on current year's production of herbs and selected shrubs for 3 years post-burn, and forage quality for 2 years post-burn in high elevation big sagebrush habitats in southcentral Wyoming. Production of perennial herbs on burned sites averaged twice that on controls, while production of annual herbs varied little 2-3 years post-burn. Burn-induced mortality of Saskatoon serviceberry (Amelanchier alnifolia (Nutt.) Nutt. Ex Roem.) was ?15%, but a 6-fold increase in twig production more that compensated for plant losses. Mortality of true mountain mahogany (Cercocarpus montanus Raf.) and antelope bitterbrush (Purshia tridentata (Pursh) DC) averaged 25% and 55%, respectively, but these losses generally were compensated by increases in browse production. Crude protein content of herbs from late spring through early fall was significantly higher on burns for 2 years post-burn. These results suggest well-managed prescribed burning programs gave potential to improve May through September diets of large herbivores in southcentral Wyoming mountain-shrub communities. (Abstract by Cook et al as printed in Journal of Range Management). (276)

Coughenour, M.B. and F.J. Singer. 1996. Herbaceous plant diversity responses to native ungulate herbivory on Yellowstone's northern winter range. Report. to U.S. National Biological Service.

Abstract in Progress (277)

D'Antonio, C. M., and P. M. Vitousek. 1992. Biological invasions of exotic grasses, the grass/fire cycle, and global change. Annual Review of Ecology and Systematics 23:63-87.

Abstract in Progress (278)

Despain, D. G. . 1990. Yellowstone vegetation. Roberts Rinehart Publishers, Boulder, Colorado.

Abstract in Progress (604)

Despain, D. G. . 1995. Postfire plant regeneration and succession. Investigator's Annual Report.

Abstract in Progress (279)

Despain, D. G. . 1998. Bedrock-controlled vegetation patterns in the Greater Yellowstone geo-ecosystem. Pages 33 in No Editor/Author. Making a place for nature, seeking our place in nature: 125th Anniversary Symposium; agenda and abstracts. Yellowstone Association, YNP

Soils in greater Yellowstone are largely derived from underlying bedrock. Bedrock pattern is determined by four tectonic episodes: Basin and range extension producing the mountain ranges in the northwest quadrant with mixtures of granite, sandstone, limestone and shales; two volcanic episodes, the andesitic Tertiary Absaroka volcanism and the rhyolitic Quaternary Yellowstone caldera in the central part; basement block uplift producing the Beartooth Range in the northeast and the Wind River Range in the southeast with large granitic cores and a fringe of mostly shale, limestone, and sandstone; and thrust faulting that produced repeating series of sandstone, shale and limestone in the mountain ranges of the southwest part of the ecosystem. Soils from sandstone, granite and rhyolite are sandy, poor in plant nutrients and hold little water. Shales, limestone, and andesites are high in nutrients and water holding capacity. Shale produces soils high in clay. Andesite and limestone can produce either course or fine soils. Alpine tundra covers areas above ca. 3000 m. Forests above 2600 m are dominated by Engelmann spruce, subalpine fir and white bark or limber pine. The courser limestones and andesites are covered by forests of Engelmann spruce and subalpine fir at elevations above 2200 m or Douglas-fir and limber pine down to 1800 m. Between 2200 and 2600 m lodgepole pine is dominant on the rhyolite, granite and sandstone and in the early successional stages on other forested substrates and higher elevations. Nonforested meadows, grasslands and sagebrush shrublands dominate finer soils derived from shales, lake sediments, loess deposits and some limestone and andesite. Grasslands above 1800 m are dominated by Idaho fescue and below by bluebunch wheatgrass. Dry shales below 1800 m usually support a desert vegetation. (Abstract by Despain. As printed in Making a place for nature, seeking our place in nature: 125th Anniversary Symposium; agenda and abstracts) (280)

Despain, D.G. 1973. Vegetation of the Big Horn Mountains, Wyoming, in relation to substrate and climate. Ecological Monographs 43:32--355

The vegetation of the Big Horn Mountains is typical of the Central Rocky Mountain region; a lower Juniperus osteosperma zone is followed by Pinus ponderosa, Pseudotsuga menziesii, Pinus contorta, and Picea engelmannii-Abies lasiocarpa zones. Rock or geologic substrate type has a strong influence in forest vegetation. Sedimentary and granitic substrates are discussed, stating that most of the rainfall, less than 30 mm per month, is received during March, April, and May, making soil water relationships important. (281)

DeVelice, Robert L., Lesica, Peter=, Montana Natural Heritage Program. 1993. Plant Community Classification for Vegetation on BLM lands, Pryor Mountains, Carbon County, MT. Montana Natural Heritage Program, Helena, MT.

The Pryor Mountains provide desert like habitats unique in Montana and contribute significantly to the overall biological diversity of the state and the region. This study developed a classification of vegetation types on USDI BLM lands of the south Pryor Mountains, Carbon County, MT. Additionally, endemic and globally rare vegetation types were identified. Using a combination of two-way indicator species analysis (TWINSPAN) and detrended correspondence analysis (DCA) 33 vegetation types were identified among the 197 study plots. Comparisons

with a "comprehensive" listing of vegetation from the western United States revealed that 9 of the types from the Pryor Mountains had not been reported from elsewhere and 14 are rare globally. This concentration of rare vegetation types, in combination with previously documented occurrences of rare plant species, highlight the significant biodiversity values of the Pryor Mountains. (282)

Dinoor, A. and E. Eshed. 1984. The role and imprtance of pathogens in natural plant communities. Annual Review of Phytopathology 22: 443-466.

Abstract in Progress (283)

Emmerich, W.E. and R.K. Heitschmidt. 2001. Impacts of drought, grazing, and burning on rangeland stability. Soc. Range Manage. Abstr. Vol. 54, p. 38.

Drought, grazing, and burning all decrease standing biomass with the potential to influence rangeland productivity and stability through changes in surface runoff, erosion, and nutrient loss. Small increases for long periods can potentially lower rangeland ecosystem stability. The purpose of this work was to evaluate increases in runoff, erosion, and nutrient loss from drought, grazing, and burning and to calculate long term changes in nutrient status to address the issue of rangeland ecosystem stability. Drought and grazing were evaluated on the northern Great Plains under natural precipitation with non-weighing lysimeters, while prescribed burning was evaluated with rainfall simulation on southwestern Sonoran/Chihuahuan desert semiarid rangelands for changes in runoff, erosion, and nutrient loss. All the treatments increased runoff, erosion, and nutrient loss. The soil contained most of the nutrient and most of the lost nutrient was attached to sediment. Even at the accelerated soil loss rates, it would require many years of nutrient loss before it would effect ecosystem processes. Precipitation was found to replace some of the lost nutrient to sustain ecosystems stability. (Abstract by Emmerich and Heitschmidt. As printed in Society of Range Management abstracts) (284)

Evans, R.D.; Ehleringer, J.R. 1994. Water and nitrogen dynamics in an arid woodland. Oecologia. 99(3-4):233-242.

Arid environments are characterized by spatial and temporal variation in water and nitrogen availability. Differences in d15 N and dD of four co-occurring species reveal contrasting patterns of plant resource acquisition in response to this variation. Mineralization potential and nitrogen concentration of surface soils associated with plant canopies were greater than inter-canopy locations, and values decreased with increasing depth in both locations. Mineralization potential and nitrogen concentration were both negatively correlated with soil d15 N. The spatial variation in soil d15 N caused corresponding changes in plant d15 N such that plant d15 N values were negatively correlated with nitrogen concentration of surface soils. Plants occurring on soils with relatively high nitrogen concentrations had lower d15 N, and higher leaf nitrogen concentrations, than plants occurring on soils with relatively low nitrogen concentrations. Two general temporal patterns of water and nitrogen use were apparent. Three species (Juniperus, Pinus and Artemisia) relied on the episodic availability of water and nitrogen at the soil surface. d15 N values did no vary through the year, while xylem pressure potentials and stem-water dD values fluctuated with changes in soil moisture at the soil surface. IN contrast, Chrysothamnus switched to a more stable water and nitrogen source during drought.

d15 N values of Chrysothamnus increased throughout the year, while xylem pressure potentials and stem-water dD values remained constant. The contrasting patterns of resource acquisition have important implications for community stability following disturbance. Disturbance can cause a decrease in nitrogen concentration at the soil surface, and so plants that rely on surface water and nitrogen may be more susceptible than those that switch to more stable water and nitrogen sources at depth during drought. (Abstract by Evans and Ehleringer as printed in Oecologia). (285)

Eversman, S. , Bennett, J. P. , Wetmore, C. M. , Glew, K. . 2002. Patterns of lichens diversity in Yellowstone National Park, Bryologist 105(1):27-42.

We here report 359 species in 103 genera from Yellowstone National Park. We found 71.3% of the total number of species in Picea engelmannii forests and 57.4% of the total number in Pseudotsuga menziesii stands. This compares to 42.3% of the species in Pinus contorta and 37.0% of the species in Pinus contorta/Pinus albicaulis stands. The presence of old Pseudotsuga menziessii and mature Picea engelmannii indicates that the forests have not burned for at least 300 yr, contributing to higher lichen diversity. The drier lodgepole pine and whitebark pine forests burn more frequently than every 300 yr and have fewer microhabitats for lichen growth. Species with thalli large enough to identify are beginning to recolonize substrates burned in the 1988 fires. Bryoria fremontii and Letharie vulpina exhibit levels of mercury and sulfur higher than those in other specimens in the region. Abstract by Eversman et al as printer in The Bryologist). (286)

Eversman, S. . 1998. Lichens of Grand Teton National Park. Pages 295-308 in Glenn, M. G., et al. Lichenographia Thomsoniana: North American lichenology in honor of John W. Thomson. Mycotaxon, Ltd, Ithaca, NY.

Two hundred twenty-one lichen species in 72 genera were identified from collections made in 1995 in Grand Teton National Park. Previous reports included four species not encountered in 1995. Nearly half the species (49%) were saxicolous, mostly on granitic substrates; 24% of the species were corticolous or lignicolous, 9% were terricolous, and the remaining species were on other substrates (decaying wood, plant debris, moss, litter, other lichens). Crustose species were 43% of the total number; 33% were foliose, 16% were fruticose, and 8% were squamulose. The lichen species and their distribution reflect the cold continental climate of the park, vegetation patterns, fire history, and perhaps human use of the valley part of the park. (Abstract by Eversman. As printed in Lichenographia Thomsoniana: North American lichenology in honor of John W. Thomson) (287)

Fahnestock, J.T., Detling, J.K. 1999. The influence of Herbivory on Plant Cover and Species Composition in the Pryor Mountain Wild Horse Range, USA. Plant Ecology. 144(2):312-320.

Effects of short-term and long-term ungulate grazing on plant species cover and composition in arid lowland and more mesic upland communities of the Pryor Mountain Wild Horse Range. (288)

Fisk, M.C., Schmidt Steven K., Timothy R. Seastedt. 1998. Topographic patterns of above- and belowground production and nitrogen cycling in alpine tundra. Ecology.79:7 p. 2253-2266.

Topography controls snowpack accumulation and hence growing-season length, soil water availability, and the distribution of plant communities in the Colorado Front Range alpine. Nutrient cycles in such an environment are likely to be regulated by interactions between topographically determined climate and plant species composition. We investigated variation in plant and soil components of internal N cycling across topographic gradients of dry, moist, and wet alpine tundra meadows at Niwot Ridge, Colorado. We expected that plant production and N cycling would increase from dry to wet alpine tundra meadows, but we hypothesized that variation in N turnover would span a proportionately greater range than productivity, because of feedbacks between plants and soil microbial processes that determine N availability. Plant production of foliage and roots increased over topographic sequences from 280 g?m-2?yr-1 in dry meadows to 600 g?m-2?yr-1 in wet meadows and was significantly correlated to soil moisture. Contrary to our expectation, plant N uptake for production increased to a lesser degree, from 3.9 g N?m-2?yr-1 in dry meadows to 6.8 g N?m-2?yr-1 in wet meadows. In all communities, the belowground component accounted for the majority of biomass, production, and N use for production. Allocation belowground also differed among communities, accounting for 70% of total production and 80% of N use for production in dry meadows compared to 55% of production and 65% of N use for production in moist meadows. Variation in microbial processes was highly related to soil moisture, and we found very consistent relationships among microbial respiration, gross N mineralization, and N immobilization among communities. These results indicate that the topographic soil moisture gradient is in fundamental control of the patterns of N turnover among communities and that differences in plant species do not appear to be as important. (Abstract by Fisk et al as printed in Ecology). (289)

Hadly-Barnosky, E.A. 1994. Grassland change over 2,000 years in Northern Yellowstone Park. Pp. 319 in plants and their environments: Proceedings of the First Biennial Scientific Conference on the Greater Yellowstone Ecosystem, D. Despain ed. Tech. Rep, NPS/NRYELL/NRTR, denver, CO: U.S. Department of the Interior, National Park Service, Natural Resources Publication Office.

Plant communities of the northern range in Yellowstone Park are composed of a patchwork of microhabitats locally governed by a variety of environmental factors including slope, aspect, substrate, effective moisture, and soil type, to name a few. Along the Lamar River, upstream of its confluence with the Yellowstone River, microhabitat ecotones are especially pronounced along moisture gradients. The majority of the large till-covered surface above the river is sparsely vegetated with grassy patches and sagebrush (Artemisia). Mesic sites with denser grass are found in small swales and drainages. North-facing slopes are covered with Douglas fir (Pseudotsuga menziesii) forest. (Abstract by Hadley-Barnosky as printed in Plants and their environments: proceedings of the first biennial scientific conference on the Greater Yellowstone Ecosystem). Evidence from a paleontological site, Lamar Cave, suggests that the spatial coverage of these and other microhabitats has changed during the past 1,700 years. At least 1,500 years ago the prairie vole (Pitymys ochrogaster) occupied the study area, as did the western jumping mouse (Zapus princeps). Neither now occupies the study area, and both are tall-grass inhabitants today. Also at 1,500 years ago, relative percentages of small mammals [voles (Microtus) that dwell in mesic microhabitats today were prevalent over those that favor open, xeric grasslands [ground squirrels (Spermophilus)]. By 1,000 years ago, this condition

was reversed, with ground squirrels dominating the faunal assemblage at the cave and the prairie vole and jumping mouse absent from the record. Slightly more mesic conditions gave returned since 1,000 years ago, as evidenced by a slight rise in vole percentages relative to ground squirrels; however, the present is still drier than the mesic condition of 1,500 years ago. This evidence from the small mammal fossils of Lamar Cave indicates that grass density has changes over 2,000 years and suggests that microhabitats expand and contract with changing environmental conditions, in this case probably effective moisture. (290)

Heidel, Bonnie, Fertig, Walter. 2001. Vascular Plant Species Checklist of Bighorn Canyon National Recreation Area (Montana and Wyoming). Wyoming Natural Diversity Database, Laramie, WY.

2001 Vascular Plant Checklist of Bighorn Canyon National Recreation Area, Montana and Wyoming. Prepared for National Park Service-Bighorn Canyon National Recreation Area and the Greater Yellowstone Network. (292)

Johnson, P. L. and W. D. Billings. 1962. The alpine vegetation of the Beartooth Plateau in relation to cryopedogenic processes and patterns. Ecological Monographs 32: 105-135.

Abstract in Progress (293)

Kay, C. E. , Wagner, F. H. . 1994. Historic condition of woody vegetation on Yellowstone's northern range: a critical test of the "natural regulation" paradigm. Pages 151-169 in Despain, D. G. . Plants and their Environments: proceedings of the First Biennial Scientific Conference on the Greater Yellowstone ecosystem, Sept 16-17, 1991, Mammoth Hot Springs Hotel. Natural Resources Publication Office, Denver, Colorado.

The Park Service's "natural regulation experiment" is predicated on the assumption that large numbers of elk (12,000-15,000) have wintered on Yellowstone's northern range for the last several thousand years. Agency biologists believe that the park's vegetation coevolved with these herbivores and reached equilibrium conditions, which they term "ecological carrying capacity." According to this model, elk influences on the vegetation are "natural" and represent the "pristine" condition of the park. If this paradigm is correct, early historic photographs of woody vegetation should show that aspen, willows, and conifers were as heavily browsed or highlined by ungulates in the early years of the park's existence as they are today, and aspen stem damage by elk was the norm then as it is now. To evaluate these predictions and to test the "natural regulation" paradigm, we reviewed approximately 50,000 early images taken in the park. Photos of aspen stands on the park's northern range taken during the 1880's and 1890's do not show any evidence of elk-induced bark damage. Photos of aspen, willows, and conifers taken from 1872 to the 1890's do not show evidence of ungulate browsing or highlining. Some early photos do show occasional conifers that lacked their lower branches, but evidence indicates that this was caused by light groundfires burning or killing the lower branches and by human removal of branches. Previous authors apparently confused fire and human highlining with that caused by ungulates.

Conifers and other woody vegetation in these 1870-1890 images were approximately 70-100 years old or older when they were photographed. Since they show no evidence of ungulate use, this suggests that few, if any, elk wintered in Yellowstone from the late 1700s through the 1870s.

Thus, ungulate highlining of conifers and repeated browsing of other woody vegetation are not "natural" and represent a departure from conditions that existed before the establishment of Yellowstone National Park. These photographs do not support the Park Service's contention that Yellowstone was always a major elk wintering area and that the northern herd did not increase and alter the vegetation. Since these data do not support one of the key assumptions upon which "natural regulation" is based, that paradigm must be rejected. (Absract by Kay and Wagner as printed in Plants and their Environments: Proceedings of the First Biennial Scientific Conference on the Greater Yellowstone ecosystem). (294)

Knight, D.H., G.P. Jones, Y. Akashi, and R.W. Myers. 1987. Vegetation ecology in the Bighorn Canyon National Recreation Area. Final Rept. To U.S. Natl. Pk. Serv. And Univ. of WY, Natl. Pk. Serv. Res. Ctr. Dept. Botany, Univ. of WY, Laramie. 114 pp.

The ecology of terrestrial vegetation in the Bighorn Canyon National Recreation Area (BCNRA) was studied during the period 1984-1986. Seventy-five stands, distributed throughout the BCNRA, were sampled for plant species cover and various environmental characteristics. A vegetation classification and map were developed, the data were analyzed using gradient analysis techniques, and the results were synthesized with those from other relevant studies in the region. In general, the vegetation of the BCNRA is 40% juniper/curlleaf mountain mahogany woodland, 16% riparian vegetation, 15% desert shrubland, 12% sagebrush steppe, 8% grassland, 6% coniferous woodland, 2% agricultural land, 1% marsh, and 0.1% Great Plains shrubland. Some of these general vegetation types were sub-divided, creating 21 types that are included on the black-and-white, 1:24,000 map. All types except marshes and agricultural land are discussed in this report, with the discussion focusing on adaptations of the dominant plant species, environmental factors affecting the distribution of each vegetation type, vegetation changes that have occurred and can be expected to occur in the future, certain aspects of weed ecology, and characteristics of the vegetation mosaic along the north-south axis of the Recreation Area. The riparian vegetation appears to be changing most rapidly, due in large part to flood control on the Shoshone and Bighorn Rivers. The suppression of fires and floods, combined with grazing and the creation of mudflats by fluctuating Bighorn Lake water levels, have produced ideal conditions in the riparian zone for the invasion of various exotic plants, saltcedar in particular. The report concludes with a section on using vegetation data to facilitate management activities. (Abstract by Knight et al as printed in the Final Report to U.S. National Park Service and the University of Wyoming). (295)

Lesica, Peter and Achuff, Peter, Mapping the distribution of Rare plants and plant communities for reserve design in Pryor Mountain Desert, Carbon County, Montana, 1992. Northwest Environmental Journal 8(1):179-181.

This report is the summary of the study which focused on 35 species of vascular plants listed as species of special concern or of limited distribution by the Montana Natural Heritage Program. Locations were mapped, population density estimated, and soil and vegetation information was recorded for each population observed. (296)

Merrill, E. H. , Stanton, N. L. , Hak, J. C. . 1996. Responses of bluebunch wheatgrass, Idaho fescue, and nematodes to ungulate grazing in Yellowstone National Park. Pages 73-84 in Singer,

F. J. . Effects of grazing by wild ungulates in Yellowstone National Park. U. S. Department of the Interior, National Park Service, Denver CO

We sampled above and belowground biomass of Idaho fescue (Festuca idahoensis) bluebunch wheatgrass (Agropyron spicatum) plants and nematode densities under these species inside and outside a 2-year old exclosure on the northern range of Yellowstone National Park in May through September, 1990. Native ungulates grazed the site primarily in winter and early spring. Grazing during this period removed essentially all the standing dead plant material. In early May, green biomass of plants of both species outside the exclosure was significantly lower than plants in the exclosure but off-take by ungulates accounted for only 18-51% of this initial difference. Indirect effects of grazing, such as the effects of removing standing dead material on microclimatic conditions, likely influenced early growth. By the end of the growing season, both species had similar biomass to ungrazed plants despite an increase in root-feeding nematodes early in the growing season. Lower root biomass, higher densities of bacteria-feeding nematodes (no./g root biomass), and higher concentrations in foliar nitrogen (N) with grazing suggested that root mortality, due to spring grazing, provided a short-term source of carbon for microbial activity and that microbial-feeding nematodes increased the turnover rates of microbial bound N. Densities (no./g root biomass) of root-feeding nematodes increased rather than decreased with grazing. Because N concentration of roots did not differ between grazed and ungrazed plants, we suggest that there was a reduction in secondary chemicals or an increase in root hairs, which are preferred sites for nematode feeding. (Abstract by Merrill et al as printed in Effects of grazing by wild ungulates in Yellowstone National Park). (298)

Mueggler, W.F. 1988. Aspen Community types of the Intermountain Region. Gen. tech. Rep. INT250. Ogden, UT: U.S. Department of Agriculture, Forest Service, Intermountain Research Station.

This vegetation classification is based upon existing community structure and composition in the aspen-dominated forest of the Intermountain Region of the Forest Service. The 56 community types occur within eight tree-cover types. A diagnostic key using indicator species facilitates field identification of the community types. Vegetational composition, productivity, and successional status are included. Tables provide detailed comparisons of community types. The classification and description are based upon field data from over 2,100 aspen stands scattered over southeastern Idaho, western Wyoming, Utah, and Nevada. (Abstract by Mueller as printed in GTR-INT-250). (299)

Mullenders, W. , Coremans, M. . 1996. Modern pollen spectra from Yellowstone National Park, Grand Teton National Park, Wind River Range and adjacent regions, Wyoming. Pages 1-44 in Gullentops, F. Pleistocene Palynostratigraphy. Edition Peeters, Leuven, Belgium.

More than 200 surface samples were collected for comparison between modern pollen spectra and present vegetation as an aid to interpretation of fossil pollen diagrams. The modern samples do not reproduce exactly the surrounding vegetation. (300)

No Editor/Author. Plants and their Environments: First Biennial Scientific Conference on the Greater Yellowstone ecosystem, Sept 16-17, 1991, Mammoth Hot Springs Hotel; agenda and abstracts.

Abstract in Progress (301)

O'Brien, E. M., Field, R. and Whittaker, R. J. (2000) Climatic gradients in woody plant (tree and shrub) diversity: water-energy dynamics, residual variation, and topography. Oikos, v. 89 pp 588-600.

Recent studies at the macro-scale have demonstrated that geographic gradients in the richness of plants, in particular of woody plants, such as trees and shrubs, can be viewed as by-products of water-energy dynamics. According to this view, they are climatic rather than latitudinal/longitudinal gradients, relating to coincident and predictable variation in planetary surface-atmosphere thermal dynamics and consequent patterns in biological activity. Previous analyses have shown that a two-variable model capturing the dynamic relationship between energy (heat/light) and water (rainfall) accounts for most of the variation in woody plant richness across southern Africa at species, genus, and family levels. Here we move towards a more complete explanation, while demonstrating how geographic analysis of residuals can be used to identify the type and sequence of additional variables for inclusion, either at the same or at more discrete scales of analysis. Residual geographic variation in richness from the two-variable model displays a geographic pattern unrelated to longitude and latitude. Regional clusters of under- and over-prediction point to macro-scale variation in topographic relief as a significant. When topographic is added as a third variable, the explanatory power (R2) increases by 7 to 12%, and the subsequent pattern of variation in residuals becomes even more unpredictable. What clustering remains points to other macro-, and meso- or micro-scale variables that need to be considered. Such a top-down, trans-scalar approach permits systematic and objective development of more complete explanations, while the three-variable macro-scale model developed herein is the basis for a powerful research tool for ecologists, biogeographers, conservationists and bio-climatologists alike. (Abstract by O'Brien et al as printed in Oikos). (302)

Patten, D.T. 1969. Succession from sagebrush to mixed conifer forest in the Northern Rocky Mountains. Am. Mid. Nat. 82: 229-240.

In northwestern Yellowstone National Park, lodgepole pine is invading sagebrush areas. The vegetational composition and environment of sagebrush, lodgepole pine, and intermediate sites were studied. Young lodgepole pine had little influence on the environment or vegetational composition of the sagebrush; however, when lodgepole pine was mature the shade-intolerant species, including sagebrush, were eliminated and shade-tolerant species developed. In the mixed conifer forest the environment was suitable for further development of climax conifers. Thus, lodgepole pine is not only a fire-successional species but part of a normal climatically caused sere originating with vegetation dominated by big sagebrush. (Abstract by Patten as printed in The American Midland Naturalist). (304)

Patten, R.S., Knight, D.H. 1994. Snow avalanches and vegetation pattern in Cascade Canyon, Grand Teton National Park, Wyoming, USA. Arctic Alpine Research. 26 1: 35-41.

Snow avalanches in Cascade Canyon, Grand Teton National Park, have a significant effect on the region's vegetation mosaic, increasing the area's community diversity and creating a fragmented vegetation pattern. The structure and persistence of communities within avalanche

tracks is a function of the frequency of avalanche occurrence. In many areas, shrub cover and conifer density increase as avalanche frequency increases. Conifers decrease in size yet increase in age as avalanches occur more often, a consequence of slower growth rates in trees within avalanche tracks. Because the probability of avalanche damage to conifers is related to the size of the tree, slow growth rates result in small trees that can survive many years in avalanche tracks, contributing to the persistence of the avalanche community. The canyon's vegetation patterns appear fairly stable due to the spatial and temporal consistency of avalanche occurrence and the persistence of communities in avalanche tracks. The primary effect avalanches have on this landscape is to increase the fragmentation of the vegetation patterns rather than to drive dynamic changes in the landscape mosaic. (305)

Peet, Robert K. 2000. Forests and meadows of the Rocky Mountains. Chapter 3 in: Barbour, M. G. and W. D. Billings (editors). North American Terrestrial Vegetation. Second Edition. Cambridge University Press. (Gives a very good description of the context for the vegetation of the parks.)

Abstract in Progress (306)

Perryman, B.L., A.M. Maier, A.L. Hild, and R.A. Olson. 2001. Demographic characteristics of 3 Artemisia tridentata Nutt. subspecies. J. Range Manage. 54:2 p.166-170.

Previous research suggested that woody plant recruitment may occur in pulses on semi-arid areas. The overall objective of this study was to determine if this pulse phenomena was recorded in the demographic structures of big sagebrush (Artemisia tridentata Nutt.) stands in Wyoming. In 1997, approximately 75 stem cross sections were collected from 9 stands of each of 3 subspecies of big sagebrush in Wyoming along elevation and climatic gradients. Annual growth-rings were used to identify year of establishment and demographic characteristics were analyzed from age-class frequencies. Mean stand ages of the 3 subspecies were different (P=0.002), and analyses revealed that Wyoming (A. tridentata spp. wyomingensis) and mountain big sagebrush (A. tridentata spp. vaseyana) stand ages (32 ? 9 and 26 ? 9 years, respectively) were significantly older than basin big sagebrush (A. tridentata spp. tridentata) (17 ? 3) stands (P < 0.05). Mean recruitment intervals (years) were shorter for basin (1.6) than for Wyoming (2.3) and mountain (2.2) sagebrush (P=0.01). The number of cohorts did not differ among the subspecies (P=0.11), but the percent of years with recruitment was significantly higher for basin (59%) compared to Wyoming (37%) and mountain (39%) subspecies (P<0.0001). Age-class frequency distributions of each stand and regional stand combination were assessed for dispersion across each associated period of record. Chi-square goodness-of-fit tests were performed for the negative binomial distribution. All stands (with one exception) and all 3 regional stand combinations fir the negative binomial distribution. Age-class frequency patterns indicate that recruitment is clustered or aggregated across each period of record. Recruitment in big sagebrush stands occurs in pulses throughout Wyoming. (Abstract by Perryman et al as printed in Journal of Range Management). (307)

Piennetti, R. R. Menezes, M. Coughenour. 2001. Changes induced by elk browsing on willow (Salix monticola) woody biomass, production and distribution,; its relationship with plant water, carbon, and nitrogen dynamics. Oecologia. 127(3):334-342.

Willows are dominant woody plants of many high elevation riparian areas of the western USA, and constitute an important food resource for various ungulates, which tend to concentrate in riparian areas. The response of willow to browsing was analyzed in the elk winter range of Rocky Mountain National Park, by considering the effect of elk browsing on Salix monticola Bebb, one of the most common willow species in this area. Unbrowsed and browsed treatments were established during the 1997 growing season (May to October), using eight long-term exclosures built in the fall of 1994. Plants in the browsed treatment were in the areas open to browsing, but they were protected from browsing by small exclosures during the experimental period. Winter browsing by elk induced the following measured responses in plant morphology and development: (1) higher shoot biomass production but similar leaf biomass and leaf area per plant, (2) a lower number of and bigger shoots, (3) a lower number of and bigger leaves, and (4) flower inhibition. In addition, we infer that browsing induces (5) lower belowground allocation and (6) a more negative N balance but a higher soil N uptake. We conclude that elk browsing negatively effects willow even though willow compensate for above ground biomass removal. Continuous browsing produces long-term changes in willow morphology which constrain plant growth and development. High browsing utilization, as occurred in this experiment, could therefore reduce the competitive ability and survivorship of willow, in particular under drier environmental conditions. (Abstract by Peinetti et al as printed in Oecologia). (308)

Pyke, D.A., J.E. Herrick, P. Shaver, and M. Pellant. 2002. Rangeland health attributes and indicators for qualitative assessment. Journal of Range Management 55

Panels of experts from the Society for Range Management and the National Research Council proposed that status of rangeland ecosystems could be ascertained by evaluating an ecological site's potential to conserve soil resources and by a series of indicators for ecosystem processes and site stability. Using these recommendations as a starting point, we developed a rapid, qualitative method for assessing a moment-in-time status of rangelands. Evaluators rate 17 indicators to assess 3 ecosystem attributes (soil and site stability, hydrologic function, and biotic integrity) for a given location. Indicators include rills, water flow patterns, pedestals and terracettes, bare ground, gullies, wind scour and depositional areas, litter movement, soil resistance to erosion, soil surface loss or degradation, plant composition relative to infiltration, soil compaction, plant functional/structural groups, plant mortality, litter amount, annual production, invasive plants, and reproductive capability. In this paper, we detail the development and evolution of the technique and introduce a modified ecological reference worksheet that documents the expected presence and amount of each indicator on the ecological site. In addition, we review the intended applications for this technique and clarify the differences between assessment and monitoring that lead us to recommend this technique be used for moment-in-time assessments and not be used for temporal monitoring of rangeland status. Lastly, we propose a mechanism for adapting and modifying this technique to reflect improvements in understanding of ecosystem processes. We support the need for quantitative measures for monitoring rangeland health and propose some measures that we believe may address some of the 17 indicators. (Abstract by Pyke as printed in Journal of Range Management). (309)

Romme, W. H. , Turner, M. G. , Wallace, L. L. , Walker, J. S. 1995. Aspen, elk, and fire in northern Yellowstone National Park. Ecology. 76 7: 2097-2106.

Most stands of trembling aspen (Populus tremuloides) in northern Yellowstone National Park appear to have become established between 1870 and 1890, with little regeneration since 1900. There has been controversy throughout this century regarding the relative roles of browsing by elk (Cervus elaphus) and fire suppression in preventing aspen regeneration. Fires in 1988 burned 22% of the northern ungulate winter range in the park, and created an unusual opportunity to investigate interactions between fire, ungulate browsing, and aspen regeneration. We tested two hypotheses. (1) The fires would stimulate such prolific sprouting of new aspen stems in burned stands that many stems would escape ungulate browsing and regenerate a canopy of large aspen stems. (2) Browsing pressure would be so intense that it would inhibit aspen canopy regeneration in the burned stands, despite prolific sprouting, but increased forage production in the burned areas would attract elk so that they would not seek out remote aspen stands, and hence, aspen regeneration would occur in unburned aspen stands remote from the burned areas. We sampled aspen sprout density, height, growth form, and browsing intensity in six burned aspen stands, six unburned stands close (lt 1 km) to the burned area, and six unburned stands remote (gt 4 km) from the burned area. Density of sprouts was generally greater in the burned stands than in the unburned stands in spring 1990 (2 yr after the fires), but was approaching the density of unburned stands by fall 1991. There were no significant differences in browsing intensity (percent of aspen sprouts browsed by ungulates) in 1990 or 1991 among burned, unburned close, or unburned remote stands, nor were there differences in relation to growth form (juvenile vs. adult sprouts). Unbrowsed sprouts generally were lower than the depth of the snowpack, suggesting that elk browsed nearly all sprouts that were accessible. The age distribution of 15 aspen stands across the northern winter range indicated that regeneration of large canopy stems had been episodic even prior to the establishment of the park in 1872. The period 1870-1890, when the present-day aspen stands were generated, was historically unique: numbers of elk and other browsers were low, climate was relatively wet, extensive fires had recently occurred, and large mammalian predators of elk (e.g., wolf, Canis lupus) were present. This combination of events has not recurred since 1900. The recent paucity of aspen regeneration in northern Yellowstone National Park cannot be explained by any single factor (e.g., excessive elk numbers or fire suppression) but involves a complex interaction among factors. (310)

Roundy, B.A., J.A. Young and R.A. Evans. 1981. Phenology of salt rabbitbrush (Chrysothamnus nauseosus ssp. consimilis) and greasewood (Sarcobatus vermiculatus). Weed Sci. 29:448-454.

Salt rabbitbrush [Chrysothamnus nauseosus (Pallas) Britt., ssp. consimilis (Greene)] and greasewood [Sarcobatus vermiculatus (Hook.) Torr.] grow slowly in early spring until mid to late May. They then begin a period of rapid growth, at which time susceptibility to foliar herbicides is probably greatest. Greasewood ceases rapid growth in mid June to early July, but salt rabbitbrush continues to grow rapidly until early August. Greasewood that resprouts after herbicide application has a longer rapid-growth period than shrubs in an untreated stand. An average leader length of 4 cm indicates that rapid growth of salt rabbitbrush is underway, and first opening of the flower buds indicates that rapid growth is over. Appearance of greasewood staminate spikes indicates that rapid growth has begun, and the first appearance of dried spikes indicates that growth has ceased. Simultaneous control of these shrubs with a single application

of phenoxy herbicides may only be possible during the relatively short period when both are growing rapidly. This period may only occur from late May to mid June in some stands and years, but may occur from mid may to early July in other cases. (311)

Schimel, D.S., W.J. Parton, T.G.F. Kittel, D.S. Ojima, and C.V. Cole. 1990. Grassland biogeochemistry: Links to atmospheric processes. Climatic Change 17:13-25. [ISI citation index = 79]

Regional modeling is an essential step in scaling plot measurements of biogeochemical cycling to global scales for use in coupled atmosphere-biosphere studies. We present a model of carbon and nitrogen biogeochemistry for the U.S. Central Grasslands region based on laboratory, field, and modeling studies. Model simulations of the geography of C and N biogeochemistry adequately fit observed data. Model results show geographic patterns of cycling rates and element storage to be a complex function of the interaction of climatic and soil properties. The model also includes regional trace gas simulation, providing a link between studies of atmospheric geochemistry and ecosystem function. The model simulates nitrogenous trace gas emission rates as a function of N turnover and indicates that they are variable across the grasslands. We studied effects of changing climate using information from a global climate model. Simulations showed that increases in temperature and associated change sin precipitation caused increases in decomposition and long-term emission of CO2 from grassland soils. Nutrient release associated with the loss of soil organic matter caused increases in net primary production, demonstrating that nutrient interactions are a major control over vegetation response to climate change. (Abstract by Shimel et al as printed in Climatic Change). (312)

Shaw, Richard J. 1992. Vascular plants of Grand Teton National Park and Teton County. Grand Teton Natural History Association, Salt Lake City, UT.

This checklist was assembled for several reasons: (1) my Field Guide to the Vascular Plants of Grand Teton National Park and Teton County, Wyoming which appeared in 1976 has long been out of print; (2) over 125 additional species have been found in the park and county that were not recoginzed in 1976; (3) tremendous changes have occurred in roads and trails within the park in the last sixteen years as well as a startling increase in the population in the county; (4) a list is needed which summarizes the known information of the flora for visitors, students and vegetation mangers. (314)

Singer, F. J. , Harter, M. K. 1991. Effects of long-term protection from elk grazing on bunchgrass and big sagebrush communities on Yellowstone's winter range. Pages 34-35 in No Editor/Author. Plants and their Environments: First Biennial Scientific Conference on the Greater Yellowstone ecosystem, Sept 16-17, 1991, Mammoth Hot Springs Hotel; agenda and abstracts.

The effects of long term protection of plant communities form elk grazing were studied at 8 large (2 ha) enclosures constructed in 1985 and 1962. Shrub transects were read at approximately 5-year intervals during the 1958-1990 period. Grassland measures were taken inside of and in adjacent grazed sites in 1986-1987 at all of the enclosures and during four of the years, 1986-1990, at the Blacktail Deer Creek enclosures.

Winter grazing by elk resulted in less standing crop biomass of grasses only in 1986, following a drier than normal spring. Total grasses were not influenced by grazing in any other year, and total forbs were not influenced by grazing in any year ($P>0.05$). Biomass of two grasses, June grass (Koeleria cristata) and thick spiked wheatgrass (Agropyron spicatum), were more abundant on grazed sites, while only one grass, Poa sandberghi, and 2 nongrasses, Artemesia frigida and Phlox hoodii, were less abundant on grazed sites ($P < 0.05$). Morphological characteristics were not influenced by grazing, with the exception that vegetative culms of grasses were shorter on grazed sites. There was one-quarter the litter and one-third more bare ground on grazed sites. Grazing enhanced the protein content of common grasses 10-36 %, but grazing did not significantly influence the digestibility of grasses. Protein content varied 8-20% between years. Grazing slightly enhanced other nutrients (Ca, Mg, K) in Idaho fescue (Festuca idahoensis) ($P < 0.05$), but not in junegrass or bluebunch wheatgrass (A. spicatum). Heights of seed stalks of bluebunch wheatgrass were shorter in 1986 than in the other three years, further suggesting that the growing conditions in 1986 were less than optimum. Seed heights are often used as an indicator of grass vigor. About 16% more grass biomass was produced under big sage cover than in open bunchgrass communities. Soil moisture was not influenced by grazing, and soil moisture did not vary between sage and open grass stands.

Protection from ungulates benefited big sagebrush growth and reproduction at the lower enclosures near Gardiner. Pronghorns (Antilocapra Americana) and mule deer (Odocoileus hemionus) also winter in this area and the big sage subspecies involved is the more palatable Artemesia tridentate Wyomingensis, or Wyoming big sage. Numbers of big sage increased 348% and cover increased 828% inside the enclosures, 1958-1962, while numbers of big sage declined 40% and cover declined 29% on grazed sites.

Big sage trends were similar on grazed and protected sites at the remaining higher elevation enclosures. Numbers of big sage declined an average of 20% on both grazed and protected sites, but the big sage individuals were taller and larger, 1958-1990. Big sage canopy volumes increased 440% on protected sites and increased 210% on grazed sites. Only elk and bison (Bison bison) winter at the higher sites; they eat less big sage, and the big sage subspecies are the less palatable Basin and Mountain big sage (A. t. triaentata and A. t. vaseyana). All shrubs, except common rabbitbrush (Chrysothamnus nauseosus), were shorter and smaller in volume on grazed sites. Big sage averaged 16% taller on protected sites, horsebrush (Tetradeymia canescens) was 91% taller and green rabbitbrush (C. viscidiflorus) was 42% taller. Common rabbitbrush individuals were 36% taller and crown volumes were 200% larger on grazed sites. Shrub seedling reproduction was more common and age class distributions were younger on grazed sites. Apparently either the reduction in competition through reduced shrub size or trampling by ungulates enhanced shrub establishment on grazed sites. Abstract by Singer and Harter. As printed in Plants and their Environments: First Biennial Scientific Conference on the Greater Yellowstone ecosystem.) (315)

Spence, John R. 1980. Vegetation of subalpine moraines in the Teton Range, Grand Teton National Park, Wyoming. Utah State University, Logan, UT.

This study attempts to characterize the environment and plants that are found growing on the neoglacial moraines and other glacial deposits of neoglacial age in front of the glaciers in the Teton Range, located in Grand Teton National Park, Wyoming. (316)

Sprugel, D. G. 1991. Disturbance, equilibrium, and environmental variability: What is "natural" vegetation in a changing environment?. Biological Conservation. 58 1: 1-18.

To most early ecologists, the "natural" ecosystem was the community that would be reached after a long period without large-scale disturbance (fire, windstorm, etc.). More recently, it has been realized that in most areas some type of large-scale disturbance is indigenous, and must be included in any realistic definition of "naturalness". In some areas an equilibrium may exist in which patchy disturbance is balanced by regrowth, but in others equilibrium may be impossible because (1) individual disturbances are too large or infrequent; (2) ephemeral events have long-lasting disruptive effects; and/or (3) climate changes interrupt any movement toward equilibrium that does occur. Examples of non- equilibrium ecosystems include the African savannas, the Big Woods of Minnesota, the lodgepole pine forests of Yellowstone National Park, and possibly the old-growth Douglas-fir forests of the Pacific Northwest. (317)

Stohlgren, T. J., M. B. Coughenour, G. W. Chong, D. Binkley, M. A. Kalkhan, L. D. Schell, D. J. Buckley, and J. K. Berry. 1997. Landscape analysis of plant diversity. Landscape Ecology. 12:3 p.155-170.

Studies to identify gaps in the protection of habitat for species of concern have been inconclusive and hampered by single-scale or poor multi-scale sampling methods, large minimum mapping units (MMU's of 2 ha to 100 ha), limited and subjectively selected field observations, and poor mathematical and ecological models. We overcome these obstacles with improved multi-scale sampling techniques, smaller MMU's (< 0.02 ha), an unbiased sampling design based on double sampling, improved mathematical models including species-area curves corrected for habitat heterogeneity, and geographic information system-based ecological models. We apply this landscape analysis approach to address resource issues in Rocky Mountain National Park, Colorado. Specifically, we quantify the effects of elk grazing on plant diversity, identify areas of high or unique plant diversity needing increased protection, and evaluate the patterns of non-native plant species on the landscape. Double sampling techniques use satellite imagery, aerial photography, and field data to stratify homogeneous and heterogeneous units and "keystone ecosystems'' (ecosystems that contain or support a high number of species or have distinctive species compositions). We show how a multi-scale vegetation sampling design, species-area curves, analyses of within- and between-vegetation type species overlap, and geographic information system (GIS) models can be used to quantify landscape-scale patterns of vascular plant diversity in the Park. The new multi-scale vegetation plot techniques quickly differentiated plant species differences in paired study sites. Three plots in the Ouzel Burn area (burned in 1978) contained 75 plant species, while only 17 plant species were found in paired plots outside the burn. Riparian areas contained 109 plant species, compared to just 55 species in paired plots in adjacent forests. However, plant species richness patterns inside and outside elk exclosures were more complex. One elk exclosure contained more species than its adjacent open range (52 species inside and 48 species outside). Two elk exclosures contained fewer species inside than outside (105 and 41 species inside and 112 and 74 species outside, respectively). However, there was only 26% to 48% overlap (using Jaccard's Coefficient) of plant species composition inside and outside the exclosures. One elk exclosure had 13% cover of non-

indigenous species inside the exclosure compared to 4% outside, but non-indigenous species cover varied by location. We compared plant diversity patterns from vegetation maps made with 100 ha, 50 ha, 2 ha, and 0.02 ha MMU's in the 754 ha Beaver Meadows study area using four 0.025 ha and twenty-one 0.1 ha multi-scale vegetation plots. Preliminary data suggested that the 2 ha MMU provided an accurate estimate of the number of plant species (–14%) for a study area, but the number of habitats (polygons) was reduced by 67%, and aspen, a unique and important habitat type, was missed entirely. We describe a hypothesis-driven approach to the design and implementation of geospatial databases for local resource monitoring and ecosystem management. (Abstract by Stohlgren et al as printed in Landscape Ecology). (318)

Tinker, D. B. , et al. 1994. Landscape-scale heterogeneity in lodgepole pine serotiny. Canadian Journal of Forest Research. 24 5: 897-903.

A 1992 study of serotiny in lodgepole pine (Pinus contorta Dougl. ex Loud. var. latifolia Engelm.) in Yellowstone National Park asked four questions: (i) are there morphological characteristics that can be used to estimate prefire proportion of serotinous trees in forests that burned in 1988?; (ii) at what spatial scale does percent serotinous trees vary across the landscape?; (iii) which environmental factors are correlated with serotiny?; and (iv) what is the relationship between prefire serotiny and postfire lodgepole pine seedling density? We first sampled cone characteristics in serotinous and nonserotinous trees along four 2950-m transects in unburned forests, and examined burned trees nearby. Results indicated that asymmetrical cones and an acute angle of cone attachment to the branch were reliable indicators of serotiny even in burned trees. We then sampled nine patches of lodgepole pine forest that had burned in 1988, and varied in size from 1-3600 ha. We sampled serotiny at varying intervals along two perpendicular transects that crossed in the center of each patch. At each sample point, the 12 nearest canopy lodgepole pines were classified as serotinous or nonserotinous. We concluded that the percentage of serotinous trees is most variable at intermediate scales of 1-10 km, and is relatively homogeneous at both fine scales (lt 1 km) and at very broad scales (tens of kilometers). Percent serotiny was generally more variable and greater at low to middle elevations. Prefire density of serotinous trees was a more important predictor of postfire seedling density than aspect, slope, or soil type. These findings have important implications for landscape-level patterns in postfire regeneration of lodgepole pine. (319)

Wambolt, C. L. , Sherwood, H. W. . 1999. Sagebrush response to ungulate browsing in Yellowstone. Journal of Range Management. 52 4: 363-369.

"Big sagebrush (Artemisia tridentata) has decreased as a result of ungulate (Odocoileus hemionus hemionus, Antilocapra americana americana and Cervus elaphus nelsoni) browsing during the first half of the twentieth century on the Northern Yellowstone Winter Range, Wyoming, USA. The shrub characteristics of Northern Yellowstone Winter Range sagebrush habitat types continually browsed were compared with those protected for 32-37 years. Measurements were taken in and out of exclosures for 19 environmentally paired, protected, and browsed sites. There were significant differences in development between protected and browsed shrubs. Big sagebrush canopy cover at the 19 sites averaged 19.7% with protection and 6.5% where browsed and plants were twice as numerous under protection. Winter forage production of

individual big sagebrush plants was also greater under protection at 16 of the 19 paired sites. Subdominant sprouting shrubs generally responded the same as big sagebrush." (320)

West, Neil E. 1994. Effects of fire on salt-desert shrub rangelands. In: Monson, Stephen B.; Kitchen, Stanley G., comps. 1994. Proceedings-ecology and management of annual rangelands; 1992 May 18-21; Boise, ID. Gen. Tech. Rep. INT-GTR-313.Ogden, UT: U.S.

Fire was not thought to be a driving variable in slat-desert shrub ecosystems prior to 1983. The El Nino related extreme wetness of 1983-85 resulted in a profusion of mostly exotic annuals followed by wildfires. Unfortunately, the most productive sites, near the upper boundary of the type, have been most often affected. Major species such as shadscale (Atriplex confertifolia) and budsage (Artemisia spinescens) do not resprout following fire. Winter fat (Ceratoides lanata), saltbush (Atriplex nuttallii), gray molly (Kochia americana) and black greasewood (Sacrobatus vermiculatus) do resprout, but subsequent populations appear reduced. (Abstract by West as printed in General Technical Report INT-313). (321)

White, C. A. ., Olmsted, C. E. , Kay, C. E. . 1998. Aspen, elk and fire in the Rocky Mountain national parks of North America. Wildlife Society Bulletin. 26 3: 449-462.

Across 6 Rocky Mountain parks aspen shows consistent responses to increased browsing by ungulates and decreased frequency of fire. Most stands are in decline. Aspen stands regenerate well in areas of low elk density and in some areas of moderate ek density, but in areas of high and very high elk density doesn't grow over 2 m. Burning accelerates clone deterioration. (322)

WATER

Boyle, T. P., and N.J. Hoefs, 1991, An Analysis of Factors Contributing to the Stability of Benthic Macroinvertebrate Communities in Lotic Ecosystems: Bulletin of the Ecological Society of America, v. 72, p. 74.

Structural and functional attributes of benthic macroinvertebrate communities have been used historically as indicators of water quality and biological criteria of the environmental health of lotic systems. There has been little examination of the limitations or qualifications of what environmental conditions make it appropriate to use various attributes of the benthic macroinvertebrate community in environmental assessments. One goal of developing ecological risk analysis techniques is to be able to distinguish the natural uncertainty in bioindicators due to environmental conditions from those anthropogenically induced. Approaches to determine the variability of the macroinvertebrate community due to natural conditions will affect their use as an environmental assessment tool. Data on the macroinvertebrate communities from the Virgin River, Utah; St. Croix River, WI&MN; Niobrara River in NE; Platte River, Otter Creek, Shalda Creek and Crystal River in MI; and Wilson Creek, MO were analyzed for community characteristics suitable for analysis for environmental impact. Key characteristics of the physical and chemical environment such as patterns of hydrological discharge, substrate, organic loading, etc. were analyzed as natural forces shaping community structure in these different areas that determine the appropriateness and type of community analysis scheme to be used in different

conditions. (Abstract by Boyle and Hoefs as printed in Bulletin of the Ecological Society of America). (656)

Brooks, K. N., P. F. Folliott, H. M. Gregersen, and L. F. DeBano. 1997. Hydrology and the Management of Watersheds. Second Edition. Iowa State University Press. Ames, Iowa. pp 502.
Abstract in Progress (323)

Clark, G. M. , et al. 1998. Water quality in the upper Snake River basin, Idaho and Wyoming, 1992-95. USGS.
Abstract in Progress (353)

Davis, J.C., G.W. Minshall, C.T. Robinson, and P.B. Landres. In press. Monitoring wilderness stream ecosystems. USDA Forest Service General Technical Report RMRS-GTR-21. Rocky Mountain Research Station, Ft. Collins, CO.
A protocol and methods for monitoring the major physical, chemical, and biological components of stream ecosystems are presented. The monitoring protocol is organized into four stages. At stage 1 information is obtained on a basic set of parameters that describe stream ecosystems. Each following stage builds upon stage 1 by increasing the number of parameters and the detail and frequency of the measurements. Stage 4 supplements analyses of stream biotic structure with measurements of stream function: carbon and nutrient processes. Standard methods are presented that were selected or modified through extensive field application for use in remote settings. (Abstract by Davis et al as printed in General Technical Report RMRS-GTR-70). (324)

Farnes, P.E., C. Heydon, and K. Hansen. 1999. Snowpack distribution across Yellowstone National Park, Wyoming. Final Report. Contract No. 291601. Yellowston Center for Resources, Yellowstone National Park, WY.
Data on snowpack distribution, snow depth and snow density, daily precipitation/snow water equivalent, daily temperature correlated with plant and animal responses. Data from National Weather Stations and NRCS SNOTEL stations; ca. 1948 on. Some data near realtime. Ca. 20 high elevation sites in YNP from which daily data is available. Has average monthly precipitation over 30 year span; differences by elevation. Info on maxiumum elevation of the Lake throughout this century; which has implications for bird nesting and trout spawning, etc. Data helps in index of winter severity (IWS) for elk, bison etc. which relates to reproduction, mortality, predation. Use different weights for different species, but snow usually weighted most. Has table of effective critical temperatures (for bison, 29 below!). Determines forage production, drought index, growing degree days (GDD), and when plants can break dormancy. Some years there aren't enough gdds to mature grasses. Affects migration patterns. Can calculate SWE for any slope or aspect. With snow structure info can predict avalanche probability. Can predict crops of whitebark pine nuts, grizzly emergence from den. (325)

Gibert, J., D.L. Danielopol, J.A. Stanford (1994): Groundwater Ecology. Academic press, San Diego, California.
Abstract in Progress (327)

Heede, B. H. 1992. Stream Dynamics: an overview for land managers. USDA Forest Service General Technical Report RM-72.
Abstract in Progress (328)

Leopold, L. B. 1995. A view of the river. Academic Press, New York.
Abstract in Progress (331)

Lowry, M.E., H.W. Lowham, and G.C. Lines. 1976. Water resources of the Bighorn Basin, northwestern Wyoming. U.S. Geol. Surv. Hydrologic Investigations, Atlas HA-512. Reston, VA. 2 color maps.
Abstract in Progress (332)

Marston, R. A. , Anderson, J. E. . 1991. Watersheds and vegetation of the Greater Yellowstone Ecosystem. Conservation Biology. 5 3: 338-346.
This paper describes major watershed systems and broad patterns of vegetation within the Greater Yellowstone Ecosystem, explains the geographic links between these systems, and proposes factors that could be used to measure the integrity (condition and naturalness) of watersheds and vegetation. The Greater Yellowstone Ecosystem is the headwaters for three major continental-scale river systems: the Missouri-Mississippi, Snake-Columbia, and Green-Colorado. Features, processes, and materials of watersheds provide structure and key functions to ecosystems of Greater Yellowstone. Changes in elevation - and the accordant changes in precipitation, temperature, land forms, and the stream network - exert the strongest control on the distribution of plant species in the Greater Yellowstone Ecosystem. The condition and naturalness of watersheds and vegetation remain to be quantified, but both decline with distance away from the core of the Greater Yellowstone Ecosystem due to timber harvest, oil and gas exploration and development, mineral exploration and development, reservoir operations, flood control, agricultural development, and livestock grazing. (333)

Maupin, Molly A. 1995. Water-quality assessment of the upper snake river basin, Idaho and Western Wyoming-environmental setting, 1980-92. U.S. Geological Survey Water Resources Investigations Report 94-4221.
The 35,800-square-mile upper Snake River Basin is one of 20 areas studied as part of the National Water-Quality Assessment (NAWQA) Program of the U.S. Geological Survey. Objectives of NAWQA are to study ground- and surface-water quality, biology, and their relations to land-use activities. Major land and water uses that affect water quality in the basin are irrigated agriculture, grazing, aquaculture, food processing, and wastewater treatment. Data summarized in this report are used in companion reports to help define the relations among land use, water use, water quality, and biological conditions. The upper Snake River Basin is located in southeastern Idaho and northwestern Wyoming and includes small parts of Nevada and Utah. Total population in the basin was about 425,000 in 1990. Major urban areas are Idaho Falls, Pocatello, Rexburg, and Twin Falls, Idaho, which make up 10, 11, 3, and 6 percent of the total population, respectively. Climate in the basin is mostly semiarid and mean annual precipitation ranges from 8 to more than 60 inches. The eastern Snake River Plain is the major geologic

feature in the basin and is delineated mostly by Quaternary and Tertiary basalt flows. It is about 55 to 62 miles wide and 320 miles long and bisects the basin in a northeast-southwest direction. The Snake River is the dominant surface-water feature and flows about 453 miles from the southern border of Yellowstone National Park in Wyoming to King Hill, Idaho, where it leaves the basin. The Snake River flows through river reservoirs that provide a total storage capacity of more than 4 million acre-feet. Gravity-flow diversions are predominant in the upper part of the basin and totaled 8.8 million acre-feet in 1980. Pumped diversions occur mainly in the lower part of the basin and totaled 08,500 acre-feet in 1980. The Snake River Plain aquifer is the predominant ground-water feature in the upper Snake River Basin and underlies the eastern Snake River Plain. The upper 500 feet of the aquifer may store 200 to 300 million acre-feet of water. Ground-water resources that supply agricultural lands are sustained by recharge from surface-water irrigation, precipitation, and tributary inflow. Major ground-water discharges are at springs and seeps of from ground-water pumpage for irrigation.
Water use in the basin is dominated by irrigated agriculture, which is the largest consumptive water use in the basin. Major crops in the basin include potatoes, wheat, sugar beets, hay, and barley. Most irrigation needs are supplied from surface-water sources through a series of canals and laterals. In 1990, about 2.5 million acres were irrigated with more than 14.2 million acre-feet of surface and ground water. About 21 percent of the basin is agricultural land and 50 percent is rangeland. Idaho leads the Nation in trout production for commercial sale. Combined mean annual discharges from 12 aquacultural facilities in the basin (1985-90) were about 787,000 acre-feet. These facilities are clustered in a reach of the Snake River between Milner Dam and King Hill where ground-water discharge is from many seeps and springs that provide sufficient quantities of good-quality water. Other facilities that release effluent to the Snake River include 13 municipal wastewater treatment plants and 3 industrial facilities. (Abstract by Maupin as printed inWater-Resources Investigations Report 94-4221). (661)

Minshall, G. W. , Brock, J. T. . 1991. Observed and anticipated effects of forest fire on Yellowstone stream ecosystems. Pages 123-136 in Keiter, R. B. , Boyce, M. S. . The Greater Yellowstone ecosystem: redefining America's wilderness heritage. Yale University Press, New Haven.

Abstract in Progress (666)

Norton, D., Friedman, I., 1991. Chloride flux and surface water discharge out of Yellowstone National Park, 1982-1989: U.S. Geol. Surv. Bull. 1959, 42 pp.

Chloride flux was calculated by the product of discharge and chloride concentration for the major rivers draining the Park. Large annual changes occur attributed to changes in height of the water table caused by variations in precipitation. (336)

Peterson, D.A. And S.D. Porter. 2002. Biological and chemical indicators of eutrophication in the Yellowstone River and major tributaries during August 2000. Proceedings: 2002 National Monitoring Conference, National Water Quality Monitoring Council.

The trophic condition of the Yellowstone River and its major tributaries during low-flow conditions was better represented by algal biomass and community autecology than by nutrient concentrations in water samples. Nutrient concentrations generally were low throughout the

length of the Yellowstone River, however indicators of algal biomass and the percentage of eutrophic and nitrogen-indicator diatoms were relatively high in the middle segments of the river and near the mouths of major tributaries. Algal biomass and community composition were influenced by the availability of nitrogen and water turbidity. Biomass increased with the abundance of eutrophic taxa, and was relatively small at sites dominated by nitrogen-fixing blue-green algae. Eutrophication of streams and rivers in the Yellowstone River basin is influenced by nitrogen inputs from human sources along the river corridors and within the watershed. Algal community indicators can provide an early warning of accelerated eutrophication processes, long before nuisance algal growths contribute to water-quality problems. (Abstract by Peterson and Porter as printed in 2002 National Monitoring Conference Proceedings). (660)

Plafcan, M., E.W. Cassidy, and M.L. Smalley. 1993. Water resources of Big Horn County, Wyoming. U.S. Geological Survey Water-Resources Investigations Report 93-4021. 142 pp.

Ground water in unconsolidated aquifers is the most reliable and accessible source of potable water in Big Horn County, Wyoming. Well yields generally ranged from 25 to 200 gal/min (gallons per minute), however, yields of 1,600 gal/min are reported from wells in the gravel, pediment, and fan deposits. Bedrock aquifers that yield the most abundant water supplies are the Tensleep Sandstone, Madison Limestone, Bighorn Dolomite, and Flathead Sandstone. The aquifers with the most potential for development as a water supply, predominately composed of sandstone, are the Lance, Mesaverde, and Frontier Formations. The Madison Limestone, the Darby Formation, and the Bighorn Dolomite form the Madison-Bighorn aquifer. Reported yields from the aquifer ranged from 40 to 14,000 gal/min. Flowing wells from the Madison-Bighorn aquifer had shut-in pressures ranging from 41 to 212 pounds per square inch (95 to 490 feet above land surface).

Shut-in pressures from flowing wells in bedrock indicate declines, from the time the wells were completed in 1988, as much as 390 feet. Flows have also decreased over time. Water samples from wells completed in unconsolidated aquifers have concentrations of dissolved solids less than 2,000 mg/L (milligrams per liter). Water from unconsolidated aquifers are classified as a calcium sulfate type, a sodium type, and sodium-calcium sulfate type. Water samples from well completed in aquifers in Paleozoic and Precambrian rocks had median concentrations of dissolved solids ranging from 111 to 275 mg/L. Water samples from wells in Tertiary and Cretaceous rocks had a medium concentration of dissolved solids raging from 1,107 to 3,320 mg/L. Water types from these aquifers were usually sodium sulfate. Perennial streams originate in the mountains and ephemeral streams originate in the Bighorn Basin. Irrigation return-flow to streams maintains perennial flow in what would otherwise be ephemeral streams. Streams that originate in the Bighorn Basin have specific conductance values generally greater than 1,000 mg/L, whereas streams that originate in the Bighorn Mountains have specific conductance values generally less than 1,000 mg/L. The predominant dissolved constituents are calcium or sodium and bicarbonate or sulfate. Concentrations of pesticides detected in surface-water samples were less than the U.S Environmental Protection Agency (USEPA) maximum contaminant levels. The detected concentration of pesticides in streambed material in the organochlorine insecticide class ranged from 0.1 to 8.0 micrograms per kilogram. Pesticides detected in ground-water samples included dicamba and picloram at a concentration of 0.40 ?g/L (micrograms per liter), atrazines (0.40 ?g/L), aldicarb sulfone (1.44 ?g/L), aldicarb sulfoxide (0.52 ?g/L), and malathion

(0.02 ?g/L). Analyses of ground-water samples for radionuclides indicate that concentrations from four municipal wells exceeded the maximum contaminant level established by the USEPA. Of these four wells, concentrations in water samples from the municipal well at Frannie consistently exceeded the USEPA maximum concentration level for dissolved gross alpha activity of 15 pCi/L (picocuries per liter) and radium-226 plus radium-228 (5 pCi/L). The source of the radioactivity is postulated to be the Madison Limestone. Surface water accounts for 96 percent and ground water accounts for 4 percent of total offstream water use in Big Horn County, Wyoming. Irrigation is the largest offstream use of both surface and ground water. About 99 percent of offstream surface water and 55 percent of ground water is used for irrigation. Eighty-two percent of the water used for irrigation is consumed, which includes a 37-percent conveyance loss and 45 percent consumed by the irrigated crops. Ground water supplies 89 percent of water used for domestic purposes and about 16 percent of water used for public supplies, which shows that ground water is a primary domestic water supply in rural areas where public supplies are not available. (Abstract by Plafcan et al. As printed in Water resources of Big Horn County) (664)

Robinson, C.T. and G.W. Minshall. Physical and chemical responses of streams in Yellowstone National Park following the 1988 wildfires. In: Greenlee, J. ed. 1996. The ecological implications of fire in Greater Yellowstone: Second biennial conference on t

Study examined 5 years of change in physical and chemical properties of 21 stream sites differently affected by the 1988 fires. Degree of physical change was assessed using summed Coefficients of Variation. (668)

Stanford, J.A. and John J. Simons (Eds.). 1992. Proceedings of the First International Conference on Ground Water Ecology. American Water Resources Association, Bethesda, MD. 420pp.

Abstract in Progress (340)

Thorpe, J., and A. Covich, editors. 1991. Ecology and Classification of North American freshwater Invertebrates. Academic Press, Inc., NY. 911 pp.

Abstract in Progress (341)

Turk, J.T. and N.E. Spahr. 1991. Rocky Mountains: controls on lake chemistry. In: D.F. Charles, ed. Acidic Deposition and Aquatic Ecosystems. Regional Case Studies. Ch 14:471-503. Springer Verlag, New York.

Abstract in Progress (342)

Winter, T.C., J.W. Harvey, O.L. Franke, and W.M. Alley. 1999. Ground water and surface water-a single resource. U.S. Geological Survey Circular 1139. 77 pages.

Abstract in Progress (659)

Wolman, M. G. and J. P. Miller. 1960. Magnitude and frequency of forces in geomorphic processes. Journal of Geology. 68: 54-74.

The relative importance in geomorphic processes of extreme or catastrophic events and more frequent events of smaller magnitude can be measured in terms of (1) the relative amounts

of "work" done in the landscape and (2) in terms of the formation of specific features of the landscape. For many processes, above the level of competence, the rate of movement of material can be expressed as a power function of some stress, as for example, shear stress. Because the frequency distributions of the magnitudes of many natural events, such as floods, rainfall, and wind speeds, approximate log-normal distributions, the product of frequency and rate, a measure of the work performed by events having different frequencies and magnitudes will attain a maximum. The frequency at which this maximum occurs provides a measure of the level at which the largest portion of the total work is accomplished. Analysis of records of sediment transported by rivers indicates that the largest portion of the total load is carried by flows which occur on the average once or twice each tear. As the variability of the flow increases and hence as the size of the drainage basin decreased, a larger percentage of the total load is carried by less frequents flows. In many basins 90 per cent of the sediment is removed by storm discharges which recur at least once every five years.
Transport of sand and dust by wind in general follows the same laws. The extreme velocities associated with infrequent events are compensated for by their rarity, and it is found that the greatest bulk of sediment is transported by more moderate events.
Many rivers are competent to erode both bed and banks during moderate flows. Observations of natural channels suggest that the channel shape as well as the dimensions of meandering rivers appear to be associated with flows at or near the bankfull stage. The fact the bankfull stage recurs on the average once every year or two years indicates that these features of many alluvial rivers are controlled by these more frequent flows rather than by the rarer events of catastrophic magnitude. Because the equilibrium form of wind-blown dunes and of wave-formed beaches is quite unstable, the frequency of the events responsible for their form is less clearly definable. However, dune form and orientation are determined by both wind velocity and frequency. Similarly, a hypothetical example suggests that beach slope oscillates about a mean value related in part to wave characteristics generated by winds of moderate speed. Where stresses generated by frequent events are incompetent to transport available materials, less frequent ones of greater magnitude are obviously required. Closer observation of many geomorphic processes is required before the relative importance of different processes and of events of differing magnitude and frequency in the formation of given features of the landscape can be adequately evaluated. (Abstract by Wolman as printed in Journal of Geology). (343)

Young, H.W., Parliman, D.J., Jones, M.L., and Stone, M.A.J., 1991, Hydrologic and water-quality data for selected sites, Grand Teton National Park, Wyoming, September 1988 through September 1990: U.S. Geological Survey Open-File Report 91-0056, 23 p.

This report presents data collected from 13 observation and 10 production wells in and near Grand Teton National Park, Wyoming, from September 1988 through September 1990. The data include measurements of depth of well, depth to waterm and analyses of selected water-quality characteristics. These data were collected as part of a continuing monitoring program being conducted in cooperation with the National Park Service. (Abstract by Young et al as printed in USGS Open File Report 91-56). (344)

WILDLIFE

Aguirre, A. Alonso, Starkey, Edward E. 1994. Wildlife Disease in U.S. National Parks: Historical and Co evolutionary Perspectives. Conservation Biology. 8 3: 654-661.

Diseases of wildlife have significant management implications in a number of lands of the U.S. National Park Service due to increasing interactions between wildlife and domestic animals. We review the paleontology, history, and coevolution of infectious diseases in North American ungulates. We provide two examples related to bovine brucellosis in bison in Yellowstone and lung-worm-pneumonia complex in bighorn sheep in several western national parks. These examples illustrate the difficulty of managing wild populations and their diseases in national parks and other protected areas. In some instances, human intervention may be justifiable in order to protect native populations, domestic animals, and humans from acquiring a disease. (348)

Bohac, J., and R. Fuchs. 1991. The structure of animal communities as bioindicators of landscape deterioration. Pp. 165-178 In D. W. Jeffrey and B. Madden (eds.) Bioindicators and Environmental Management. Academic Press, London, England, UK.

Biodiagnostic evaluation methods were developed during the five years 1986-1990. Biodiagnostic investigations are made on a range of life forms and at various scales. They are performed both at population and community level. The data on plants and animals must e obtained at the appropriate scale of the investigation (local, regional, fluvial). Biomonitoring at regional and fluvial scales is mainly by using populations of small mammals and communities of birds. These groups, owing to their large size and migratory birds, are optimal bioindicators of the complex of factors which degrade the landscape and lead to air pollution. Populations and communities of invertebrates are mainly used for biomonitoring at a local scale. These groups have small body sizes and a lower tendency for migration, and are therefore suitable for indicating local environmental factors such as unsuitable application of fertilizers and pesticides, unsuitable methods of landscape management, overdrainage and the consequential desiccation of the landscape. Biomonitoring at the local scale is often the sole method for the investigation of biotic conditions in reserves and national parks. The investigation of key organisms and their communities in portions of the landscape is important for the research at the regional scale. The mosaic of various well-preserved landscape units increases the stability of the landscape. (Abstract by Bohac as printed in Bioindicators and Environmental Management). (349)

Coleman, S. . 1995. Disease research and monitoring of Yellowstone's wildlife. Investigator's Annual Report.

primarily bison to begin with (350)

Consolo-Murphy, S., and K. Murphy. 1999. Wildlife at Yellowstone: the story behind the scenery. K.C. Publications, Inc., Las Vegas, Nev. 64 pp.

Abstract in Progress (351)

Olliff, T., K. Legg, and B. Kaeding, eds. 1999. Effects of winter recreation on wildlife of the GYA: a literature review and assessment. Report to the Greater Yellowstone Coordinating Committee. Yellowstone National Park, Wyoming. 315 pp.

Abstract in Progress (665)

Ream, C. H. . 1980. Impact of backcountry recreationists on wildlife: an annotated bibliography. General Technical Report INT-84.

An annoted bibliography and evaluation of the literature on the effects of backcountry recreationalists on wildlife. Literature was taken from biological, managerial, sociological, and popular publications. Orientation includes decriptions of impacts and methods of reducing impacts of recreationists on wildlife. (Research summary by Ream as printed in GTR-INT-84). (352)

VI. CONCEPTUAL MODELS

A. AQUATIC ECOSYSTEM NARRATIVE CONCEPTUAL MODEL—BOB HALL

The GYRN contains a diverse group of lakes , both natural and human-made. There are numerous glacier-carved lakes in high alpine areas of the Teton Range, and several large lakes formed from tectonic processes. Bighorn Canyon contains a large impoundment, and the top 8 m of Jackson lake is regulated by a dam at its outlet. The large lakes contain substantial biological and economic resources. For example, Yellowstone lake has the largest population of Yellowstone cutthroat trout (*Onchoryncus clarki bouveri*) (Gresswell and Varley 1988). These lakes are used extensively for recreation, such as boating and fishing. Bighorn and Jackson lake are used for water storage.

River ecosystems are equally diverse in the GYRN. Rivers ranges from large lake outlets (e.g. Snake and Yellowstone rivers, to many high-mountain streams, and geothermally influenced rivers in the Madison drainage and South Boundary area of YNP. High variation in groundwater source, parent material, and topography lead to high variation in the types of streams within GYRN. In terms of ecosystems functions such as whole stream metabolism and nitrogen processing, streams within GTNP are more variable than 11 streams within different biomes ranging from the tropics to Alaska (Hall and Tank 2003).

In this narrative I will only consider the aquatic part of rivers as the riparian section is covered elsewhere, though stressors to streams and lakes can come from habitat damage to the riparian zone..

Drivers.

Lakes are formed by exogenous processes (glacial scour, plate movement, dams, differential cooling of lava in the case of Yellowstone lake), and these processes shape the morphometry of the lake which, in turn will determine most aspects of its function. Climate plays a large role in temperature, hydrology and mixing regime of lakes. Human activities can affect lakes by altering hydrology, climate, nutrient load and biotic assemblages. Drivers for rivers are similar to those for lakes, except with the fundamental difference that rivers morphology is a function of the hydrology (driven by climate) of the river and geology of the drainage basin as channel structure changes through time. Changes in climate will affect hydrology and temperature of rivers, and humans can strongly impact rivers by altering hydrology, geomorphology and biotic assemblages.

Stressors and impacts to ecological processes.

Temperature: Climate change may be an important stress to Yellowstone ecosystems over the long term. Lakes can be used as bellwethers of climate changes and will likely be affected by global climate change. Long term records of ice-out on lakes suggest warming of lakes (Likens 2000, Magnuson 2000) and effects of climate change in the watershed, e.g. increased fire frequency, may alter lake dynamics (Schindler et al. 1996). Increasing temperature will affect biota of rivers directly, e.g. by limiting distribution of coldwater species (Rahel et al. 1996). Alternatively increased temperature could provide for faster growth rates of fish in rivers and lakes,

including invasive lake trout (Hill and Magnuson 1990), which may change predator-prey dynamics in lakes.

Water level and river hydrology: Lakes that are hydrologically managed (e.g. Jackson Lake, Bighorn lake) will have fluctuating water levels that can potentially lake food webs and ecosystem function. Lakes are linked to their shoreline and receive a fraction of their energy inputs from allochthonous inputs, coarse woody debris which provides habitat, and may control terrestrial predator interactions (Schindler and Scheuerell 2002). Changing water level may decrease allochthonous inputs and may limit access of the lake by terrestrial predators (e.g. otters).

Rivers can by altered hydrologically from dam operations (e.g. Snake river), which can alter biotic assemblages (Stanford and Ward 1989). Water removal for irrigation can reduce instream flows and flood peaks in the summer, (e.g. Gros Ventre River, Bighorn River, Shoshone River, Spread Creek). Additionally climate change may alter stream hydrology (Poff 2002) which will affect all aspects of river ecosystem function (Meyer et al. 2000, Firth and Fisher 1995) ranging from food web interactions (Power et al. 1995) to nutrient cycling.

Sedimentation and geomorphology. An important stress, covered in the riparian narrative.

Solute concentrations. Solutes include all dissolved solids in water, which strongly affect lake ecosystems. Drought, and fire change cation import to lakes (e.g. Schindler et al. 1996) High mountain lakes may be subject to acidification if they are poorly buffered; however western mountains tend to have lower acid inputs than Northeastern US mountains. In the Snowy Range, SE Wyoming, despite low acid-neutralizing capacity of lakes, acidification is not yet evident because pH of precipitation is higher than that in the Eastern US. (Reuss et al. 1995)

Nutrient loading. Eutrophication from excess nutrients is a pervasive stress on many lakes and rivers in the US by increasing primary production, changing biotic assemblages and lowering water clarity; estimating the effects of this eutrophication has a long history (Smith 1998). Local development and atmospheric deposition can cause nutrient loading even in large mountain lakes such as Lake Tahoe. For example, increased N loading to Lake Tahoe has increased primary production and decreased water clarity (Goldman 1988). The effect of excess nutrients to rivers is much less well known; experimentally increased P loading to a tundra river increased primary productivity, moss biomass and secondary production (Peterson et al. 1993). Phosphorus is often considered the limiting nutrient for lakes and streams, however it is now recognized that nitrogen often limits production as well (Elser et al. 1990). Nitrogen is most likely to be the limiting nutrient for most lake ecosystems within the GYRN; almost all streams in GTNP are N limited (J. L. Tank and R. O. Hall unpublished data). Planktonic algae responded greatly to N additions in experimental bioassays showing that N was primarily limiting in Yellowstone and Jackson lakes (Interlandi and Kilham 1998), thus we suggest that N will be a more important pollutant than P in the GYRN.

In the West, there are areas with high N loading from atmospheric deposition, particularly near cities and areas downwind from power plants or intensive agriculture Fenn et al. 2003b). Loch Vale in Rocky Mountain National Park receives 3-5 kg N ha^{-1} y-1, (Baron et al. 2000), and this N has been implicated in changing the phytoplankton assemblages in these lakes (Wolfe et al. 2001). Lakes in the GRYN are fairly low-nutrient (Interlandi et al. 1999) thus they

are likely to respond to small increases in nutrients similarly to Tahoe. Indeed, eastern Idaho and the Teton range are projected to have high rates of N deposition (Fenn et al. 2003b). Primary sources would most likely be atmospheric deposition or from local inputs from towns and settlements within the parks. High mountain lakes could be most susceptible because they can receive high N loads from atmospheric deposition, and many lakes in the west have high nitrate concentrations (Fenn et al. 2003a), although there are almost no data represented in their paper from western Wyoming, despite have large high elevation areas with crystalline bedrock that is potentially susceptible to increased nitrate loading.. Although N deposition rates are low in areas far from cities (e.g. west slope of Colorado Rockies, Baron et al. 2000), deposition could increase as NO_x emissions and local development increases (see Vitousek et al. 1997).

Rivers upstream of Bighorn canyon run through agricultural areas an have elevated nutrient loads ands N and P (Water Resources Division, National Park Service1998), which might contribute to the eutrophic nature of Bighorn Lake (Lee and Jones 1981).

Exotic species: Exotic species are one of the most pervasive environmental problems in the US and the GYRN has received some well-publicized invasions that can potentially alter aquatic ecosystems. Lake trout (*Savelinus namaycush*) have invaded Yellowstone lake and may lower native cutthroat trout populations (Stapp and Hayward 2002a, Ruzyicki et al. 2003) and may extend to predators outside the lake (Stapp and Hayward 2002b). Lake trout can consume 14% of juvenile cutthroat trout (*Onchorhyncus clarki*) populations per year, even when numbers are controlled by gill-netting. Whirling disease has also invaded rivers in Yellowstone which may impact cutthroat trout populations (Ruzyicki et al. 2003). New Zealand mud snails (*Potamopyrgus antipodarum*) have invaded many rivers in the GYRN and are likely having severe impacts. In Polecat Creek, New Zealand mud snails constitute 90% of invertebrate biomass, and represent the largest fluxes in the nitrogen cycle (Hall et al. in review). Secondary production of mud snails in Polecat Creek is one of the highest rates ever recorded for an aquatic invertebrate (Hall et al. in preparation). It is not likely that these will be the last invasions, as Simberloff and Von Holle (1999) suggest that invasions beget more invasions; evidence in the Great Lakes suggests that this hypothesis is true, as the invasion rate is increasing non-linearly. (Ricciardi 2001).

Potential Indicators

Indicators can be integrative assessments of biological condition (Karr 1981, 1999) (i.e. looking for the effect). Measuring biotic condition is important because it represent the impact that managers and visitors to the parks care about: Are there fish to catch? Are there wildlife to observe? Is the lake clear? Also, biota can indicate multiple stressor and often provide a better information on change than hard-to measure-stressors (such as episodic pollution events (Karr 1999). Alternatively we can examine the stressor itself. Measuring changes in the stressor (if possible) is important for 2 reasons: One is that it may be possible to detect change in the stressor long before there is an impact to ecological processes. For example, N inputs or temperature may increase before the biotic assemblage responds. Invasion of an animal to a new ecosystem can be detected more easily than the impact to native populations or ecosystem processes. The other reason is that measuring the stressor may help to understand causes of observed biological changes. If lake clarity decreases concomitantly with nutrient loading, then increased nutrients are a strong causal hypothesis for this biological change.

1. Indicator: Nitrogen inputs

Justification. Atmospheric nitrogen input is a stressor that, if high enough, could increase primary production in lakes and streams. Given that most N loading to Yellsostone and Teton Parks is via atmospheric inputs (as opposed to urbanization or agriculture), measurement of nitrogen concentrations in precipitation may detect early changes to these inputs. There are few NADP sites in the GYRN and the one in Yellowstone is a low elevation where concentration and of nitrate and volume of precipitation are expected to be low. There are few high-elevation sites for N deposition in the intermountain west (Fenn et al. 2003b), thus inputs on N and changes of those inputs are relatively unknown for the GYRN.

Examples of specific measures: Annual wet and dry deposition of N at a few high and mid elevation sites within the GYRN.

2. Indicator: Nitrogen concentrations in aquatic ecosystems

Justification.: Atmospheric nitrogen input is a stressor that, if high enough, could increase primary production in lakes and streams. High alpine watershed lose most of their nitrogen during snowmelt (e. g. Reuss et al. 1995), and losses are proportional to inputs (Williams et al. 1996), despite processing of N in the shallow soils. Stream monitoring can detect long-term trends in deposition (Likens et al. 1996), and may provide a means to detect watershed-level response to N additions (Williams et al. 1996).

Examples of specific measures: Temporal sampling of stream water N throughout the year in Teton Range streams, Bighorn River and Lake and possibly some Yellowstone rivers. Surveys of N concentrations in lakes.

3. Indicator: Water Temperature

Justification. Global climate change may increase temperatures of lakes and streams which may alter animal habitat and interactions. Additionally, geologic change (e.g earthquake in Firehole River basin) may alter groundwater inputs with corresponding temperature changes in rivers. Measurement of temperature may be able to detect these changes which can be linked to any biological changes.

Examples of specific measures: Hourly recording of temperature in lake epilimnia and rivers via inexpensive recording thermometers. Ice out dates for major lakes.

4. Indicator: Surface hydrology

Justification: Hydrology of lakes and rivers in the GYRN can change from direct human modification (e.g. impoundments, water abstraction) or via changes in climate (Meyer et al. 1999). This monitoring is already occurring for several of the rivers in GYRN, e.g. Snake, Bighorn, Madison, Yellowstone, and 2 of the lakes, Jackson and Bighorn.

Examples of specific measures Lake water level, and large river discharge.

5. Indicator, River morphology and habitat assessment (as specified in riparian narrative)

6. Indicator. Algal species composition and biomass

Justification. Increased nutrients of changes to the food web (e.g. Carpenter et al. 1985) may change algal biomass, water clarity and species composition. Research in Yellowstone Lakes has shown that diatom species compositions predictably respond to slight changes nutrients according to their physiology (Interlandi et al. 1999), and these changes in assemblages may be sensitive indicators to nutrient inputs and associated climate change (Kilham et al. 1996). Algal species in high-elevation lakes can also signal changes in nutrient concentrations (Wolfe et al. 2001).

Specific measures: Chlorophyll a concentrations of algae in lakes. Secchi disk measurements (a measure of water clarity). Algal (mostly diatoms and some cyanobacteria) assemblage structure.

7. Indicator: Cutthroat trout responses to exotic predators.

Justification. Exotic lake trout and whirling disease can potentially lower densities of native Yellowstone cutthroat trout in Yellowstone lake; these effects may cascade to streams and predators outside of the lake (Stapp and Hayward 2002).

Specific measures. Long-term quantification of Yellowstone cutthroat trout density, age structure, spawning and recruitment in Yellowstone lake and its tributaries..

8. Indicator: River invertebrate assemblages.

Justification. Stream invertebrate assemblages may change in response to exotic species, sedimentation, nutrient load or predator population change. Stream invertebrates are often used as measures of water quality (Karr 1999) and is the current approach used by the state of Wyoming for water quality analyses (King 1993). They are sensitive indicators of change and they can integrate physical stressors that might otherwise be difficult to measure, and these changes can relate to changes in ecosystem function (Wallace et al. 1996). There are several approaches to using invertebrates to measure water quality; two current methods either develop a set of additive metrics (Kerans and Karr 1994), a local examples is Wyoming index of biotic integrity (WYIBI) (Stribling), Another method uses multivariate approaches to estimate predicted invertebrate assemblages which can be compared to measured assemblage structure. e.g. Hawkins et al. (2000). Long term monitoring of invertebrates may be able to detect change in response to exotic mud snails, and new, unforeseen invasions

Specific measures: Invertebrate assemblage structure, following approaches of current bioassessment methods.

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B. ALPINE-TIMBERLINE ECOSYSTEM NARRATIVE CONCEPTUAL MODEL—DUNCAN PATTEN

Although the alpine and timberline ecosystems are closely linked, they represent quite different sets of dynamic processes which result in potentially different indicators. Consequently, to understand these systems and model them to address possible indicators (vital signs), they are treated in many of the discussions below and in conceptual models (Figures x and y) as separate, but interrelated, systems.

Alpine Ecosystem General Description

The alpine ecosystem is one of the smallest in area within the GRYN. It occurs only at high elevations on summits, slopes and ridges above the local timberline (Billings 1988). The environments of the alpine ecosystem often are extreme with intense radiation, cold temperatures and wide temperature fluxes, extreme wind velocities, thin air, and often long-lasting snow and ice. Substrates in the alpine may be barren, rocky outcrops which create highly exposed environments, while other areas may have well developed soils, or substrates that are constantly being altered by frost action. Consequently, plants that survive in these extremes tend to grow near the ground, often in mats but also as isolated plants. Their productivity results from the combined stress of alpine environments (Scott and Billings 1964).

Timberline Ecosystem General Description

The sharpest environmental gradient in mountains is the ecotone between alpine and forest, the timberline zone. This ecotone is broadly defined as the upper limit of trees, a response to environmental stress (White 1996). It is related to the declining amount of biologically useful thermal energy with summer temperatures dictating the length of the growing season (Billings 1974). Physical factors such as weather, temperatures, snowdrifts, and soil conditions control whether woody forest species will establish and survive at high elevations. Trees growing at timberline grow at the same rate as several hundred meters below timberline (Paulsen et al. 2000), although isolated trees above the extensive timberline ecotone may have very slow growth, in part, because of foliage loss to wind and other factors. Treeline vegetation is sensitive to many environmental factors. Over a half century period, Klasner and Fagre (2202) saw changes in timberline forests in Glacier National Park with forests below the timberline becoming more dense and krummholz (twisted wood) stands becoming fragmented near trails.

Drivers and Related Stressors

Extreme environments of the alpine and timberline areas are common elements in these two systems allowing a combined discussion of the drivers. The drivers fall into five major categories: climate, geology, fire, human activities and biotic factors.

Climatic drivers or natural stressors are the most obvious set of parameters controlling processes at high elevations in the GRYN. At high elevations several factors become limiting and dominate physiological and growth processes of organisms (Tranquillini 1979). Temperature extremes with wide fluctuations play an important role both for organism survival but also physical processes. High radiation levels at high elevations can cause the ground surface to heat up during the day followed by rapid nighttime cooling. Extreme cold temperatures dictate physiological processes and are considered one of the primary causes of timberline, that is, only plants with

metabolic systems that can function at very cold temperatures during the short alpine growing season can grow at these elevations. Temperature extremes may function synergistically with other natural stressors to create even more extreme conditions. For example, wind combined with low temperatures may limit high elevation forest growth.

Wind is a constant force in the alpine environment. It may cause alpine temperatures to become more extreme by breaking down the boundary layer formed on physical and biological surfaces. Consequently, low temperatures become more "penetrating" and potential for freezing increases, while daytime highs on ground and other surfaces may be far above ambient temperatures. Wind may bring warmer temperatures from lower elevations to the alpine. Wind also drives ice and snow which scour and abrade surfaces and plant tissues, and causes snow to accumulate. Snow drifts often do not melt until well into the alpine growing season limiting early phonological stages of alpine plants.

The thin air at high elevations results in two different environmental drivers. Thin air allows a greater amount of solar radiation, especially in the ultraviolet (UV). UV-B can differ by a whole order of magnitude between a dry environment at sea-level and high alpine environments (Caldwell et al. 1980). Alpine plants have adapted to high UV by either absorbing it in the epidermis or reflecting it off leaves or other plant parts. Thin air also means lower partial pressure of gases, CO2 being the one of concern. Low CO2 levels control photosynthetic rates, and yet, photosynthetic efficiency of alpine plants is often greater than low-elevation plants tested within the same low CO2 atmosphere.

Drought is a climatic factor that can influence both composition of alpine plant communities and timberline. Alpine zones range from very wet to dry. Both extremes may produce conditions with low water availability, however, moisture gradients do create concomitant vegetation gradients in the alpine zone (Oberbauer and Billings 1981).

Fire is not a common driver in alpine ecosystems; however, in the past it was common in GRYN forests and thus played a role in modifying timberline forests. Forest fires in the montane and subalpine forests often reached to timberline destroying living timberline trees, or burning dead and down trees at that elevation zone. Evidence of the location of timberline may have been destroyed or reduced by fires reaching timberline. Remains of burned trees are used to determine extent of timberline forests. Dendrochronological techniques are used to date remnants of timberline forests allowing establishment of dates of forest encroachment into the alpine or withdrawal from alpine/timberline ecotones.

Disease is a natural occurrence in most ecosystems; however, disease and insect infestations, although cyclical, can alter the structure of alpine and timberline vegetation. Several types of conifer insect infestations and diseases have altered timberline forests, for example, bark beetle and bud worm. The cyclical nature of these diseases and infestations do not permanently alter the forest as it normally recovers at the end of the cycle.

High elevation ecosystems are permanently under environmental stress as environments at these elevations do not allow robust vegetation development, either in the alpine or at timberline.

Climate, geology, fire, human activities and biotic factors all play a role in creating stressful conditions. Here the term stressful applies not only to the normal extremes at these elevations but also to changing environments that may be natural or of human origin.

Climate and the resulting local weather conditions constantly influence alpine and timberline ecosystems. Many of these conditions are discussed above; however, long-term climatic cycles may ameliorate timberline environments and allow trees to grow at higher elevations. On the other hand, long-term colder and drier conditions may play a reverse role and cause the forest line to retreat in elevation. Recent human influence of the world climate may influence these long-term climatic patterns and indirectly alter "normal" timberline fluctuations. Climate models may allow predictions of possible climate change and thus concomitant changes in timberline elevations.

Short-term warm/cold cycles, sometimes only 24 hours long, may cause disruption of wet alpine soils, resulting in churning of soil particles and instability of the substrate. These disturbance can form small, fine soil "frost boils", extensive "rock nets", and solifluction terraces (Johnson and Billings 1962). Climatic changes that might prevent short-term freeze/thaw cycles, or extend the period between a thaw and freeze period, may alter the extent of frost action soils and greatly change the types of alpine vegetation establishing in these areas.

High elevations have thin air, consequently, the partial pressure of photosynthetic gases (i.e., CO2) is low resulting in the need for photosynthetically efficient plants. Reduced CO2 may not be considered a stressor as it is normal in the alpine zone, however, human caused increases of atmospheric CO2 may result in reduced need for photosynthetic efficient plants and possible changes in alpine plant communities. Also, timberline trees may produce more growth under an increased CO2 environment and better withstand the extreme environmental gradient at the alpine/timberline ecotone.

Wind also is a normal part of the alpine/timberline environment (Hadley and Smith 1986). . Climate models do not predict local wind patterns or velocities, but it is probable that with climate change, including changes in temperature gradients, wind patterns and velocities could change.

High elevations are known for high levels of radiation and the magnitude of UV is discussed above. However, human caused reduction in stratospheric ozone has increased the amount of UV entering the earth's atmosphere. Consequently, elevations that already receive high levels of UV can be expected to have increasing UV levels which will directly affect most biotic functions and survival of high elevation organisms. Eventual UV resistant adaptations may develop but this type of evolutionary process is long-term and plant community changes may take place before UV resistant adaptation does.

Fire has been mentioned as a normal part of forest dynamics directly influencing the timberline forest stands. However, fire suppression has modified the occurrence and extent of fires in the GRYN area directly changing an important timberline environmental factor. Reduced fires or possibly more extensive wildfires resulting from long-term fire suppression and fuel build up must be considered an environmental stressor of timberline forests even if fires are a normal part of forest dynamics.

Topography, that is, slope aspect and angle, is a relatively stable part of the alpine environment. Some changes occur under frost action solifluction (soil surface movement), but stability is the norm. It is included here as a stressor because at high elevations small changes in topography alter the extremes of the environment. Thus, plants growing in the shelter of an organic mound, or behind a rock in the alpine zone cannot grow out in an exposed location. The very limitations created by topography can be stressful to alpine plants.

Alpine vegetation is one of the most sensitive vegetation types in the Rocky Mountains (Billings 1973). It grows only in sheltered areas or on deeper soils that have existed for some time. Its sensitivity to external physical stress is illustrated recently by the loss of alpine communities in areas where there is high human use (Cole and Monz 2002). Human trampling loosens the plant surface, especially cushions or mats, making it susceptible to wind scour (Hartley 1976, Jackson 1998). National parks have put in trails with off-trail foot traffic excluded with the hope of protecting alpine plant communities in heavy human use areas. Increasing human use can only exacerbate human impacts.

Grazing (wild and domestic) alters composition of alpine areas through plant consumption and trampling. In the GRYN parks, grazing is limited to wild animals, but adjacent alpine areas (e.g., Beartooth Plateau) shows evidence of long-term erosion and trail development where domestic livestock have grazed. Although this is not as significant a stressor as some of the climatic factors, it works synergistically with other factors in the alteration of the alpine vegetation community.

Introduction of exotic plants in the alpine/timberline zone does not play as important a role in vegetation community modification as found in lower elevation zones. However, care should be taken to avoid introduction of exotic species, especially where trails and roads have been established in these high-elevations.

Disease is evident in all biotic communities of the GRYN. In alpine/timberline areas disease can be found in timberline forests, and in high elevation ungulate populations. White pine blister rust has become a disease of concern in the high elevation forests of the GRYN. Whitebark pine, a timberline species, has become infected over the past several decades (Kendall and Keane 2001). Although the magnitude of the disease is less in the GRYN than in areas like Glacier National Park, it still has potential of eliminating or greatly reducing the whitebark pine community, thus eliminating whitebark pine seeds, a primary food source for grizzly bear. Disease in the alpine community, although probably present, does not have the potential yet of greatly altering that community.

Processes, Outcomes, and Indicators

Interaction of several stressors influence alpine and timberline processes (Figures x and y). These interactions can be represented in several process submodels which explain in greater detail how factors influence each other.

Alpine Zone Processes, Outcomes, and Indicators

Soil frost dynamics. Interaction of temperature changes and soil moisture greatly modifies areas of the alpine zone through cyropedogenic processes (Johnson and Billings 1962). Cryopedogenic or soil frost action causes water to shrink and expand thus moving soil particles around. In some cases these processes are limited to small areas called "frost boils" where larger soil particles are pushed outward. These frost churned soils create instable locations that often prevent establishment of vegetation and long-term stability of the alpine vegetation community. Soil frost action can also sort larger rocks creating what are called "rock nets" or "rock polygons" in the alpine zone. In this case, sod may develop between the rocks and dense alpine plan communities establish. Alpine soils on steeper slopes my form "solifluction terraces" when the soil frost action expands the wet soils and gradually moves them down slope. These terraces are usually covered with alpine vegetation.

Scree slope dynamics. Many alpine and subalpine slopes are steep and relatively unstable. These scree and fellfield slopes often cannot support vegetation, although in some cases pockets of alpine herbs or shrubs may find sufficiently stable sites to establish (Griggs 1956). Again, thaw-freeze action can maintain instability of these slopes.

Alpine vegetation dynamics. Alpine plant communities are a product of all of the factors (and stressors) that influence the mountain plant communities found above timberline. Winds, high UV, wide temperature fluctuations, human and animal use, disease and introduced species all play a role, but the magnitude of that role varies. If future climatic changes reduce the potential for thaw-freeze actions, then those plants dependent on disturbed soils may decline. Increased human and animal activities in the alpine zone will also alter the vegetation composition of alpine communities. Consequently, plant species composition of in the alpine zone becomes a measure of the synergistic effects of all of the stressors.

The primary outcome of the several process models is vegetation composition and cover and shows the importance of environmental stress on plant communities (Kammer and Mohl 2002). Scree slopes and greatly altered frost action areas will have little vegetation cover, while alpine areas with well developed soils may have a continuous, dense plant cover. Changes in these vegetation characteristics in response to environmental stresses thus becomes indicators of the influence of these stressors on the alpine zone.

Timberline Processes, Outcomes and Indicators

Timberline elevation dynamics. Timberline, that is the elevation location of the ecotone between forest and alpine vegetation, has fluctuated over the past millennia (Carrera et al. 1991). The fluctuation is mostly driven by climatic factors, warmer or cooler climates, and/or wetter or drier climates (Hessl and Baker 1997). Human induced climate change may cause a rise in the elevation of timberline, if warmer is expected. Although this change is slow, evidence of past location of timberline can be found in presence of remnants of trees well up in the alpine zone. Dating of these trees can establish the time when forests occurred at higher elevations (Graumlich 1991, 1994). Establishment of a long-term record of timberline fluctuations may be a useful indicator of natural and human-induced influence on timberline forests.

Timberline woody plant dynamics. Composition of timberline forests vary according to the combined influence of those factors that limit forest species from advancing upwards on a mountain. For example, protective structures such as rocks, and coarse stable soils may allow forest species to establish at high elevations. Lack of these conditions may prevent forests from establishing higher, unless climatic factors ameliorate. Fire and disease have recently become more important factors in modifying timberline forest location and composition. If white pine blister rust mostly eliminates whitebark pine, then timberline forests will be primarily spruce and fir, or may be reduced to dead and dying trees above the subalpine forest. Extensive fires, a result of forest fire suppression, may also reach into the timberline forest destroying the existing trees. Recovery from fires then will be a result of ability of timberline tree species to regain their normal elevation location, a process that is difficult because of the extreme environments at these elevations. Consequently, the composition of the timberline forest, a product of natural and human activities, may be a good indicator of changes occurring within the GRYN regions parks.

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DSS INFORMATION FOR ALPINE/TIMBERLINE POTENTIAL INDICATORS

The ecosystems that compose alpine and timberline areas have developed in extreme environments. Wind, cold and thin air characterize the extremes that control these ecosystems, and yet, human activities also have influenced their present state. Changing environments, both natural and human caused, may alter the future conditions of alpine and timberline zones. Consequently, the indicators selected for the vital signs program will give a warning of the gradual changes these ecosystems may have as a changing local and global environment alters the drivers that form these sensitive, high elevation ecosystems.

Indicator: Timberline forest densities and health

Resource Monitored: Timberline forest, including large trees such as whitebark pine, and krummholz stands in exposed and protected areas.

Justification: Timberline in the Rocky Mountains, as in most temperate-zone mountains, has fluctuated in elevation over the past millennia. Changes in the elevation of timberline occur slowly; however, the actual elevation should be monitored (see another indicator). The forest trees and woody plants near timberline begin to show new recruitment at higher elevations, or decline in forest stature long before the actual timberline change stables for some time. Timberline is dynamic, and yet there are periods when it appears to be stable allowing long-term monitoring of forest conditions at or near timberline to show possible precursor forest modification prior to solid evidence of timberline change. Recently, introduced diseases (e.g., whitepine blister rust) have initiated more rapid changes in timberline forest health. For this reason alone, timberline forests should be part of a long-term monitoring program.

Comment: The long-term dynamic nature of timberline and the variation of forest types require that any sampling of forest condition at or near timberline must include the variability of forest structure. Measurement of health of krummholz stands is quite different than measurement of health of high elevation whitebark pine stands.

Example of specific measurements for indicator: In randomly selected, representative timberline zones in the GRYN area, sampling transects within and just above the forest, and randomly selected krummholz patches should be monitored on a regular basis (e.g., 2-5 years). Forest transects will measure the density of living and dead trees and the condition (e.g., percent canopy dead). The cover and ratio of dead to living canopy should be measured in the krummholz patches.

Indicator: Timberline elevation boundaries

Resource Monitored: Elevation where the forest ends and alpine tundra begins, and the highest elevation of krummholz patches.

Justification: The justification for monitoring timberline elevation is essentially the same as that for monitoring the timberline forests. Timberline is dynamic and has fluctuated in the past in response to long-term climate changes (i.e., warming and cooling, and/or wetter or drier periods). More recently, disease may be accelerating the rate of forest change which justifies monitoring not only the effects of the disease on the forest but how it may be altering the elevational dynamics of the ecotone between forest and alpine zones.

Comment: Monitoring changes in timberline elevation is obviously a long-term procedure. However, with more rapid changes in climate expected, elevational changes may occur more

rapidly, especially upward encroachment of forest species. Thus, monitoring techniques should be established to address the upward encroachment expected from a warming climate without forgetting to monitor potential downward changes or forest withdrawal which may result from other factors such as disease or other human induced influences.

Example of specific measurements for indicator: Monitoring elevational limits of forest species is easily done by establishing markers (stakes and GPS) at representative timberline locations. Aspect (compass direction) plays an important role in elevation of timberline, thus markers should be at all aspects. Markers should be place at the extent of any upward forest reproduction, edge of mature forest, and highest elevation of krummholz patches. The long-term aspect of timberline change does not require frequent measurement, but annual (or 2-3 year) reconnaissance of timberline edge relative to the markers is necessary.

Indicator: Alpine plant community characteristics

Resource Monitored: Alpine vegetation on different substrates in the alpine zone.

Justification: The extreme environments of the alpine zone limit the types of plants that can survive. In most cases alpine plants are low in stature, often in cushions, or isolated in microhabitats where environmental extremes are attenuated. Different alpine plant communities occur on stable and unstable soils, the latter being scree slopes and frost altered ground. Human activity, especially recreation, but also livestock use of alpine vegetation and introduction of exotic plants, has modified alpine plant communities. These pressure will unlikely decrease and thus the alpine plant community can be expected to decline in cover and vigor. Once lost, alpine vegetation takes decades or more to reestablish. Monitoring of select alpine plant communities may offer shorter notice of change than casual observation of the alpine zone.

Comment: Monitoring alpine plant communities will require establishment of sampling locations in a variety of habitats. Some habitats appear to be more stressed by human use and these might have priority over others that continue to be unaltered. However, assuming that some plant communities are more resistant or resilient to human use and changes in other driving variables such as changing climate should not cause these communities to be omitted from a monitoring program. The interval between monitoring for these plant communities might be longer than the more sensitive, less resistant communities.

Example of specific measurements for indicator: Establish randomly selected quadrats (plots) on different alpine plant community types: meadow, scree slope, wind blown semi-barren coarse soils, solifluction terraces, and high-organic wet soils, and frost-boil areas. Set priorities on sensitivity of each type based on literature and early monitoring. Monitor plant composition and cover (including density of patches where dispersed, a form of frequency measurement). Monitoring should be done annually until evidence of sensitivity is established and then longer-term monitoring can be established for more resistant and/or resilient plant community types.

C. ASPEN ECOSYSTEM NARRATIVE CONCEPTUAL MODEL—DUNCAN PATTEN AND DAN TINKER

Overview of Aspen Ecosystems

General characteristics of aspen ecosystems.

Aspen (*Populus tremuloides*) is an important component of landscapes in the Greater Yellowstone Ecosystem (GYE), but is absent or rare in the Bighorn Canyon region (Knight et al. 1987). Notably, aspen is the only native upland deciduous tree found in Yellowstone National Park (YNP). Aspen stands play important ecological roles, supporting high numbers and diversity of breeding birds (DeByle 1985) and providing critical habitat and an important source of forage for summer and winter browsing ungulates (Olmsted 1979). Aspen stands throughout the GYE appear to have been declining through the 20th century, and the causes and consequences of this apparent decline have caused considerable discussion (Schier 1975, Olmstead 1979, Bartos and Hinds 1985, Boyce 1989, Kay 1990, Bartos et al. 1994, Romme et al. 1995, Baker et al. 1997). In the northern range of YNP, aspen occurs in relatively small stands and is associated with more mesic conditions. However, aspen stands in the GYE are often not as complex or robust as stands in the mid-intermountain regions of Utah and Colorado (Mueggler 1988).

In the Rocky Mountain region and in the GYE, aspen is primarily a clonal species which reproduces almost exclusively via root sprouting and produces stands composed of stems from only one or a few genetic individuals (Barnes 1966, McDonough 1985, Tuskan et al. 1996). Aspen most commonly regenerates by means of vegetative sprouting from the root system following disturbances such as fire that kills the mature trees (See also Aspen-Fire Dynamics Submodel). These shoots grow rapidly and rely upon the root system of the parental tree for growth for the first 25 years (Zahner and DeByle 1965). However, rare episodes of seedling recruitment sometimes occur (Jelinski and Cheliak 1992), including widespread establishment of aspen seedlings in the GYE following the 1988 fires (Kay 1993, Romme et al. 1997, Stevens et al. 1999).

Aspen, like most *Populus* species, is recognized as a preferential browse species for ungulates during the growing season and even in winter (Olmstead 1979). In fact, in many parts of the GYE, elk commonly browse nearly all root sprouts present in aspen stands (Romme et al. 1995, Larsen and Ripple 1999). Several studies have suggested that elk browsing is the primary cause for the lack of aspen regeneration in the GYE (Beetle 1974, 1979, Krebill 1972, Kay 1990, Bartos et al. 1994).

Fire effects in aspen ecosystems.

Fire is the primary disturbance agent in aspen forests of the GRYE, where large, infrequent, stand-replacing fires dominate the fire regime, and human efforts at fire suppression have historically had little effect (Romme and Despain 1989). Because of its ability to resrpout following disturbance (See Aspen-Fire Dynamics Submodel), fire often facilitates secondary succession and the reestablishment of aspen. However, these stands are often eventually

dominated by lodgepole pine, Engelmann spruce, or subalpine fir after several decades. Fire suppression in the GRYE may lead to a reduction in the abundance and vigor of many of the aspen stands (Knight 1994).

Conceptual Model Development

Drivers

Climate, working with soils and topography, creates appropriate site conditions for establishment and/or maintenance of aspen communities. Aspen communities are found in mesic sites and may be in riparian locations. Climate of the GRYE is characterized by long, cold winters, and cool, dry summers. Much of the precipitation falls in the form of snow and summers may be dry. Winter snowpack melts rapidly in May and June, wetting low areas and recharging groundwater which provides much of the water available for growth of aspen. Seasonal drought, such as were experienced during the summer of 1988, may exert considerable influence on soil and fuel moisture, as well as fire regimes which influence the presence of aspen.

Soils across GRYN area are diverse, a product of highly variable parent materials. For example, soils across much of YNP are mostly volcanic in origin, while glacial outwash and older Precambrian material dominates the Grand Teton landscape (Knight 1994). In Yellowstone, two different parent materials, derived from underlying bedrock, determine the soil characteristics. Differences in these parent materials lead to variation in soil texture, and therefore, water holding capacity, as well as nutrient supply and availability (see Soil and Ground Water Processes Submodel).

Fire is also an important driver in aspen ecosystems, and the management of prescribed fires and wildfires may greatly influence many natural ecosystem processes. Aspen reproduction may be closely aligned with fire dynamics (see Aspen-Fire Dynamics Submodel).

Aspen is susceptible to several biotic drivers. The Browse Dynamics Submodel illustrates how large ungulate herds, as well as domestic animals in surrounding national forests, may utilize aspen shoots and suckers for forage. Management policies of the ungulates may influence the magnitude of impacts of herbivory. Other biotic drivers include such phenomena as beaver dams, competition from vegetation (See Aspen/Vegetation Submodel), and insect herbivory. These drivers may directly and indirectly affect many ecological processes in aspen ecosystems as described below.

Stressors and Ecological Responses

Beaver dams may affect aspen growth and establishment through herbivory and tree removal, as well as influencing availability of soil and ground water, important components of mesic sites selected by aspen. Herbivory of aspen sprouts and bark stripping by ungulates, often the result of limited forage during severe winters, may greatly reduce long-term establishment of

mature aspen stands (Kay 1997). Similarly, reduction in vigor of adult and sprout aspen is possible as a result plant competition and of other forms of herbivory.

Wildfire affects many aspects of these ecosystems, including both the volatization and creation of essential nutrients from the organic materials combusted or consumed by fire (Knight et al. 1991). Fires managed for fuel reduction or wildfires that are allowed to burn will alter availability of aspen for forage, but also stimulate aspen reproduction, both sexual and asexual.

Droughts, and other forms of wet and dry climatic cycles, affect aspen systems directly through alteration of surface and ground water processes, and the concomitant effects on plant growth and reproduction (See Aspen Growth and Reproduction Submodel). Indirectly, such climatic events may alter the establishment and survival of aspen through impacts on natural fire dynamics.

Indicators

Many non-vegetative components of aspen communities are important indicators of community structure and function. The presence, or relative abundance of some of the **associated populations of faunal assemblages** such as songbirds, amphibians, or ungulates, may serve as indicators of community integrity by their use of aspen stands. The absence of some of these assemblages may represent a decline in community health.
Population estimates of selected major taxa such as birds or ungulates, as well as measures of stand use through behavioral studies, are useful measures for monitoring these assemblages.

The **structure and function of aspen communities** is important for understanding the condition of many aspen stands. For example, aspen may function as riparian species when elevated groundwater levels create moist soil conditions. In drier areas, the size and abundance of aspen sprouts and seedlings, which are rare, may serve as indicators of future stand development. Given the abundance and impact of large herbivores, and the rarity of establishment by seed, aspen seedlings or sprouts that survive to heights greater than browsing abilities of ungulates could signify significant recruitment into new or mature stands.

Measuring **browsing effects** by both large and small herbivores within mature aspen stands, as well as on new seedlings, provides a quantitative assessment of impacts on aspen such as truncated growth. These measures may also indicate the likelihood that root sprouts and suckers or new seedlings will be recruited into an adult growth form. Other browsing effects such as gnarling of mature trees may quantify browsing pressure within specific stands.

Landscape-scale parameters such as the spatial pattern of aspen stands across the GRYE, helps quantify and characterize heterogeneity in landscape structure, which influences many important ecosystem functions. In addition, topographic and elevational analyses may identify potential sites for future aspen recruitment by delineating more potentially moist sites from drier sites.

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Indicator: Associated Animal Populations

Resource Monitored: Faunal community structure.

Justification: Many non-vegetative components of aspen communities are important indicators of community structure and function. These components intimately occupy niches within the aspen community and thus may change as the aspen community changes. The presence, or relative abundance of some of the associated populations or faunal assemblages such as songbirds, amphibians, or insects, may serve as indicators of community integrity by their use of aspen stands. The absence of some of these assemblages may represent a change or decline in aspen community health.

Example of Specific Measurements of this Indicator: Population estimates of selected major taxa such as birds, as well as measures of their use of particular stand structural niches.

Indicator: Aspen community parameters

Resource Monitored: Ecosystem structure and function.

Justification: Aspen may function as riparian species when elevated groundwater levels create moist soil conditions. In addition, the size and abundance of aspen sprouts and seedlings, which are rare, may serve as indicators of future stand development. Given the abundance and impact of large herbivores, and the rarity of establishment by seed, aspen seedlings or sprouts that survive to heights greater than browsing abilities of ungulates could signify significant recruitment into new or mature stands.

Example of Specific Measurements of this Indicator: Belt transect or quadrat estimates of sprout or seedling presence and size. Associated measurements should include, soil moisture measurements and community descriptions through plant surveys.

Indicator: Browsing Effects

Resource Monitored: Ecosystem structure

Justification: Measuring browsing effects by both large and small herbivores within mature aspen stands, as well as on new seedlings, provides a quantitative assessment of impacts on aspen such as truncated growth. These measures may also indicate the likelihood that root sprouts and suckers or new seedlings will be recruited into an adult growth form. Other browsing effects such as gnarling of mature trees may quantify browsing pressure within specific stands.

Example of Specific Measurements of this Indicator: Repeated measures of sprout and seedling heights within a given stand or plot. An alternative metric would be repeated measurements of percent browsing on representatively selected sprouts and seedlings.

Indicator: Landscape parameters

Resource Monitored: Ecosystem structure and function.

Justification: The spatial pattern of aspen stands across the Greater Yellowstone landscape influences many important ecosystem functions. In addition, topographic and elevational analyses may identify potential sites for future aspen recruitment by delineating moist sites from drier sites.

Example of Specific Measurements of this Indicator: Metrics commonly quantified using landscape description software (FRAGSTATS) and GIS. Vegetative cover most common base map used.

D. DRY WOODLAND ECOSYSTEM NARRATIVE CONCEPTUAL MODEL—CATHIE JEAN

Dry Woodlands are a characteristic feature of Bighorn Canyon National Recreation Area (BICA), occupying 40% of the land area (Knight et al 1987) between 1127 – 1545 (m) elevation. Dry woodlands in the Wyoming Basin are found on shallow – coarse textured rocky sites on fractured bedrock (Wight and Fisser 1968). This environment has an inverse texture effect; roots penetrate deep in the fractured bedrock to underground water sources.

Knight et al (1987) divide the dry woodlands into three types, mountain mahogany shrublands (*Cercocarpus ledifolius*), juniper woodlands (*Juniperus osteosperma*) and juniper / mountain mahogany woodlands based solely on the abundance of dominant species. Although the authors were unable to determine any environment differences that could distinguish a juniper site from a mountain mahogany site, the latter is more usually found on stepper, more barren sites. All three types of woodlands are present on a variety of geologic substrates (Knight et al 1987). The dry woodland ecosystem as described here also includes stands of limber pine (*Pinus flexilis*) and Rocky Mountain juniper (*Juniperus scopulorum*).

The juniper zone is often considered low value, but nevertheless, it is an important component of the range complex by providing forage and shelter for wild game. The dry woodland ecosystem is important wildlife habitat Bighorn Sheep (*Ovis canadenis)* Mule deer (*Odocoileus hemionus*) and feral horses (*Equus caballus*). Dry woodlands provide thermal cover for wildlife, although a dense woodland cover is a barrier to Bighorn Sheep as sheep are more secure in open habitats where they can see predators.

Bighorn sheep reintroduction efforts in the Bighorn, Pryor Mountains and surrounding areas by the Wyoming Department of Game and Fish and subsequent dispersal from translocations have resulted in the Bighorn Canyon bighorn sheep population (Sloan 1995 as cited in Gudorf et al 1996). These sheep occupy areas adjacent and within the dry woodland ecosystem.

Drivers

Dry woodlands were formally restricted to rocky – fire free settings – largely controlled by geology and topographic position. Modern distribution of juniper species is traditionally attributed to overgrazing and fire suppression, however historic invasions could also mark the current progress of continued migration resulting from climate fluctuation (Betancourt 1987).

Drought in combination of fire suppression and grazing favor an increase in juniper cover and invasion into new sites. Grass and shrublands are vulnerable to juniper invasion, especially where herbivory results in a decrease of palatable plants which can lead to an increase of woody species or where herbivory results in the redistribution of fine fuels (Waugh 1986 as cited in Knight et al 1987) and a subsequent change in burn patterns. Fire suppression can accelerate succession grassland or shrublands to woodlands in two ways: directly preventing mortality in young, more easily burned juniper stands and indirectly by favoring the development of shrublands

that serve as nurse plants for juniper seedling survival (Wright et al 1979). Once juniper is established, it is self-perpetuating as it competes well for available light, water and nutrients.

Stressors and Ecological Responses

Fire suppression and grazing of palatable plants can lead to an increase in juniper cover and invasion of juniper into grassland and shrublands. This phenomenon is documented throughout the western states (see Burkhardt and Tisdale 1976). Furthermore, grasses are reduced due to juniper invasion (Jameson 66, 70 as cited in Knight et al 1987) and quality forage habitat for Bighorn Sheep and other wildlife is diminished. Low forage availability creates a need for Bighorn Sheep to forage further from escape terrain, thus increasing susceptibility to predators. Juniper leaf litter is high in phytotoxic chemicals (Jameson, 66, 70 as cited in Knight et al 1987) and this may further restrict available forage.

The decline and elimination of bighorn sheep from most of their historical range (Buechner 1960 as cited in Gudorf et al 1996), during the past century is believed to be attributed to human activities and land management practices that alter bighorn sheep habitat (Gudorf et al 1996). The steep, rugged escape terrain in Bighorn Canyon and its tributaries are a critical feature of bighorn sheep habitat. The openness of plant communities, or horizontal visibility, is fundamental determinant of bighorn sheep habitat quality (Gudorf et al 1996). Natural succession of dry woodlands into these habitats will make them increasingly less suitable for bighorn sheep as the thicker vegetation will obscure visibility and reduce forage availability.

Wild horse herbivory in the Pryor Mountain Wild Horse Range and it's effect on range and forage condition is a concern to wildlife and park managers. Fahnestock and Detling (2000) investigating the effects of short- and long-term ungulate grazing on plant species cover and composition found that long-term ungulate herbivory has significantly reduced grass cover and increased plant species diversity at some sites, especially lowlands in the Pryor Mountain Wild Horse Range.

Potential Indicators:

Indicator: Extent and distribution of woodlands

Resource Monitored: Juniper and mountain mahogany woodlands in BICA

Justification: The spatial distribution and density of juniper and mountain mahogany woodlands influence habitat quality for Bighorn Sheep in Bighorn Canyon NRA. As forage grasses are reduced due to juniper invasion (Jameson 66, 70 as cited in Knight et al 1987), quality forage habitat is diminished. Low forage availability creates a need for sheep to forage further from escape terrain an increases the chance of predation. Dry woodlands have the capability to both increase thermal cover, a valuable asset during the winter months, and the decrease security for bighorn sheep.

Indicator: Ungulate population abundance, distribution, productivity

Resource Monitored: Demographic parameters (survivorship and population structure) of Bighorn Sheep.

Justification: The decline and elimination of bighorn sheep from most of their historical range (Buechner 1960 as cited in Gudorf et al 1996), during the past century is believed to be attributed to human activities and land management practices that alter bighorn sheep habitat (Gudorf et al 1996). Environmental stressors and management actions affect vital rates directly. Concerns persist regarding habitat quality, predation and disease and the effect on population viability in BICA.

Indicator: Dry woodland community structure and composition

Resource Monitored: Abundance of potential forage for bighorn sheep and other wildlife species

Justification: Forage for wild and native ungulates is a management concern in BICA because of increased cover and density of juniper woodlands, increased pressure on available forage due to competition with feral horses and the spread of exotic species.

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E. GEOTHERMAL ECOSYSTEM NARRATIVE CONCEPTUAL MODEL—HANK HEASLER AND CHERYL JAWOROWSKI

Introduction

In this paper, we present two conceptual models: a geologic conceptual model and a vital signs conceptual model. The geologic conceptual model of Yellowstone's geothermal system and processes is well understood. Among geologists, it is standard practice to draw schematic or geologic cross sections of the Earth that summarize geologic knowledge and earth processes. In geologic cross sections or schematic diagrams, the bottom of the diagram shows the deepest portion of the Earth and the top of the diagram represents the Earth' surface. In contrast, the vital signs conceptual model places Yellowstone's magma chamber (deepest portion of the Earth) at the top of the diagram as the driver for the model. We inverted the well-accepted geologic conceptual model of Yellowstone and generated a vital signs conceptual model that integrates with ecological conceptual models of Yellowstone.

Geological Conceptual Model

The geologic conceptual model of Yellowstone's geothermal system is well documented (Fournier and others, 1994; Smith and Siegel, 2000; White and others 1975). A partially molten (10-30% molten) magma chamber (45 by 30 miles wide and 3-8 miles deep) exists beneath Yellowstone National Park (Smith and Siegal, 2000). The magma chamber beneath Yellowstone National Park is in contact with a self-sealing high temperature and high concentration brine (See Figure 1, Appendix A). The brine exits in a porous rock layer between 1.5 to 3 miles deep. This tectonically sensitive brine may leak geothermal fluids to a high temperature reservoir. Geothermal fluids from the high temperature (~350°C) reservoir may discharge directly to the surface as hydrothermal features with unusual chemistry such as Beryl Springs. Or fluids from the high temperature reservoir may first discharge to medium temperature reservoirs (~250°C) and subsequently to the Earth's surface as neutral chloride springs. Medium temperature reservoirs may discharge fluids (water or gases) to low temperature (~150 ^{o}C) reservoirs. Low temperature reservoirs may discharge fluids (water or gases) to the Earth's surface and form acid sulfate springs. Precipitation of silica and zeolites along fractures provides a self-sealing mechanism. The competing effects of a self-sealing mechanism and earthquakes control the upflow of geothermal fluids to reservoirs.

Acid sulfate thermal springs, neutral chloride thermal springs, mud pots, paint pots geysers, or fumaroles exist where there is an appropriate combination of water chemistry, plumbing, heat, and hydrology. Neutral chloride springs represent unrestricted discharge of thermal waters from reservoirs. Above the local water table where there is more heat than water, steam vents to the surface forming fumaroles. At the Earth's surface, oxidation of H_2S will form acid sulfate springs. Additionally, acidic waters will cause chemical decomposition of the bedrock, generate clay minerals and form mud pots or paint pots (with ferric-oxides). A key to understanding the geochemistry of thermal waters in the Upper Geyser Basin is knowledge of dissolved gases such as CO_2 (Fournier and others, 1994). In the Upper Geyser Basin, the amount of boiling (no boiling to maximum boiling) in the intermediate reservoirs determines the chemical composition of thermal waters in the shallow, low temperature reservoirs and ultimately the geochemistry of thermal springs at the Earth's surface. Annual, generally widespread changes in thermal features in the Norris Geyser Basin are the result of changes in the potentiometric surface

of cold water adjacent to or interconnected with the hydrothermal system (Fournier and others, 2002). Thus, to understand short-term cyclical and catastrophic changes as well as long-term changes that may be natural or anthropogenic to the Yellowstone hydrothermal system both cold ground water and hydrothermal systems the must be monitored and assessed.

Rainfall and snowmelt (meteoric waters) from the Earth's surface may recharge fluids in the low temperature, medium temperature or high temperature reservoirs. The amount of meteoric waters entering the various subsurface reservoirs depends upon the amount of precipitation falling over the Yellowstone National Park. During times of glaciation, the balance between meteoric waters entering subsurface reservoirs and fluids from the magma chamber changes. During the last glacial maximum (Pinedale), geochemical evidence indicates that cold-water recharge entered the hydrothermal system (Fournier and others, 1994). As the glaciers melted, fluid flow reversed and became a hydrothermal system dominated by discharge. Changes in the magma chamber itself also affect the release of geothermal waters and gases. Thus, monitoring hydrothermal waters in Yellowstone's geyser basins will yield information about the mixing of fluids and the health of the geothermal system.

Vital Signs Conceptual Model

The Driver: Yellowstone's Magma Chamber

Yellowstone's magma chamber is the ultimate geophysical driver of the vital signs conceptual model (See Figure 2, Appendix A). Geothermal fluids convect towards the surface via fracture systems that are self-sealing and tectonically sensitive. Geothermal fluids from deep, intermediate and shallow depths mix and interact with meteoric waters and eventually are discharged as hydrothermal features in Yellowstone's geyser basins.

Stressors

Precipitation, climate change, volcanic activity, earthquakes and human activity affect thermal feature chemistry, thermal feature extent, hydrothermal fluids, and thermal feature temperature. Yellowstone National Park has two distinct climates within YNP (Despain, 1987) and YNP is located near the boundary between regional atmospheric flow patterns. Depending upon where this boundary is located the annual climate and precipitation may be above or below normal precipitation in different areas of the park. Climate and weather (precipitation) directly influence the amount of "cold" meteoric waters in thermal areas. Earthquakes and volcanic activity can rejuvenate thermal features by opening new pathways for fluids or close existing thermal pathways. Human activities such as geothermal development, oil & gas exploration, the drilling and production of water wells or vandalism may affect the fluid flow of thermal features.

Effects

Stressors affect changes in the chemistry of thermal features, extent of thermal features, fluid flow, and temperature of thermal features.

Outcomes

Acid sulfate thermal springs, neutral chloride thermal springs, mud pots, geysers, fumaroles and heated ground are consequences of Yellowstone's magma chamber and its stressors.

Measures or Vital Signs

The following vital signs are measures of Yellowstone's geothermal systems: chloride flux, the temperature of well waters, water levels in wells, the spatial extent of features, and the heat flux.

Vital Signs

Indicator: *Chloride Flux*

Over 94% of the chloride in waters originating in Yellowstone is of magmatic origin (Norton and Friedman, 1985). A study of variations in chloride flux can be used to establish a baseline for measuring the interaction of the deep geothermal waters with the surficial geothermal system. In addition, chloride flux baseline information may be used to assess any future adverse impacts on the Park's thermal features that may be caused by commercial development of geothermal energy, gas, oil and groundwater adjacent to the Park.

Resource Monitored: *Thermal Features (mud pots, geysers, fumaroles, neutral chloride thermal springs and acid sulfate thermal springs)*

Justification:

The chloride flux method for estimating geothermal activity in YNP has been extensively peer reviewed, accepted, and published (Fournier and others, 1976, Norton and Friedman, 1985; Friedman and Norton, 1990; Norton and Friedman, 1991; and Friedman and others, 1993). In addition, 19 years of chloride flux data exists for Yellowstone's major rivers-the Fall, Madison, Snake, and Yellowstone.

Indicator: *Heat Flux*

Yellowstone's heat flux has been estimated using the chloride flux method, airborne sensors and satellite images. Increased heat flux in an area may indicate changes in subsurface hydrothermal activity. Additionally, warm ground affects the health of vegetation, migration of animals, and safety of park visitors.

Resource Monitored: *Heated Ground*

Justification:

The chloride flux method for estimating heat flux in YNP has been extensively peer reviewed, accepted, and published (Fournier and others, 1976, Norton and Friedman, 1985; Friedman and Norton, 1990; Norton and Friedman, 1991; and Friedman and others, 1993). Remote sensing is a cost-efficient method to map and monitor heated ground. In the early days of remote sensing, Haze (1971) estimated heat flow and geothermal resources. In 2002, Watson and others used Landsat 7 sensors to estimate ground that was snow-free or minimal snow cover due to thermal activity. In the winter and spring, animals make use of thermal areas with minimal snow cover. In 2002, thermal airborne sensors were flown over the Mammoth-Norris corridor. Mapping new areas of heated ground and yearly changes in the heated ground can assist with maintenance of roads and visitor safety.

Indicator: *Temperature of Water in Wells*

In Yellowstone National Park, water can come from several sources: a high temperature, deep reservoir (~350°C), medium temperature, intermediate depth reservoirs (~250°C), or low temperature, shallow reservoirs (~150°C). Water from the high temperature reservoir directly connected to the magma chamber may be discharged as the unique thermal feature known as Beryl Springs. Water from medium temperature reservoirs may be directly discharged to the surface and form neutral chloride thermal features or flow to low temperature reservoirs. Water from the low temperature reservoirs may be directly discharged to the surface and form acid sulfate springs.

Resource Monitored: *Groundwater system associated with thermal features.*

Justification:

In Yellowstone, human activities such as road construction can adversely impact unique thermal features such as Beryl Springs or the many neutral chloride and acid sulfate springs. Potential threats outside of Yellowstone (geothermal development, oil and gas development, groundwater development) may also effect Yellowstone's thermal features.

Indicator: *Water Level in Wells*

Water levels in wells respond to variations in climate, precipitation, geothermal development or development of petroleum resources adjacent to the Yellowstone National Park. Monitoring of water levels in wells will capture changes in the groundwater system. Comparison of water levels with meteorological data, seismic data, ground deformation or recent earthquakes will aid in distinguishing natural changes in thermal features from climatic change or human causes (geothermal, oil or gas wells outside of Yellowstone).

Resource Monitored: *Groundwater system associated with thermal features.*

Justification:

Comparison of water levels in wells will aid in distinguishing natural changes in thermal features from climatic change or human causes (geothermal development, oil or gas wells, groundwater development).

Indicator: *Spatial Extent of Thermal Features*

Geologists use various visible, infrared, and microwave sensors to map surficial deposits, flow structures in lava flows, faults, fractures, ash flows, basalts, rhyolites, andesites, and allow lithologic discrimination of sedimentary rocks. Additionally, visible, infrared, thermal and microwave sensors (AVIRIS, TIMS, LANDSAT and RADAR) can detect subsidence, predict movements of animals, discriminate between healthy versus stressed vegetation, map active hot springs, map hydrothermal mineralization, and generate detailed mineral maps of specific areas (Dzurisin and others, Evans, 1988; 1990; Kokaly and others 1998; Kokaly and others 1999; Kruse, 1997, Shafer, 1998; Wicks and others, 1998).

Resource Monitored: *Thermal features (mud pots, geysers, fumaroles, neutral chloride thermal springs and acid sulfate thermal springs)*

Justification:

Remote sensing technologies are a cost-efficient method of mapping and monitoring the spatial extent of thermal features. Change detection maps of thermal features can aid the assessment of natural changes versus human-caused changes of thermal areas. Maps derived from

remote sensing technologies have applications to geology, hydrology, geobiology, archeology, and ecology. Additionally, these colorful images can be used by park interpreters to educate visitors and by park managers to inform politicians or other resource managers.

Summary

We propose to monitor the following vital signs as indicators of the thermal activity and integrity of Yellowstone's geothermal areas: (1) chloride flux, (2) the temperature of water wells, (3) water levels in wells, (4) the spatial extent of thermal features, and (5) heat flux.

A more complete discussion of methodology proposed for monitoring Yellowstone National Park's geothermal resources can be found in the draft version of "A Geothermal Monitoring Plan for Yellowstone National Park", March 2003 by H. Heasler, C. Jaworowski, and D. Susong.

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F. GRASSLAND ECOSYSTEM NARRATIVE CONCEPTUAL MODEL—GLENN PLUMB

Overview of Grassland Ecosystems

Grass plants evolved between seventy to eighty million years ago with adaptations that allow them to survive under intense and frequent disturbances including tremendous removal of living phytomass (e.g. fire and herbivory) and drought. Grasses often grow in vast concentrations, most often in semi-arid climates (Brown 1985) with a fairly uniform and continuous cover. Grasslands are the largest of the four major natural vegetation formations covering the planet (Gould 1968) and have certain characteristics in common, including a rolling to flat topography with precipitation between ten and 40 inches per year distributed unevenly with seasonal peaks followed by extended periods of drought (Sims 1988). Historically, grasslands covered up to 800 million ha in North America (Kuchler 1964) and still remain the largest native biome covering approximately 125 million ha (USFS 1980). Although most grasslands were historically located on extensive plains, relatively small pockets of mountain grasslands and grassland-forest combinations occur in the western coniferous forests (Sims 1988). Grasslands are dominated by grasses and grass-like plants (e.g. Cyperaceae) with a particular grassland's biomass dominated by fewer than 6 species (Coupland 1974). Yet, typically grasses contribute less than 20% of the total vegetative species richness to a grassland community. Forbs (non-grass-like herbs) are seasonally important along with dwarf shrubs and occasional trees (Coupland 1979). Grassland plants invest carbohydrates in structural development early in the growing season when moisture is adequate and thus during successive drought, grassland plants can utilize stored labile carbohydrates, decrease dark respiration and maintain gas-exchange process under stressed water potentials. Nutrient uptake is rapid when moisture is available and at these times, plants are most palatable and tolerant of herbivory with removal of phytomass often stimulating increased rates of photosynthesis by the remaining tissues and intercalary meristems of grasses permitting growth after herbivory (Risser 1985). Under periodic drought stress grassland plats close stomata with extensive leave curling to reduce water loss (Risser 1985).

Conceptual Model Development

Drivers

The climate of the GRYN parks is characterized by long, cold winters and cool, dry summers with much recipitation occurring as snowpack that melts rapidly April – June, depending on elevation providing much of the water available for annual growth in mountain grasslands. Snowpack generally begins to accumulate in October and November, reaches maximum in early to mid-April. Due to late-winter rates of accumulation, the annual snowpack can become isothermic before peak accumulation and thus melts rapidly beginning in May to July depending on elevation. Despain (1990) describes two major local climatic types as a valley type with peak precipitation coming in the spring and a mountain type with peak precipitation in the winter. Merrill and Boyce (1996) evidenced that mountain grassland seasonal biomass production was more correlated with climate and snowpack controls that the total number of herbivores occupying the grassland.

Soils of grasslands often differ markedly from those soils found under forest canopy due to variation in underlying depositional origins and the differences in soil formation processes unique

to vegetation types (Coupland 1979). In grasslands, leaching is often limited due to general aridity and so grassland soils are often more basic with organic matter distributed throughout the soil profile. While many grassland soils are derived from glacial and associated outwash sand and gravel parent materials, the GRYN mountain grasslands are also heavily influenced by volcanic rhyolitic and andecitic parent materials (Despain 1990). The GRYN parks are also influenced by glacial depositional/windblown loess that was strongly influenced by the distribution and duration of glacial icecaps (Despain 1990).

Stressors and Ecological Responses

Frank and McNaughton (1992) examined the interactive roles of large animal herbivory and drought on mountain grasslands and found that although the process of aboveground net primary productivity, large herbivore consumption and dung deposition varied widely among different grassland sites, grassland production and consumption, and consumption and dung deposition were positively correlated across sites. Despite the evedinced role of herbivory and dung deposition in controlling site-level production, they also concluded that climate is the principal driving variable of ecosystem processes and that direct and indirect effects of single-season drought will persist for several years after the event. Frank and McNaughton (1993) concluded that in the absence of drought, herbivory at the site level can result in a compensatory growth response and hence stimulate mountain grassland productivity due in part that the migratory behavior of native ungulates tracks young, high quality forage as it varies temporally and spatial along an elevational gradient across these ecosystems. The nutrient dynamics of mountain grasslands that support abundant migratory large-body sized wildlife are generally poorly understood (Frank et al. 1994), but evidence from Yellowstone National Park suggests that grazers are important component of mountain grassland N budgets with 1) landscape position and soil water affecting nutrient dynamics, 2) annual mineralization positively associated with soil N content, 3) the proportion of soil N mineralized negatively correlated to soil C/N, and 4) rates of nitrogen mineralization higher in mountain grasslands than in other temperate grassland ecosystems, possibly due to grazers promoting N cycling.

Detling (1998) reviewed the effects of mammalian herbivores on GRYN park grassland plant species composition, biomass, productivity and nitrogen cycling and concluded that patch dynamics controlled by local small mammal soil disturbances, fire, grazing, and urine/dung deposition underpinned temporal and spatial variability in grazing intensity and facilitated N mineralization and persistence of grassland communities. The role of fire in mountain grasslands was also examined by Norland et al. (1996) who concluded that forage biomass decreased where moderate soil heating occurred, forage quality (N and digestibility) increased, herbivore diets and habitat use patterns did not change, but that large herbivore use of riparian shrubs did increase. Simulation model experiments by Turner et al. (1994) explored the effects of fire size, fire pattern and winter severity on large herbivore foraging and population dynamics on a mountain grassland. Although, fire pattern (clumped vs fragmented) and winter severity seemed to control temporal and spatial variation in grassland foraging and habitat use patterns, the interactions between fire scale and grassland spatial patterns suggest that fire size along is not sufficient to predict grassland response and ungulate survival. A review of ecological stressors and responses in a mountain grassland in northern Yellowstone National Park (YNP 1997) concluded that 1) large ungulate herds and intensive grazing did not appear to be affecting native or Alpha diversity (Singer 1996), 2) there is no consistent effects of large animal grazing on forbs (Coughenour et al. 1995, Reardon 1996), 3) soil bulk densities were higher on grazed areas (Lane 1990, Lane and Montagne 1996)

and soil moisture levels were unaffected by grazing (Lane 1990, Coughenour 1991, Singer and Harter 1996), 4) accumulated organic litter was greater in ungrazed sites and exposed bare ground was higher in grazed areas (Frank 1990, Singer 1996), and 5) mountain grassland root biomass and nitrogen exhibited no responses to grazing (Merrill et all 1994).

Indicators

Grasslands of the GRYN are characterized generally by montane communities dominated by varying levels of perennial C4 graminoids, C3 graminoids, forbs and dwarf or small shrubs with local sites often dominated by either C4 or C3 graminoids. There are few if any sites that would be characterized as true short or mixed grass prairie. Aboveground vegetative biomass production is a cumulative process within a single growing season, with peak biomass roughly equivalent to Annual Net Primary Production (Briggs and Knapp 1995). In these montane systems, peak vegetative biomass production occurs dependent on elevation and aspect controls on soil temperature and precipitation regimes. Grassland annual aboveground vegetative biomass production responds directly to a suite of intra- and inter-annual primary stressors including grazing (e.g. herbivory), fire, drought, snowpack, and in some circumstances trampling by hoofed medium and large herbivores, and directly reflects the primary photosynthetic capacity that can be quantified across multiple spatial and temporal scales. Although climate has been described as the primary driving variable of montane grassland processes (McNaughton and Frank 1992), each park has qualitative and quantitative models to partition the interactive effects of these multiple primary stressors. Extra-normal variation in grassland vegetative biomass capacity will be a direct response indicator of both short and long term stressor effects. Multiple factors can control and limit ANPP at larger scales in grasslands including fire, climatic variability, various activities by herbivores, with soil nitrogen and water limitations often operating at local scales. Knapp et al. (1998) suggest that these scale-dependent controls on ANPP underpin patterns of temporal switching among limiting resources that results in non-equilibrium behaviors in which transient periods occur where no resources are limiting. Thus, ANPP becomes a reliable predictive ecological indicator only with long-term records and a non-equilibrium perspective.

In GRYN montane grassland communities, vegetative biomass production is underpinned by temperature and soil moisture availability that are generally controlled temporally by delayed onset of the growing season according to increasing elevation. Onset and timing of herbivory of the annual increment of primary vegetative production by large and medium sized herbivores is generally synchronized with onset of seasonal "growth pulse" of greenup as it moves from winter ranges to higher elevation summer ranges. Migratory native GRYN herbivores (e.g. elk, bison) often utilize the initial greenup phase but move to higher elevations prior to onset of plant reproduction. Non-migratory GRYN herbivores (e.g. wild horses) will sustain utilization of montane grasslands until current annual growth or residual cover is depleted. Frank (1990) showed that seasonal utilization of montane grasslands could stimulate total annual productions beyond levels of ungrazed sites. Thus, offtake as a measure of the amount of annual vegetative growth increment that is removed by these native large and medium sized herbivores can serve as a variably important stressor on the resiliency of montane grasslands. Although, short-term interannual variation in vegetation offtake can be explained by inherent variability of climate and herbivory interactions, long-term trends and patterns of montane grassland resiliency can be inferred from measures of offtake as an integrative indicator of whether there are immediate or long-term concerns for residual effects of overgrazing of these systems. Unlike fire or climatic influences that can generate some levels of uniform grassland vegetation responses, seasonal

grazing of montane grasslands can generate patchy heterogeneity. Overlaid on these patterns of heterogeneity are heterogeneous patterns of trampling, urine and dung deposition and the issues of patchy compensation and even overcompensation by grazed plants. Thus, although annual temporal and spatial patterns of offtake can be variable, long-term measurements of offtake can be an important integrative ecological indicator of grassland non-equilibrium dynamics.

The availability and cycling of nutrients, especially N, is a primary controlling stressor on grassland community structure and function, and in turn are directly affected by variation in ecosystem processes such as vegetation production and decomposition (Blair et al. 1998). Variation in N availability can determine and limit productivity, species composition, and plant physiological responses to disturbances and rates of litter decomposition. Additionally, N cycling processes can be directly altered by human activities such as prescribed fire and external influences such as climate and topography (Turner 1997). Thus, long-term measurements of N cycling processes and outcomes can provide the basis for evaluating the role of natural or anthropogenic stressors on ecosystem function, small and large scale redistribution or transport of N between summer and winter ranges, grassland plant and animal communities, and abiotic ecosystem characteristics such as soil chemistry. In GRYN parks there are important and sizeable large and medium body-sized herbivore populations that are very important components of nitrogen cycle processes and outcomes. In addition to local defoliation processes and outcomes, redistribution of N through urine and feces, these herbivores play an important role in stimulating patterns of aboveground and belowground production. They also contribute to nutrient cycling through the return of carcasses to these systems. Despite these important processes, N limitation is not a universal feature of montane grasslands and that its relative importance can vary with influences of fire, grazing, elevation, topography and precipitation regimes. This loose coupling of relationships is due to the potential for the direct influences of these same variables under variable environmental and management regimes. Thus N cycling process and outcomes reinforce the viewpoint that montane grasslands operate as a nonequilibrium system in which the relative importance of N varies in space and time (Knapp and Seastadt 1998).

The native species richness of montane grasslands are often characterized by a matrix of widely distributed, temporally stable, and abundant “core” species, a second tier of localized, less abundant, and temporally dynamic and somewhat unpredictable “satellite” species (subdominant graminoids and forbs). The exotic species richness of montane grasslands often follows a two-tiered similar pattern with species such as timothy, smooth brome, bluegrass and annual bromes dominating some landscapes while other montane grassland landscapes include only few subdominant exotic forbs. These “satellite” species suggest a subdominant role for non-equilibrium dynamics in the persistence of native montane grassland community abundance and distribution. By contrast, the spatial and temporal stability of the “core” species richness suggests a certain dominant equilibrium dynamic to native montane grassland community abundance and distribution. Still, although there can be a dominant equilibrium matrix of montane grassland species, these systems are far from static and can be disrupted severely by the emergence of dominant exotic species described above. Indeed, the increasing presence of exotic species, described above, has greatly altered some GRYN grassland communities. Thus, long-term measures of native and exotic species abundance and distribution can serve as an important integrative ecological indicator to asses the interplay between equilibrium and nonequilibrium processes that regulate montane grassland plant species persistence and coexistence. For this vital sign to be useful, GRYN parks will need robust models of the relationship between montane

grassland condition and exotic species presence and resultant effects on broader ecological processes and outcomes.

Research from a variety of grassland types indicates that there are important mechanisms by which the dominant disturbance regimes (e.g. fire, grazing, drought, trampling, wallowing) can have important interactive effects on the emergent spatial and temporal patterns of populations and communities of grassland small mammals, birds and insects. Variation in scale-dependent effects on abundance and distribution of taxon can be attributed to variation in food and/or habitat requirements (generalist versus specialist), differences in vagility (e.g. flying versus walking), differences in life span (annual vs. perennial) and combinations of these factors. Additionally, population-level mechanisms that underpin fire- or grazing- induced dynamics on animal populations or communities are taxon- and species-specific. For example, many species of grasshoppers overwinter as eggs in soil and are mobile as adults and spring conditions may be independent of grasshopper abundance, whereas sedentary insect species that are above ground during fires can suffer catastrophic mortality (Fay and Samenus 1993). Thus there exists opportunity to identify taxon that are relatively tightly coupled to key ecosystem stressors and that when coupled to measures of grassland production and offtake could serve as key integrative ecological indicators. There is some evidence that grassland small mammals, birds and insects conform to Hanski's (1982) core-satellite hypothesis wherein these communities are characterized by several abundant, widely distributed, and relatively stable species, accompanied by a larger number of rare, localized, and dynamically variable species. Thus, the temporally variable patterns in species abundance, distribution and diversity are influenced strongly by changes in the distribution and abundance of rare species. Climate and topographic influences can also control spatial and temporal heterogeneity in montane grassland animal populations and communities. Hence, the spatial and temporal variation in population abundance and community structure require multifactoral explanations (Kaufmann et al. 1998) and may make single-limitation explanations for population and community dynamics unrealistic (Belovsky and Joern 1995).

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CVS 1: Grassland Annual Net Primary Productivity – ANPP (e.g. Aboveground Vegetation Production, Photosynthetic Capacity)

Justification: Grasslands of the GRYN are characterized generally by montane communities dominated by varying levels of perennial C4 graminoids, C3 graminoids, forbs and dwarf or small shrubs with local sites often dominated by either C4 or C3 graminoids. There are few if any sites that would be characterized as true short or mixed grass prairie. Aboveground vegetative biomass production is a cumulative process within a single growing season, with peak biomass roughly equivalent to Annual Net Primary Production (Briggs and Knapp 1995). In these montane systems, peak vegetative biomass production occurs dependent on elevation and aspect controls on soil temperature and precipitation regimes. Grassland annual aboveground vegetative biomass production responds directly to a suite of intra- and inter-annual primary stressors including grazing (e.g. herbivory), fire, drought, snowpack, and in some circumstances trampling by hoofed medium and large herbivores, and directly reflects the primary photosynthetic capacity that can be quantified across multiple spatial and temporal scales. Although climate has been described as the primary driving variable of montane grassland processes (McNaughton and Frank 1992), each park has qualitative and quantitative models to partition the interactive effects of these multiple primary stressors. Extra-normal variation in grassland vegetative biomass capacity will be a direct response indicator of both short and long term stressor effects.

Comment: Multiple factors can control and limit ANPP at larger scales in grasslands including fire, climatic variability, various activities by herbivores, with soil nitrogen and water limitations often operating at local scales. Knapp et al. (1998) suggest that these scale-dependent controls on ANPP underpin patterns of temporal switching among limiting resources that results in non-equilibrium behaviors in which transient periods occur where no resources are limiting. Thus, ANPP becomes a reliable predictive ecological indicator only with long-term records and a non-equilibrium perspective.

CVS 2: Grassland Vegetation Annual Offtake (e.g. Current year growth utilization by primary consumers)

Justification: In GRYN montane grassland communities, vegetative biomass production is underpinned by temperature and soil moisture availability that are generally controlled temporally by delayed onset of the growing season according to increasing elevation. Onset and timing of herbivory of the annual increment of primary vegetative production by large and medium sized herbivores is generally synchronized with onset of seasonal "growth pulse" of greenup as it moves from winter ranges to higher elevation summer ranges. Migratory native GRYN herbivores (e.g. elk, bison) often utilize the initial greenup phase but move to higher elevations prior to onset of plant reproduction. Non-migratory GRYN herbivores (e.g. wild horses) will sustain utilization of montane grasslands until current annual growth or residual cover is depleted. Frank (1990) showed that seasonal utilization of montane grasslands could stimulate total annual productions beyond levels of ungrazed sites. Thus, offtake as a measure of the amount of annual vegetative growth increment that is removed by these native large and medium sized herbivores can serve as a variably important stressor on the resiliency of montane grasslands. Although, short-term interannual variation in vegetation offtake can be explained by inherent variability of climate and herbivory interactions, long-term trends and patterns of montane grassland resiliency can be

inferred from measures of offtake as an integrative indicator of whether there are immediate or long-term concerns for residual effects of overgrazing of these systems.

Comment: Unlike fire or climatic influences that can generate some levels of uniform grassland vegetation responses, seasonal grazing of montane grasslands can generate patchy heterogeneity. Overlaid on these patterns of heterogeneity are heterogeneous patterns of trampling, urine and dung deposition and the issues of patchy compensation and even overcompensation by grazed plants. Thus, although annual temporal and spatial patterns of offtake can be variable, long-term measurements of offtake can be an important integrative ecological indicator of grassland non-equilibrium dynamics.

CVS 3: Grassland Nitrogen (e.g. availability, inputs, loss and associated processes)

Justification: The availability and cycling of nutrients, especially N, is a primary controlling stressor on grassland community structure and function, and in turn are directly affected by variation in ecosystem processes such as vegetation production and decomposition (Blair et al. 1998). Variation in N availability can determine and limit productivity, species composition, and plant physiological responses to disturbances and rates of litter decomposition. Additionally, N cycling processes can be directly altered by human activities such as prescribed fire and external influences such as climate and topography (Turner 1997). Thus, long-term measurements of N cycling processes and outcomes can provide the basis for evaluating the role of natural or anthropogenic stressors on ecosystem function, small and large scale redistribution or transport of N between summer and winter ranges, grassland plant and animal communities, and abiotic ecosystem characteristics such as soil chemistry.

Comment: In GRYN parks there are important and sizeable large and medium body-sized herbivore populations that are very important components of nitrogen cycle processes and outcomes. In addition to local defoliation processes and outcomes, redistribution of N through urine and feces, these herbivores play an important role in stimulating patterns of aboveground and belowground production. They also contribute to nutrient cycling through the return of carcasses to these systems. Despite these important processes, N limitation is not a universal feature of montane grasslands and that its relative importance can vary with influences of fire, grazing, elevation, topography and precipitation regimes. This loose coupling of relationships is due to the potential for the direct influences of these same variables under variable environmental and management regimes. Thus N cycling process and outcomes reinforce the viewpoint that montane grasslands operate as a nonequilibrium system in which the relative importance of N varies in space and time (Knapp and Seastadt 1998).

CVS 4: Grassland Vegetation Community Structure (Patterns of abundance and distribution)

Justification: The native species richness of montane grasslands are often characterized by a matrix of widely distributed, temporally stable, and abundant “core” species, a second tier of localized, less abundant, and temporally dynamic and somewhat unpredictable “satellite” species (subdominant graminoids and forbs). The exotic species richness of montane grasslands often

follows a two-tiered similar pattern with species such as timothy, smooth brome, bluegrass and annual bromes dominating some landscapes while other montane grassland landscapes include only few subdominant exotic forbs. These "satellite" species suggest a subdominant role for non-equilibrium dynamics in the persistence of native montane grassland community abundance and distribution. By contrast, the spatial and temporal stability of the "core" species richness suggests a certain dominant equilibrium dynamic to native montane grassland community abundance and distribution. Still, although there can be a dominant equilibrium matrix of montane grassland species, these systems are far from static and can be disrupted severely by the emergence of dominant exotic species described above. Indeed, the increasing presence of exotic species, described above, has greatly altered some GRYN grassland communities. Thus, long-term measures of native and exotic species abundance and distribution can serve as an important integrative ecological indicator to asses the interplay between equilibrium and nonequilibrium processes that regulate montane grassland plant species persistence and coexistence.

Comment: For this vital sign to be useful, GRYN parks will need robust models of the relationship between montane grassland condition and exotic species presence and resultant effects on broader ecological processes and outcomes.

CVS 5: Grassland Insect and Vertebrate Community Structure

Justification: Research from a variety of grassland types indicates that there are important mechanisms by which the dominant disturbance regimes (e.g. fire, grazing, drought, trampling, wallowing) can have important interactive effects on the emergent spatial and temporal patterns of populations and communities of grassland small mammals, birds and insects. Variation in scale-dependent effects on abundance and distribution of taxon can be attributed to variation in food and/or habitat requirements (generalist versus specialist), differences in vagility (e.g. flying versus walking), differences in life span (annual vs. perennial) and combinations of these factors. Additionally, population-level mechanisms that underpin fire- or grazing- induced dynamics on animal populations or communities are taxon- and species-specific. For example, many species of grasshoppers overwinter as eggs in soil and are mobile as adults and spring conditions may be independent of grasshopper abundance. Sedentary insect species that are above ground during fires can suffer catastrophic mortality (Fay and Samenus 1993). Thus there exists opportunity to identify taxon that are relatively tightly coupled to key ecosystem stressors and that when coupled to measures of grassland production and offtake could serve as key integrative ecological indicators.

Comment: There is some evidence that grassland small mammals, birds and insects conform to Hanski's (1982) core-satellite hypothesis wherein these communities are characterized by several abundant, widely distributed, and relatively stable species, accompanied by a larger number of rare, localized, and dynamically variable species. Thus, the temporally variable patterns in species abundance, distribution and diversity are influenced strongly by changes in the distribution and abundance of rare species. Climate and topographic influences can also control spatial and temporal heterogeneity in montane grassland animal populations and communities. Hence, the spatial and temporal variation in population abundance and community structure require multifactoral explanations (Kaufmann et al. 1998) and may make single-limitation explanations for population and community dynamics unrealistic (Belovsky and Joern 1995).

Indicators

Many shrubland communities area characterized by a matrix of shrub growth forms and interspaces that may be occupied by variable levels of native graminoid and herbaceous non-graminoid cover. The floristic composition of shrubland interspace communities can be heavily controlled by moisture competition and allelopathy. The natural evolutionary resilience of shrubland communities can be altered under severe disturbance regimes such as fire in fire-intolerant communities or excessive grazing/trampling by large herbivores. The natural resilience of shrubland communities can be further stressed by the introduction of aggressive exotic plant species into these interspaces. Foremost among these aggressive exotics is *Bromus tectorum* that can, by virtue of completing its annual growth cycle by early summer, outcompete native C3 or C4 graminoids through moisture competition. This continuous fine fuel layer can then facilitate increased fire frequency and intensity, reducing fire-intolerant shrub species, resulting in reduced soil organic matter and nutrient pools and a spiral of downward ecosystem degradation. Shrubland interspaces are often characterized by either a microcryptic crust dominated by mosses, lichens, and algae between the perennials or abundant exposed mineral soil surface between the perennials. Excessive grazing or trampling of microcryptic crusts can predispose shrubland communities to invasion by aggressive exotic species. Thus, for shrubland exotic species to serve as a meaningful ecological indicator, there needs to be relatively strong models that predict the interactive relationships between natural system resilience, excessive disturbance, and the ecology of exotic species.

Woody, lignified or partially lignified shrubs provide food or feeding sites, security, and breeding areas for aboveground and belowground small vertebrates and insects in montane shrubland communities. Research from a variety of shrubland types indicates that there are important mechanisms by which the dominant disturbance regimes (e.g. fire, grazing, drought, trampling, wallowing) can have important interactive effects on the emergent spatial and temporal patterns of populations and communities of small mammals, birds and insects. Variation in scale-dependent effects on abundance and distribution of taxon can be attributed to variation in food and/or habitat requirements (generalist versus specialist), differences in vagility (e.g. flying versus walking), differences in life span (annual vs. perennial) and combinations of these factors. Additionally, population-level mechanisms that underpin fire- or grazing- induced dynamics on animal populations or communities are often taxon- and species-specific. For example, many species of grasshoppers overwinter as eggs in soil and are mobile as adults and spring conditions may be independent of grasshopper abundance, whereas sedentary insect species that are above ground during fires can suffer catastrophic mortality (Fay and Samenus 1993). Thus there exists opportunity to identify taxon that are relatively tightly coupled to key ecosystem stressors and serve as key integrative ecological indicators. There is some evidence that shrubland small mammals, birds and insects conform to Hanski's (1982) core-satellite hypothesis wherein these communities are characterized by several abundant, widely distributed, and relatively stable species, accompanied by a larger number of rare, localized, and dynamically variable species. Thus, the temporally variable patterns in species abundance, distribution and diversity are influenced strongly by changes in the distribution and abundance of rare species. Climate and topographic influences can also control spatial and temporal heterogeneity in montane shrubland animal populations and communities. Hence, the spatial and temporal variation in population

abundance and community structure require multifactoral explanations (Kaufmann et al. 1998) and may make single-limitation explanations for population and community dynamics unrealistic (Belovsky and Joern 1995).

In montane shrublands primary production is segregated into patches of relatively high (undershrub) and low (interspace) long-term response and it follows that nutrient cycling will be anisotropic. As shrubs or shrub patches accumulate under-canopy litter, nutrient pools will also collect there. These spatial patterns occur because of absorption of nutrients that extend beyond plant crown area, N fixation by the plant or associate symbiotic organisms and net import of N by fauna using shrubs for nesting, resting, roosting, feeding or burrowing, and deposition of litter and soil by wind and water. Thus, long-term measurements of N cycling processes and outcomes can provide the basis for evaluating the role of natural or anthropogenic stressors on ecosystem function, small and large scale redistribution or transport of N between summer and winter ranges, shrubland plant and animal communities, and abiotic ecosystem characteristics such as soil chemistry. In GRYN parks there are important and sizeable large and medium body-sized herbivore populations that are very important components of nitrogen cycle processes and outcomes. In addition to local defoliation processes and outcomes, redistribution of N through urine and feces, these herbivores play an important role in stimulating patterns of aboveground and belowground production. They also contribute to nutrient cycling through the return of carcasses to these systems. Despite these important processes, N limitation is not a universal feature of montane shrublands and that its relative importance can vary with influences of fire, grazing, elevation, topography and precipitation regimes. This loose coupling of relationships is due to the potential for the direct influences of these same variables under variable environmental and management regimes. Thus N cycling process and outcomes reinforce the viewpoint that montane shrublands might operate as a nonequilibrium system in which the relative importance of N varies in space and time.

Adequate vegetation cover is one of the most critical aspects of any watershed ecosystem in terms of upland water infiltration and sediment yields. The natural evolutionary vegetal cover resilience of shrubland communities can be altered under severe disturbance regimes such as fire in fire-intolerant communities or excessive grazing/trampling by large herbivores. The natural resilience of shrubland community vegetal cover can be further stressed by the introduction of aggressive exotic plant species. Alteration and loss of shrubland understory vegetal cover will increase overall soil erosion processes and outcomes. Montane shrubland communities with moderate to steep slopes will be most stable where shrub roots permeate soils to the geologic parent material. A diverse cover of both deep-rooted shrubs and shallow-rooted shrubs will serve to minimize soil erosion processes and outcomes. Thus, measures of soil erosion processes and outcomes can be strongly indicative of important declines in vegetal cover and the interactive processes that underpin such declines. Not all shrubs provide a positive feedback to erosional processes. Some shrubs have chemicals in their foliage or litter that can lead to hydrophobic soil surfaces resulting in less infiltration and xerification of microsites. Indeed, not all erosional processes and outcomes should be seen as outside the natural range of variability for montane shrubland communities. Cupped interspace depressions arising from differential erosion (aggredation, infiltration, growth and soil genesis) have been occurring at the microsite level for extended intervals in shrubland communities.

Some structural characteristics of montane shrublands can be coupled closely with spatial organization of growth forms and the interplay of ecosystem functional attributes that center around energy flow and nutrient and water cycles. The primary character involved in shrublands is that of dispersion (West 1989) that underpins the aggregation and deviation from random spatial arrangement. The vertical and horizontal structures of a variety of shrublands are remarkably similar across relatively undisturbed examples. In sagebrush steppe, shrubs have a cover of 10%-80%, depending on site and successional status (West 1988) with a herbaceous stratum that can reach 30-40 cm during the growing season. On many sagebrush steppe sites, cover usually exceeds 80% and can exceed 200%. Measures of shrubland cover and vertical or horizontal structure can track the tendency for stable shrubland community structure and function. Thus, measurable deviation in these parameters could provide a relatively rapid integrative assessment of shrubland community stability. Shrub non-random aggregation can serve as the grit starting a pearl (Vasek and Lund 1980), the nucleus of successional change and ecosystem development (West 1989) that leads towards system stabilization.

Overview of Lodgepole Pine Ecosystems

General characteristics of lodgepole pine forests. Lodgepole pine (*Pinus contorta* var. *latifolia*) is the most common tree in the northern Rockies, especially in northern Wyoming. These montane forests range from 1,800-3,200 m in elevation in the GRYE. Although commonly described as a seral, or pioneer species that often gives way to Engelmann spruce (*Picea engelmanii*) and subalpine fir (*Abies lasiocarpa*) during later stages of succession, climax stands of lodgepole pine may be found on very dry and nutrient-poor sites, where other tree species are unable to survive (Moir 1969; Despain 1983; Lotan and Perry 1983). Lodgepole pine usually forms relatively young, even-aged stands as a result of regeneration following severe fires (see below), but older, uneven-aged stands may exist at higher elevations where fire frequency is low (Despain 1990).

Fire regimes in lodgepole pine forests. Fire is the primary disturbance agent in lodgepole pine forests of the GRYE. Large, infrequent, stand-replacing fires dominate the fire regime, and human efforts at fire suppression have historically had little effect (Romme and Despain 1989). Lodgepole is a fire-adapted species, rather than fire-resistant, due to its relatively thin bark and the production of serotinous cones. These serotinous cones remain closed at maturity, and only open to release their seeds when exposed to very high temperatures, such as fires will create (Lotan 1975). Following stand-replacing fires, seedlings establish quickly, usually within two years, creating new stands where post-fire seedling density may vary by six orders of magnitude (Turner et al. In review).

Conceptual Model Development

Drivers

The parent materials for soils across the subalpine plateaus of YNP, where lodgepole pine dominates the vegetation, are mostly volcanic in origin. Two different parent materials, derived from underlying bedrock, determine the soil characteristics in Yellowstone. Rhyolitic soils are found most often on drier sites, and are typically very nutrient limited. Andesitic soils are relatively more fertile, and often occur at higher elevations (Despain 1990). Differences in these parent materials is responsible for soil texture, and therefore, water holding capacity, as well as nutrient supply and availability. Rhyolitic soils are more sandy while andesitic soils contain much more clay (Despain 1990). Calcium is ten times more abundant in soils derived from andesite (Despain 1990).

Yellowstone's climate is characterized by long, cold winters, and cool, dry summers. Most of the precipitation falls in the form of snow. Winter Snowpack melts rapidly in May and June, providing much of the water available for growth in lodgepole pine forests. In addition, periods of seasonal drought, such as were experienced during the summer of 1988, may exert considerable influence on soil and fuel moisture, as well as fire regimes.

Topography on the subalpine plateaus in Yellowstone is quite varied. Much of the landscape is dominated by gently rolling hills, however, steep canyons and mountains may break

up the continuous nature of the plateaus. Topographic effects on snow accumulation and on the spread of natural disturbances such as fire or exotic species may be significant.

Biotic drivers such as insects, plant pathogens and disease, and herbivory by both ungulates and insects may directly and indirectly affect many ecological processes in lodgepole pine ecosystems. As more fully described below in the section on *Stressors*, these biotic drivers can lead to extensive episodes of tree mortality, which can affect critical processes such as coarse woody debris accumulation and net primary productivity.

Given the importance of fire in lodgepole pine ecosystems, the management of prescribed fires and wildfires may greatly influence many natural ecosystem processes. For example, large, intense crown fires may help control episodic outbreaks of Mountain Pine Beetle by burning entire stands where significant outbreaks have occurred. Many of the indirect effects of fire suppression will be discussed below in subsequent sections.

Stressors and Ecological Responses

Drought, snowpack, and windstorms, all driven by weather and climate, affect many important ecosystem processes. Drought will affect soil moisture during the growing season, thereby affecting plant development and primary productivity, as well as forage abundance. Reduced soil moisture may also reduce nutrient supplies by a reduction in microbial activities such as decomposition and mineralization (Litton et al in press). Snowpack is the single largest contributor to soil moisture, and therefore water and nutrient availability during the growing season. Windstorms may cause large blowdowns, such as the 6,000-ha event that occurred in the Teton Wilderness in 1987. These events directly affect forest and landscape structure through widespread tree mortality and creation and accumulation of large quantities of coarse woody debris (CWD). Large areas of uprooted trees may also allow for the invasion of new plant species, and may also affect the growth rates of the new and existing species.

Biotic stressors, primarily insects and plant pathogens, have important effects in lodgepole pine forest ecosystems (Romme et al. 1986; Veblen et al 1991). Openings may be created in the forest canopy through tree mortality, which can result in increases in understory vegetation production (Knight 1994). Plant parasites, such as dwarf mistletoe and comandra blister rust, are also common in these forests. Mistletoe may reduce tree growth or even result in tree death, and has been labeled the most important problem in lodgepole pine forests (Knight 1994). The native mountain pine beetle is present at low population levels most of the time (Brown 1975; Baker and Veblen 1990), but periodic outbreaks, such as occurred during the 1970s in YNP, resulting in the death of thousands of trees (Despain 1990). This, in turn, also leads to changes in CWD biomass and distribution, plant species composition and productivity, and fuel availability, as well as broad-scale changes in landscape patterns (Romme et al. 1986). Herbivory, both by insects and ungulates, may reduce plant cover and may result in the mortality of young seedlings and saplings (Houston 1982; Singer et al. 1989).

Abiotic stressors such as wildfire, and human-induced changes to the ecosystem via management impacts can also alter ecological characteristics of lodgepole systems. Wildfire affects many aspects of these ecosystems, including both the volatization and creation of essential nutrients from the organic materials combusted or consumed by fire (Knight et al. 1991). Wildfire directly kills many trees during severe surface or crown fires, which results in significant additions to the CWD biomass of these forests (Tinker and Knight 2000). Notably, fire regimes seem to be the controlling mechanism for the production of serotinous cones (see section on fire regime), which is the most important predictor of postfire seedling density, and therefore productivity

(Tinker et al. 1994; Turner et al. 1997; Turner et al. in review). Also, fire clearly can eliminate plant cover, but also provides new substrate for rapid reestablishment of residual plants (Turner et al. 1997). If fire suppression efforts are successful, this will obviously result in a reduction of tree mortality and CWD accumulation, and may allow for the build-up of high levels of woody fuels.

Indicators

The vegetation dynamics of lodgepole pine ecosystems are fairly well-understood (Turner et al. 1997) and the composition of the forest **plant community composition**, as well as the proportions of exotic and native species, could provide an excellent index of ecosystem structure and function. Similarly, **plant species diversity**, and the historic range of variability in this measure, will also allow for relatively straightforward assessment of ecosystem stability. The amount and distribution of **forest floor litter and coarse woody debris** are critical for key forest floor ecosystem processes such as decomposition and mineralization (Tinker and Knight 2000), and are directly linked to the **availability and loss of essential nutrients** from the soil (Knight 1994). All of these indicators are easily measured, and reflect the potential for the ecosystem to maintain long-term site productivity. Similarly, an excellent measure of potential ecosystem productivity is leaf area index, or **LAI**, which is the square meters of leaf area per square meter of forest floor). LAI is highly correlated with aboveground net primary productivity (**ANPP**) as well as evapotranspiration, and is routinely estimated through the use of remotely sensed data. Finally, landscape structure and forest stand age structure are also easily quantified through the use of geographic information systems and software designed to characterize landscape structure (McGarigal and Marks 1995). The historic range of variability in landscape structure has been recently described for portions of the Greater Yellowstone Ecosystem (Tinker et al, in press) and monitoring landscape heterogeneity may provide a much needed broad-scale assessment with which to compliment the finer, stand-level metrics.

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Lodgepole Pine Ecosystem Type – Ecological Indicators and Justifications

Indicator: Plant community composition

Resource Monitored: Flora – plant species presence and abundance

Justification: Lodgepole pine communities are relatively uniform systems (Knight 1994). Departures from the natural range of variability in community composition may indicate structural and functional changes in the ecosystem resulting from natural perturbations such as drought, fire, or windstorm, or human-caused disturbances or alterations such as non-prescribed fire or fire management (Pickett 1976). Vegetative reproduction following disturbance is the most common mechanism for plant reestablishment (Anderson and Romme 1991) and departures from this contribution may indicate considerable degradation of the seed bank.

Comment: This indicator is relatively well-understood and may therefore be most useful when attempting to evaluate current ecosystem conditions.

Example of Specific Measurements of this Indicator: Total species present and estimate of percent cover of each in relation to *expected* species present within the community. Common measures include quadrat and relevé methods.

Indicator: Plant species diversity

Resource Monitored: Flora - Biodiversity

Justification: High species diversity may maintain ecosystem stability through redundancy of the ecological roles of different species.

Comment: This is a very easy indicator to measure and has much public appeal, and is likely a priority of many agencies.

Example of Specific Measurements of this Indicator: Common measures include quadrat and relevé methods.

Indicator: Forest floor litter and coarse woody debris (CWD)

Resource Monitored: Ecosystem structure - forest floor structure; ecosystem processes

Justification: Forest floor litter and coarse woody debris play important ecological roles in lodgepole pine systems (Tinker and Knight 2000). CWD may provide habitat for many organisms (Harmon et al. 1986), and many decomposers such as bacteria and fungi derive energy and nutrients from decaying forest floor materials (Frankland et al. 1982). CWD and litter are also important inputs to soil organic matter (Edmonds 1991).

Comment: Lodgepole pine systems are often nitrogen- and nutrient-limited. Forest floor litter and CWD provide critical raw organic material for decomposition and mineralization processes.

Example of Specific Measurements of this Indicator: Litter depth and biomass; CWD biomass and percent cover. Common measures include line intercept method for CWD percent cover, planar intercept for CWD biomass, and randomly placed measures of litter depth, with subsamples for dry weight.

Indicator: Landscape structure and heterogeneity

Resource Monitored: Landscape structure – patchiness, fragmentation, core habitat, patch edge density

Justification: The spatial pattern of lodgepole pine landscapes influences many important ecosystem functions such as habitat use and foraging patterns (Pearson 1993; Turner et al. 1994), nutrient movement (Peterjohn and Corell 1984), and disturbance dynamics (Turner 1987).

Comment: Disturbance is now considered an integral part of lodgepole pine ecosystems. Various disturbance types such as fire, insect outbreaks, windstorms, and earthquakes may significantly alter landscape structure in these ecosystems. This, in turn, will likely influence future processes such as net primary productivity, animal movement, forage availability, and habitat.

Example of Specific Measurements of this Indicator: Metrics commonly quantified using landscape description software and GIS, such as FRAGSTATS (McGarigal and Marks 1995) or *r.le* (Baker and Cai 1992) programs; vegetative cover most common base map used.

Indicator: Leaf area index (LAI)

Resource Monitored: Ecosystem structure and function - primary productivity

Justification: Leaf area index is highly correlated with net primary productivity, a critical ecosystem process that describes the accumulation of biomass over some time period. Productivity reflects many current conditions within ecosystems such as climatic trendsLeaf area index is relatively easy to measure with today's remote sensing technology and, given its strong relationship to primary productivity

Comment: Because of its relationship with aboveground net primary productivity, estimates of LAI provide maximum information about the productivity of the ecosystem with a single measure. Leaf area index is also a good surrogate for photosynthetic capacity (greenness)

Example of Specific Measurements of this Indicator: Remotely sensed data such as NDVI (Normalized Difference Vegetation Index) may be used. These data are inexpensive and are published on a regular basis.

I. MIXED CONIFER ECOSYSTEM NARRATIVE CONCEPTUAL MODEL—DAN TINKER

Overview of Mixed Conifer Forest Ecosystems

General characteristics of mixed conifer forests. For the purposes of this document, mixed conifer forests are considered to be forest types that are dominated by species other than lodgepole pine (*Pinus contorta* var. *latifolia*) or aspen (*Populus tremuloides*). This would include primarily Douglas-fir (*Pseudotsuga menziesii*) forests and spruce-fir (Engelmann spruce (*Picea engelmanii*) and subalpine fir (*Abies lasiocarpa*)) forests. Notably, all of these forest types may contain some component of the other, and may also contain individuals of limber pine (*Pinus flexilis*) lodgepole pine or aspen; however, in many areas, Douglas-fir forests occur at lower elevations than lodgepole pine forests, and spruce-fir forests are typically found to occur at higher elevations than lodgepole pine (Peet 2000). These montane forests are relatively ubiquitous in the GRYE, and range from 1,800-3,200 m in elevation. In BICA, mixed conifer forests are found primarily on the eastern slopes of East Pryor Mountain, in the western portion of the Bighorn Canyon Recreation Area.

Fire regimes in mixed conifer forests. Fire regimes are quite different between Douglas-fir forests and spruce-fir forests, and are addressed separately here. Douglas-fir trees produce very thick bark, enabling individual trees to survive many surface fires (Veblen and Lorenz 1986). Crown fires also occur periodically in Douglas-fir forests, and fire return intervals have been estimated from 20-25 years in northern areas of Yellowstone National Park (Houston 1973) up to 60 years in northwest Montana (Arno and Gruell 1986). Because spruce-fir forests are often the climax condition of stands that began as lodgepole pine, fire return intervals for spruce-fir forests are more similar to lodgepole pine, and may be even longer than 100-300 years at higher elevations where spruce and fir dominate the forest composition (Knight 1994).

Conceptual Model Development

Many of the drivers, stressors, and ecological responses in mixed conifer forests are similar to those in lodgepole pine forests, because of the coexistence of many of the species.

Drivers

Yellowstone's climate is characterized by long, cold winters, and cool, dry summers. Most of the precipitation falls in the form of snow. Winter Snowpack melts rapidly in May and June, providing much of the water available for growth in lodgepole pine forests. In addition, periods of seasonal drought, such as were experienced during the summer of 1988, may exert considerable influence on soil and fuel moisture, as well as fire regimes. Precipitation in BICA is quite variable, with the northern end of the Area receiving over 19 inches of precipitation per year, while the drier southern end receives, on average, only slightly more than seven inches per year (Knight et al. 1987). The climate is relatively more cool and moist at higher elevations, where mixed conifer forests occur. Because of its effects on precipitation, growing season, and tree mortality in both the GRYE and the BICA, elevation is also an important factor in determining the occurrence of wildfires.

Given the importance of fire in mixed conifer ecosystems, the management of prescribed fires and wildfires may greatly influence many natural ecosystem processes. For example, large, intense crown fires may help control episodic outbreaks of Mountain Pine Beetle by burning entire stands where significant outbreaks have occurred. Many of the indirect effects of fire suppression will be discussed below in subsequent sections.

Biotic drivers such as insects, plant pathogens and disease, and herbivory by both ungulates and insects may directly and indirectly affect many ecological processes in mixed conifer ecosystems. As more fully described below in the section on *Stressors*, these biotic drivers can lead to extensive episodes of tree mortality, which can affect critical processes such as coarse woody debris accumulation, changes in plant species composition, and net primary productivity.

The parent materials for soils across much of the Greater Yellowstone Area are largely volcanic in origin. Two different parent materials, derived from underlying bedrock, determine the soil characteristics in Yellowstone. Rhyolitic soils are found most often on drier sites, and are typically very nutrient limited. Andesitic soils are relatively more fertile, and often occur at higher elevations (Despain 1990). Differences in these parent materials is responsible for soil texture, and therefore, water holding capacity, as well as nutrient supply and availability. Rhyolitic soils are more sandy while andesitic soils contain much more clay (Despain 1990). Calcium is ten times more abundant in soils derived from andesite (Despain 1990). In the BICA, mixed conifer forests on East Pryor Mountain occur primarily on shallow soils, where fractured bedrock reservoirs may serve as water sources during an otherwise dry growing season (Knight et al. 1987).

Stressors and Ecological Responses

Drought, snowpack, and windstorms, all driven by weather and climate, affect many important ecosystem processes. Drought will affect soil moisture during the growing season, thereby affecting plant development and primary productivity, as well as forage abundance. Reduced soil moisture may also reduce nutrient supplies by a reduction in microbial activities such as decomposition and mineralization (Litton et al. 2003). Snowpack is the single largest contributor to soil moisture, and therefore water and nutrient availability during the growing season. Windstorms may cause large blowdowns, such as the 6,000-ha event that occurred in the Teton Wilderness in 1987. These events directly affect forest and landscape structure through widespread tree mortality and creation and accumulation of large quantities of coarse woody debris (CWD) and standing dead trees. Large areas of uprooted trees may also allow for the invasion of new plant species, and may also affect the growth rates of the new and existing species.

Abiotic stressors such as wildfire and human-induced changes to the ecosystem via management impacts can also alter ecological characteristics of mixed conifer forest systems. Wildfire affects many aspects of these ecosystems, including both the volatization and creation of essential nutrients from the organic materials combusted or consumed by fire (Knight et al. 1991). Wildfire directly kills many trees during severe surface or crown fires, which results in significant additions to the CWD biomass of these forests (Tinker and Knight 2000). Also, fire clearly can eliminate existing plant cover, but also provides new substrate for rapid reestablishment of residual plants, as well as the establishment of seral species such as aspen and lodgepole pine (Turner et al. 1997). If fire suppression efforts are successful, this will obviously result in a reduction of tree mortality and CWD accumulation, and may allow for the build-up of high levels of woody fuels.

Biotic stressors, primarily insects and plant pathogens, have important effects in mixed conifer forest ecosystems (Romme et al. 1986; Veblen et al 1991). Openings may be created in the forest canopy through tree mortality, which can result in increases in understory vegetation

production (Knight 1994). Plant parasites, such as dwarf mistletoe and comandra blister rust, are also common in many of these forests. The native mountain pine beetle is present at low population levels most of the time (Brown 1975; Baker and Veblen 1990), but periodic outbreaks, such as occurred during the 1970s in YNP, resulting in the death of thousands of trees (Despain 1990). This, in turn, also leads to changes in CWD biomass and distribution, plant species composition and productivity, and fuel availability, as well as broad-scale changes in landscape patterns (Romme et al. 1986). Herbivory, both by insects and ungulates, may reduce plant cover and may result in the mortality of young seedlings and saplings (Houston 1982; Singer et al. 1989).

Nutrient availability can be important for determining the proportions of spruce and fir in many mixed conifer forests. On sites where nutrients are limiting, as is common on many of the drier sites at lower elevations in the GRYE, lodgepole pine may be the only coniferous tree that is able to survive; on more nutrient rich sites, spruce and fir will generally be more abundant in mature forests (Peet 2000).

Indicators

Departures from the natural range of variability in **plant community composition** in mixed conifer ecosystems may indicate structural and functional changes in the ecosystem resulting from natural perturbations such as drought, fire, or windstorm, or human-caused disturbances or alterations such as non-prescribed fire or fire management (Pickett 1976). Vegetative reproduction following disturbance is the most common mechanism for herbaceous and shrubby plant reestablishment, as well as invasion by **exotic species** (Anderson and Romme 1991) and departures from this contribution may indicate considerable degradation of the seed bank. High **population levels of spruce beetle or budworms** within a stand may indicate that a stand has relatively low growth rates, which is often indicative of low vigor. Spruce beetles typically attack older stands that contain a high proportion of Engelmann spruce in the canopy. If stand-replacing fires are reduced through fire suppression, these older, senescent stands may facilitate increases in beetle population numbers. The **density of standing dead trees, or snags**, is an indicator of the amount of chronic, baseline mortality occurring within a stand, or across the landscape, and can help predict areas where beetle infestations may increase. **Forest floor litter and coarse woody debris** play important ecological roles in mixed conifer systems (Tinker and Knight 2000). CWD may provide habitat for many organisms (Harmon et al. 1986), and many decomposers such as bacteria and fungi derive energy and nutrients from decaying forest floor materials (Frankland et al. 1982). CWD and litter are also important inputs to soil organic matter (Edmonds 1991). Mixed conifer systems in the Greater Yellowstone Ecosystem and in BICA are often nitrogen- and nutrient-limited. Forest floor litter and CWD provide critical raw organic material for decomposition and mineralization processes. The **heterogeneity of mixed conifer landscapes** influences many important ecosystem functions such as habitat use and foraging patterns (Pearson 1993; Turner et al. 1994), nutrient movement (Peterjohn and Corell 1984), and disturbance dynamics (Turner 1987). Disturbance is now considered an integral part of mixed conifer ecosystems. Various disturbance types such as fire, insect outbreaks, windstorms, and earthquakes may significantly alter landscape structure in these ecosystems. This, in turn, will likely influence future processes such as net primary productivity, animal movement, forage availability, and habitat. Along with landscape metrics, an understanding of the age structures of the mixed conifer forests provides insights into the long-term effects of fire suppression, grazing, and other human influences within the ecosystem.

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Mixed Conifer Ecosystem Type – Ecological Indicators and Justifications

Indicator: Plant community composition and exotic species

Resource Monitored: Flora – plant species presence and abundance

Justification: Departures from the natural range of variability in community composition in mixed conifer ecosystems may indicate structural and functional changes in the ecosystem resulting from natural perturbations such as drought, fire, or windstorm, or human-caused disturbances or alterations such as non-prescribed fire or fire management (Pickett 1976). Vegetative reproduction following disturbance is the most common mechanism for herbaceous and shrubby plant reestablishment (Anderson and Romme 1991) and departures from this contribution may indicate considerable degradation of the seed bank.

Comment: This indicator is relatively well-understood and may therefore be most useful when attempting to evaluate current ecosystem conditions.

Example of Specific Measurements of this Indicator: Total species present and estimate of percent cover of each in relation to *expected* species present within the community. Common measures include quadrat and relevé methods.

Indicator: Beetle and budworm population levels

Resource Monitored: Insect fauna

Justification: High population levels of spruce beetle within a stand may indicate that a stand has relatively low growth rates, which is often indicative of low vigor.

Comment: Spruce beetles typically attack older stands that contain a high proportion of Engelmann spruce in the canopy. If stand-replacing fires are reduced through fire suppression, these older, senescent stands may facilitate increases in beetle population numbers.

Example of Specific Measurements of this Indicator: Surveys of actual numbers through the use of insect traps, or surveys of beetle evidence within a stand, which may serve as a proxy of beetle populations.

Indicator: Understory Plant species diversity

Resource Monitored: Flora - Biodiversity

Justification: High species diversity may maintain ecosystem stability through redundancy of the ecological roles of different species.

Comment: This is a very easy indicator to measure and has much public appeal, and is likely a priority of many agencies.

Example of Specific Measurements of this Indicator: Common measures include quadrat and relevé methods.

Indicator: Snag Density

Resource Monitored: Ecosystem Structure

Justification: This measure is an indicator of the amount of chronic, baseline mortality occurring within a stand, or across the landscape, and can help predict areas where beetle infestations may increase.

Example of Specific Measurements of this Indicator: Common measures include belt transect, quadrat, and relevé methods.

Indicator: Forest floor litter and coarse woody debris (CWD)

Resource Monitored: Ecosystem structure - forest floor structure; ecosystem processes

Justification: Forest floor litter and coarse woody debris play important ecological roles in mixed conifer systems (Tinker and Knight 2000). CWD may provide habitat for many organisms (Harmon et al. 1986), and many decomposers such as bacteria and fungi derive energy and nutrients from decaying forest floor materials (Frankland et al. 1982). CWD and litter are also important inputs to soil organic matter (Edmonds 1991).

Comment: Mixed conifer systems in the Greater Yellowstone Ecosystem are often nitrogen- and nutrient-limited. Forest floor litter and CWD provide critical raw organic material for decomposition and mineralization processes.

Example of Specific Measurements of this Indicator: Litter depth and biomass; CWD biomass and percent cover. Common measures include line intercept method for CWD percent cover, planar intercept for CWD biomass, and randomly placed measures of litter depth, with subsamples for dry weight.

Indicator: Landscape structure and heterogeneity

Resource Monitored: Landscape structure – patchiness, fragmentation, core habitat, patch edge density

Justification: The spatial pattern of mixed conifer landscapes influences many important ecosystem functions such as habitat use and foraging patterns (Pearson 1993; Turner et al. 1994), nutrient movement (Peterjohn and Corell 1984), and disturbance dynamics (Turner 1987).

Comment: Disturbance is now considered an integral part of mixed conifer ecosystems. Various disturbance types such as fire, insect outbreaks, windstorms, and earthquakes may significantly alter landscape structure in these ecosystems. This, in turn, will likely influence future processes such as net primary productivity, animal movement, forage availability, and habitat.

Example of Specific Measurements of this Indicator: Metrics commonly quantified using landscape description software and GIS, such as FRAGSTATS (McGarigal and Marks 1995) or *r.le* (Baker and Cai 1992) programs; vegetative cover most common base map used.

Indicator: Age structure of forest

Resource Monitored: Ecosystem structure

Justification: Along with landscape metrics, an understanding of the age structures of the mixed conifer forests provides insights into the long-term effects of fire suppression, grazing, and other human influences within the ecosystem.

Example of Specific Measurements of this Indicator: Age determination using tree increment borers to estimate the age of dominant trees within a stand.

Overview of Ponderosa Pine Ecosystems

General characteristics of ponderosa pine forests.

Ponderosa pine woodlands occur only along the fringes of the eastern Rocky Mountains (Peet 2000) and, specifically within the GRYE, only in the Bighorn Canyon Recreation Area. These relatively open community types do not occur in the mountains of western Wyoming in GTNP or YNP, but exist on lower elevation sites where summer precipitation is higher and the growing season is longer (Knight 1994). The importance of ample summer precipitation for the establishment and maintenance of Ponderosa pine woodlands is illustrated by its absence in the southern portion of the BICA, where summer precipitation is ~30% of that of the more mesic northern portions of the Area, where it is currently found. Many Ponderosa pine woodlands in the Western U.S. have undergone dramatic transformation as a result of successful fire suppression and the introduction of grazing by domestic cattle (Peet 2000). This often results in a change to more of a true forest condition, rather than a woodland, or savannah physiognomy. Mechanisms for this shift are thought to be either a reduction in the density of grasses (Savage and Swetnam 1990) or increased establishment of seedlings following fires (Marr 1961).

Fire regimes in ponderosa pine forests.

While many Ponderosa pine communities of the southwestern U.S. have experienced frequent, low-intensity fires that often limit regeneration, pine woodlands in more northerly latitudes such as in BICA may have evolved with longer fire-return intervals, on the order of 25-40 years (Rowdabaugh 1978; Laven et al 1980).

Conceptual Model Development

Drivers

The climate of the BICA area is often described as temperate and semi-arid. As noted earlier, the occurrence of critical summer precipitation limits the distribution of ponderosa pine to the more northern areas of the Area, where annual precipitation averages 49 cm; approximately two-thirds of this falls during spring and early summer, and the rest as snow (Knight et al. 1987).

Given the importance of fire in ponderosa pine ecosystems, the management of prescribed fires and wildfires can dramatically influence tree regeneration, as well as many other natural ecosystem processes. Some of the indirect effects of fire suppression will be discussed below in subsequent sections.

The biotic drivers may, in the case of BICA, be among the most important in the development, maintenance, or loss of ponderosa pine woodlands. Biotic drivers such as insects, plant pathogens and disease, and cattle grazing may directly or indirectly affect many ecological processes in ponderosa pine ecosystems. As more fully described below in the section on

Stressors, these biotic drivers can lead to extensive episodes of tree mortality or creation of dense doghair stands, both of which can affect critical processes such as coarse woody debris accumulation and stand density.

Stressors and Ecological Responses

As previously mentioned, summer precipitation, and its effect on soil moisture, is very important for the establishment and growth of ponderosa pine (Knight 1994). Successive drought years may result in the mortality of mature trees and particularly seedlings, even though young trees are somewhat drought resistant (Wellner 1970). Many human activities, including fire suppression, introduction of exotic plant species, and grazing by domestic cattle currently affect many aspects of ponderosa pine woodlands in BICA. For example, because historic frequent fires normally reduce the number of new seedlings that establish, elimination of these fires during the last century allows for the development of dense, doghair stands of ponderosa pine, which creates additional woody fuels for more severe crown fires (Knight 1994). Livestock or wild horse grazing may also improve conditions for seedling establishment through the removal of plant competition. Further, as mature trees die or are killed by pine beetles or other plant pathogens, invasion by exotic plant species may inhibit the germination and establishment of replacement trees, causing a shift in plant community composition and tree density. The pine beetle outbreaks may occur during years of inadequate precipitation, when mature trees are unable to produce sufficient resins to defend against beetle infestation (Knight 1994).

Indicators

Ponderosa pine is very sensitive to **soil moisture** availability. As an example, it is conspicuously absent from the southern end of the Bighorn Canyon, where summer rainfall is quite low, but is relatively abundant at similar elevations in the northern end of the canyon, where summer precipitation is much higher (Knight 1994). Ponderosa pine is also sensitive to cold pockets, such as collect in some drainages. However, many drainages in Bighorn Canyon contain ponderosa pine, where soil moisture availability is higher than surrounding uplands. Many ponderosa pine forests have dramatically increased in **stand density** as a result of fire suppression (Covington and Moore 1994). This is thought to be a significant departure from more park-like stand structure characteristic of pre-European settlement. If fire suppression continues, stand densities may continue to increase, resulting a increased susceptibility to intense, stand-replacing fires. **Exotic species composition and abundance** is a critical issue in these ecosystems. Many ponderosa pines, especially in riparian areas and in drainages, are being eliminated in Bighorn Canyon by the invasion of exotic species such as tamarisk and Russian olive (Laura Gianakos, personal communication; personal observation, 2003). **The proportion of standing dead trees** serves as an indicator of both the susceptibility to intense, stand-replacing fires, which is not the typical fire regime for most ponderosa pine stands, as well as a response variable to mountain pine beetle infestation. The suppression of fire may allow mortality from beetle outbreaks to increase, as well as increase the risk of severe fires.

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Ponderosa Pine Ecosystem Type – Ecological Indicators and Justifications

Indicator: Soil Moisture

Resource Monitored: Ecosystem structure and function.

Justification: Ponderosa pine is very sensitive to soil moisture availability. As an example, it is conspicuously absent from the southern end of the Bighorn Canyon, where summer rainfall is quite low, but is relatively abundant at similar elevations in the northern end of the canyon, where summer precipitation is much higher (Knight 1994).

Comment: Ponderosa pine is also sensitive to cold pockets, such as collect in some drainages. However, many drainages in Bighorn Canyon contain ponderosa pine, where soil moisture availability is higher than surrounding uplands.

Example of Specific Measurements of this Indicator: Seasonal soil moisture monitoring.

Indicator: Stand Density

Resource Monitored: Ecosystem structure and function.

Justification: Many ponderosa pine forests have dramatically increased in density as a result of fire suppression (Covington and Moore 1994). This is thought to be a significant departure from more park-like stand structure characteristic of pre-European settlement.

Comment: If fire suppression continues, stand densities may continue to increase, resulting a increased susceptibility to intense, stand-replacing fires.

Example of Specific Measurements of this Indicator: Belt transect measures of stand density, or other quadrat or plot measurements.

Indicator: Exotic species composition and abundance

Resource Monitored: Flora – species composition and abundance.

Justification: Many ponderosa pines, especially in riparian areas and in drainages, are being eliminated in Bighorn Canyon by the invasion of exotic species such as tamarisk and Russian olive (personal observation, 2003).

Example of Specific Measurements of this Indicator: Plant species surveys and percent cover estimates using quadrats.

Indicator: Proportion of standing dead trees

Resource Monitored: Ecosystem structure and function.

Justification: This serves as an indicator of both the susceptibility to intense, stand-replacing fires, which is not the typical fire regime for most ponderosa pine stands, as well as a response variable to mountain pine beetle infestation. The suppression of fire may allow mortality from beetle outbreaks to increase, as well as increase the risk of severe fires.

Example of Specific Measurements of this Indicator: Belt transects or other quadrat methods for quantifying density of live and dead trees.

Overview of Whitebark Pine Ecosystems

General characteristics of whitebark pine forests. Whitebark pine (*Pinus albicaulis* Elgelm.) is a high-elevation tree of the Northern Rocky Mountains, forming open woodlands on relatively xeric slopes (Arno and Hammerly 1977). Whitebark pine is a member of the white pine group (*Pinus* subgenus *Haploxylon*), which also contains limber pine, and does not typically form continuous, closed stands characteristic of other montane forest species of the Northern Rockies (Peet 2000). Regeneration of whitebark pine occurs almost solely via seed dispersal by the Clark's Nutcracker (Hutchins and Lanner 1982). The birds will cache multiple seeds together in open areas, often in recently burned forests, and unclaimed caches will germinate and grow in the absence of shade and competition (Tomback et al. 1990). This form of avian dispersal of seeds often results in the germination and establishment of multi-stemmed trees (Furnier et al. 1987). The relatively large seeds serve as an important food source for at least 110 species of animals, including grizzly bears and red squirrels (Tomback 1989).

Following intense fires in lodgepole or spruce-fir stands, whitebark pine may act as a seral species, but is more typically found as a climax species, since seedling establishment often ceases with the establishment of more shade-tolerant species such as Engelmann spruce and subalpine fir (Schuster et al. 1995). It is relatively abundant across the subalpine plateaus of YNP, but only comprises about 2% of the vegetation in GTNP (Greater Yellowstone Coordinating Committee 1987).

Fire regimes in whitebark pine forests. Because of higher elevations, lower fuel accumulations, and much bare ground below the canopy, whitebark pine ecosystems burn less frequently than other Rocky Mountain conifers (Peet 2000). Depending on the location and site conditions, presettlement fire return intervals ranged from 30-300 years (Morgan et al. 1995).

Conceptual Model Development

Drivers

Moisture and temperature are the two factors that largely control the occurrence of different habitat types in the region (Despain 1990). The climate of the Greater Yellowstone Area is characterized by long, cold winters, and cool, dry summers. Most of the precipitation falls in the form of snow. Winter Snowpack melts rapidly in May and June, providing much of the water available for growth in high elevation whitebark pine forests. In addition, periods of seasonal drought, such as were experienced during the summer of 1988, may exert considerable influence on soil and fuel moisture, as well as fire regimes.

Biotic drivers such as plant competition, insects, and plant pathogens and disease, particularly white pine blister rust may directly and indirectly affect many ecological processes in whitebark pine ecosystems. As more fully described below in the section on *Stressors*, these biotic drivers can lead to extensive episodes of tree mortality, which can affect critical processes such as coarse woody debris accumulation and net primary productivity.

Given the importance of fire in lodgepole pine ecosystems, the management of prescribed fires and wildfires may greatly influence many natural ecosystem processes. For example, large, intense crown fires may help control episodic outbreaks of Mountain Pine Beetle by burning entire stands where significant outbreaks have occurred. Many of the indirect effects of fire suppression will be discussed below in subsequent sections.

As mentioned earlier, the regeneration of whitebark pine occurs almost solely via seed dispersal by the Clark's Nutcracker (Hutchins and Lanner 1982). The birds will cache multiple seeds together in open areas, often in recently burned forests, and unclaimed caches will germinate and grow in the absence of shade and competition (Tomback et al. 1990).

Stressors and Ecological Responses

Wildfire and management-related changes to the ecosystem such as fire suppression can also affect whitebark pine systems. Wildfire affects many aspects of these ecosystems, including both the volatization and creation of essential nutrients from the organic materials combusted or consumed by fire (Knight et al. 1991). Wildfire directly kills many trees during severe surface or crown fires, which results in significant additions to the CWD biomass of these forests (Tinker and Knight 2000). Also, fire clearly can eliminate plant cover, but also provides new substrate for rapid reestablishment of residual plants (Turner et al. 1997). If fire suppression efforts are successful, this will obviously result in a reduction of tree mortality and CWD accumulation, and may allow for the build-up of high levels of woody fuels (Keane 2001). In addition, removing fire from these systems may result in increases in late successional forest and replacement of whitebark pine by more shade-tolerant species such as subalpine fir and Engelmann spruce (Arno and Hoff 1990; Keane et al. 1994).

Drought and wind, snow, and ice abrasion, all driven by weather and climate, affect many important ecosystem processes. Drought will affect soil moisture during the growing season, thereby affecting plant development and primary productivity, as well as forage abundance. Reduced soil moisture may also reduce nutrient supplies by a reduction in microbial activities such as decomposition and mineralization (Litton et al. 2003). Snowpack is the single largest contributor to soil moisture, and therefore water and nutrient availability during the growing season. Because many whitebark pine communities occur at higher elevations, where growing conditions are often quite harsh, abrasion from wind, snow and ice can affect tree growth and vigor, or in extreme conditions, may result in the mortality of individual trees.

Biotic stressors have also accelerated the successional process in many whitebark pine forests, largely through epidemic outbreaks of the exotic white pine blister rust and native mountain pine beetles (Keane 2001). Other plant parasites, such as dwarf mistletoe is also common in these forests. The native mountain pine beetle is present at low population levels most of the time (Brown 1975; Baker and Veblen 1990), but periodic outbreaks, such as occurred during the 1970s in YNP, may result in the death of numerous trees (Despain 1990). This, in turn, can also leads to changes in runoff and erosion in high-elevation stands, along with an increase in establishment of other tree species such as Engelmann spruce and subalpine fir (Keane et al. 1994; Arno 1986).

Ecological Indicators

Clark's Nutcracker abundance is critical for the regeneration of whitebark pine, which occurs almost solely via seed dispersal by the Clark's Nutcracker (Hutchins and Lanner 1982). The birds will cache multiple seeds together in open areas, often in recently burned forests, and

unclaimed caches will germinate and grow in the absence of shade and competition (Tomback et al. 1990). Following intense fires in lodgepole or spruce-fir stands, whitebark pine may act as a seral species, establishing in the newly burned forest floor, where cached seeds distributed by Clark's Nutcrackers can germinate and establish in the absence of competition (Tomback et al. 1993). The **burned forest seedbed availability** is therefore very important for the germination and establishment of new whitebark pine seedlings. Whitebark pine is considered a "keystone" species for upper elevation areas in the Greater Yellowstone Ecosystem (Tomback et al. 2001), and the monitoring of the **density of high-elevation whitebark pine trees** is likely a good indicator of population trends. Further, because of fire suppression and recent outbreaks of Mountain Pine Beetle and White Pine Blister Rust, whitebark pine is thought to be declining throughout the GYE (Tomback et al. 2001). Fire exclusion may have reduced fire frequency in many high elevation forests of the GYE, and consequently, the **abundance of replacement tree species** such as subalpine fir and Engelmann spruce may be another excellent indicator of population trends in whitebark pine (Arno 1986; Keane et al. 1994). The **production of whitebark pine cones**, and therefore seeds, is critical as forage for both Clark's Nutcrackers and Grizzly bears, as well as for the reestablishment of whitebark pine at both high and low elevations (Tomback et al. 2001). In addition, reduction of cone production can be an early indicator of infection by White Pine Blister Rust, which often kills cone-bearing branches prior to killing the entire tree (Tomback et al. 2001). Cone production in whitebark pine does not occur until trees reach the age of 20-30 years (Krugman and Jenkinson 1974). A significant reduction in cone – and therefore seed – production could represent a major shift in age classes at higher elevations. White pine blister rust is an exotic plant pathogen that only infects five-needle pines such as whitebark or limber pine (Tomback et al. 2001). In some areas of the Rocky Mountains, whitebark pine mortality has reached 90 percent (Keane et al. 1994). Monitoring of **blister rust abundance and spread** may help identify newly-developed strains of the organism, such as drought-tolerant strains that could accelerate the spread of the rust (Tomback et al. 2001). Finally, Whitebark pine in the Greater Yellowstone Ecosystem is a major food source for grizzly bears, which primarily forage on pine squirrel middens (Mattson et al. 1991) during the fall of the year. During years of low cone and seed production, grizzly bears will forage at lower elevations, searching for alternative sources of food. This low elevation foraging by grizzly bears in autumn can serve as a surrogate for estimates of annual cone and seed production. Grizzly bear foraging at lower elevations has historically resulted in increases in management actions, i.e., trapping and relocating, as well as increases in bear mortality (Mattson et al. 1992).

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Whitebark Pine Ecosystem Type – Ecological Indicators and Justifications

Indicator: Clark's Nutcracker Abundance

Resource Monitored: Fauna – Seed disperser

Justification: Regeneration of whitebark pine occurs almost solely via seed dispersal by the Clark's Nutcracker (Hutchins and Lanner 1982). The birds will cache multiple seeds together in open areas, often in recently burned forests, and unclaimed caches will germinate and grow in the absence of shade and competition (Tomback et al. 1990).

Comment: This indicator is relatively well-understood and may therefore be most useful when attempting to evaluate future establishment of whitebark pine.

Example of Specific Measurements of this Indicator: Census measures of Clark's Nutcrackers could include simple counts or nesting successes.

Indicator: Burned forest seedbed availability

Resource Monitored: Ecosystem structure and function.

Justification: Following intense fires in lodgepole or spruce-fir stands, whitebark pine may act as a seral species, establishing in the newly burned forest floor, where cached seeds distributed by Clark's Nutcrackers can germinate and establish in the absence of competition (Tomback et al. 1993).

Comment: Fire suppression may reduce the amount of available seedbed for whitebark pine establishment, especially at lower elevations, where it acts as a seral species.

Example of Specific Measurements of this Indicator: Landscape analysis using Geographic Information Systems to annually map the locations and extent of fires within the ecosystem.

Indicator: Low elevation foraging by grizzly bears in autumn

Resource Monitored: Fauna – forage and behavior.

Justification: Whitebark pine in the Greater Yellowstone Ecosystem is a major food source for grizzly bears, which primarily forage on pine squirrel middens (Mattson et al. 1991) during the fall of the year. During years of low cone and seed production, grizzly bears will forage at lower elevations, searching for alternative sources of food. This presence at lower elevations can serve as a surrogate for estimates of annual cone and seed production.

Comment: Grizzly bear foraging at lower elevations has historically resulted in increases in management actions, i.e., trapping and relocating, as well as increases in bear mortality (Mattson et al. 1992).

Example of Specific Measurements of this Indicator: Monitoring grizzly bear movements and foraging habits during late summer and early fall using radio-collared bears and GIS.

Indicator: Density of high-elevation whitebark pine trees

Resource Monitored: Flora – species abundance and density.

Justification: Whitebark pine is considered a "keystone" species for upper elevation areas in the Greater Yellowstone Ecosystem (Tomback et al. 2001).

Comment: Because of fire suppression and recent outbreaks of Mountain Pine Beetle and White Pine Blister Rust, whitebark pine is thought to be declining throughout the GYE (Tomback et al. 2001).

Example of Specific Measurements of this Indicator: Repeated measures of whitebark pine stand densities at high elevations using belt transects or remotely sensed data.

Indicator: Abundance of replacement tree species

Resource Monitored: Ecosystem structure and function

Justification: Fire exclusion has reduced fire frequency in many high elevation forests of the GYE, and consequently, it is being replaced by shade-tolerant species such as subalpine fir and Engelmann spruce (Arno 1986; Keane et al. 1994).

Example of Specific Measurements of this Indicator: Repeated measures of high elevation community composition using belt transect surveys or remotely sensed data.

Indicator: Whitebark pine cone production

Resource Monitored: Flora – regeneration and food source.

Justification: The production of whitebark pine cones, and therefore seeds, is critical as forage for both Clark's Nutcrackers and Grizzly bears, as well as for the reestablishment of whitebark pine at both high and low elevations (Tomback et al. 2001). In addition, reduction of cone production can be an early indicator of infection by White Pine Blister Rust, which often kills cone-bearing branches prior to killing the entire tree (Tomback et al. 2001).

Comment: Cone production in whitebark pine does not occur until trees reach the age of 20-30 years (Krugman and Jenkinson 1974). A significant reduction in cone – and therefore seed – production could represent a major shift in age classes at higher elevations.

Example of Specific Measurements of this Indicator: Repeated measures of stand-level cone production.

Indicator: Blister Rust abundance and spread

Resource Monitored: Ecosystem structure and function – plant pathogens.

Justification: White pine blister rust is an exotic plant pathogen that only infects five-needle pines such as whitebark or limber pine (Tomback et al. 2001). In some areas of the Rocky Mountains, whitebark pine mortality has reached 90 percent (Keane et al. 1994).

Comment: Monitoring of blister rust abundance and spread may help identify newly-developed strains of the organism, such as drought-tolerant strains that could accelerate the spread of the rust (Tomback et al. 2001).

Example of Specific Measurements of this Indicator: Repeated collections and analysis of samples of infected branches or trees.

L. RIPARIAN/RIVERINE ECOSYSTEM NARRATIVE CONCEPTUAL MODEL—DUNCAN PATTEN

INTRODUCTION

Riverine systems often include terrestrial habitat: riparian ecosystems, stream-edge wetlands and nearly-barren sediment deposits; and aquatic habitats. This discussion of riverine systems is limited to the terrestrial ecosystems. Riparian and edge-wetlands are grouped as riparian ecosystems. Riparian ecosystems, the transition from stream to upland, occupy a very small part of the landscape, often less than 1 %, and yet play an important role in stream dynamics, wildlife ecology, and biodiversity . (Naiman et al., 1993; Naiman and Decamps, 1997; Patten, 1998). In most cases riparian ecosystems occur on alluvial sediment deposits where the hydrological connection between river and alluvial groundwater supplement water available from precipitation (Gregory et al., 1991). Riparian ecosystems offer many ecological services and functions. These services and functions are closely related to the structure, composition and abundance of the riparian vegetation and its location within the landscape. Riparian ecosystems not only influence hydrologic and geomorphic processes, but are driven by these processes as well. This synergistic relationship between riparian vegetation and hydrogeomorphic phenomena complicates the understanding of riparian response to human activities. One important function of riparian systems is that of habitat for a wide variety of organisms. In semi-arid regions over 75% of animals species use riparian ecosystems for all or part of their life cycle (Brinson et al. 1981; Kondolf et al. 1996). Because of close affinity with various characteristics of riparian ecosystems, avian community composition often is used as a surrogate for condition of riparian systems (Anderson et al. 1983; Hunter et al. 1987).

The occurrence of most riparian communities in the Greater Yellowstone Network (GRYN) parks results from recruitment and survival of obligate riparian plant species in response to seasonal hydrological events, variation in groundwater depth, and availability of favorable fluvial geomorphic surfaces. For example, most cottonwood species recruit along streams on bare moist surfaces during the declining limb of spring high flows (Friedman et al., 1995; Scott et al., 1997; Stromberg et al., 1997). Willow species may follow a similar pattern but tend to spread clonally. Survival of these woody riparian species is dependent on maintenance of a high alluvial water table and avoidance of scour events such as floods and ice flows. Mortality, or inability to survive following recruitment, may result from a water table lowered below those tolerated by young or maturing plants (Rood and Mahoney, 1995). Other factors, especially those human controlled, also play a role in riparian decline throughout the West.

LANDSCAPE DIVERSITY

The parks represented in the GRYN (i.e., Yellowstone, Grand Teton and Big Horn) have heterogeneous landscapes ranging from mountains to broad valleys and deep canyons. Consequently, streams and rivers flowing from the mountains transect a diverse geomorphology that creates steep gradients through shallow-bedrock narrow valleys as well as low-gradient, broad valleys with deep alluvial. Throughout this region, variability in valley morphology directly influences the extent and type of riparian communities (Patten, 1998). Streams flowing through broad valleys with low gradients may be lined by woody and/or herbaceous riparian vegetation. If the water table is shallow, wetland herbaceous plants (e.g., sedges and wetland grasses) may extend

for some distance from the river creating fens in some areas. These wetland areas often are devoid of woody species because the herbaceous cover may prevent establishment of willows, cottonwoods or other woody plants. Willows (*Salix* spp.) and sometimes cottonwoods (*Populus* spp.) may occur near the stream where floods enhance their recruitment. Once established, these species may spread asexually and expand within the floodplain often occurring away from the stream as it migrates across the floodplain. Steep gradient mountain streams may have riparian communities of mixed willows and conifers but cottonwoods may occur on suitable sites at lower elevations. Other woody species such as dogwood (*Cornus* spp.) and alder (*Alnus* spp.) also occur along these higher gradient streams.

Elevational differences also may influence riparian composition and structure. High elevation streams may not support large woody species such as cottonwood for physiological reasons. Alpine streams only support wetland herbaceous species or, occasionally, dwarf willows. Shrub willows and alders may be common along upper elevation streams sometimes mixed with stream-side conifer communities. With decreasing elevation, low stature riparian woody vegetation gives way to, or mixes with deciduous tree species. The gradient in the northern Rockies and represented in some of the GRYN parks goes from cottonwood/willow forests at lower elevations through alder/willow communities to spruce/aspen communities into alpine wetlands.

COMMON FEATURES

Structural similarities of riparian communities occur across the GRYN because they are related to successional dynamics which are driven by common fluvial-geomorphic processes. For example, point-bars, channel margin, and island deposits provide exposed sediment that supports young riparian plants along meandering and braided rivers throughout the region. Also, sediment accumulation on terraces accompanies aging of riparian vegetation and establishment of later successional species. Cottonwood species found along streams from different regions have been shown to have similar recruitment requirements (Bradley and Smith, 1986; Scott et al., 1996, 1997; Shafroth et al., 1995; Stromberg et al., 1997; Auble and Scott, 1998; Rood and Kalischuk, 1998; Shafroth et al., 1998). For example, recruitment of cottonwood and associated riparian species is most often tied to hydrological events (i.e., high flows) occurring during the period of seed dispersal. The timing and cause of these events may differ throughout the region, but early succession woody riparian species (e.g., cottonwood and willow) respond the same way to high flow, recruiting new seedlings on the receding limb of the high flow event. The year of recruitment may be delayed along GRYN rivers because snow melt floods may extend beyond the seed dispersal period, and recruitment occurs during high flows in succeeding years. Other species, for example, shrubby cinquefoil (Potentilla fruticosa) and water birch (Betula glandulosa) are also found in the riparian zone responding to other factors such as very moist soil or snow bank accumulation.

Patterns of riparian communities along elevation gradients and geomorphic gradients are similar throughout most of the GRYN. This region is arid to semi-arid thus availability of water and similarity of riparian vegetation structure allow ready transfer of information developed in one area to another.

DRIVERS OR FORCING FUNCTIONS OF RIPARIAN SYSTEMS

Hydrological factors controlling riparian processes may be quite different between the mountainous, headwater parks of Yellowstone and Grand Teton, and Big Horn Canyon NRA. Snow and ice may play a predominant role in the Yellowstone and Grand Teton while storm events on the arid landscape of Big Horn may be the primary hydrological driver. Snowmelt in the headwater parks creates a reliable hydrographic peak while erratic storms and controlled mainstem flows produce uncertain hydrographs in Big Horn. Recruitment of many riparian species is triggered by or coincides with the spring snowmelt peak which occurs in May to June (Scott et al., 1993). However, the peak may extend beyond seed dispersal causing recruitment to be delayed by a year if peak flows of the succeeding year are sufficiently high. If insufficient, recruitment may be delayed further.

Heavy local storms may have greater impacts on stream flows in Big Horn than Yellowstone or Grand Teton. Less vegetative cover at Big Horn may result in flash floods in mountainous low order streams. Recruitment of spring seed-dispersal species such as cottonwood and willow is usually most successful when high spring flows that trigger riparian recruitment are followed by a relatively dry summer, and/or absence of large floods during the next year or two (Stromberg et al., 1991). Predicting future stream flows might allow projection of changes in riparian vegetation (Auble et al. 1994 Non-native species such as tamarisk (*Tamarix ramosissima*), Russian olive (*Elaeagnus angustifolia*), and many noxious weeds disperse seeds over long periods and thus take advantage of summer storms (Stromberg, 1998).

Riparian ecosystems of GRYN region may occasionally be scoured by flash floods but some are regularly affected by ice formation. Ice forms on the surface of rivers in the northern Rockies during extreme cold periods. During ice drives, ice may be elevated and scours the bank often well above levels of spring floods (Smith, 1980). Ice scour damages existing trees, removes riparian vegetation, forms new channels and controls the elevation of successful riparian recruitment (Johnson, 1994; Scott et al., 1997).

Geomorphic influences in the GRYN region may effect how successful recruitment might be for riparian species. Many riparian species require bare moist soil for recruitment (Stromberg et al., 1991; Scott et al., 1996). Many rivers of the north Rockies have gravel- or cobble-lined channels; however, fine sediment in these rivers may be held in overbank ice in winter and deposited in spring where riparian recruitment may occur. Fine sediments also are deposited within the interstices on the cobble and gravel bars.

River geomorphology, especially on smaller streams, is often controlled or altered by beaver activity (Naiman et al. 1986). Relatively permanent beaver dam structures collect sediment, altering sediment delivery downstream, and elevate local groundwater, enhancing growth and survival of most riparian species (Johnston and Naiman 1987). When beaver dam sites are active, beavers may alter the surrounding woody vegetation, harvesting and felling stream-side trees and shrubs (Hall 1960). Eventual abandonment of beaver dam sites results in floodplains covered in fine sediments and a vegetational successional process that leads towards the vegetation that occurred prior to beaver arrival.

ENVIRONMENTAL STRESSORS

Hydrological Stressors. Factors that have created and maintained riparian systems within the GRYN parks are changing. Most changes are tied to water and channel management, land use, ungulate management, and introduction of non-native species. Throughout the region, rivers have been managed to produce water for irrigation, generate hydroelectric power, and for flood control. This is especially true in Grand Teton and Big Horn parks. In Grand Teton NP the Snake River is dammed at Jackson Lake, retaining irrigation water to be used during the growing season downstream in Idaho. Short reaches of the Snake River channel are also stabilized within GTNP. In BICA, the Big Horn River is dammed both upstream of the park and within the park. Dams and their impoundments have greatly altered downstream ecosystems (Ligon et al., 1995; Dynesius and Nilsson 1994; Collier, et al., 1996; Shafroth, et al. 2002). They impound spring floods that normally would scour channels, deposit sediment, and produce riparian vegetation along the high water zone (e.g., Johnson, 1991). Dam releases to satisfy downstream water uses, exemplified by operation of Buffalo Bill and Boysen dams upstream of BICA and the Jackson Lake dam, often do not coincide with normal high flow periods for the river, eliminating recruitment enhancing high flows and often producing scouring summer flows (Fenner et al., 1985; Rood and Mahoney, 1990, 1995; Johnson, 1992; Dominick and O=Neill, 1998; Mahoney and Rood, 1998). Reduction of peak flows though may result in widespread narrowing of channels resulting in riparian vegetation establishment in areas that once were active channels (Johnson, 1994, 1998; Friedman et al., 1996, 1997, 1998; Shafroth et al., 1998). Even when dams allow normal flows for recruitment and maintenance of riparian species, the river below the dam may carry little sediment, material important for creation of recruitment sites (Scott et al., 1997).

Stream diversion for irrigated agriculture may reduce surface flows or effect local floodplain vegetation. Several irrigation take out channels on tributaries of the Snake River within Grand Teton NP may be modifying the adjacent riparian communities. Grand Teton NP still has remnants of past agricultural uses within those areas of the park added in the 1950s. Where agriculture existed near rivers, removal of floodplain vegetation may still be evident as the floodplains recover. Recreational use of riparian areas has been found to leave them vulnerable to over-use and degradation (Johnson and Carothers, 1982). Although limits on use of streamside areas may occur in some of the GRYN parks, BICA is established as a recreation area and potential heavy use along the Big Horn Lake margins may have deleterious effects. Effects of campers and day hikers on riparian vegetation along small mountain streams often are locally evident in Yellowstone and Grand Teton NPs.

Biological Stresssors. Ungulate grazing in riparian areas may disrupt the reproductive cycle of riparian trees such as cottonwoods, whose broad-leaved seedlings and saplings are extremely desirable forage. Removal of reproductive shoots also diminishes reproductive potential of willows (Kay 1994). Heavy ungulate use, both wild and domestic, of floodplains and riparian areas may greatly reduce riparian ground cover, destabilize streambanks, and increase sediment loads to streams (Patten 1968, Armour et al., 1991; Elmore, 1992; NRC 2002). Wild ungulate use in areas of Yellowstone NP, for example, the northern range, and Grand Teton NP, has altered the cover and structure of the riparian community (Singer et al. 1994, Singer 1996, Keigley 1997).

Beaver activity, although a normal component of riverine ecosystems in the GRYN parks, under specific conditions may be considered an ecosystem stressor. While beavers usually alter streams when occupying dam sites, or modify riparian vegetation whether housed in ponds behind dams or in stream banks, their absence may result in water table declines and associated long-term alteration or loss of riparian vegetation. Conversely, over-population of beavers in any reach of a river may cause major alterations of riparian vegetation through excessive harvesting of riparian woody plants. Several areas of the GRYN, for example, streams in the northern range of YNP, once supported extensive beaver populations but these are now absent (Bailey 1930, Wright and Thompson 1935, Jonas 1955). Also, continued beaver trapping outside the parks maintained low populations. Recently, however, beaver populations have dramatically increased in several areas of the GRYN parks. This recovery may ultimately result in "over-population" of beavers in some areas because many areas that once were suitable for beaver habitat in the region are no longer suitable for beaver population expansion because of unacceptable consequences of beaver activities in most areas of human habitation.

Non-native Species As Stressors. Introduction of non-native species has greatly altered the west=s riparian ecosystems and has become a major management issue in all three GRYN parks. Grazing and altered hydrology often favor the survival of introduced species (e.g., tamarisk) and allows thriving non-natives to displace native species. Russian-olive and tamarisk are two non-native species that have greatly altered western riparian communities (Brock, 1984; Shafroth et al., 1995). Not only have they altered the communities they have invaded, they are difficult to remove. For example, tamarisk can repeatedly resprout after fire, cutting, or browsing, and it survives in very wet, very dry, or very salty soils (Gladwin and Roelle, 1998; Smith et al., 1998). An example of major tamarisk invasion in these parks is the exposed lake bed in BICA where the Big Horn River enters the park. Here tamarisk has developed a dense cover of young invasive woody plants. Extended inundation may be the only way to eliminate this extensive stand of tamarisk. Herbaceous non-natives are also becoming prevalent in many riparian areas creating dense ground cover that competes with native species, increases fuel for fires, and may be enhanced by grazing (Stromberg and Chew, 1997). All the parks are now contending with increasing cover of non-native herbaceous plants. This has become a sufficiently important issue that the Biennial Science Conference in Yellowstone NP in 2001 (ref) emphasized this issue.

Climate Fluctuation as a Stressor. Climatic fluctuations over the past century have resulted in changes in local watershed hydrology which directly affect the condition of riverine and riparian systems. Long-term droughts not only reduce stream flows but diminish groundwater supplies, lowering water tables which are critical sources of water for riparian phreatophytic plants (Stromberg et al. 1996, Shafroth et al. 2000). Human accelerated climate change may create more erratic climatic fluctuations and could potentially produce extended droughts, much longer than that of the 1930s and similar to the 30-50 year droughts of 300 years ago. Riparian communities within the GRYN parks will respond relatively quickly to extended drought periods, reducing cover to only those areas that can maintain a shallow water table. These areas will be immediately adjacent to shallow bedrock streams and along margins of larger rivers where low flows may support alluvial groundwater. Climatic change and drought in the northern Rockies region will affect all three GRYN parks. Vegetation that is dependent on supplemental water, such as riparian vegetation, may be more altered by these changing conditions than upland vegetation.

Cumulative Effects of Stressors. Riparian ecosystem condition reflects the cumulative effects of all activities that influence watershed hydrology and thus may be an important indicator of changing environmental conditions within the GRYN parks. Multiple resource uses on mountains and in valleys have modified the quantity and quality of water entering rivers. This is true for BICA, as the headwaters of the Big Horn River are used for many forms of resource extraction, ranching and agriculture often with release of stream contaminants. Sometimes the results of land use can be subtle, while in other cases, downstream impacts on riparian ecosystems can be dramatic. Timber harvest may result in larger and flashier floods which carry increased sediment. Leaving a buffer zone may help reduce sedimentation rates and provide for continued ecological interactions between streams and riparian vegetation (Kauffman, 1988).

APPLICATION TO GREATER YELLOWSTONE NETWORK PARKS

Riverine and riparian systems within the three GRYN parks are influenced by many of the same stressors. The conceptual models illustrate the linkages between the many stressors (Figures 1-5). Although there may be many stressors that influence riverine and riparian systems in the parks, the conceptual model applies only a few that are known to potentially significantly alter these systems. As discussed above, stressors that influence riparian systems and that should be addressed in any inventory and monitoring program include (1) altered hydrology, (2) altered channel morphology, (3) climatic changes, especially droughts, (4) ungulate utilization of the riparian zone, (5) exotic plants, and (6) recreation. The discussion illustrates the importance of these stressors to each park but does not apply them specifically to park units. The importance to a park depends on extent and magnitude of a particular stressor. For example, altered hydrology is not a primary stressor in Yellowstone NP, but it plays and important role along the mainstem of the Snake River in Grand Teton NP, and is the primary stressor for the main water course and lake in BICA. Ungulates, on the other hand, may not be important in BICA along the river and lake, but are important locally in YNP and GTNP. BICA, on the other hand, may have ungulate herbivory issues in the uplands.

The conceptual model(s) (Figure 1 a-e) show linkages among stressor and how they relate to dynamics of components of the riverine/riparian ecosystem. Following the flow of connected processes, it is possible to end up with a limited set of potential indicators that, if monitored, will offer evidence of changing watershed and river conditions within each park.

Each park has been geographically divided into watershed units (HUC units) for the purpose of addressing variability across the landscape of the parks. Within the GRYN parks there are several riparian vegetation community types, some may occur in all parks while others may be specific to one or two parks, a consequence of geographic and environmental diversity. Table 1 presents riparian community types that occur within GRYN parks and identifies within HUC unit for each park those environmental threats or stressors that potentially may have an impact on long-term survival and condition of the riparian community. Eight different riparian vegetation community types are presented. Some of these relate to seral stages in riparian vegetation development and maturation, for example, gravel bar/river edge riparian communities up to mature cottonwood communities. Some riparian communities also relate to geographic locations, such as large river margins, lake shores, small mountain streams, or broad valley wetted-sediment deposits. The list of riparian community types is simplified for application to the whole GRYN. If expanded

based on diversity within community type, the variability would create hundreds of types. For example, twenty four species of willow are found in the northern range of YNP and these produce a diverse set of willow communities based upon diverse environmental drivers (YNP 1997).

To allow comparisons across community types, a brief description follows:

A. Gravel bar/edge wetlands: this community type is found on point bars and the edges of rivers where flood disturbance is frequent. In most cases the vegetation cover includes herbaceous pioneer species, but young woody riparian species like Salix exigua and Populus spp. may also be present. In most cases the vegetation cover is sparse.

B. Herbaceous meadow: the community type may occur in broad alluvial valleys where the river is downcut and few woody plants are present. Herbaceous species are predominantly wetland sedge and grass species. Wetland forbs also may be present.

C. Willow/shrub: this is a diverse community because of the potential number of willows that may be present throughout the GRYN. The community is dominated by shrub willows and occurs on the edge of streams, adjacent floodplains, wet alluvial flats and along seeps where groundwater is shallow. Some may be short willows (e.g., wolf willow), while some willow/shrub communities have tall willows (e.g., xxx). Other shrubs may be present with willows such as alder (Alnus spp.) in moist areas or shrubby cinquefoil (Potentilla fruticosa) in drier areas. In most cases, except where heavy browsing has reduced cover, aerial cover of this community is high.

D. Cottonwood: this community type, usually found in mid to lower elevations within the GRYN, is dominated by mature cottonwoods and may have some cottonwood recruitment under the canopy or in adjacent floodplain and point bar areas. There is little understory of other woody plants. This type of community may be found in areas with heavy browsing pressure, or in relatively sterile gravel or cobbled areas where cottonwood has established and has resisted scour when it occurs, but other woody plants either never established or were scoured away by high magnitude floods.

E. Cottonwood/willow/shrub: this community type found in mid to lower elevations in GRYN represents a mature cottonwood community with a well established understory of shrubs, often willows, and herbaceous ground cover. These usually are undisturbed sites with no deficiency of shallow groundwater.

F. Conifer/willow/shrub: this community type is more typically found along mid to higher elevation streams that have limited overbank scour. The conifer overstory represents mesic upland species growing near the stream, whereas willow and shrubs such as alder are more typically riparian and phreatophytic.

G. Lake shore: this community type could be represented by several of those above but also may include true wetlands where saturated sediment occurs along the lake margin. Willows may grow along stable lake shores whereas gravel bar type communities may be common along fluctuating lakes. Mid to higher elevation lakes may have conifer communities growing along the shoreline.

H. Riparian exotics (dominant): this community type occurs in highly disturbed areas or where hydrological controls are greatly altered from the norm. Nearly pure stands of tamarisk represent this type of community which often occurs in moist sediment upstream and at tributaries mouths of lakes with fluctuating levels. Altered downstream hydrology below dams also often creates riparian communities dominated by extensive stands of exotic species. Communities

dominated by herbaceous exotic species (often noxious weeds) may occur on floodplain areas following a high magnitude, overbank, scouring flood.

Stressors that play an important part in each park differ, except perhaps for climate change and drought stress. Riparian communities in YNP, especially in the northern range, are greatly influenced by ungulate herbivory. GTNP has altered hydrology of the Snake River as a major issue, but it also has herbivory problems along some streams within the park. Primary stressors of riparian condition in BICA are altered hydrology and invasion of non-native riparian species. Table 1 summarizes the similarities and differences among the parks and the HUC units within the parks. Because riverine/riparian systems are linear and cover only a small percentage of the landscape, comparisons by watershed units within each park may be difficult; however, different conditions within each watershed, especially if they are some distance apart, might allow identification of different responses of riparian communities to similar environmental stressors.

POTENTIAL INDICATORS

Several indicators related to riverine and riparian ecosystems can be identified from the conceptual model and the discussion above. Some indicators may be stressors or other non-"outcome" parameters, but the best may be an outcome parameter that functions as an integrator of several processes.

A. *Riparian condition* is one indicator, in actuality an index, that includes several riparian community parameters and channel geomorphic parameters. Riparian ecosystems are integrators of hydrogeomorphic conditions as well as local land use processes. Riparian condition includes metrics of horizontal and vertical vegetation structure, vegetation diversity and channel stability. The U.S. Forest Service and BLM have developed an index, Proper Functioning Condition (PFC), that attempts to address these parameters but it is subjective and includes little biological information. A modified version of PFC may be an appropriate index to use for "riparian condition".

B. *Channel geomorphological metrics* may also be a useful indicator of the condition of riverine and riparian systems. The ratio of channel width to depth and channel sinuosity in relation to floodplain type can be combined to develop a channel index that would indicate whether the channel is be changed from the "expected" geomorphic conditions.

C. *Riparian avian community structure* may be used as an indicator of riparian condition. Species diversity of riparian avian communities, including presence and/or absence of certain species that have been identified as species commonly found in "healthy" or "degraded" riparian vegetation, can be used as a surrogate of riparian condition, including linear connectivity of riparian patches along a river.

D. A biological stressor, *exotic plants*, may also be a useful indicator of riparian vegetation condition. Increasing presence of exotic plant species has greatly altered many riparian systems in the West. A degraded riparian community may be altered primarily because of the presence of exotic species. If a relationship between altered condition and abundance of exotic species can be established, cover and diversity of exotic plant species in the riparian zone may be a useful long-term indicator.

E. *Aquatic biota*, that is macroinvertebrates and/or fish populations, often indicate the geomorphology of a channel, the bedload materials, flow velocities at various stages as well as

water quality. For general riverine and riparian conditions, aquatic biota may not be the best indicator, but if a combination of physical and chemical qualities need to be evaluated, aquatic biota may be a useful indicator. This indicator applies more to the river or lake systems of the GRYN parks and is discussed in more detail in that section.

Measurement of any of the above indicators would be done at randomly selected locations along reaches of rivers of interest. For lakes shores, randomly selected locations along a shore would be used in place of reach locations along a river. For the various parks, rivers of different sizes (orders) would be identified and long-term monitoring stations would be established.

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DSS INFORMATION FOR RIPARIAN POTENTIAL INDICATORS

Riparian ecosystems occur as the result of several environmental factors, hydrology being primary. However, new stressors such as heavy browsing, changes in beaver populations, introduction of exotic plants and recreation have become important in the health of overall distribution and condition of riparian communities. Because some of the "new" stressors have played a significant role in altering riparian communities, they may be important indicators, offering evidence of potential changes in the riparian communities of the GRYN area.

Indicator: Riparian Condition.

Resource Monitored: Riparian vegetation structure and channel stability.

Justification: Riparian ecosystems, although a small part of the GRYN area landscape, support some of the greatest biodiversity. Changes in the health or condition of riparian communities will directly influence the assemblage of animal species found in the parks of the GRYN. Consequently, it is imperative that riparian condition (health) be included in a long-term monitoring program. Riparian condition is an indicator, in actuality an index, that includes several riparian community parameters and channel geomorphic parameters. Riparian ecosystems are integrators of hydrogeomorphic conditions as well as local land use processes. They respond to changes in the watershed as well as the floodplain. They are very sensitive to climatic shifts that influence stream flows and groundwater levels. The woody vegetation in riparian areas is often the primary food source for wild and domestic ungulates during periods with forage shortages such as severe winters with deep snow, or summer drought.

Comment: Riparian condition includes metrics of horizontal and vertical vegetation structure, vegetation diversity and channel stability. The U.S. Forest Service and BLM have developed an index, Proper Functioning Condition (PFC), that attempts to address these parameters but it is subjective and includes little biological information. Other metrics of riparian condition include HGM (hydrogeomorphic methodology). This, however, is very comprehensive and would be difficult to apply to a large number of riparian areas.

Example of specific measurements for indicator: A modified version of PFC may be an appropriate index to use for "riparian condition".

Indicator: Channel Dimensions

Resource Monitored: Variability and changes in channel cross section geometry and river length to floodplain length relationships.

Justification: Riparian vegetation not only responds to changing channel geomorphology but plays a role in its formation. Any change in channel geomorphology will consequently alter the amount and distribution of the riparian community. Thus, channel geomorphological metrics may be a useful indicator of the condition of riverine and riparian systems. Altered hydrological conditions and concomitant degraded riparian systems play a role in channel changes. For example, changing regional hydrology or influences of upstream flow regulators, e.g., dams, will cause channels to adjust to new conditions and offer less or more habitat for riparian plant communities.

Comment: The ratio of channel width to depth and channel sinuosity in relation to floodplain type can be combined to develop a channel index that would indicate whether the channel is being altered from "expected" geomorphic conditions. Decreasing width/depth ratios

tend to indicate a degraded, incised channel; however, a greatly increasing width/depth ratio may result from excessive bank destabilization by ungulate use.

Example of specific measurements for indicator: Width-depth ratios at selected reach types along rivers of different sizes, along with geographic measurements of river sinuosity can be combined to offer an "index" metric for channel dimensions. Just the width-depth ratio on selected reaches may be satisfactory.

Indicator: Riparian wildlife species.

Resource Monitored: Abundance of potential indicator wildlife/avian species.

Justification: Riparian avian community structure may be used as a wildlife species indicator of riparian condition. Species diversity of riparian avian communities, including presence and/or absence of certain species that have been identified as species commonly found in "healthy" or "degraded" riparian vegetation, can be used as a surrogate of riparian condition, including linear connectivity of riparian patches along a river.

Comment: Many studies have used presence and abundance of resident birds at select times of the year to demonstrate potential sources and sinks of avian populations. Riparian communities are usually the source of birds and thus any changes or loss of bird species and/or population composition may be an important indicator of riparian condition.

Example of specific measurements for indicator: Presence and abundance measurements taken within specific sized plots for 10 minutes at a number of sites along selected reaches of rivers of concern can be used as the metric for this indicator.

Indicator: Exotic plants.

Resource Monitored: Exotic plant component of riparian plant community.

Justification: One of the biological stressors in the riparian conceptual model, exotic plants, may also be a useful indicator of riparian vegetation condition. Increasing presence of exotic plant species has greatly altered many riparian systems in the West. A degraded riparian community may be altered primarily because of the presence of exotic species. If a relationship between altered condition and abundance of exotic species can be established, cover and diversity of exotic plant species in the riparian zone may be a useful long-term indicator.

Comment: For this indicator to be useful, a relationship between riparian condition and exotic plant presence, especially for herbaceous species, needs to be established. Recent literature addresses increasing exotic plant presence in riparian areas, but a statistical connection between presence and riparian degradation is not well developed.

Example of specific measurements for indicator: The metric would be percentage cover of specific exotic species within riparian vegetation. This will only be useful if that percentage can be related to reduced function of the riparian area. This percentage should be determined by establishing permanent transects in selected representative riparian areas within the three GRYN parks. The transects will be used to sample woody vegetation, while small quadrats (e.g., 1x1 m plots) along the transects will be used to sample herbaceous vegetation.

DSS INFORMATION FOR WETLANDS POTENTIAL INDICATORS

Wetlands sustain some of the highest biodiversity of any GRYN ecosystem. Wetlands are rapidly being altered or are disappearing in the United States. The cause of their alteration and/or loss includes modified hydrology, drainage, heavy grazing, and changing climatic patterns that no longer sustain wetland conditions. There are many types of wetlands, and each is maintained by separate, but similar, sets of conditions, all relating to maintenance of wetland hydrology and wetland plant communities.

Indicator: Wetland Vegetation Parameters

Resource Monitored: Plant species composition, cover, abundance, or diversity for each wetland type (i.e., depression, willow, spring, beaver dam, and herbaceous wetlands).

Justification: The high biological diversity of wetlands is found in the plant community as well as associated animal communities and populations. The plant community is the foundation of the wetland ecosystem. It responds to the hydrological events that create inundation and hydric soils. Wetland plants, especially obligate wetland plants, are limited to wetland physical conditions. Consequently, plant associations in wetlands change in response to the magnitude of stressors that may alter the influence of hydrology or ability of the plants to establish and grow in wetland conditions. These changes, when determined in different types of wetlands will, over time, signal both short-term and long-term local and regional wetland changes.

Comment: Abundance is a term often applied to quantification of some ecosystem or community parameter. Because wetlands plant communities tend to be dense, estimates of cover of individual species may be the best metric to use. Cover classes (e.g., 1-5) may be appropriate. Sampling vegetation cover at representative wetlands of each type, when present, will produce data on increasing or decreasing cover of individual species and the whole community. This type of sampling will also produce data on community composition and species diversity.

Example of specific measurements for indicator: An example of a sampling scheme for determining species and total community cover, as well as species composition might be a series of random quadrats within a grid placed on the selected representative wetland, or stratified portion of the wetland if it is large. If the wetland has large woody species (e.g., willows), nested quadrats should be used (i.e., large (4x4 m) for woody and small (1x1 m) for herbaceous). The grid should be permanently marked to allow continued sampling of the same area of the wetland. Resampling (e.g., every 10 years) should be part of the long-term monitoring program.

Indicator: Wetland associated species

Resource Monitored: Abundance of associated animal species (e.g., amphibians, birds, small mammals, etc.) in each wetland type (i.e., depression, willow, spring, beaver dam, and herbaceous wetlands).

Justification: Wetlands sustain a high diversity of associated species including, for example, birds, amphibians, small mammals, insects, etc. The abundance or presence of these species and/or the aggregate of these species (aka community) often act as surrogates for the condition or health of the wetland. Within a functional group, like birds, a change in composition of species from wetland specialists to generalists may indicate a change in food sources such as

seeds and insects. In this way, the bird assemblage may be an easier metric to measure than comprehensive vegetation samples.

Comment: Avian (bird) species assemblages have been widely used within the GRYN to determine the health of different ecosystems as well as avian source and sink vegetation communities. Riparian areas are a primary source and one could expect localized wetlands might also function in this capacity. Of the various associated species groups, the avian community probably is the easiest to sample, and long-term data sets for this group also exist for parts of the GRYN.

Example of specific measurements for indicator: Avian sampling includes regular (e.g., monthly) short-time (10 minute) visits to specific locations, in this case, specific wetland communities. The presence of every bird species within a pre-determined radius is recorded. The data can be organized into functional groups, such as resident, nesting migrants, neo-tropical migrants, etc. Sampling should be repeated on an annual, or pre-determined time frame (e.g., every 1, 2 or 5 years) and this repeat sampling should be part of the long-term monitoring program.

Indicator: Beaver populations

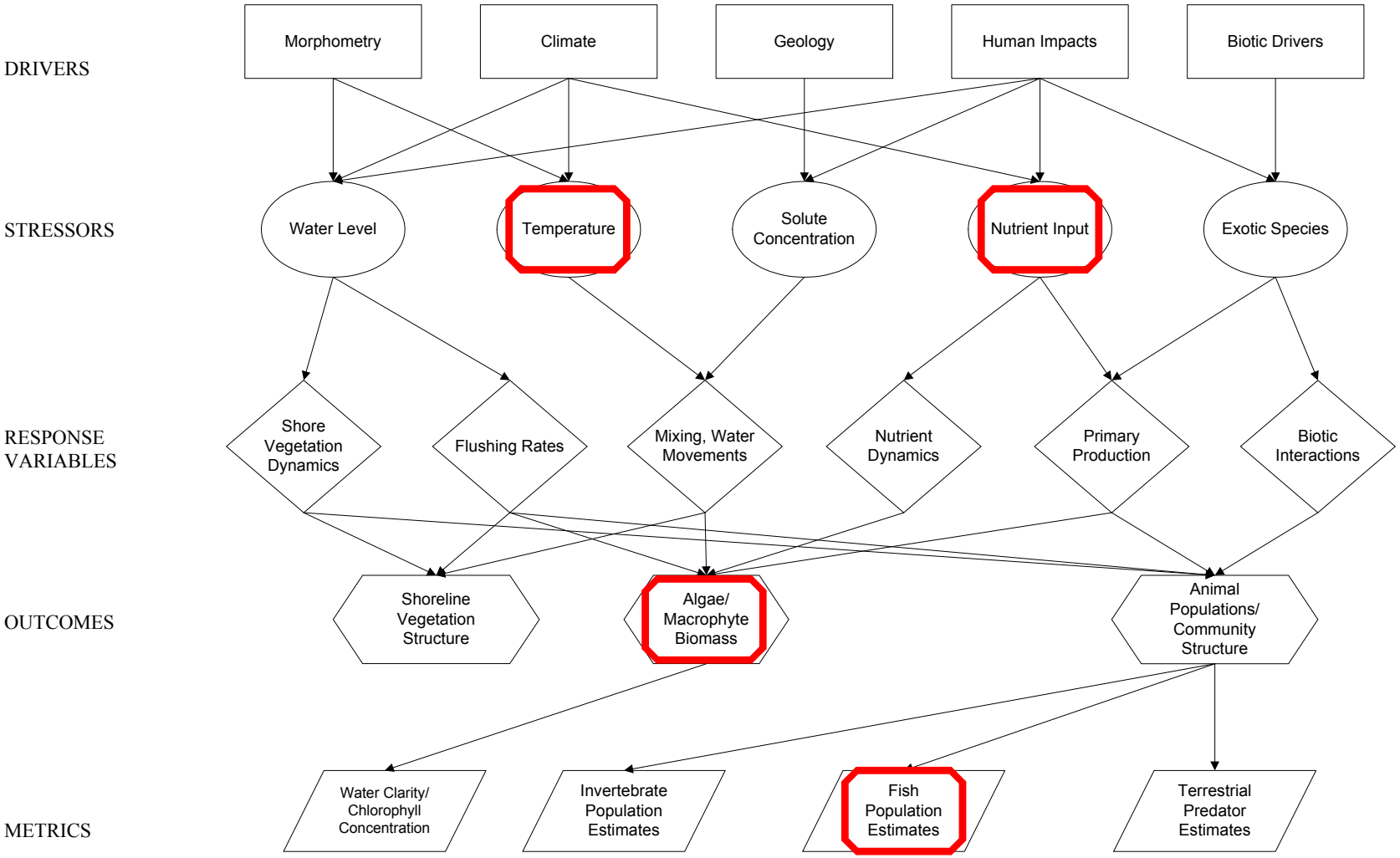
Resource Monitored: Presence of beaver activities (e.g., dams, mounds and/or bank burrows), and estimates of associated beaver numbers.

Justification: Beaver produce one kind of wetland within GRYN area that is associated with dams, ponds and elevated water tables. The presence or absence of beaver and these types of wetlands has reduced the diversity of wetlands and ecosystem types within the GRYN area. Consequently, biodiversity in valleys and along streams where beaver activity once occurred has declined. Beaver abundance tends to be cyclical, but some causes for these cycles may be related to human influence as well as changes in population of competitors for woody plants, predators and climate. There appears to be a resurgence of beaver in parts of the GRYN area. Although in many places with higher density human population the return of beaver is not welcome, within the natural areas of the GRYN region return of beaver is a sign of improving health of the landscape. For this reason, use of beaver population as an indicator (vital sign) may allow long-term evaluation of landscape health within those areas of the GRYN were beaver can occur and develop associated wetlands.

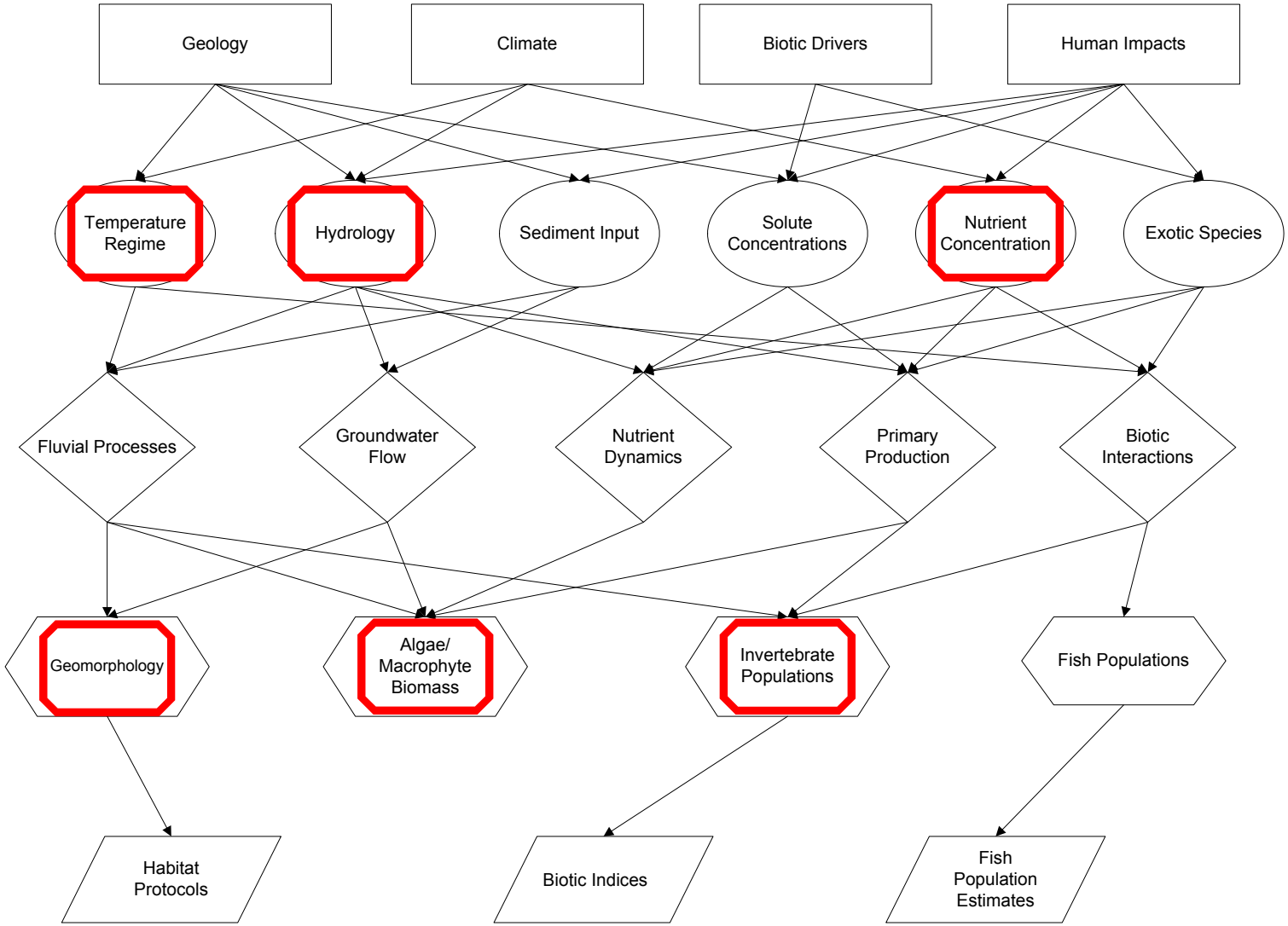
Comment: Within parts of the GRYN there has been some semblance of tracking beaver over the past few decades. A more systematic effort needs to be established that will not only determine where they are located and how many might inhabit each location, but also will determine the trends in beaver expansion or decline and the associated movements or migration of beaver families.

Example of specific measurements for indicator: All beaver locations within GRYN should be mapped (GIS recorded). This can be done by a combination of remote sensing and ground-truthing. A representative number of beaver sites should be visited to determine the population size at each site, if this type of data doesn't presently exist. These data sets, location and site population should be archived and regular (2-5 years) resampling of the GRYN region for beaver should become part of the long-term monitoring plan.

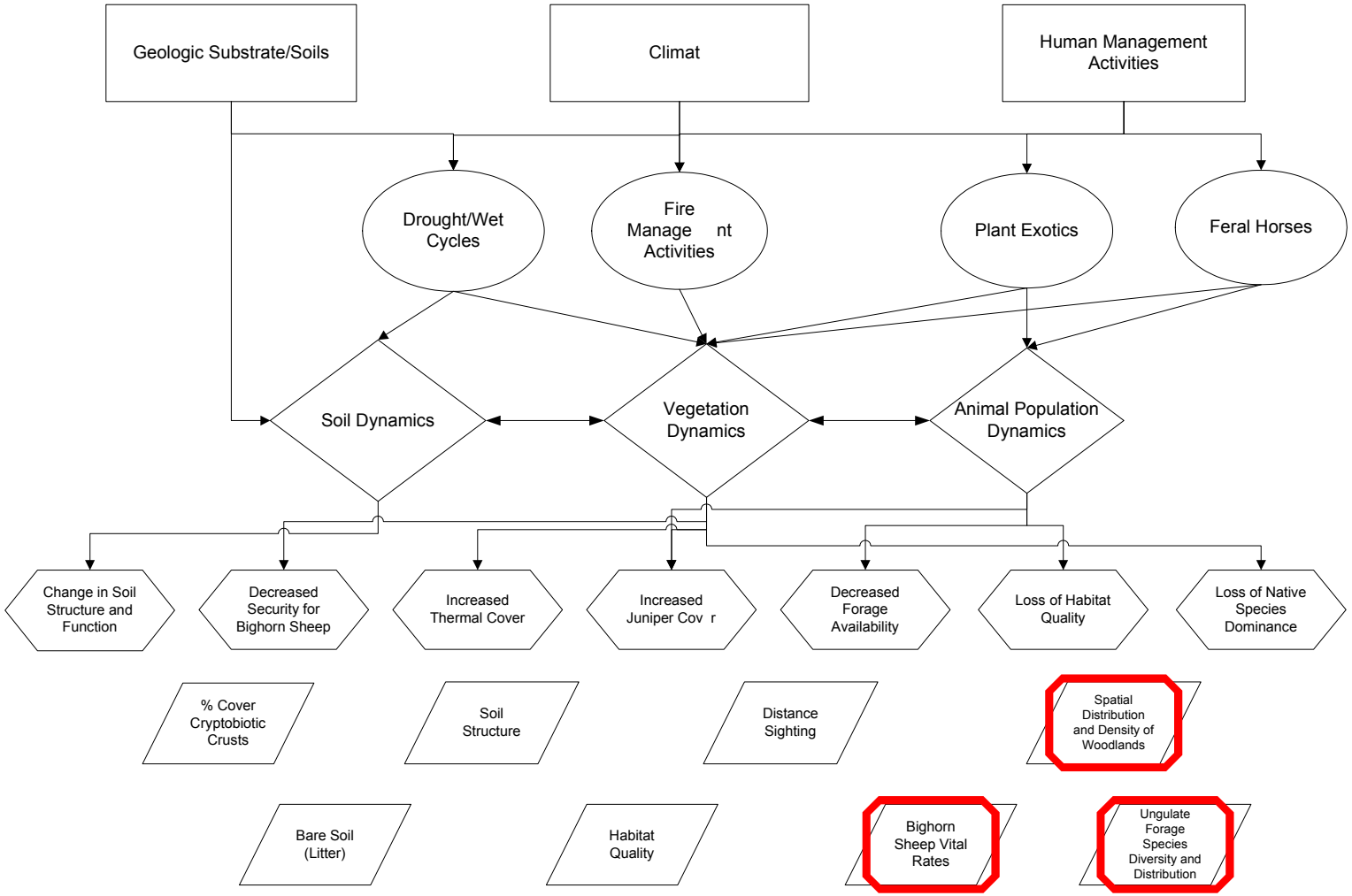
Lake Model-Bob Hall



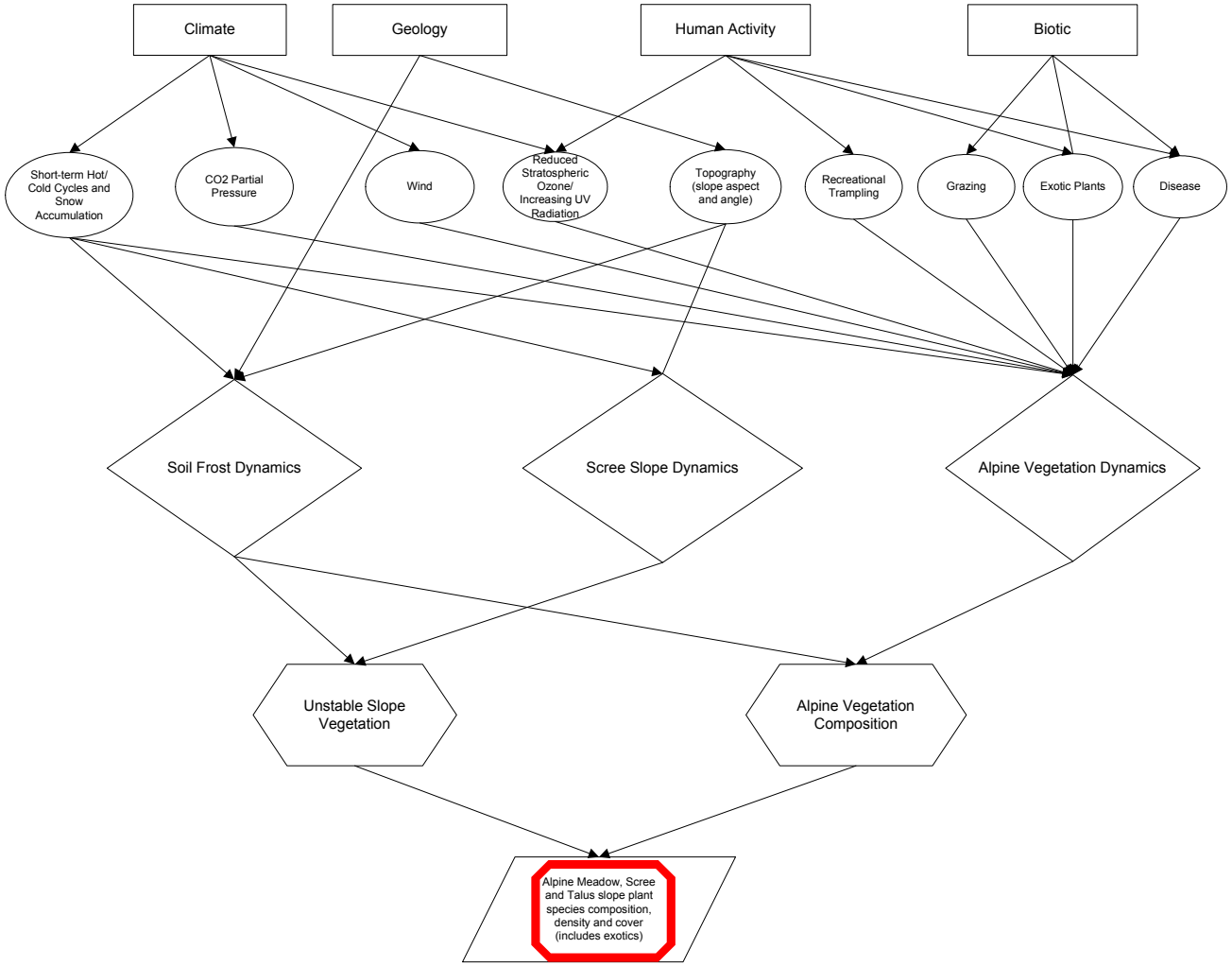
River Model-Bob Hall



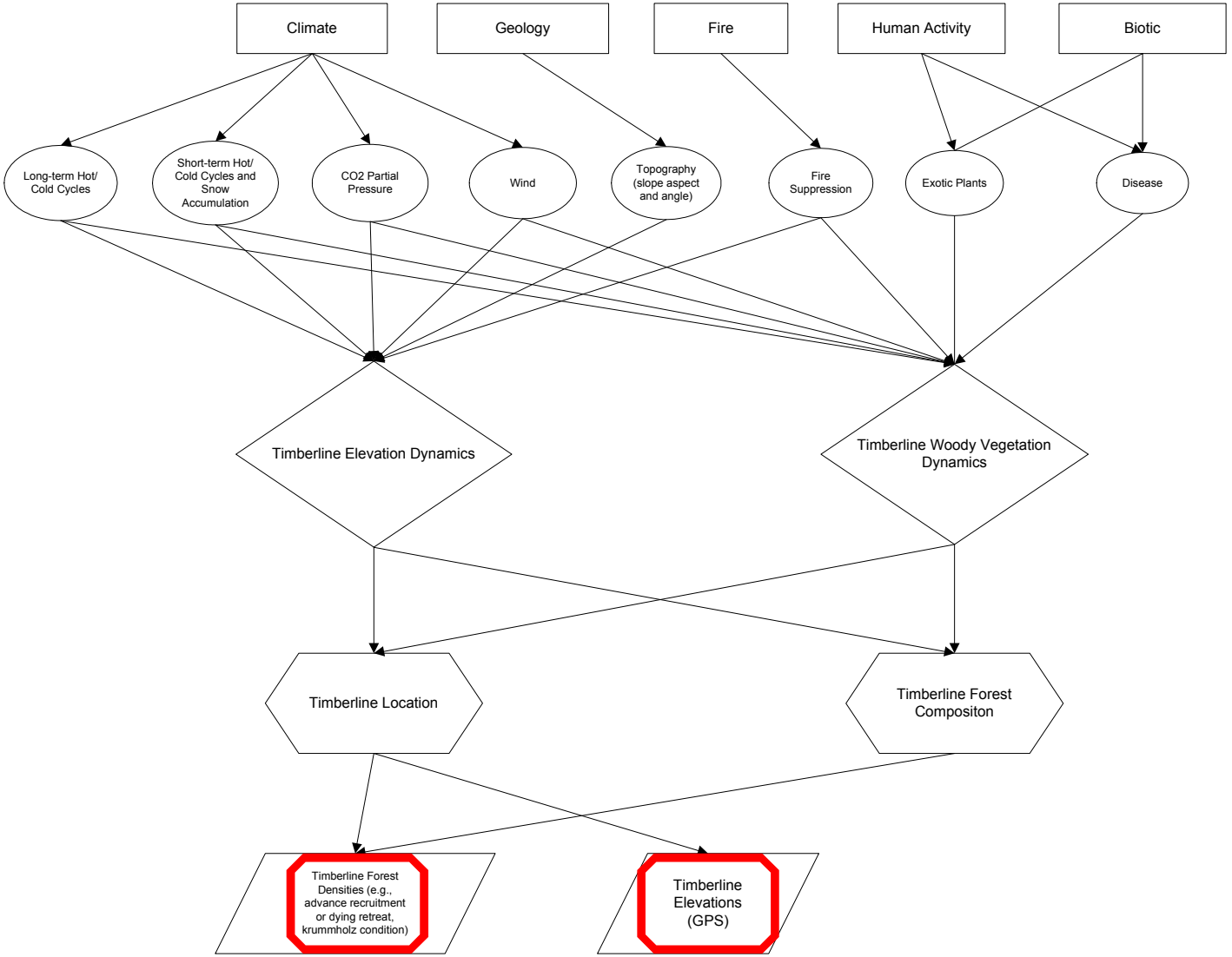
Dry Woodland Model-Cathie Jean



Alpine Model-Duncan Patten

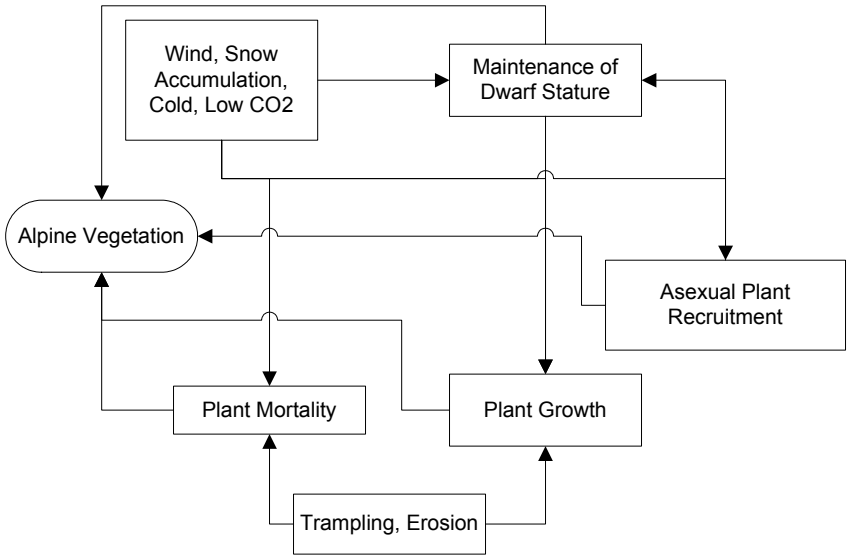


Timberline Models-Duncan Patten

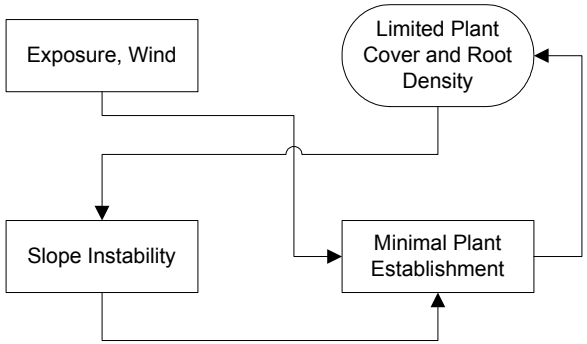


Alpine and Timberline Submodels-Duncan Patten

Alpine Vegetation

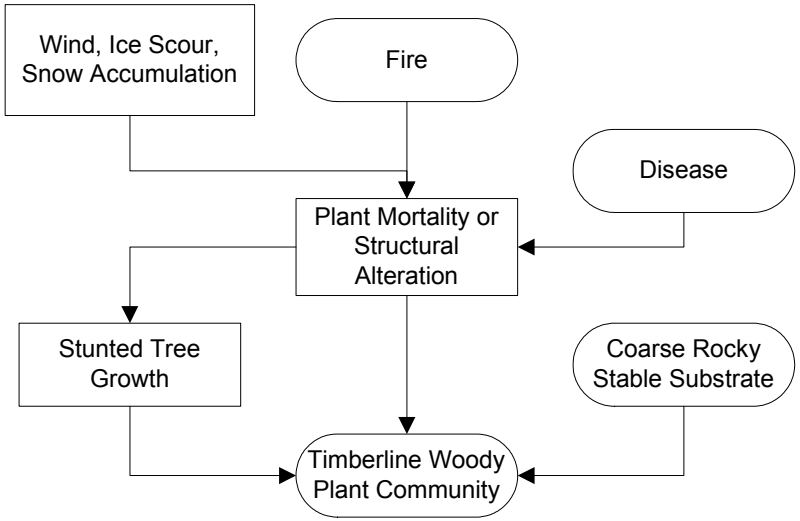


Scree Slope Dynamics

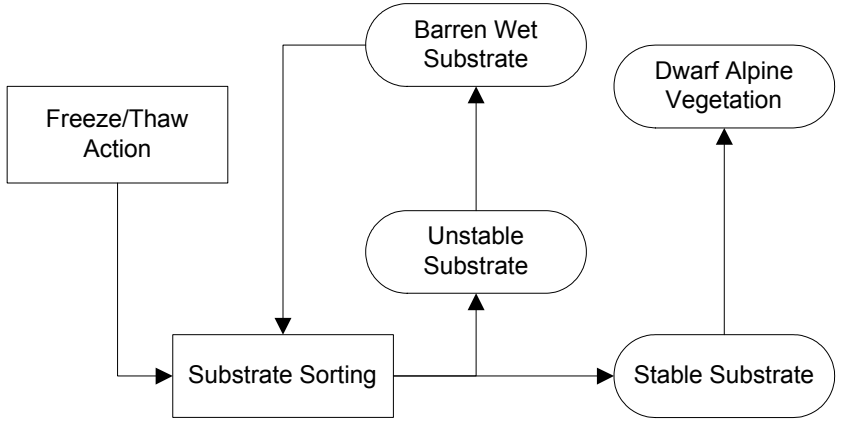


Alpine and Timberline Submodel (continued)-Duncan Patten

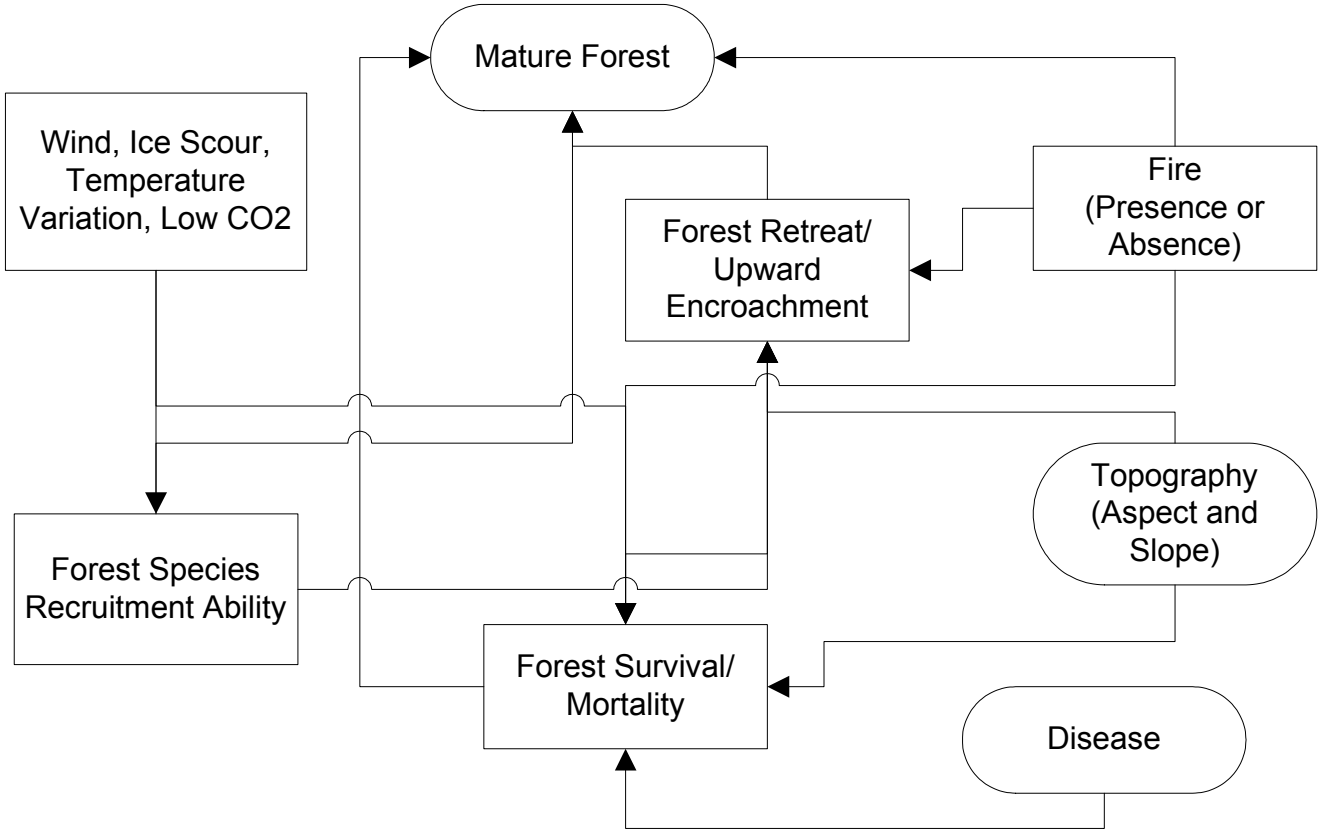
Timberline Woody Vegetation



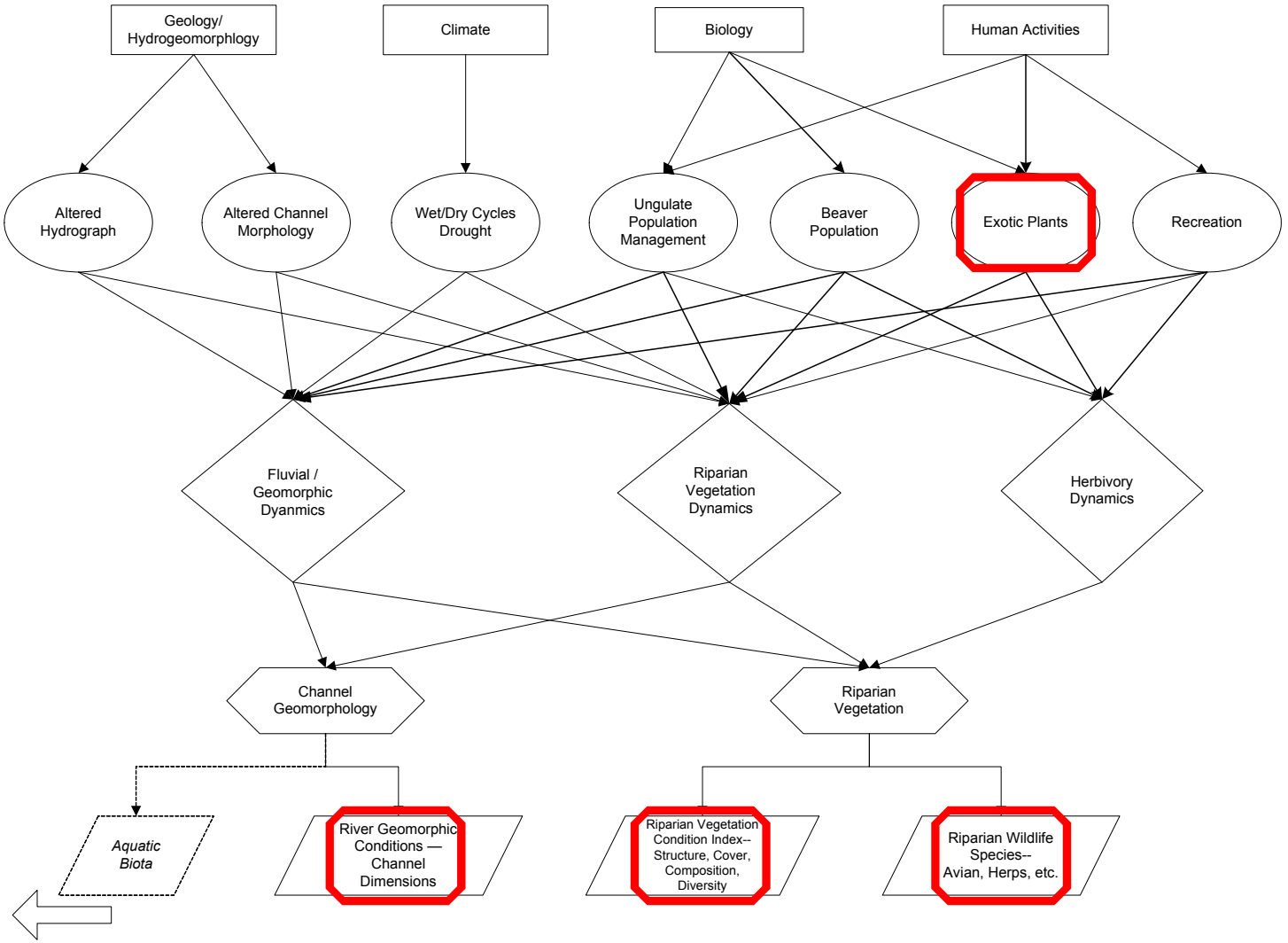
Soil Frost Dynamics



Timberline Elevation

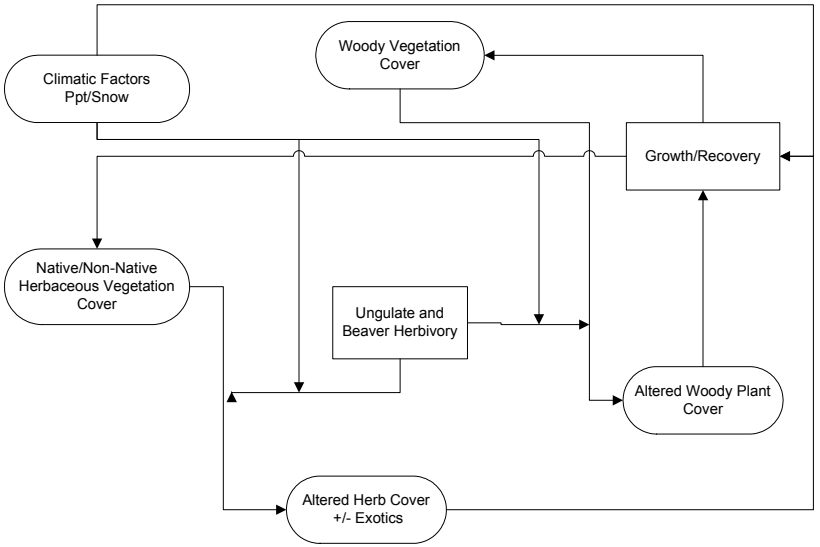


Riparian Model-Duncan Patten

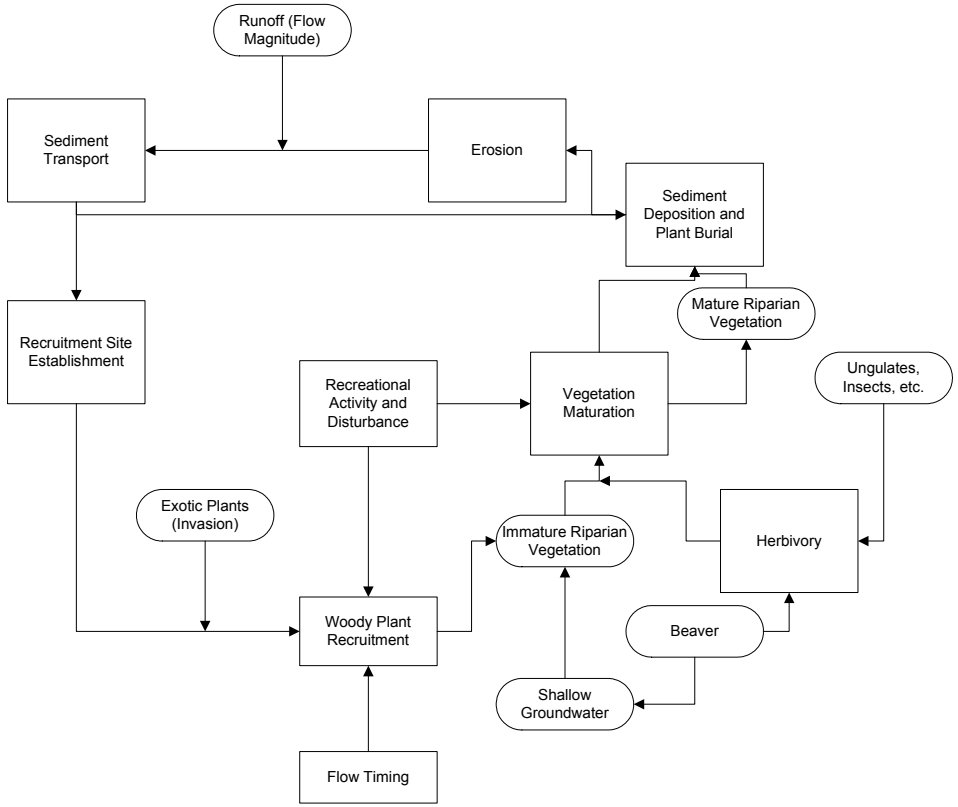


Riparian Submodels-Duncan Patten

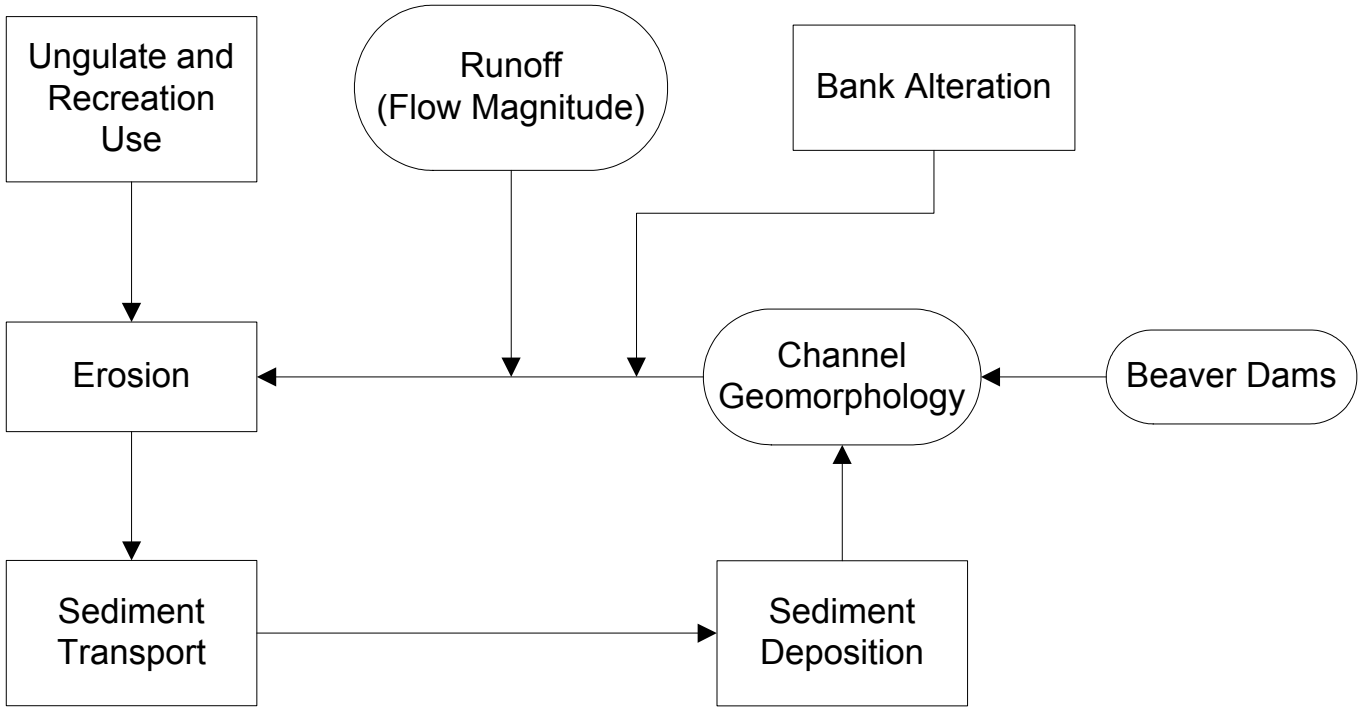
Herbivory Dynamics



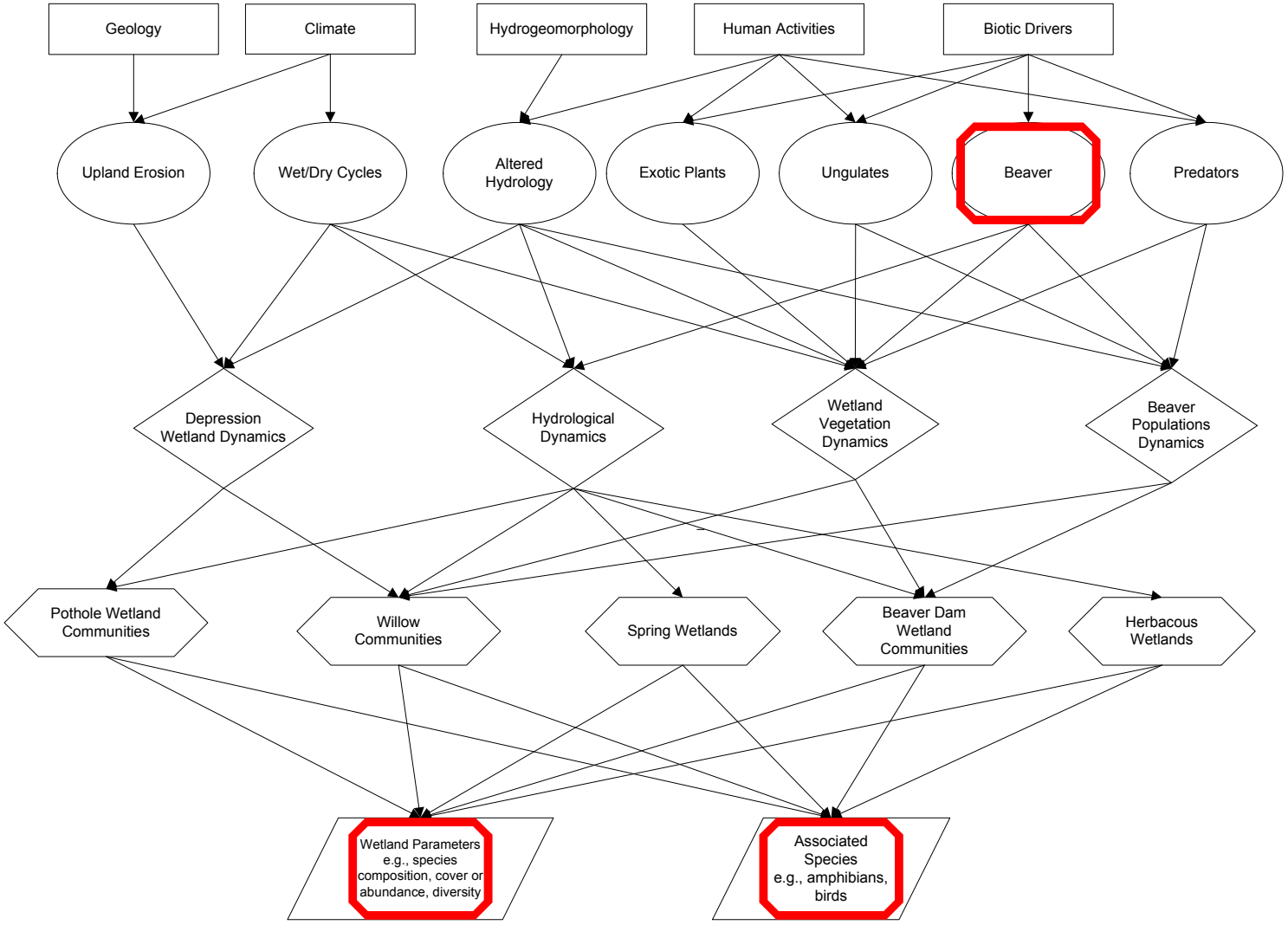
Riparian Vegetation Dynamics



Fluvial Geomorphology Dynamics

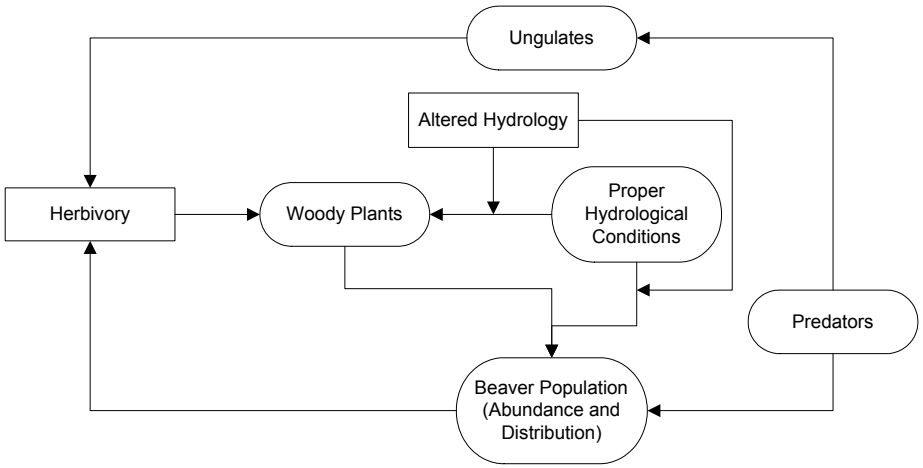


Wetland Model-Duncan Patten

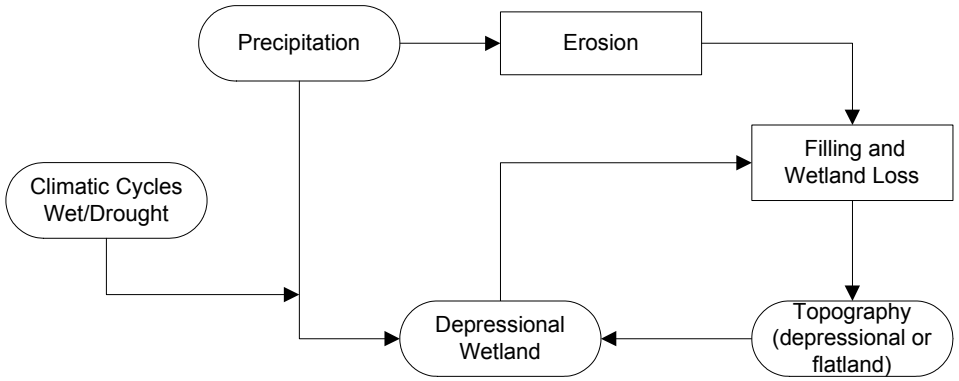


Wetland Submodels-Duncan Patten

Beaver Population Dynamics

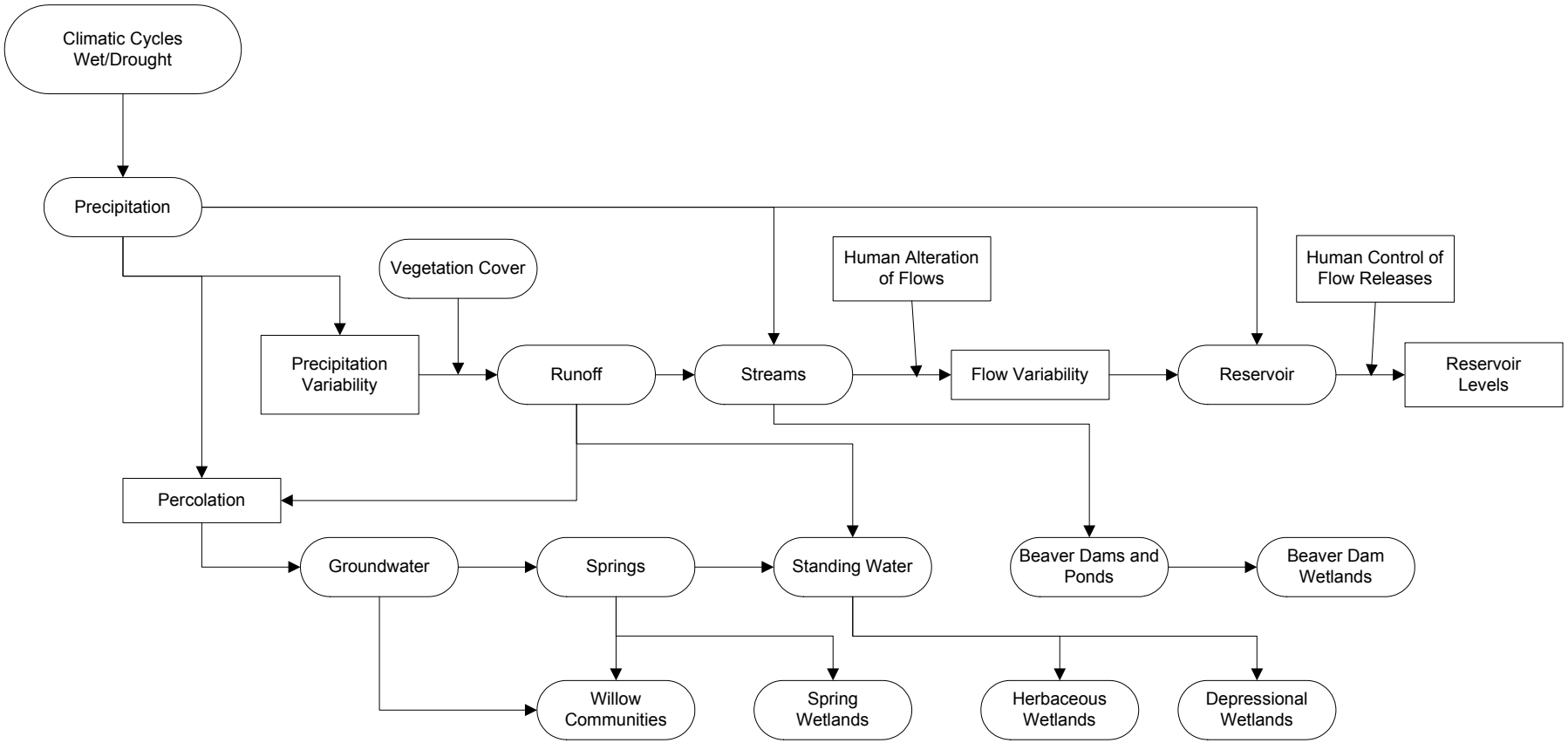


Depressional Wetland Dynamics



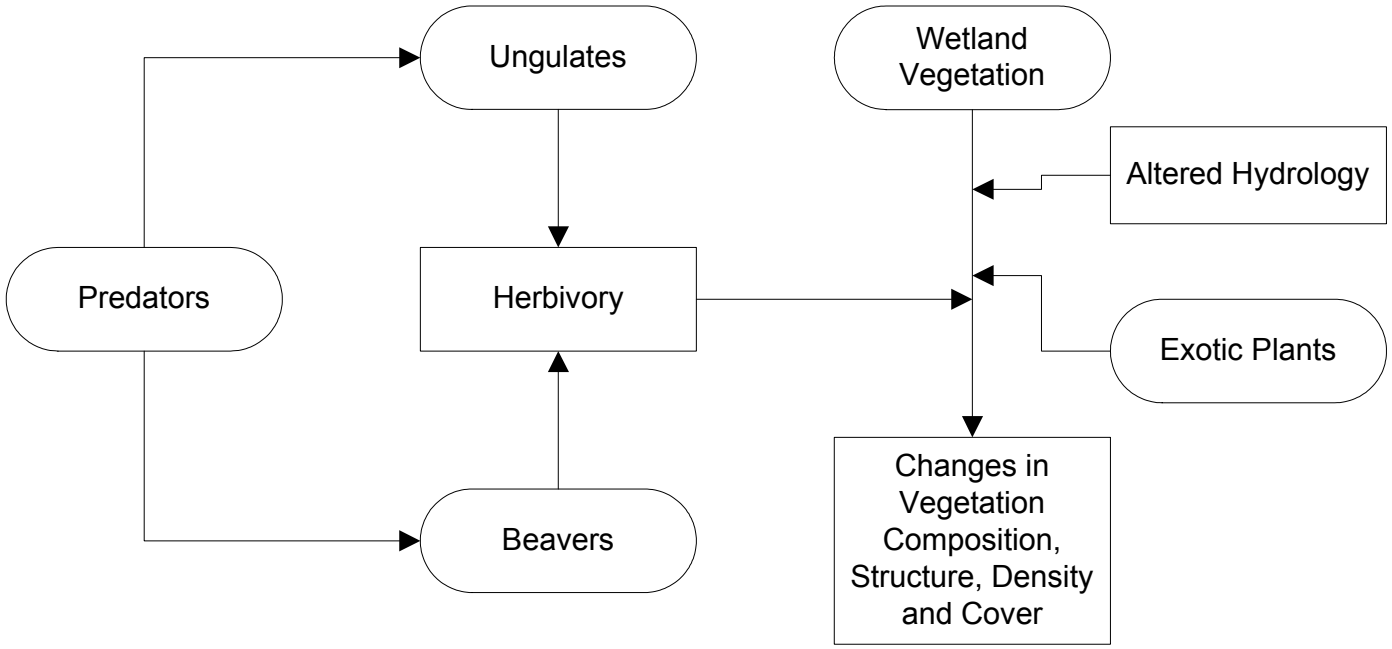
Wetland Submodels (continued)-Duncan Patten

Hydrology Dynamics

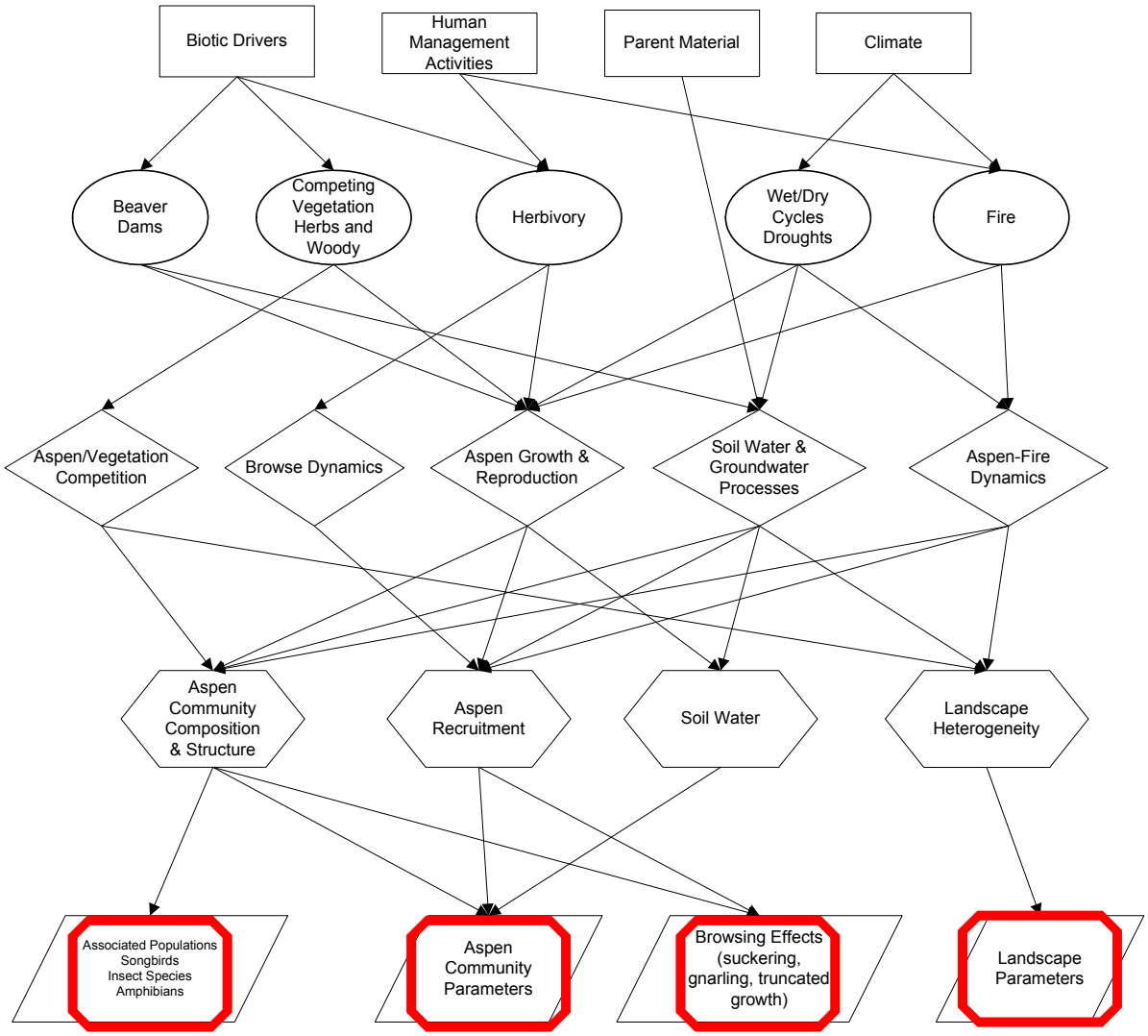


Wetland Submodels (continued)-Duncan Patten

Wetland Vegetation Dynamics

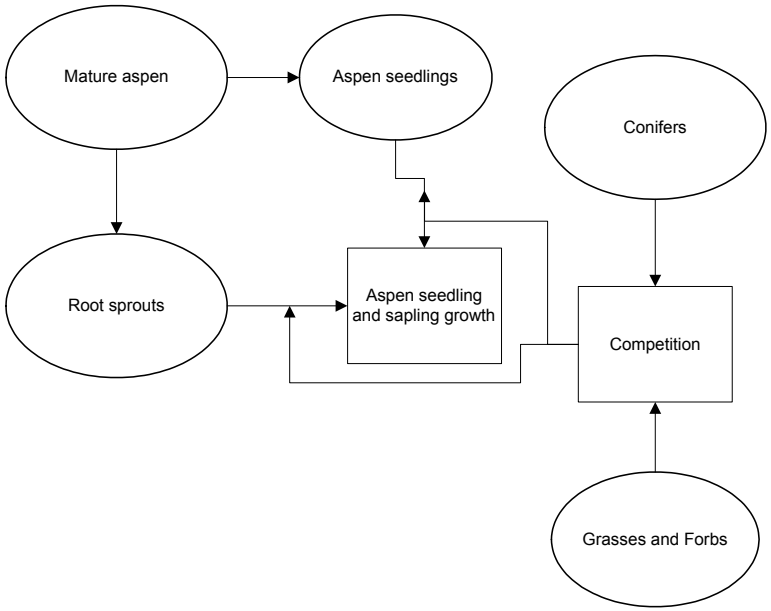


Aspen Model-Duncan Patten and Dan Tinker

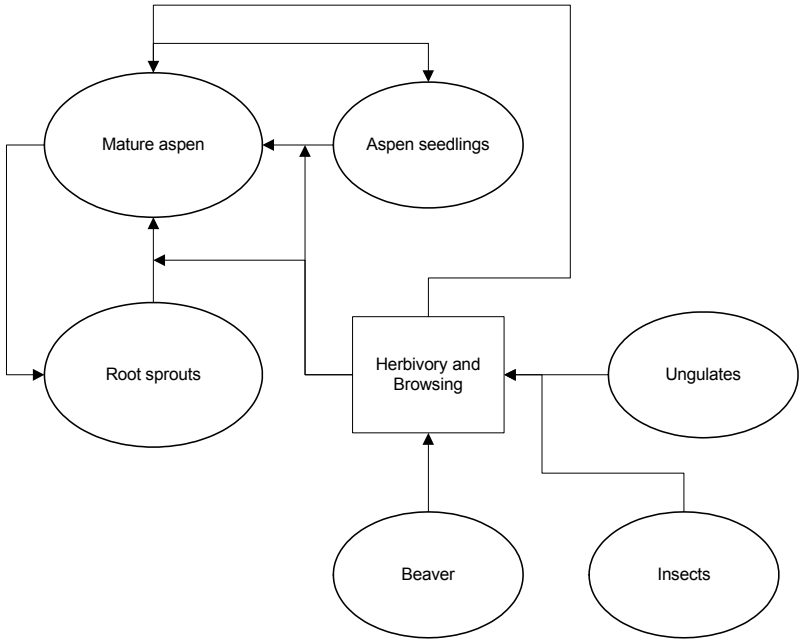


Aspen Submodels-Duncan Patten and Dan Tinker

Vegetation Competition

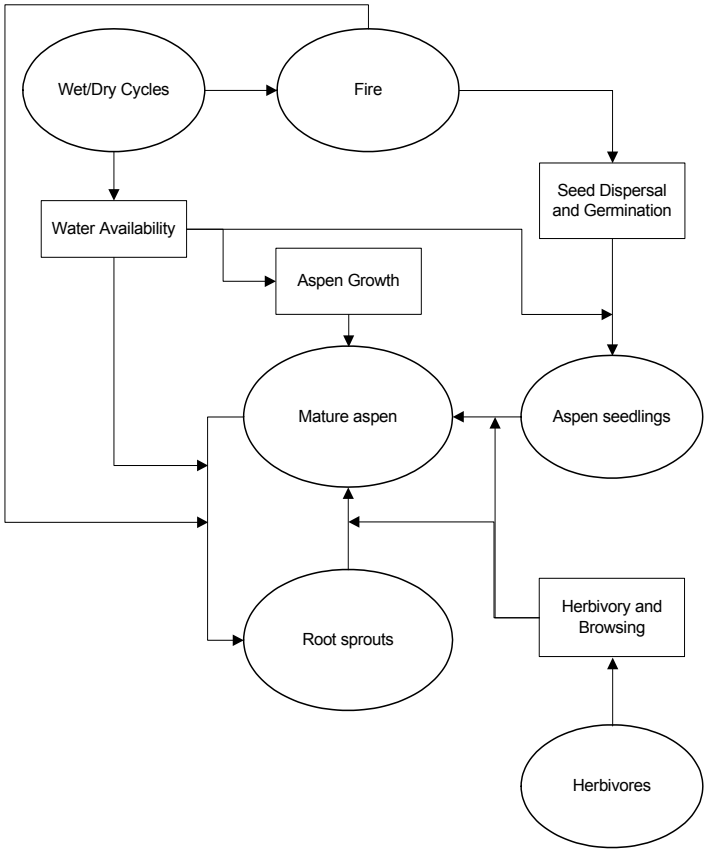


Browse Dynamics

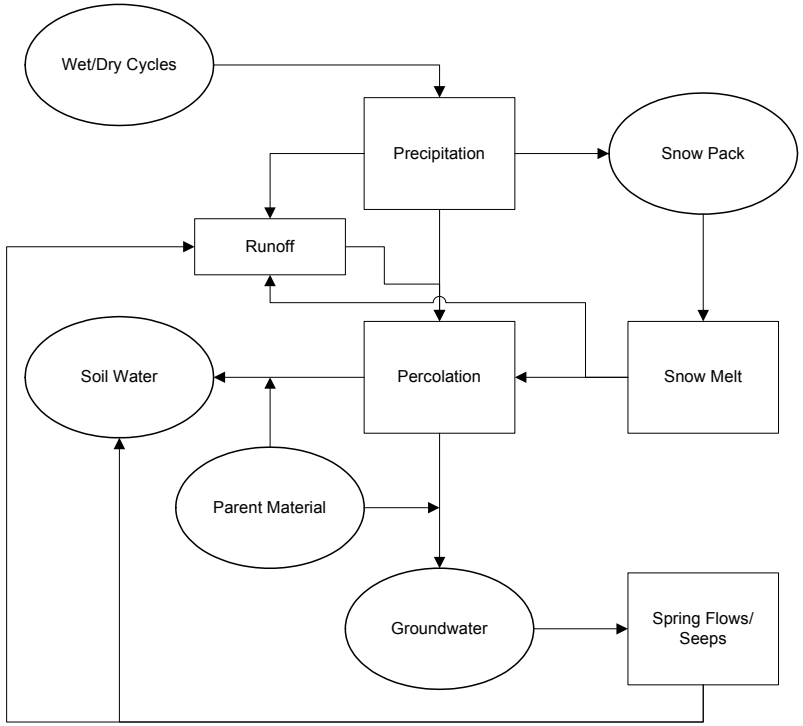


Aspen Submodels-Duncan Patten and Dan Tinker

Aspen Growth and Reproduction

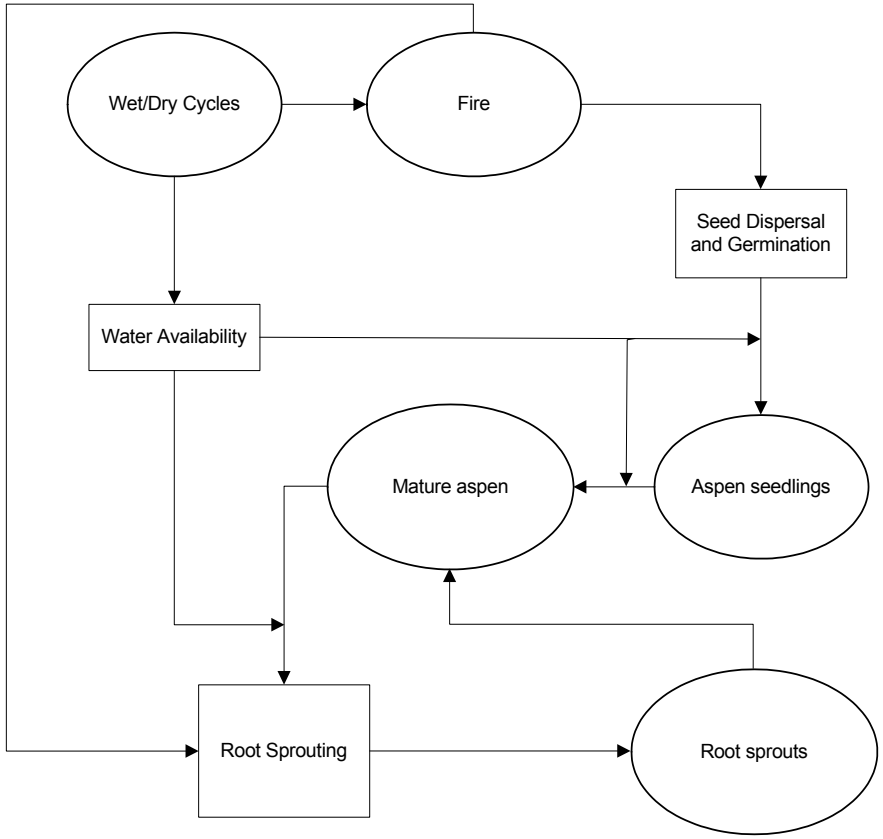


Soil and Groundwater Processes

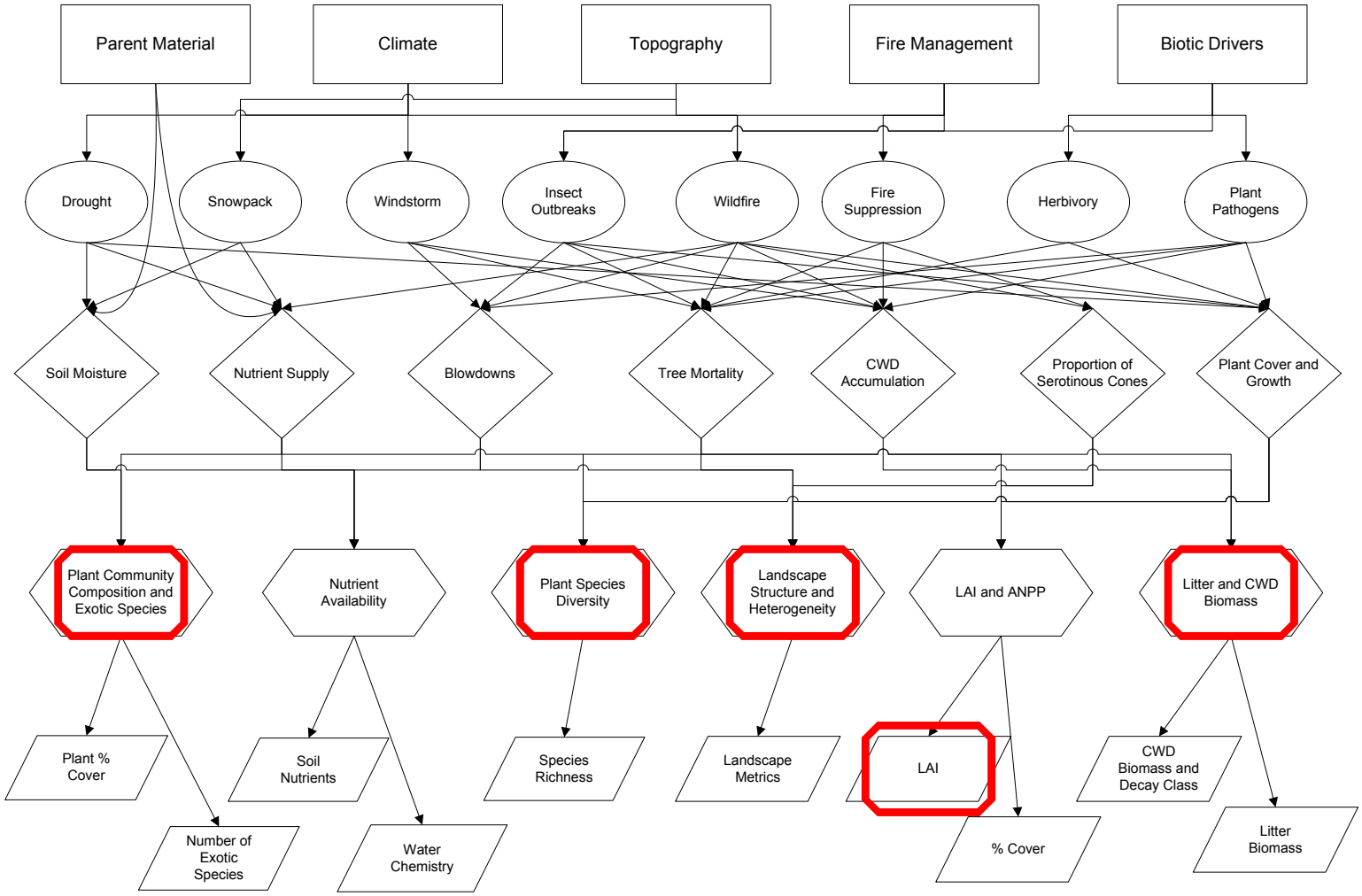


Aspen Submodels-Duncan Patten and Dan Tinker

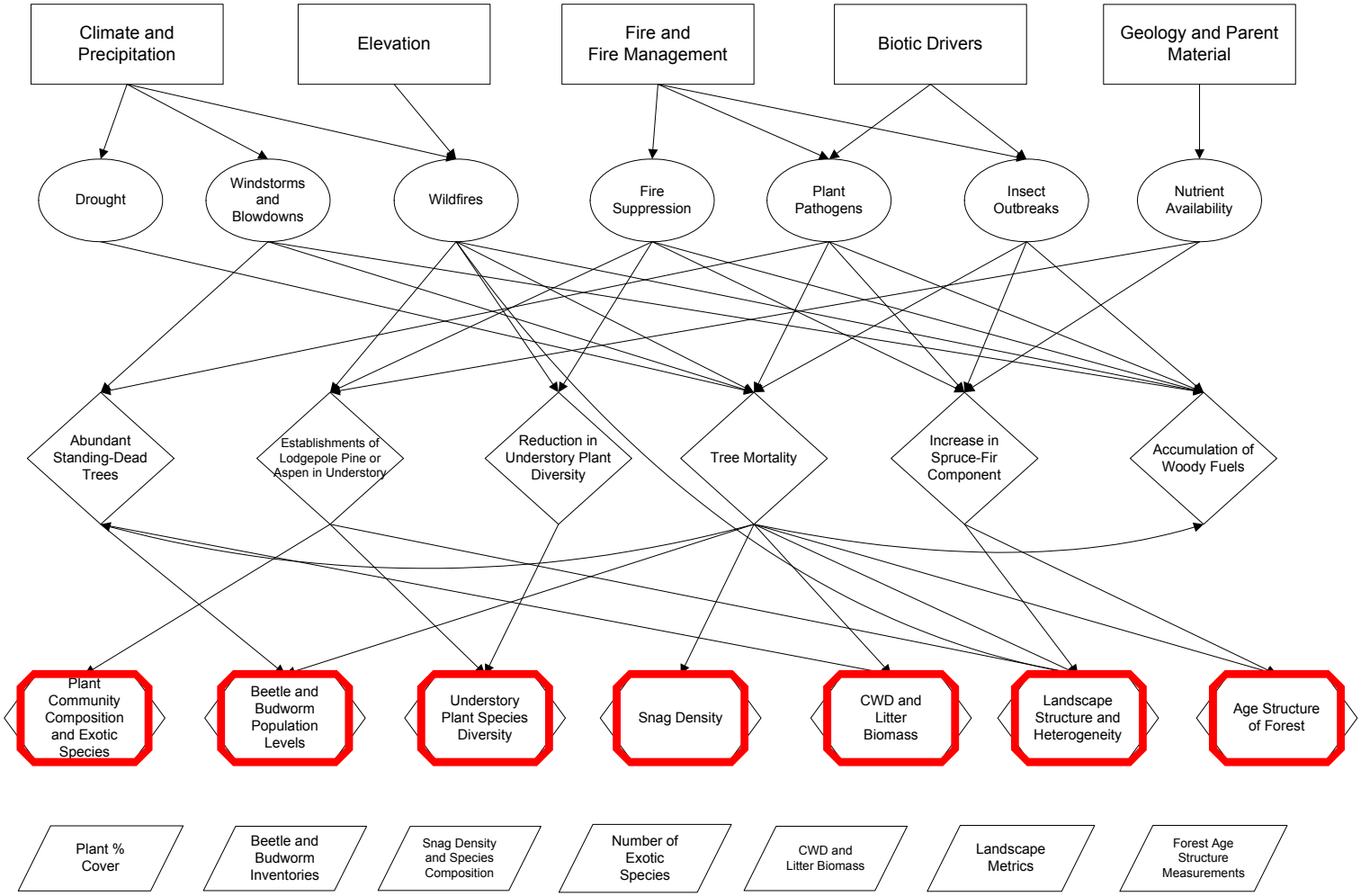
Aspen Fire Dynamics



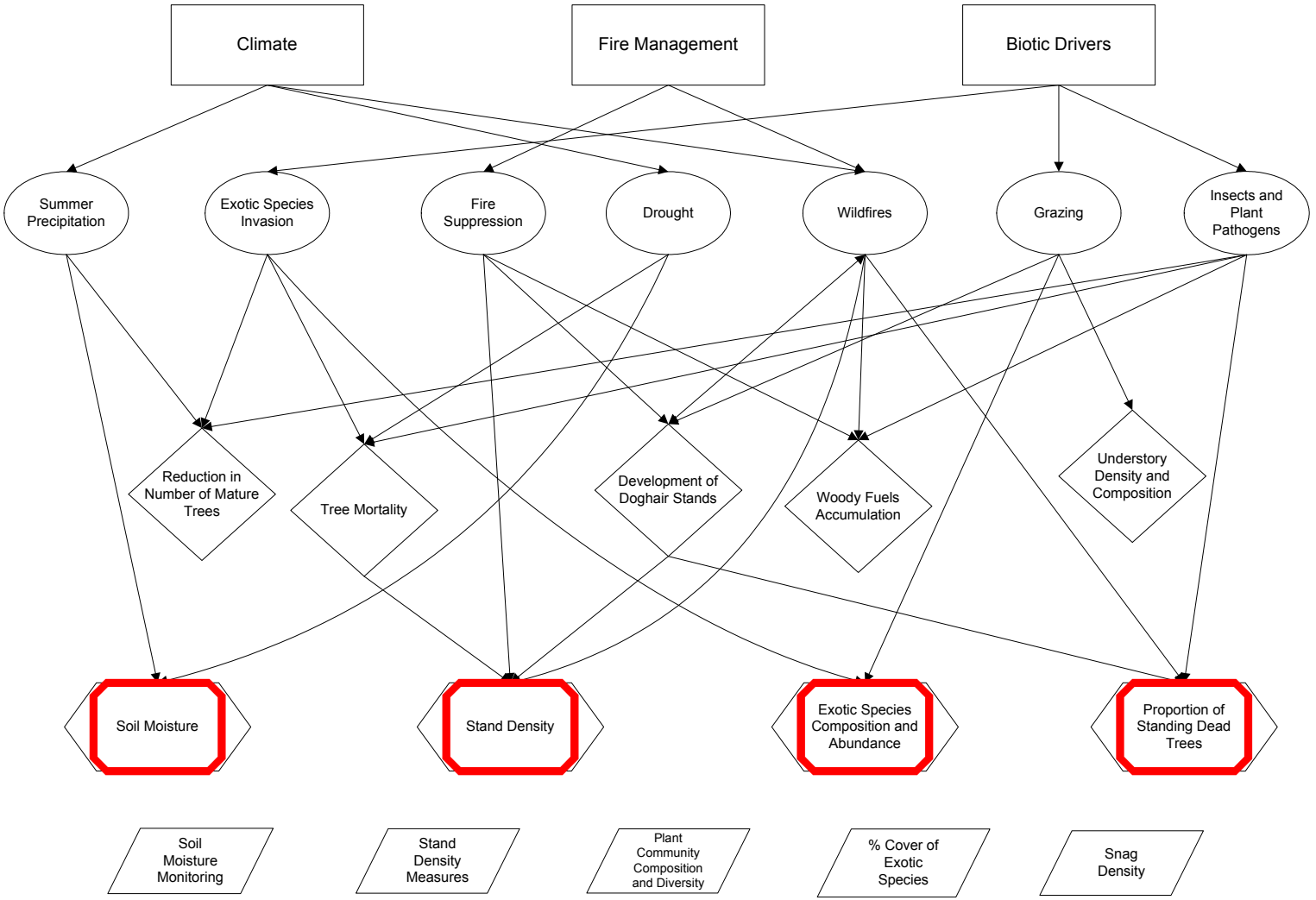
Lodgepole Pine Model-Dan Tinker



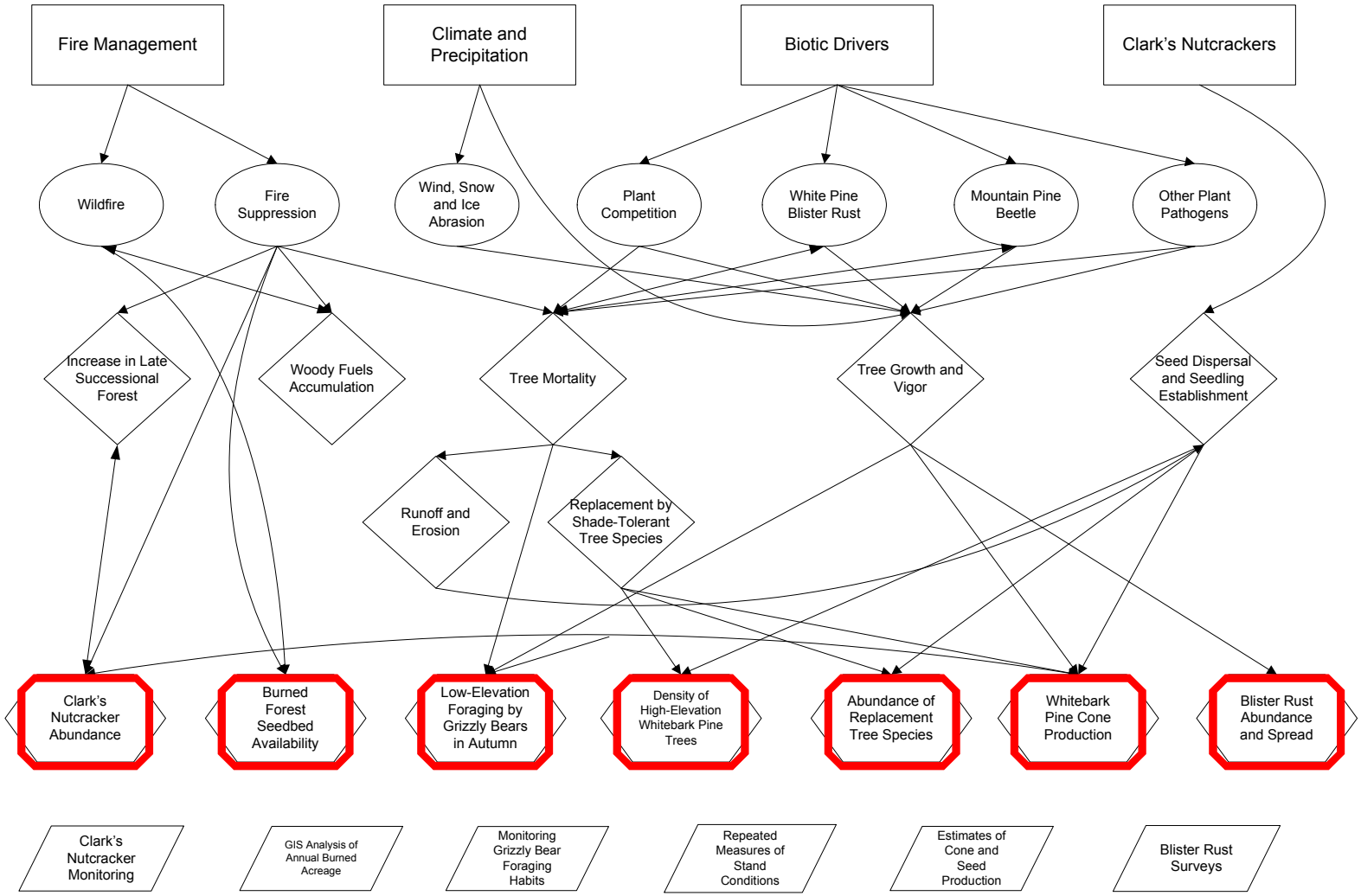
Mixed Conifer Model-Dan Tinker



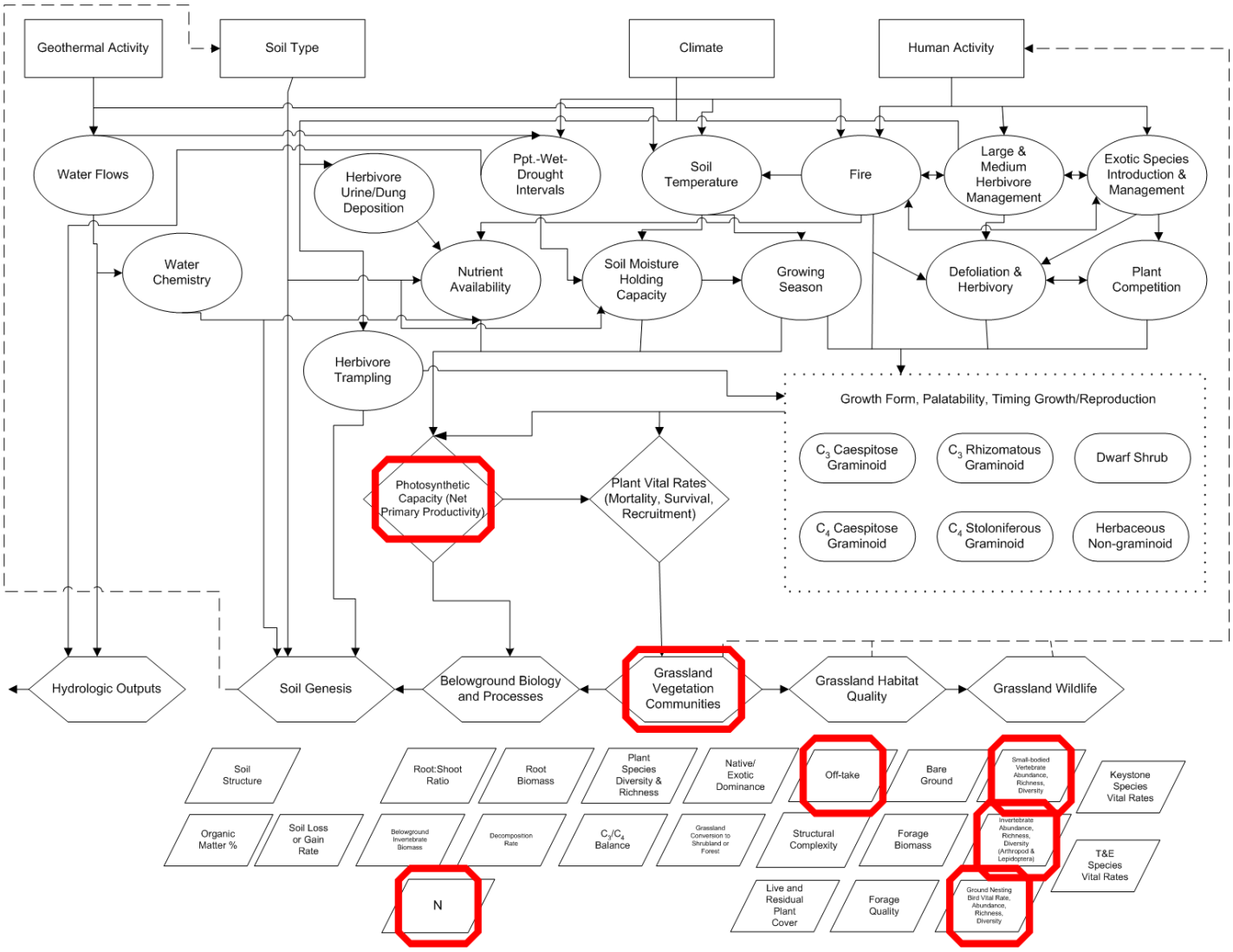
Ponderosa Pine Model-Dan Tinker



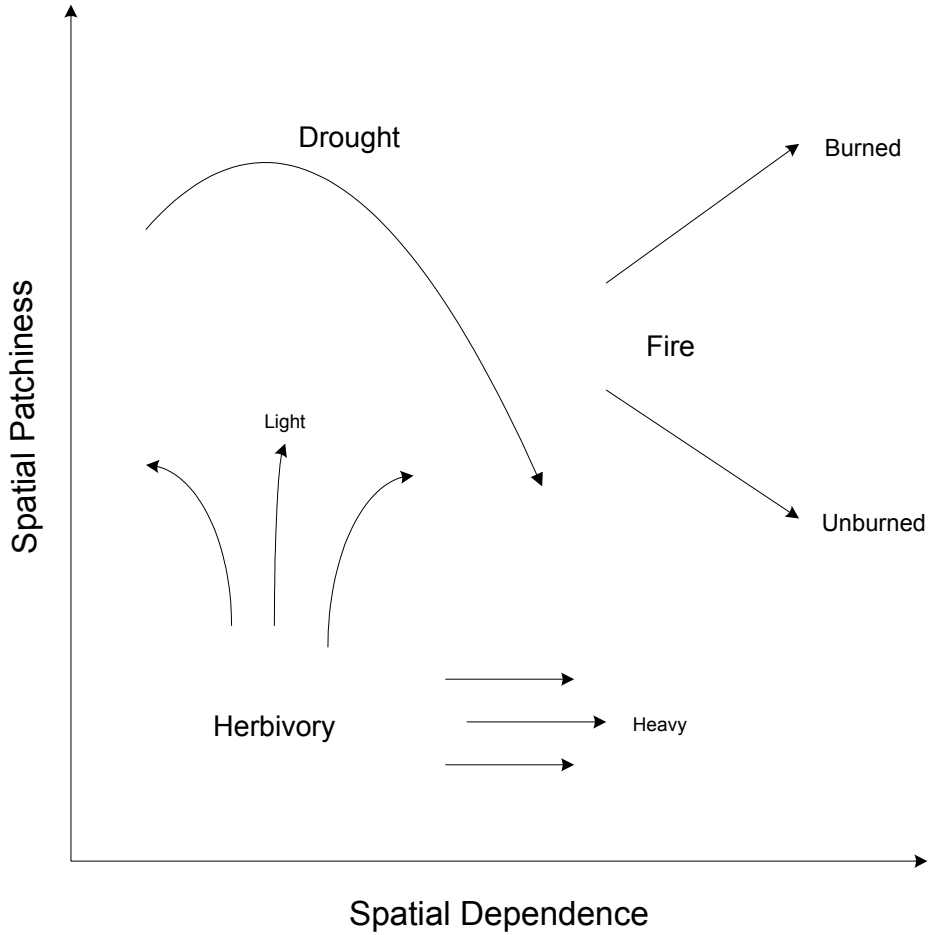
Whitebark Pine Model-Dan Tinker



Grassland Model-Glenn Plumb

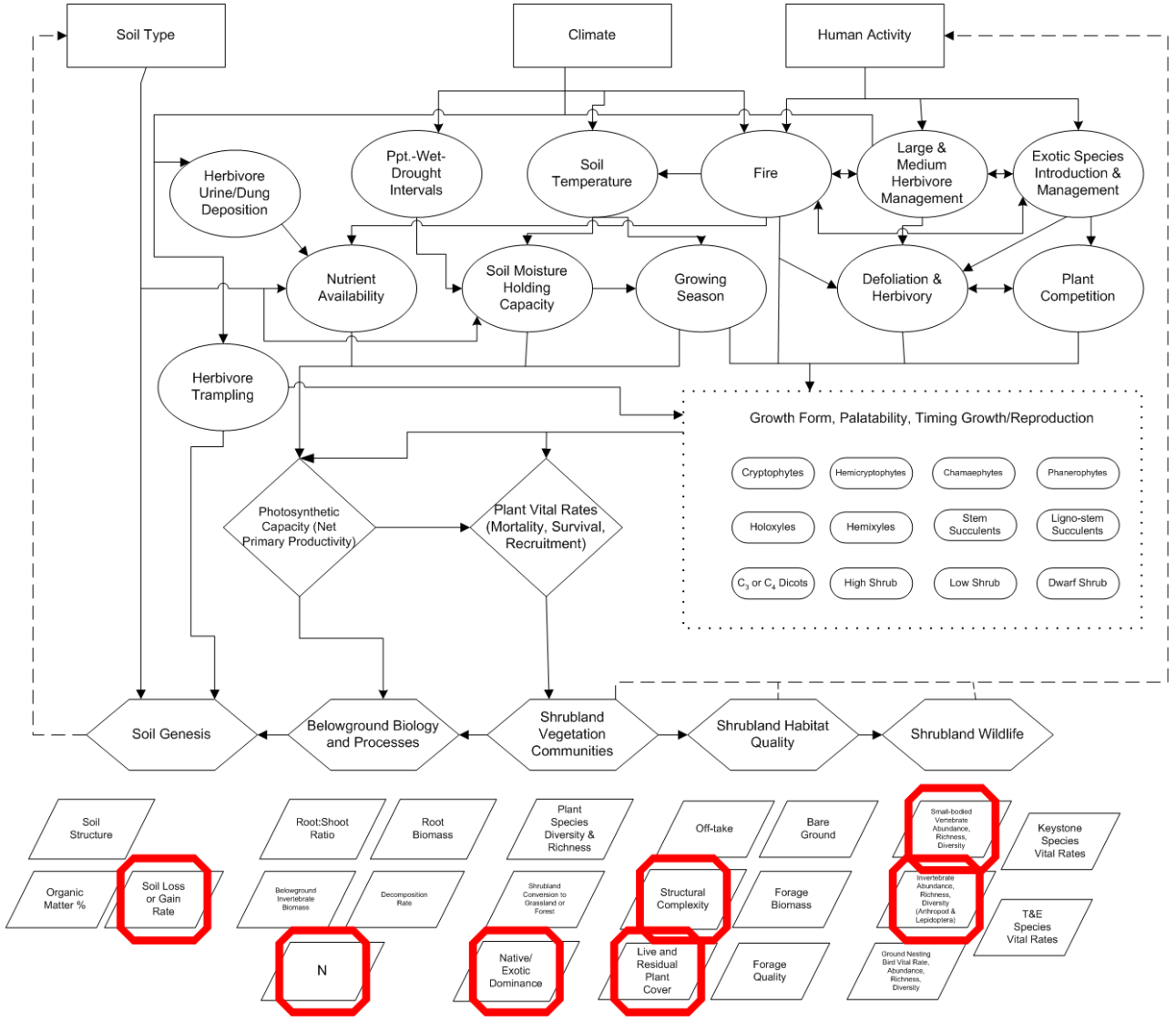


Grassland Submodel-Glenn Plumb
Net Primary Productivity

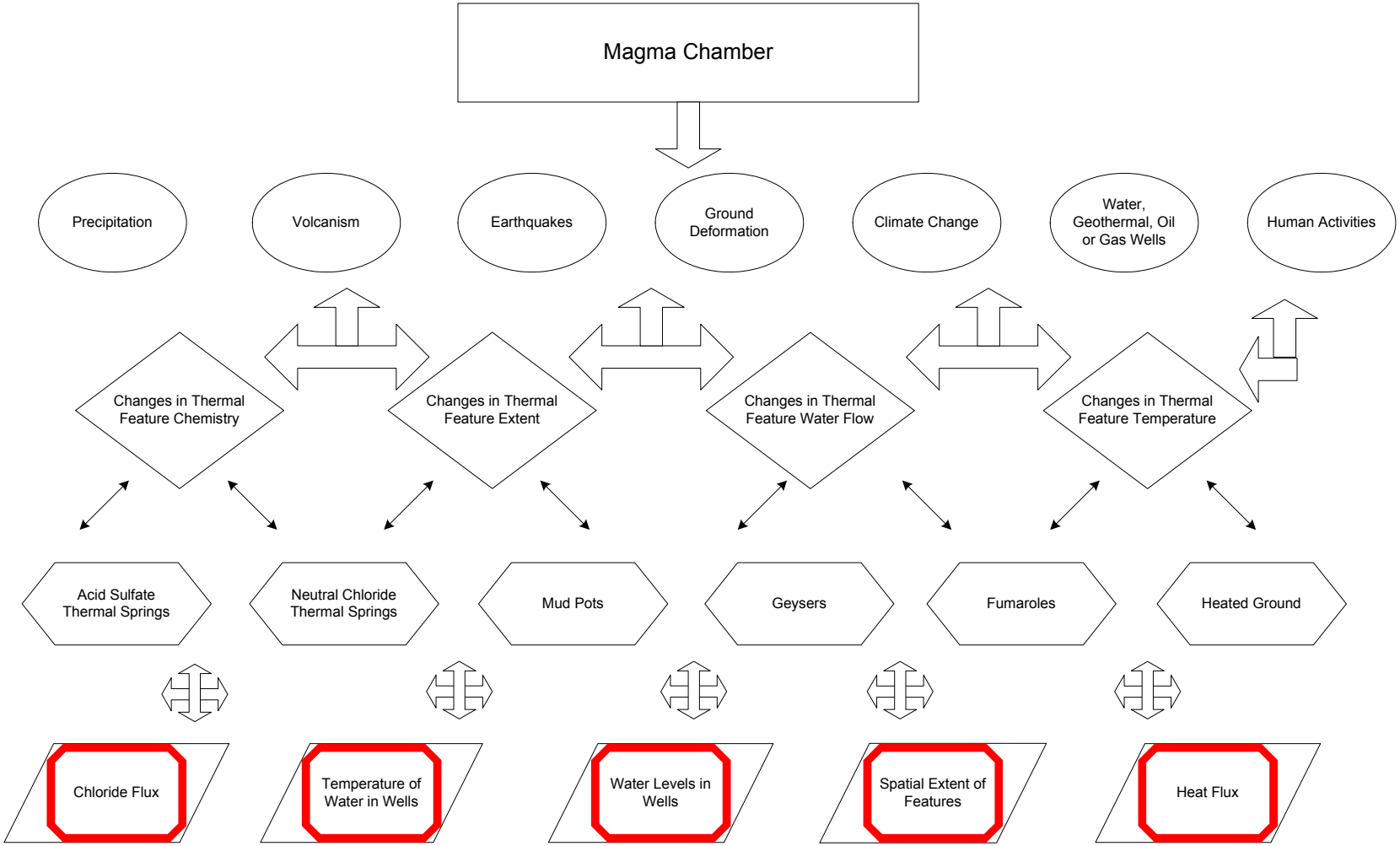


Adapted from *Briggs, et al. 1998. A landscape perspective of patterns and processes. In: Grassland dynamics. Eds. A.K. Knapp, J.M. Briggs, D.C. Hartnett, S.L. Collins. LTER Publications, Oxford University Press, New York.*

Shrubland Model-Glenn Plumb



Geothermal Model-Henry Heasler and Cheryl Jaworowski



VII. DELPHI SURVEY-ROUND III

The following table contains a list of those indicators scored or nominated by the Delphi III survey participants. Scoring was based on a scale of 1 to 5, with 1 being unimportant and 5 being highly important. The scores were then averaged across all responses, giving the average score seen in the right-hand column of the table. Participants were also invited to add indicators they deemed important that did not appear on the original list to score. These responses have a score of 0.0 and are highlighted in yellow.

Indicator	Score
AIR	
Loading chemical species in snowpacks	3.85
Atmospheric deposition of sulfur	3.78
Acid neutralizing capacity in headwater lakes	3.54
Accumulation of toxic air contaminants in biota	3.52
Change in visibility deciviews	3.52
Atmospheric deposition on nitrogen	3.46
Loss of forest productivity	3.46
Ozone exposure index--W126	3.14
Nitrogen concentration in streams during spring snowmelt	3.00
Number of days with smoke	2.48
Human health-related air quality	0.00
Emission rates of key gases to the atmosphere over Yellowstone NP.	0.00
Environmental contaminants	0.00
AQUATIC	
Aquatic species at risk	4.16
Native fish community structure, composition, stability	4.14
Native aquatic macroinvertebrate diversity/richness	4.14
Aquatic habitat loss and degradation	4.00
Exotic fish community structure, composition, stability	3.72
Lake phytoplankton & zooplankton community assemblages	3.60
Exotic aquatic macroinvertebrate diversity/richness	3.50
Aquatic disease & pathogen prevalence, contagion, vulnerability	3.40
Stream periphyton and zoobenthos community assemblages	3.30
Spawning fish vital rates	3.25
Critical food abundance, distribution and stability in aquatic habitats	3.00
Aquatic/terrestrial trophic relationships	0.00
Wetland birds	0.00
Hot spring microorganism	0.00
Genetic integrity of native fishes	0.00
Aquatic sediment fossil records of all types.	0.00
Fish (native & alien) population abundance, distribution, and vital rates	0.00
Wetland vegetation communities	0.00
CLIMATE	
Total precipitation	4.29

Indicator	Score
Stream flow patterns	3.61
Plant phenology	3.50
Extreme hydrologic events	3.43
Snow water equivalence of snowpack	3.41
Number of days ground is snow-covered	3.40
Maximum air temperature	3.38
Date of "spring green-up"	3.32
Alpine/subalpine climatic conditions & micro-environment	3.29
Minimum air temperature	3.29
Snow covered area	3.24
Soil moisture	3.13
Period of lake ice cover	3.10
Extent of frozen ground	3.00
Surface UV	2.96
Date of lake overturn	2.95
Soil temperature	2.77
Number of severe storms	2.65
Photosynethically active radiation (PAR)	2.61
Number of rain-on-snow events	2.52
Number of cloudy days	2.50
GEOLOGY & GEOTHERMAL	
Earthquake activity	4.23
Geothermal water chemistry & temperature	4.13
Geothermal water flow rate	3.91
Geothermal feature abundance & distribution	3.78
Volcanic unrest	3.75
Contamination of thermal microbial populations	3.73
Active geological processes (e.g. slope failure, etc)	3.55
Thermal heat transfer	3.45
Geyser eruption volume & rate	3.24
Native microbial populations	0.00
Paleontological Resources	0.00
Fumarole degassing	0.00
Annual sinter layering	0.00
Streamflow; stream channel morphology	0.00
HUMAN	
Landscape heterogeneity & habitat fragmentation	3.96
Winter use activities (snowmobiles, skiers, other winter recreationists)	3.93
Land use--land cover	3.62
Secure wildlife habitat	3.61
Human-wildlife interaction (habituation)	3.54
Hydrologic modification (dams, diversions, return flow)	3.54
Sound quality	3.52
Visitor experience and satisfaction	3.36

Indicator	Score
Backcountry overnight use (people, stock, & boat use nights)	3.32
Backcountry day use (hikers, stock users, boaters, anglers, etc.)	3.16
Bio-prospecting	3.00
Road-killed wildlife	2.88
road corridor impacts	0.00
Night Sky Pollution	0.00
Urban develop near park and in wildlife corridors	0.00
INVERTEBRATES	
Critical habitat abundance, distribution & stability	3.68
Insect biodiversity	3.64
Insect herbivory	3.08
Insect biomass	2.88
Disease in terrestrial invertebrate communities	2.64
links between vertebrates and invertebrates and the changes in the landscape	0.00
Exotic insects	0.00
Insect species distribution	0.00
Invertebrate (all groups) diversity and distribution	0.00
SOIL	
Below-ground biomass	3.83
Hydrothermal soil chemistry	3.75
Soil chemistry (nitrogen, organic matter)	3.25
Soil structure and stability	3.25
Soil biodiversity	3.23
Cryptobiotic crust integrity	3.08
Soil and sediment erosion	2.92
VEGETATION	
Exotic terrestrial plant species diversity/richness	4.30
Whitebark pine ecology, distribution, mortality, recruitment	4.03
Native terrestrial plant species diversity/richness	4.00
Wetland vegetation community structure & composition	3.82
Aspen distribution, growth & recruitment	3.69
Grassland & shrub steppe community structure & composition	3.66
Willow – cottonwood community structure & composition	3.63
Alpine/ subalpine community structure & composition	3.58
Wetland species at risk	3.53
Vegetation chemistry	3.46
Forest community structure & composition	3.41
Fire and fuel loading	3.38
Quality and diversity of sagebrush habitat	3.28
Riparian vegetation community structure & composition	3.21
Taxonomy & distribution of aquatic vegetation	3.11
Browse community structure & composition	3.10
Net primary productivity	3.09
Beaver dam wetland community structure & composition	3.09

Indicator	Score
Desert shrub community structure and composition	3.00
Stream bank stability	2.97
Tree line elevation	2.92
Floodplain development	2.90
Sediment deposition in depressional wetlands	2.58
Juniper community structure & composition	2.56
Impacts of livestock grazing	0.00
Bryophytes	0.00
Distribution of exotic plant diseases	0.00
Bark beetle trends	0.00
Impacts of browsing by ungulates	0.00
Demographics of selected plants	0.00
Cushion plant community species richness and diversity	0.00
Lichen abundance and distribution	0.00
Area occupied by rare or declining plant community types	0.00
Plant disease trends	0.00

GREATER YELLOWSTONE NETWORK
VITAL SIGNS
TECHNICAL NOTES



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**Please note: these technical notes were developed in conjunction with the list of vital signs chosen by the Technical Committee and approved by the Board of Directors, as shown in Table III.3 of the Phase II Report. Those vital signs whose names were changed or that were added during the Science Committee meeting are not included in these technical notes.

ACRONYMS

Acronym	Definition
ANC	Acid-Neutralizing Capacity
APHIS (USDA)	Animal and Plant Health Inspection Service
ARD (NPS)	Air Resources Division
ARMI (USGS)	Amphibian Research and Monitoring Initiative
ARS (USDA)	Agricultural Research Service
BICA	Bighorn Canyon National Recreation Area
BLM	Bureau of Land Management
BOD	Board of Directors
BRD (USGS)	Biological Resources Division
CAFO	Concentrated Animal Feeding Operations
CASTNet	Clean Air Status and Trends Network
CDC	Centers for Disease Control
CFC	Chlorofluorocarbons
CSU	Colorado State University
DO	Double-Observer Method
DOI	Department of the Interior
EPA	Environmental Protection Agency
EPMT (NPS)	Exotic Plant Management Teams
ESA	Endangered Species Act
GPRA	Government Performance and Results Act
GRTE	Grand Teton National Park
GRYN	Greater Yellowstone Inventory and Monitoring Network
GYA	Greater Yellowstone Area
GYCC	Greater Yellowstone Coordinating Committee
GYE	Greater Yellowstone Ecosystem
HCN	Historical Climate Network
HUC	Hydrologic Unit Code
I&M	Inventory and Monitoring
IGBST	Interagency Grizzly Bear Study Team
IMPROVE (NPS-ARD)	Interagency Monitoring of Protected Visual Environments

INEEL	Idaho National Engineering and Environmental Laboratory
INSTAAR (UC-Boulder)	Institute of Arctic and Alpine Research
ISU	Idaho State University
JODR	John D. Rockefeller, Jr. Memorial Parkway
MAPS	Monitoring Avian Productivity and Survival
MSU	Montana State University
MT FW&P	Montana Fish, Wildlife and Parks
MTDEQ	Montana Department of Environmental Quality
NADP/NTN	National Atmospheric Deposition Program/National Trends
NASA	National Aeronautics and Space Administration
NAWQA (USGS)	National Water-Quality Assessment Program
NBII (USGS)	National Biological Information Infrastructure
NCAR	National Center for Atmospheric Research
NCDC (NOAA)	National Climatic Data Center
NHD (USGS)	National Hydrography Dataset
NLCD	National Land Cover Dataset
NOAA	National Oceanic and Atmospheric Administration
NPS	National Park Service
NRCS	Natural Resources Conservation Service
NSIDC	National Snow and Ice Data Center
NTU	Measurement of turbidity
NVCS	National Vegetation Class Standards
NWHC (USGS)	National Wildlife Health Center
PAO	Proportion of Area Occupied
PCA	Predator Conservation Alliance
PMWHR (BICA)	Pryor Mountains Wild Horse Range
RAWS	Remote Automated Weather Station
RM-CESU (NPS)	Rocky Mountain-Cooperative Ecosystems Studies Unit
SC	Science Committee
T&E	Threatened and Endangered Species
TC	Technical Committee
TMDL	Total Maximum Daily Loads
UM	University of Montana

USBR	United States Board of Reclamation
USDA	United States Department of Agriculture
USFS	United States Forest Service
USFWS	United States Fish and Wildlife Service
USGS	United States Geological Survey
UTM	Universal Transverse Mercator Coordinates
UW	University of Wyoming
VAM	Vesicular-arbuscular mycorrhizae
VCP	Variable Circular Plot
WCS	Wildlife Conservation Society
WEBB (USGS)	Water, Energy and Biogeochemical Budgets
WGF	Wyoming Game and Fish
WRD (USGS)	Water Resources Division
WYDEQ	Wyoming Department of Environmental Quality
YELL	Yellowstone National Park
YVO (USGS)	Yellowstone Volcano Observatory

ATMOSPHERIC DEPOSITION OF NITROGEN, SULFUR AND ALL MAJOR ANIONS AND CATIONS (INCLUDING WET AND DRY DEPOSITION)

What is this vital sign and why is it important?: Atmospheric deposition is the process whereby precipitation (rain, snow, fog), particles, aerosols and gases move from the atmosphere to the earth's surface. Materials reaching the earth in precipitation or as dry deposition originate from a variety of air pollution sources and can be harmful to the environment and public health. Snowpack and wet-deposition data collected in the GYA show the importance of understanding the sources of nitrogen pollutants (NPS-ARD 2002, Turk et al. 2001, Ingersoll et al. 1997); the potential for additional sulfur deposition is present due to the possible increase in coal burning in the western U.S. Local sources of air pollution, such as snowmobile exhaust, can result in greater loadings of organics, nitrogen and sulfur species to snowpacks (Ingersoll 1999), and snowpack surveys conducted annually since 1993 have shown consistent "hot spots" of inorganic nitrogen deposition downwind of agricultural and industrial (INEEL and fertilizer) plants in Idaho (Turk et al. 2001, Clow et al. 2002). The future may well bring accelerated energy development in Montana and Wyoming, with plans for extensive development of coalbed methane wells and the possibility of new electrical generating plants (e.g. Roundup plant in Montana). Southern Idaho has become a major location for confined animal feeding operations (CAFOs), resulting in the uncontrolled emission of ammonia. There is international concern about the possibility of exponential growth in inorganic nitrogen emissions from industrial, vehicular and agricultural sources worldwide (Cowling et al. 2002). All of these atmospheric deposition sources need to be considered as threats to the Outstanding Natural Resource Waters in both YELL and GRTE. Melting of contaminated snowpacks can result in changes to soil processes and alterations in surface water chemistry, which can, in turn, affect aquatic biota in high elevation lakes and streams.

Proposed Metric: Atmospheric loading in kg/ha/yr of wet deposition of major anions and cations (nitrate, sulfate, ammonium, calcium, sodium, potassium, chloride – see suite of chemicals measured by NADP/NTN at http://nadp.sws.uiuc.edu)

Workshop Score: 1.00 (GRTE and YELL)

Current Monitoring: There is currently a wet deposition collector at Tower Junction in YELL. CASTNet dry deposition monitor is located at Lake in YELL. USGS Synoptic Snow Survey network (NPS-ARD 2002) has sample locations in both GRTE (2) and Yellowstone (4) to collect total integrated snowpack samples at maximum accumulation.

Relative Annual Cost of Monitoring: $: NADP/NTN – annual operations; $: CASTNet dry deposition – annual operations; $: Snowpack sampling and analysis – annual operations

Comments:

- Direct and subsidized costs: The point measurements of dry and wet deposition at Lake and Tower in Yellowstone allow us to make point estimates of total loading. To extrapolate to high elevations, additional snowpack measurements are needed. There is no year-round monitoring of wet deposition chemistry in Grand Teton, although the

location that has a modeled "hot spot" of nitrogen deposition (Fenn et al. 2003). The recommendation to truly characterize wet deposition chemistry in the sensitive areas of YELL and GRTE would include the following:

- Install wet and dry deposition monitoring equipment at a site in GRTE:
  - Capital equipment for both NADP/NTN and CASTNet - $25,000
  - Annual operations – approx $25,000 – part of national networks
  - Assistance with installation from NPS-ARD; GRTE should absorb cost for weekly servicing of the site by biotechs
  - Need a site that has line power and can be accessed annually; siting criteria for met tower and sampling equipment

- Continue annual snowpack sampling and expand to sensitive, high-elevation areas
  - Partnership with NPS-ARD and USGS-WRD
  - Cost of approximately $4000/site
  - Some in-kind support from USGS-WRD
  - NPS-ARD contributes annually to the chemical analysis
  - GRTE and YELL need to provide biotechs to assist USGS with snow collection during one week per year
  - Access to snowpack sites on skis or snowmobiles

Technical Note Author: Susan O'Ney

CHANGE IN VISIBILITY DECIVIEWS

What is this vital sign and why is it important?: A deciview is a measure of visual quality. According to the NPS (2001), a deciview is "a constant, fractional change in light extinction (the sum of light scattering and absorption per unit distance). Higher deciview values signify poorer visibility." The deciview measurement allows for comparisons across different conditions. Such changes in visibility can be viewed as a measure of cumulative impacts to air quality or of a specific parameter that then should be studied further. As of the GPRA 2000 Review, YELL did not meet the NPS GPRA Air Quality goals (GRTE and BICA were not reported); however, YELL did show a significant improvement in number of clear days and sulfate content in acid precipitation, and an improvement (although not significant) in the number of dirty days and nitrate content in precipitation (NPS 2001). Scenery and pristine viewsheds, especially in YELL and GRTE that are Class 1 areas, are one of the primary reasons people visit all three units. To have views diminished by poor air quality would greatly diminish the appeal of the parks. Continuing to study changes in our atmosphere will help to maintain air quality and discover any hazardous trends, as other parks such as Glacier and Grand Canyon have done. Within the GRYN, it is a concern that smoke and other pollutants such as dust from over-utilized rangelands are drifting in from the south and west and both air quality and views are being degraded more frequently. Threats to visibility from new and imminent energy development (especially power plants) near all three parks are also a concern.

Proposed Metric: A one (dv) change is equivalent to a 10% change in the extinction coefficient (another commonly used visibility index). The deciview is also known as the haziness index and can be expressed by the following equation: haziness (dv)= 10 ln (bext/0.01 km -1)= 10 ln (391 km/vr), where bext=extinction coefficient and vr=visual range.

Workshop Score: 1.00 (GRYN)

Current Monitoring: The NPS currently has ongoing monitoring of visibility changes through the IMPROVE (Interagency Monitoring of Protected Visual Environments) Program, a joint venture between the NPS, EPA and other state and local agencies. Class 1 area webcam images can be viewed at the site: http://vista.cira.colostate.edu/improve/Data/other/webcam/webcam.htm. The objectives of the program can be viewed at: http://vista.cira.colostate.edu/improve/Overview/Overview.htm. Monitoring is ongoing in YELL and GRTE, but not BICA.

Relative Cost of Monitoring: $

Comments:

- Direct costs: If the GRYN uses the IMPROVE data, the only direct cost is possible data analysis.
- Costs that can possibly be subsidized: Using the available IMPROVE data for YELL and GRTE would decrease overall costs. However, no current monitoring is ongoing in

BICA. This oversight needs to be addressed if monitoring is to occur in all three units, as stated by workshop participants.

Technical Note Author: Anne Schrag

BASIC CLIMATOLOGICAL MEASUREMENTS

What is this vital sign and why is it important?: Climate, simply put, is the "long-term characteristics of weather" (NOAA 2003). Basic climatological measurements include: temperature (maximum, minimum and average), precipitation, relative humidity, wind, surface pressure and snow cover, depth and water equivalent. Because climate is a basic driver of all ecological systems, these measurements are important for understanding the relationship between climate and other components of biotic and abiotic systems. Without climate data, it is impossible to appreciate the causes of a variety of ecosystem changes—from vegetative cover changes to shifts in aquatic systems. In fact, the most important components of useful climatological measurements are the length and accuracy of the data. Maintenance of climate stations, therefore, is extremely important in order to assure high-quality data.

Proposed metric: Air temperature (°C), surface wind (m/s), atmospheric humidity/water vapor in percent (%) or mixing ratio in g H_2O/Kg-air or concentration in g H_2O/m^3, surface pressure (hectopascals (hPa) or millibars (mb)), snow cover and depth (water equivalent) km^2 and/or % of area for cover and mm/cm for depth.

Workshop Score: 1.00 (GRYN)

Current Monitoring: All such measurements are already being monitored to some extent in each of the GRYN parks. There are 136 weather station locations in or bordering Wyoming. Major organizations involved in such climate data collection are the International Council for Science World Data Center for Snow and Ice, National Snow and Ice Data Center (NSIDC), NOAA-National Climatic Data Center (NCDC), Natural Resources Conservation Service (NRCS-collaborates with NPS) and the National Center for Atmospheric Research (NCAR). In particular, GRTE regularly works with the NCDC and is scheduled to become part of the Climate Reference Network. Additional metrics being measured in each of the parks include solar radiation, ground temperature, soil temperature, soil moisture and fuel temperature.

Relative Annual Cost of Monitoring: $

Comments:

- Direct costs to the GRYN: In addition to yearly maintenance by park staff of the climate stations, new monitoring dollars may be need to fill holes in the GRYN, given current locations of climate stations. The GRYN should ensure that new climate stations have adequate funding for long-term data collection, as "spotty" data is not useful in climate monitoring.
- Costs that can possibly be subsidized: Data from existing climate stations can be obtained through the Natural Resources Conservation Service (NRCS) database (low cost, but holes in the data), the National Climatic Data Center (NCDC) (higher cost, but more complete records) or through the U.S. Historical Climate Network (HCN) (highest quality data, but fewer records).

Technical Note Author: Anne Schrag

GLACIAL RETREAT OR ADVANCE

What is this vital sign and why is it important?: Glacial advance occurs when a mountain glacier's terminus extends farther down valley than previous measurements, while glacial retreat happens when the position of a mountain glacier's terminus is farther up valley than previous measurements or when a glacier ablates more material at its terminus than it transports into that region (NSIDC 2003). Glaciers are indicators of climate change; glacial retreat follows periods of above-average temperatures and below-average precipitation. Monitoring the advance or retreat of glaciers in GRTE and YELL will give insight into possible changes in climate in these areas. In addition, monitoring can indicate the effect of glaciers on water resources.

Proposed metric: The likelihood of an advance or retreat is measured by calculating the net mass balance (in m) of the glacier over time. Mass balance is calculated by monitoring accumulation (in the accumulation area where snowfall exceeds snowmelt) and ablation (in the ablation area where snowmelt exceeds snowfall) with respect to preset levels. After numerous years of positive mass balance, the glacier will advance; after years of negative mass balance, glacial retreat occurs (USGS 1997).

Workshop Score: 0.80 (GRTE and YELL)

Current Monitoring: No monitoring is currently ongoing in GRTE and YELL. However, protocols developed by the USGS are widely accepted and used and can be found at: http://ak.water.usgs.gov/glaciology/reports/circular1132/Circular1132.pdf

Relative Annual Cost of Monitoring: $$$-$$$$$ (for direct measurements through groundwork); $-$$ (for indirect measurements through aerial photography)

Comments:

- Direct costs to the GRYN: Direct ground measurements are expensive; however, indirect measurements through methods such as aerial photography could eliminate costly groundwork.
- Costs that can possibly be subsidized: Collaboration with current USGS glacial monitoring is essential for data sharing.

Technical Note Author: Anne Schrag

EXOTIC AQUATIC COMMUNITY STRUCTURE AND COMPOSITION

What is this vital sign and why is it important?: Exotic aquatic community structure and composition includes the abundance and distribution of exotic fish species, including lake trout in Yellowstone, as well as invertebrates such as the New Zealand mud snail, that are causes of concern in park aquatic ecosystems. Fish especially are good indicators of long-term environmental effects and broad habitat conditions because they are relatively long-lived and mobile, life history information is extensive for many species, fish distribution information is commonly available, and the environmental requirements of most fish are well known. Fish assemblages generally include a range of species that represent a variety of trophic levels (omnivores, insectivores, planktivores, and piscivores) and they tend to integrate the effects of lower trophic levels, thus reflecting integrated environmental health. Fish are at the top of the aquatic food web and are consumed by humans, making them important for assessing tissue contamination. Similarly, aquatic life uses (water quality standards) are typically characterized in terms of fisheries (coldwater, coolwater, warmwater, sport, forage) and monitoring fish provides direct evaluation of "fishability", which emphasizes the importance of fish and their ecology to anglers. Lastly, fish account for nearly half of the endangered vertebrate species and subspecies the United States; therefore, it is extremely important to maintain genetic integrity in native populations. In general, fish are easy to collect, easy to identify to the species level and most specimens can be sorted and identified in the field by experienced fisheries professionals and subsequently released unharmed. Therefore, monitoring the spread of exotic species will allow managers to understand the environmental consequences of these communities.

Proposed metric(s): species richness and composition metrics, trophic composition metrics, fish abundance and condition metrics, distribution (geographical location) and genetic purity analysis.

Workshop Score: 1.00 (GRYN)

Current Monitoring: Both YELL and GRTE are actively involved in inter-agency research on fish ecology, angler catch, and restoration and preservation of native species, subspecies, and genotypes, and major revisions in fisheries regulations and management. More specifically, YELL is undertaking ongoing monitoring of the zebra mussel invasion of Yellowstone and Lewis lakes, native Montana grayling populations, Yellowstone cutthroat trout populations, Lake trout in Yellowstone lake, fish populations in backcountry lakes, fish populations in streams, Whirling disease monitoring, New Zealand mud snail populations, Westslope cutthroat trout populations, anglers and angler success, and is currently developing an empirical model for predicting the stream invertebrate fauna of the GYE.

Relative Annual Cost of Monitoring: Genetic analysis can be expensive.

Comments:

- Direct costs to the GRYN: Where important, most such studies are already occurring. The GRYN data manager will need to spend time in the management, analysis and reporting of such data sets.

- Costs that can possibly be subsidized: There are many opportunities for inter-agency cooperation/cost subsidies through USGS, USFWS, WY Game & Fish, MTFW&P, universities, etc.

Technical Note Author: Laura Gianakos

EXOTIC PLANT SPECIES ABUNDANCE AND DISTRIBUTION

What is this vital sign and why is it important?: Under Executive Order 13112 (1999), the official definition of an invasive species is "an alien species whose introduction does or is likely to cause economic or environmental harm or harm to human health." Meanwhile, the NPS Management Policies define invasive species as "those occurring outside their native ranges in a given place as a result of actions by humans," thus differentiating between human-caused invasions and those occurring due to natural processes. Over 190 parks have identified invasive species as a critical issue (NPS 1997). According to the DOI Invasive Species Fact Sheet (2000), "invasive species cost our Nation's economy an estimated $123 billion annually and are second only to habitat destruction in threatening extinction of native species." The control or elimination of invasive plant species is critical to the health of the parks' ecosystems. Invasive species easily take over sections of ecosystems, choking out native species and consuming valuable resources. Many times, these invasive species are not palatable to native ungulates, thus decreasing available forage. In addition, the possibility exists for invasive plants to pass diseases to native species and hybridize with natives, causing loss of genetic integrity. By monitoring the species richness and distribution of invasive plant species, the status and trends of these populations, as well as the effectiveness of current management techniques and possible preventative actions, can be determined (NPS 1997).

Proposed Metric: Data analysis and management (possible mapping)

Workshop Score: NEW Vital Sign (created from parts of many terrestrial vegetation vital signs)

Current Monitoring: An exhaustive list of current monitoring is not feasible for the purpose of this technical note. However, many agencies, including the NPS, USGS and USFS have established monitoring protocols for invasive plant species. An important program of note is the USGS-NBII Information Node, currently being established, that will synthesize and assess the extent of the invasive plant problem. Information will be stored in MS Access database form and linked to GIS maps. (This USGS-NRMSC section of this information node is located on the campus of MSU). The NPS has created Exotic Plant Management Teams (EPMT) to help create and carry out eradication methods. These teams strive for interagency cooperation in the fight against weeds. Exotic plant monitoring (through EPMT and in conjunction with Exotic Plant Control in YELL) is currently being performed in YELL (contacts: Roy Renkin, Mary Hektner, Dan Reinhart, Craig McClure) and GRTE (contact: Steve Haynes). An assessment of non-native vegetation has also been performed in YELL (contact: Ken Meyer). Myriad journal publications, books and popular press articles are available on the impact of weeds on native ecosystems.

Relative Cost of Monitoring: $-$$ for data analysis, management and reporting

Comments:

- Direct costs: seasonal employees with relatively little prior training can do much of the groundwork.

- Costs that can possibly be subsidized: The NPS is already allocating much funding to this problem, through EPMT's and other projects. *However*, the GRYN can be of great use in data management of the huge amount of information being collected on invasive plant distribution and abundance, as well as helping with modeling and possible hiring of seasonal employees. Interagency collaboration with the USGS-NBII on the campus of MSU is essential. Information from this node can help in future modeling and monitoring pursuits.

Technical Note Author: Anne Schrag

FOREST INSECTS AND DISEASE

What is this vital sign and why is it important?: Forest insects and disease refers to a variety of insect species and diseases that are problematic throughout the GYE, including, but not limited to, spruce beetle, mountain pine beetle, gypsy moths, spruce budworm, tussock moths, annosum root rot and blister rust. Insect outbreaks are generally cyclical in nature and tend to prove most devastating to populations that are already ravaged by the effects of disease or animal browse. Many of the insects that cause outbreaks, as well as most of the diseases, are exotic. Monitoring the amount of disease and the outbreak cycles due to insects allows for predictive modeling of the population dynamics and can lead to such practices as selecting for individuals that are disease-resistant.

Proposed Metric: Generally, monitoring programs for these insects and diseases consist of a detection and survey phase (i.e. pheromone traps), aerial surveys (to detect large areas of defoliation) and ground work.

Workshop Score: NEW Vital Sign

Current Monitoring: Data on white pine blister rust has been collected by the Greater Yellowstone Coordinating Committee (GYCC), in conjunction with YELL and the Whitebark Pine Ecosystem Foundation, but have not yet been analyzed. Gypsy moth detection is ongoing in YELL (Contact: Paul Miller). Many of the common forest insects and diseases are monitored by the U.S. Forest Service and USDA-APHIS.

Relative Annual Cost of Monitoring: $-$$$$$ (highly variable depending upon extent of involvement)

Comments:

- Direct costs to the GRYN: Many of the direct costs will be the data analysis of already collected datasets. However, some crews may need help hiring additional seasonal staff.
- Costs that can possibly be subsidized: Working in conjunction with the GYCC, Whitebark Pine Ecosystem Foundation, U.S. Forest Service and USDA-APHIS can reduce overall costs.

Technical Note Author: Anne Schrag

VERTEBRATE DISEASES

What is this vital sign and why is it important?: Vertebrate diseases of note include, but are not limited to: brucellosis, chronic wasting disease, West Nile Virus, pasturella pneumonia, chlamydia, Rana virus, Chytrid fungus and whirling disease. Vertebrate diseases pose a serious threat to animal population demography both inside and outside of the GRYN parks, as well as create socioeconomic issues. Not only does the eradication of infected animals create public relations concerns, but infected animals also become undesirable to hunters, thus eliminating one of the most active regulators of the populations. In order to appreciate the wide-ranging effects of these diseases, it is important to understand the responses of the diseases to stress in the population. However, stress-response monitoring is sometimes only possible in highly restricted situations, causing the results to be both hard to interpret and less useful. In addition, identifying the cause of population fluctuations and the population's vulnerability to the disease under stress (i.e. poor forage, crowding) is important in understanding the cause of increases in diseased animals. An overall understanding of the balance of the ecosystem can aid in the predictive capabilities of modeling and sampling programs.

Proposed Metric: Developing models that create useful sampling designs, etc. that include components of the overall ecosystem balance. The following metrics can be used to determine actual or predicted rates of infection: carcass inspection, hunter-killed animal inspection, live animal testing, population demography sampling, vegetation/habitat sampling (i.e. forage availability).

Workshop Score: 0.92 (GRYN)

Current Monitoring: A sampling of organizations currently performing research on the previously mentioned diseases includes: NPS, USDA APHIS, CDC, USGS-NWHC, EPA, Chronic Wasting Disease Alliance, USFWS, MT FW&P, MSU and many others.

Relative Cost of Monitoring: $-$$ for model creation and data analysis, management and reporting

Comments:

- Direct costs: this monitoring can probably not be funded in full by the GRYN
- Indirect costs: this monitoring can have high indirect costs due to socioeconomic effects, such as protesting, public relations concerns, decrease in hunters, etc.
- Costs that can possibly be subsidized: Many opportunities for collaboration with current monitoring are possible. Perhaps the greatest role of the GRYN could be in developing models that can help increase sampling efficiency and predictive power. In addition, the USGS-National Wildlife Health Center will conduct a free pathology report for two or more collected amphibian specimens (pathologist's salary paid by ARMI).

Technical Note Author: Anne Schrag

WHITEBARK PINE DECLINE

(includes limber pine)

What is this vital sign and why is it important?: Whitebark pine stands throughout the GYE are rapidly declining due to white pine blister rust, fire suppression and mountain pine beetle infestations. This decline in whitebark pine (and limber pine), known as a "keystone" species, affects an entire ecosystem, as grizzly bears and Clark's nutcrackers depend upon the seeds found in whitebark pine cones for food. Since white pine blister rust was introduced to North America, it has spread throughout the populations, severely decreasing the number of healthy whitebark pine trees. In addition, decades of fire suppression in the Rocky Mountains have caused whitebark pine ecosystems to be overrun by later successional trees, such as Engelmann spruce, shading out sun-loving whitebark pine. Outbreaks of mountain pine beetle cause stress to an already unstable ecosystem.

Proposed Metric: Possible metrics for monitoring white pine blister rust abundance and spread include repeat sampling and removal of rust-infected branches or areas of the bark; mountain pine beetle infestations may also be monitored using repeat sampling.

Workshop Score: NEW Vital Sign (Whitebark pine community composition and structure=0.92 [YELL])

Current Monitoring: The Whitebark Pine Ecosystem Foundation (Missoula, MT) is a collaboration of many agencies (including the Greater Yellowstone Coordinating Committee [GYCC], USDA Forest Service, RM-CESU and the USGS) has identified long-term monitoring of whitebark pine populations as an urgent need and is working to develop protocols and data analysis techniques to aid in this process. YELL is currently monitoring cone production on 19 whitebark pine transects (contact: Kerry Gunther).

Relative Cost of Monitoring: $-$$ (for data analysis, management and reporting)

Comments:

- Direct costs: If the GRYN uses the data already collected on whitebark pine in the GYE, the only direct cost would be for data analysis and possible seasonal employees.
- Costs that can possibly be subsidized: Interagency collaboration (especially with the Whitebark Pine Ecosystem Foundation) is imperative.

Technical Note Author: Anne Schrag

EARTHQUAKE ACTIVITY

What is this vital sign and why is it important?: Earthquake activity refers to the frequency, magnitude and location of earthquakes in the GYE. Monitoring earthquake activity is necessary for human safety and understanding possible damage to infrastructure. Unexpected earthquakes tend to cause devastation to an area. Earthquake monitoring can lead to more accurate earthquake prediction by measuring rock properties, such as rock magnetism, electrical conductivity and porosity (Skinner et al. 1999). Moreover, understanding earthquake activity can aid in the fundamental understanding of the geologic processes that are basic to the GRYN. This is especially important with respect to the Yellowstone Caldera and, therefore, has lead to the creation of the Yellowstone Volcano Observatory (YVO), an interagency team of experts who monitor, among many things, seismic activity in the GRYN.

Proposed Metric: Information on specific locations (latitude, longitude and location), date (month, day, year), time, depth (m) and magnitude (according to the Richter scale) are available through the Yellowstone Volcano Observatory using the University of Utah Seismograph Stations. Monitoring is also needed both as adjunct to monitoring for volcanic activity and along fault lines for patterns of seismicity in time and space, direct measure of seismic activity and changes in seismic activity.

Workshop Score: 0.87 (GRYN)

Current Monitoring: The YVO is currently monitoring seismic activity in the GRYN.

Relative Cost of Monitoring: $

Comments:

- Direct costs: Although most of the essential data is being collected, the GRYN could help with data analysis expenses and possible broadening of the scope of data that is collected.
- Costs that can possibly be subsidized: Much interagency collaboration is possible, especially with the YVO.

Technical Note Author: Anne Schrag

GEOTHERMAL FEATURE ABUNDANCE AND DISTRIBUTION

What is this vital sign and why is it important?: Geothermal feature abundance and distribution refers to the number and location of geothermal features, including mud pots, geysers, fumaroles, neutral chloride thermal springs and acid sulfate thermal springs. "Geologists use various visible, infrared, and microwave sensors to map surficial deposits, flow structures in lava flows, faults, fractures, ash flows, basalts, rhyolites, andesites, and allow lithologic discrimination of sedimentary rocks. Additionally, visible, infrared, thermal and microwave sensors (AVIRIS, TIMS, LANDSAT and RADAR) can detect subsidence, predict movements of animals, discriminate between healthy versus stressed vegetation, map active hot springs, map hydrothermal mineralization and generate detailed mineral maps of specific areas. Remote sensing technologies are a cost-efficient method of mapping and monitoring the spatial extent of thermal features. Change detection maps of thermal features can aid the assessment of natural changes versus human-caused changes of thermal areas. Maps derived from remote sensing technologies have applications to geology, hydrology, geobiology, archeology, and ecology. Additionally, these colorful images can be used by park interpreters to educate visitors and by park managers to inform politicians or other resource managers" (Jaworowski 2003).

Proposed Metric: Using remote-sensing technology to map thermal features, including mud pots, geysers, fumaroles, neutral chloride thermal springs and acid sulfate thermal springs

Workshop Score: 0.73 (GRTE and YELL)

Current Monitoring: Many of these data already exist, as remote sensing in the GYE is common.

Relative Cost of Monitoring: $

Comments:

- Direct costs: The main role of the GRYN will be in data analysis, management and reporting in support of the geothermal monitoring plan, currently under development.
- Costs that can possibly be subsidized: Much interagency collaboration is possible, especially with other agencies using remote sensing data of this type.

Technical Note Author: Anne Schrag

GEOTHERMAL WATER CHEMISTRY

What is this vital sign and why is it important?: Geothermal water chemistry refers to the monitoring of water chemistry, especially cations (As, F, Hg) and chloride concentrations, in geothermal areas, along with temperature and associated volume and flow patterns. For example, chloride is a good indicator of hydrothermal activity. Similarly, geothermal water chemistry and temperature are exceedingly important parameters for monitoring as they relate to the habitats for thermal spring extremophiles and influence water quality in receiving waters. Human-caused or naturally occurring changes in water chemistry and/or temperature may drive changes in the microbial ecosystem. Also, changes in water chemistry and/or temperature can be a key indicator of volcanic or tectonic unrest. Overall, monitoring geothermal features will help meet the legal mandates under the 1970 Geothermal Steam Act, as current monitoring does not comply with these mandates.

Proposed Metric: Water chemistry (especially As, F, Hg), temperature, associated volume and flow patterns

Workshop Score: 0.95 (GRTE and YELL)

Current Monitoring: Most of the proposed metrics are being monitored through the USGS-NAWQA program.

Relative Cost of Monitoring: $

Comments:

- Direct costs: The main role of the GRYN will be in data analysis, management and reporting in support of the geothermal monitoring plan, currently under development.
- Costs that can possibly be subsidized: Much interagency collaboration is possible, especially with the USGS-WRD.

Technical Note Author: Anne Schrag

HEAT FLOW—CHLORIDE FLUX

What is this vital sign and why is it important?: According to Aguilar et al. (2002), "chloride is a conservative and non-reactive ion that is used as a geothermal tracer." The Yellowstone Volaco Observatory (2003) says heat flow "refers to the heat that is transmitted from the hot interior of Earth to the surface in a specified time across a specified area." "Over 94% of the chloride in waters originating in Yellowstone is of magmatic origin (Norton and Friedman 1985). A study of variations in chloride flux can be used to establish a baseline for measuring the interaction of the deep geothermal waters with the surficial geothermal system. In addition, chloride flux baseline information may be used to assess any future adverse impacts on the Park's thermal features that may be caused by commercial development of geothermal energy, gas, oil and groundwater adjacent to the Park. Yellowstone's heat flow has been estimated using the chloride flux method, airborne sensors and satellite images. Increased heat flow in an area may indicate changes in subsurface hydrothermal activity. Additionally, warm ground affects the health of vegetation, migration of animals, and safety of park visitors. In the winter and spring, animals make use of thermal areas with minimal snow cover. Mapping new areas of heated ground and yearly changes in the heated ground can assist with maintenance of roads and visitor safety" (Jaworowski 2003).

Proposed Metric: Monitoring of chloride flux relies on river gauging stations. The chloride flux method for estimating geothermal activity in YNP has been extensively peer reviewed, accepted and published (Fournier et al. 1976, Norton and Friedman 1985; Friedman and Norton 1990). Monitoring should include the following thermal features: mud pots, geysers, fumaroles, neutral chloride thermal springs and acid sulfate thermal springs. Remote sensing is a cost-efficient method to map and monitor heated ground.

Workshop Score: 1.00 (YELL)

Current Monitoring: Nineteen years of chloride flux data exists for Yellowstone's major rivers-the Fall, Madison, Snake and Yellowstone. The YVO is active in chloride flux measurements (see work by Friedman and Norton). These measurements are carried out by the NPS (contact: Steve Miller). In the early days of remote sensing, Haze (1971) estimated heat flow and geothermal resources. In 2002, Watson and others used Landsat 7 sensors to estimate ground that was snow-free or minimal snow cover due to thermal activity. In 2002, thermal airborne sensors were flown over the Mammoth-Norris corridor. Many ongoing efforts by the USGS and USGS-YVO include monitoring data such as heat flow.

Relative Cost of Monitoring: $

Comments:

- Costs that can possibly be subsidized: Much interagency collaboration is possible, especially with the USGS.

Technical Note Author: Anne Schrag

SOIL STRUCTURE AND STABILITY (INCLUDING CRYPTOGAMIC CRUSTS)

What is this vital sign and why is it important?: Soil structure and stability is the physical, chemical and biological characterization of soils within the GRYN and particularly within the boundaries of BICA where cryptogamic crusts represent the majority of the living ground cover. This vital sign is quantified by calculating one or more physical, chemical or biological properties that are sensitive to change. Soil is made of rock fragments (some microscopic), decaying organic matter, water and air and is an environmental factor that governs many natural community relationships (for example, the soil-vegetation-wildlife relationship). Factors affecting soil formation include parent material, climate, groundwater, microbiotic species, physiography, drainage and time. Heavily influenced by its use and management, the structure, function and stability of soil and its associated foodwebs have been suggested as prime indicators of ecosystem health (Foissner 1986). Measurement of erosion, disrupted soil processes, decreased bacterial or fungal activity and biomass, changes in the ratio of fungal to bacterial biomass, decreases in the number or diversity of protozoa, and a change in nematode community structure can serve to indicate a problem long before natural vegetation is lost and the direction of vegetative succession is ultimately altered. Soil and foodweb structure damage often result in sites that cannot be regenerated, even with years of effort (Harper and Marble 1988). Especially in the arid environs and cold deserts that are found in BICA, cryptobiotic soil crusts (consisting of soil cyanobacteria, lichens and mosses) often represent the majority of the local living ground cover, microscopically increase the stability of otherwise easily eroded soils, increase water infiltration and increase fertility where essential nutrients such as nitrogen and carbon are limited (Williams et al. 1995). Many soils in these areas are thin and easily removed; cyanobacterial filaments, lichens and mosses are brittle when dry and easily destroyed when subjected to activities such as human or ungulate trampling or vehicular traffic (Belnap and Gardner 1993). Small amounts of erosion can have profound consequences for ecosystem dynamics and, as crust organisms are only metabolically active when wet, re-establishment time is slow in arid systems. While cyanobacteria are mobile, and can often move up through disturbed sediments to reach needed light levels for photosynthesis, lichens and mosses are incapable of such movement, have extremely slow colonization and growth rates and often die as a result. Previously stable areas can become moving sand dunes in a matter of only a few years with continued disturbance. Because soils take thousands of years to form in arid areas such as in BICA, accelerated soil loss due to non-native ungulate grazing and agriculture may be considered an irreversible loss (Belnap 1995).

Proposed Metric: Soil class, texture, HM-% (percent humic matter), w/v (weight/volume), CEC (cation exchange capacity), BS-% (the base saturation percent is an expression of the portion of the cation exchange capacity [CEC] that is occupied by nutrient cations, principally calcium, magnesium, and potassium), Ac (extractable acidity), pH, P-I and K-I (index values representing the nutrient availability of phosphorus and potassium to plants), Ca% and Mg% (the percent of cation exchange capacity that is occupied by calcium and magnesium), Mn-I, Zn-I and Cu-I, salts, electrical conductivity (E.C. x 10^3), exchangeable sodium, nitrate nitrogen, bicarbonate phosphorus, soluble potassium, DTPA extractable iron, ratio of total fungal to total bacterial biomass, biomass of total fungi, biomass of active fungi, numbers of total bacteria, biomass of active bacteria, protozoan numbers, nematode numbers and community structure, VAM (Vesicular-arbuscular mycorrhizal) spore numbers and percent VAM colonization.

VSM Workshop Score: 0.47 (GRYN)

Current Monitoring: Very little soil monitoring, outside of thermal features in YELL, occurs in the parks of the GRYN; however, each of the parks has had some soil inventory work.

Relative Annual Cost of Monitoring: Entirely variable depending on the initial amount of inventory that must be done and what kinds of laboratory/taxonomic work must be done. Basic index soils tests to the highly specialized tests range from approximately $10.00 to $300.00 per sample. This does not include field work or personnel costs.

Comments:
Direct costs to the GRYN: While seasonal employees may be trained to conduct physical sampling and some on-site measurements, there may be significant costs associated with contracted laboratory and taxonomic efforts.
Costs that can possibly be subsidized: There are great possibilities of interagency cooperation, especially with the NRCS. As the NRCS, BLM and USGS are already active in the field, it would be possible to piggy-back onto their programs to attain samples and analysis.

Technical Note Author: Laura Gianakos

STREAM SEDIMENT TRANSPORT

What is this vital sign and why is it important?: "Knowledge of the erosion, transport, and deposition of sediment relative to land surface, streams, reservoirs, and other bodies of water is extremely important to those involved in the management of water and land resources (Edwards and Glysson 1999)." A complete understanding of hydro geomorphologic processes associated with sediment requires the measurement of suspended and bed sediments in a wide range of hydrologic environments. Sediment data is entirely necessary to evaluate sediment yield with respect to background environmental conditions (geology, soils, climate, runoff, topography, ground cover, and size of drainage area), historic and current land uses, and erosion and deposition in channel systems. Additionally, and perhaps of greatest importance, especially in relation to the health of instream aquatic communities and riparian ecosystems, is the understanding of the temporal distribution of sediment concentration, size characteristics, and transport rates, as well as the relations between sediment chemistry and water quality. There are threshold concentrations, especially for suspended sediments, above which there are high probabilities of adverse effects on aquatic life from sediment contamination. The sediment sampling method and frequency of collection will be dictated by the hydrologic and sediment characteristics of the waterbodies to be sampled in the GRYN (which will vary greatly), the required accuracy of the data, the funds available, and the proposed use of those data collected.

Proposed metric: Load (discharge, tonnes/year), yield (tonnes/km^2/year), mg/L, NTU, etc. The estimation of suspended load by sampling is relatively simple, but bedload is difficult to sample and is rarely monitored, even though its movement is critical to stream health.

VSM Workshop Score: 0.95 (GRYN)

HUC Units Occupied: All units in GRYN

Current Monitoring: USGS NAWQA, watershed studies, WYDEQ, MTDEQ, Hydrology/water and river agencies, departments of highways (at bridge crossings), geological surveys. Each GRYN park currently has active at least one NAWQA station at which sediment monitoring is conducted (Bighorn River, Soda Butte, and Snake River). There are also permanent NAWQA sediment gauging stations both upstream and downstream of Bighorn Canyon, downstream of Yellowstone, and downstream, in the Columbia River Basin, of Grand Teton.

Relative Annual Cost of Monitoring: $ (per site). One way or another, your labor and laboratory costs are going to be approximately 2/3 to 3/4 of the total project cost. Here is a typical breakdown: Sample Collection and Laboratory Analysis: 71%, Data Interpretation: 18%, Program Coordination: 4%, Administration: 4%, Training: 3%. Assuming at least six samples per year. Approximate cost for sediment sampling outside of coring: $8,000-$20,000 (from small streams like Crooked Creek to larger streams like Snake or Yellowstone). This pricing is per watershed; at least one site per watershed in necessary, preferably at the mouth; costs are extremely variable depending on watershed characteristics and sampling locations.

Comments:

- Direct costs to the GRYN: Seasonal employees may be used but they need to be well trained. Equipment costs are not significant.
- Costs that can possibly be subsidized: There is great possibility of interagency cooperation with the USGS and the USFS. Travel costs will depend on who does the work.

Technical Note Author: Laura Gianakos

LAND-COVER CLASSIFICATION

What is this vital sign and why is it important?: Land-cover classification is the identification and mapping of the different land-cover types, or vegetation classes, that exist on the Earth's surface. The most time- and cost-efficient method of mapping land cover is by using satellite images from satellites such as Landsat 5, Landsat 7 and Terra, which capture infrared wavelengths that allow for distinction between different vegetation types. By using this information, it is possible to monitor land-use change, habitat fragmentation and changes in vegetation types. (Please see the *Land-use change and habitat fragmentation technical note* for more information.) These changes have cascading effects on animal species, water resources and soil structure, as well as being able to give information on possible changes in climate.

Proposed Metric: Using differences in infrared wavelengths emitted by vegetation, it is possible to classify land cover using Landsat 5, Landsat 7 or Terra images, eliminating costly groundwork and, therefore, allowing the parks to follow changes in vegetation cover.

Workshop Score: NEW Vital sign (renamed from landscape heterogeneity; 0.55 [BICA]; 0.65 [YELL]; 0.75 [GRTE])

Current Monitoring: NASA is currently flies these satellites and collects land-cover classification data. Many other agencies also use these data.

Relative Cost of Monitoring: $$-$$$ for data analysis, management and reporting

Comments:

- Direct costs: The full scope of this project cannot be funded by the GRYN.
- Costs that can possibly be subsidized: Many collaborations with other agencies are both possible and necessary in order to collect the data for this monitoring.

Technical Note Author: Anne Schrag

LAND-USE CHANGE AND HABITAT FRAGMENTATION

What is this vital sign and why is it important?: Land-use change occurs when humans decide to change their use of areas for a purpose different than that which was previously intended. For the purposes of this indictor, land-use change refers to both changes within and outside of National Park Service boundaries. Fragmentation is the process that occurs when a habitat is subdivided either by a natural disturbance or by human activities, including, in part, urban and suburban development, roads, farmlands and railroads (Varona 1999). Therefore, it can be concluded that land-use change causes habitat fragmentation. This indicator has been recognized as a *core national indicator* in the *State of the Nation's Ecosystems Report* (Heinz 2002). According to the Heinz report (2002), the shape and extent of the landscape is directly linked to the condition of wildlife habitat, the ability of the landscape to filter sediment and contaminants from runoff and the value of solitude and recreation for humans. In fact, according to Heinz (2002), "a recent review of threats to imperiled species in the U.S. found that 85% of all imperiled species were threatened by habitat degradation or loss (including 92% of vertebrates, 87% of invertebrates and 81% of plants)." Not only does this indicator enjoy widespread support as a defining characteristic of ecosystem health, but it also spans the ecosystem types, from forests to grasslands to shrublands to urban/suburban areas. Land-use change causes dramatic alterations to vegetative cover, biodiversity and biogeochemical cycles. Meanwhile, the reduction of once-continuous wildlands into smaller patches creates fragmented habitat that, when reduced to a critical threshold level, becomes more susceptible to species loss, non-native species invasion and overall deterioration. In addition to the loss of species, fragmented habitats create "edges" that facilitate the invasion of non-native species, thus reducing the quality of the habitat. The effects of fragmentation can affect species in two main ways: through loss of adequate habitat and/or through increased contact with humans, vehicles or predators. Many sensitive species, including many of the "charismatic" large mammals, cannot survive in moderately to highly fragmented areas. Because these animals need extremely large home ranges, the land-use patterns outside the park are especially critical to their survival. While relatively insignificant land-use changes (i.e. modest fragmentation in a large, intact area) may not cause immediate and direct deterioration of the habitat, the cumulative effects of many such events can cause permanent, catastrophic changes (Heinz 2002).

Proposed Metric: Remote-sensing data are highly useful for determining the extent of land-use change and habitat fragmentation. Many of the data already exist; however, suitable analytical methods have not yet been developed. Analyses on forest cover have used the USGS's National Land Cover Dataset, a 30-meter-resolution remote-sensing dataset (Vogelmann et al. 2001). Possible analysis techniques include the "moving window" technique, described in Heinz (2002). NASA's Land Cover Land Use Change Program should be of great use to the GRYN.

Workshop Score: 1.00 (GRYN)

Current Monitoring: NASA Land Cover Land Use Change (LCLUC) Program, NPS GIS Program, USGS National Land Cover Characterization Project, USFS Remote Sensing Applications Center, USFWS GIS, as well as numerous non-governmental agencies and academic institutions

Relative Cost of Monitoring: $-$$ for analysis of current datasets

Comments:

- Direct costs: the full extent of the monitoring (i.e. mapping, etc.) probably cannot be funded by the GRYN
- Costs that can possibly be subsidized: Many opportunities for collaboration with current monitoring are possible. The GRYN can be most effective in creating tools for analyzing current datasets.

Technical Note Author: Anne Schrag

LEVELS OF BACKCOUNTRY DAY USE, LEVELS OF BACKCOUNTRY OVERNIGHT USE, VISITOR USE LEVELS

(combined technical note for three separate vital signs)

What is this vital sign and why is it important?: The level of backcountry day use is the number of individuals who use backcountry areas within park boundaries but do not stay overnight. (This measurement is not applicable to BICA due to low levels of backcountry use and lack of backcountry permitting.) The level of backcountry overnight use is the number of individuals who use backcountry areas within park boundaries and do stay overnight. Visitor use levels refer to the total number of visitors using areas within park boundaries. Many times this information also includes visitor satisfaction data. Data about visitor use is important because of the driving force humans have on ecosystems. Not only are total numbers of visitors important in understanding overall usage of park resources, but understanding the trends in visitor use (i.e. higher numbers in winter and summer in YELL) can aid managers in minimizing the impacts of humans on sensitive animals and ecosystems.

Proposed Metric: Backcountry day use: This measurement is difficult and may involve the use of site-specific measurements or calibrated trailhead registers. Backcountry overnight use: This measurement can be made by using the number of backcountry permits sold. Visitor use levels: These data are generally collected through surveys as the number of people visiting the park per day, generally by car surveys. Other than pure numbers of people visiting, May workshop participants were also interested in the following measurements: number of winter recreationalists in YELL and GRTE (including snowmobiles, backcountry skiers, etc.), motorized recreation on Bighorn Lake in BICA, expansion of user-created trails in off-trail areas in GRTE, number of boaters on Yellowstone and Lewis Lakes in YELL.

Workshop Score: Backcountry day use: 0.75 (GRTE and YELL); Backcountry overnight use: 0.75 (GRTE and YELL); Visitor use levels: 0.52 (GRYN)

Current Monitoring: Backcountry overnight use and overall visitor use are already being monitored by YELL. Backcountry overnight use is being monitored by GRTE through backcountry permitting.

Relative Cost of Monitoring: $

Comments:

- Direct costs: Some additional surveys may be required to fully understand the impacts of visitor use in specific areas of the parks during different times of the year.
- Costs that can possibly be subsidized: The GRYN can make use of already existing data from the parks.

Technical Note Author: Anne Schrag

OVERSNOW VEHICLE EMISSIONS AND EFFECTS

What is this vital sign and why is it important?: Oversnow vehicle emissions and effects refers to the chemical deposition of particles and gases from snowmobile exhaust into snowpacks. Local sources of air pollution, such as snowmobile exhaust, can result in greater loadings of organics, nitrogen and sulfur species to snowpacks (Ingersoll 1999). Melting of contaminated snowpacks can result in changes to soil processes and alterations in surface water chemistry, which can, in turn, affect aquatic biota in high elevation lakes and streams. Oversnow emissions to the air can affect human health, via inhalation of carbon monoxide and volatile organic compounds.

Proposed Metric: Snowpack chemistry (concentrations of organic and inorganic compounds) is used as an indicator of snowmobile emissions and is frequently expressed as atmospheric loading in kg/ha/yr. If carbon monoxide is a concern relative to human health risk, then the concentration per cubic meter of air is the correct metric.

VSM Workshop Score: 1.00 (GRTE and YELL)

Current Monitoring: USGS Synoptic Snow Survey network (NPS-ARD 2002) has sample locations in both GRTE (2) and YELL (4) to collect total integrated snowpack samples at maximum accumulation. YELL monitors as part of the Winter Use Record of Decision. There has been some ambient air quality monitoring at entrance stations for carbon monoxide.

Relative Annual Cost of Monitoring: $ (for annual snowpack sampling and analysis)

Comments:

- Direct costs:
  - Cost of approximately $4000/site
  - GRTE and YELL will need to provide biotechnicians to assist USGS with snow collection during one week per year
- Costs that can possibly be subsidized:
  - USGS-WRD can provide some in-kind support
  - Partnerships with NPS-ARD and USGS-WRD
  - NPS-ARD contributes annually to the chemical analysis

Technical Note Author: Susan O'Ney

SOUNDSCAPES

TBA

AMPHIBIAN OCCURRENCE

What is this vital sign and why is it important? This vital sign indicates amphibian population status and trends. It is quantified by calculating the proportion of wetland sites occupied by amphibians per water catchment. Amphibians are important functional components of many aquatic, wetland, and riparian ecosystems, serving roles as herbivores, predators, prey, hosts, transporters of nutrients and energy, and as biomass. Amphibians are good candidates for the Greater Yellowstone monitoring program for several reasons:

- A variety of environmental variables / stressors may influence site occupancy, including habitat alteration, weather, pollutants, parasites, pathogens, and introduced species.
- Some amphibian populations appear to have declined over the past 50 years in the Greater Yellowstone Area, including Western Toads (*Bufo boreas*) and Northern Leopard Frogs (*Rana pipiens*). Both of these species are considered sensitive species by the BLM and Forest Service and are Wyoming Species of Special Concern (Wyoming Natural Diversity Database, 15 July 2002)
- Many species of amphibians have a relatively high visibility because of advertisement calls, breeding congregations, and relatively long larval stages.
- Several additional amphibian response variables exist (e.g., spatial distribution, malformations, die-offs, disease, species richness) that, if needed, can be added relatively easily to the field surveys used to determine site occupancy. Amphibian site occupancy information also can be added to data from other taxa to calculate Biointegrity Indices.
- Rigorous study designs and statistical analyses have or are being developed for amphibian monitoring (see next section).
- Monitoring protocols are relatively well developed for pond breeding amphibians.
- A national program for monitoring amphibian populations has been in place since 2000 (the USGS Amphibian Research and Monitoring Initiative [ARMI]). {http://edc2.usgs.gov/armi/}
    - The ARMI program has focused on Department of Interior Lands, especially national parks, including Yellowstone and Grand Teton National Parks.
    - The Greater Yellowstone Area is the middle portion of an ARMI study of a cline in amphibian population declines from Glacier NP (little or no decline) to Rocky Mtn. NP (extreme declines)
    - The USGS ARMI funds a pathologist at the National Wildlife Health Center in Madison, Wisconsin who is available to examine specimens from amphibian die-offs. Analysis of over 60 Greater Yellowstone amphibian specimens from the last 3 years has revealed the existence of two important amphibian pathogens/diseases: *Ranavirus* and chytrid fungus.
    - An ARMI supported environmental stressors project is now being developed.

Proposed Metric: The actual response variable for quantifying amphibian occurrence is the **proportion of area** or **sites occupied (PAO).** For a detailed description of PAO, see Mackenzie et al. 2002. The use of PAO rather than abundance makes it feasible to monitor many amphibian populations over a broad spatial scale. The basic idea is to survey for amphibians, as comprehensively as feasible, all wetland sites within a defined area (in this case water catchments equivalent to 7th level hydrological units). A "naïve" occupancy estimate is

calculated by dividing the number of sites at which a species is present or breeding by the total number of wetland sites surveyed. Some sites are resurveyed within a short time period to determine species detectabilities. For example, if two visits are typically required to determine that a species occurs at sites known to be occupied by that species, the detectability is 0.5 or 50%. The detectability estimates are then used to adjust the "naïve" occupancy estimates. All of these calculations can be done with the program PRESENCE that was developed by the USGS. These PAO estimates provide an indication of the status of each species per watershed. PAO estimates from the catchments (which were selected with a stratified / random design) can then be combined to provide an indication of amphibian species status within each park and for the entire study area. Changes in PAO over time will be used to assess amphibian population trends.

Workshop Score: 1.00 (GRYN)

Current Monitoring: Historical amphibian occurrence, distribution, and/or population data were gathered by Charles Carpenter (New York Zoological Society) and Frederick Turner (University of California, Berkeley) in Grand Teton and Yellowstone National Parks, respectively. In 1991, Charles Peterson (Idaho State University), Edward Koch (USFWS), and Stephen Corn (then USFWS), established a 10-site amphibian monitoring program in Yellowstone and Grand Teton National Parks. The Herpetology Laboratory at Idaho State University has conducted the monitoring of these 10 sites since 1991 at varying levels of effort, depending on the funding available. The National Park Service and University of Wyoming initially funded this program and have supported it in a variety of ways over the past 12 years. For example, Grand Teton National Park personnel annually survey two amphibian sites in the park. In 2000 and 2001, the stratified-random amphibian surveys of catchments within Yellowstone and Grand Teton National Park were initiated with funding from the USGS ARMI project and the NPS Inventory and Monitoring program. These surveys are conducted by the ISU Herpetology Laboratory and are part of the National USGS ARMI program. For further information about the USGS ARMI program, visit the following website: {http://edc2.usgs.gov/armi/}. Dr. Stephen Corn (USGS BRD, Steve_Corn@usgs.gov) is the primary contact person. For 2002 and 2003, most of the funding for the amphibian monitoring in the GYE has been obtained from annual grants from USGS research competitions. For a summary of recent monitoring efforts, see: Patla, D.A. and C.R. Peterson. 2003. Amphibian and Reptile Inventory and Monitoring: Greater Yellowstone Network Grand Teton and Yellowstone National Parks. 2002 Progress Report.

Relative Annual Cost of Monitoring: For the past 2 years, the annual cost of the amphibian-monitoring program in the GYE has been about $60,000. To continue the program at the current level of effort would require NPS funding in the range of $25,001-$50,000.

Comments:

- Direct costs to the GRYN
    - type of employee needed to monitor (professional vs. seasonal)
        - 1 coordinator for 8 months per year
        - 4 seasonal technicians for 2 months each year.
    - All of the needed equipment is already owned by ISU but some of it will need to be replaced or upgraded in the future.

        - 2 handheld GPS units ($300 each)
        - 2 digital cameras ($400 each)
        - 2 Personal Data Assistants (PDAs) – ($200 each)
        - 1 Notebook PC ($1,000)
        - 3 conductivity and 3 pH meters ($100 each)
    - ease of species identification
        - Employee will need to be trained in species identification. It takes about 3 days to learn how to conduct the surveys, including species identification. The cost of the training is only the salaries / wages of the coordinator and technicians.
- Costs that can possibly be subsidized
    - USGS BRD ARMI has funded ISU amphibian inventory and monitoring efforts since 2000. Although it is unlikely that they will continue to fund monitoring in the Greater Yellowstone at previous levels, it is likely that they would continue to partially fund monitoring if the costs were shared with the National Park Service. The USFWS has funded amphibian inventory and monitoring at the National Elk Refuge over the past 3 years. The potential for collaborating with the USDA Forest Service needs to be pursued. For example, the ISU Herpetology Laboratory is repeating amphibian surveys every decade to detect changes in amphibian population status for the Caribou-Targhee National Forest.
    - The coordinator and seasonal technicians currently use their own vehicles and are reimbursed for travel costs. They rent housing in the Utah dorm at Lake from the NPS.
    - Charles R. Peterson, Professor of Zoology in the Department of Biological Sciences at Idaho State University and the Curator of Herpetology at the Idaho Museum of Natural History, currently helps oversee the amphibian-monitoring program for no additional cost except travel expenses. His involvement currently includes assisting with project planning, proposal, report, and paper writing, technician training, data analysis, and attending scientific meetings to report the results of the inventory and monitoring studies.

Technical Note Author: Chuck Peterson

BEAVER PRESENCE AND DISTRIBUTION

What is this vital sign and why is it important?: Beaver presence refers to the presence or absence of beaver at selected sites to be re-sampled every 2-5 years, while beaver distribution refers to locations of known beaver activity across park landscapes. "Beaver produce one kind of wetland within the GRYN that is associated with dams, ponds and elevated water tables. The absence of beaver and these types of wetlands has reduced the diversity of wetlands and ecosystem types within the GRYN area. Consequently, biodiversity in valleys and along streams where beaver activity once occurred has declined. Beaver abundance tends to be cyclical, but some causes for these cycles may be related to human influence as well as changes in population of competitors for woody plants, predators and climate. There appears to be a resurgence of beaver in parts of the GRYN area. Although in many places with higher density human population the return of beaver is not welcome, within the natural areas of the GRYN region return of beaver is a sign of improving health of the landscape. For this reason, use of beaver population as a vital sign may allow long-term evaluation of landscape health within those areas of the GRYN where beaver can occur and develop associated wetlands" (Patten 2003).

Proposed Metric: All beaver locations within the GRYN should be mapped (GIS recorded). This can be done by a combination of remote sensing and ground truthing. A representative number of beaver sites should be visited to determine the presence or absence at each site (with re-sampling every 2-5 years) and the distribution should be mapped.

Workshop Score: 1.00 (GRYN)

Current Monitoring: Beaver presence/absence data collection is ongoing in YELL (please also reference: Smith, D.W. 1998. Beaver Survey in Yellowstone National Park. Mammoth, WY. YCR-NR-93-3). The dataset consists of beaver locations including UTM's, location descriptions and activity, as well as ground truthing by foot and horseback (contact: Doug Smith). Some monitoring of beaver damage within BICA has occurred.

Relative Cost of Monitoring: $

Comments:

- Direct costs: The GRYN can probably be most useful in helping to achieve the most beneficial sampling design and data-analysis techniques for the datasets already being collected.
- Costs that can possibly be subsidized: The GRYN can greatly benefit from the data already being collected by YELL.

Technical Note Author: Anne Schrag

BELOWGROUND BIOTA AND PROCESSES

TBA

BROWSE EFFECTS ON RIPARIAN WOODY VEGETATION

What is this vital sign and why is it important?: Browse effects on riparian woody vegetation are the impacts of ungulate grazing on riparian species, such as willow and aspen. Riparian areas are the narrow strips of land that border many bodies of water and usually support diverse biological communities, which help to reduce flooding and filter runoff (Heinz 2002). According to Heinz (2002), about 60% of wetlands (whose status is known) are imperiled, including an imperilment rate of greater than 50% in all regions except the Northeast. Riparian ecosystems offer many ecological services and functions, closely related to the structure, composition and abundance of the riparian vegetation and its location within the landscape. "One important function of riparian systems is that of habitat for a wide variety of organisms. In semi-arid regions over 75% of animals species use riparian ecosystems for all or part of their life cycle (Brinson et al. 1981; Kondolf et al. 1996)...Grazing and altered hydrology often favor the survival of introduced species (e.g., tamarisk) and allow thriving non-natives to displace native species. Herbaceous non-natives are also becoming prevalent in many riparian areas, creating dense ground cover that competes with native species, increases fuel for fires, and may be enhanced by grazing (Stromberg and Chew, 1997). Riparian communities, especially in the YELL Northern Range, are greatly influenced by ungulate herbivory. GRTE has altered hydrology of the Snake River as a major issue, but it also has herbivory problems along some streams within the park" (Patten 2003). Ungulate herbivory is also affecting the riparian areas in BICA.

Proposed Metric: Wildlife exclosures in high- and low-use areas across different riparian vegetation types with plant cover sampling (based upon McEachern et al. 2001)

Workshop Score: 0.92 (GRYN)

Current Monitoring: Monitoring has occurred in YELL's Northern Range in various forms, including: monitoring wolf populations and their effects on elk and, consequently, aspen regeneration (contact: Bill Ripple); monitoring elk effects on non-woody plants (contact: Bob Crabtree); monitoring the trophic cascade of wolves on riparian vegetation (contact: Francis Singer); trophic cascade research by park employees and led by outside PI ongoing but seeking additional funding (contact: Glenn Plumb, Doug Smith)

Relative Cost of Monitoring: $

Comments:

- Direct costs: Twenty weeks for a two-person team; plus eight weeks of data analysis by one person (McEachern et al. 2001)
- Costs that can possibly be subsidized: Although studies have been conducted in YELL's Northern Range, long-term monitoring is needed and funds are being sought by all three park units; therefore, subsidized costs are probably limited to collaborations with any ongoing studies.

Technical Note Author: Anne Schrag

COMMUNITIES OF CONCERN
(RIPARIAN, SHRUB-STEPPE, ASPEN AND ALPINE COMMUNITIES)

What is this vital sign and why is it important?: Vegetation composition and structure in terrestrial communities of concern refers to the species make-up of areas of concern in the GRYN, including shrub-steppe, riparian, aspen and alpine areas. However, in some communities, vertebrate or invertebrate species may be a better indicator of overall health than the vegetation composition. For example, in riparian communities avian species are known as good indicators of ecosystem health and, therefore, it may be beneficial to measure bird species presence in these systems. Riparian communities throughout the GRYN are experiencing overgrazing, altered hydrology and invasion of exotic species. A decline in sage grouse populations is the major reason the sagebrush community is of concern, along with grazing pressure. Aspen communities are experiencing a decline throughout the GRYN due to a lack of regeneration by seed and pressure from ungulate grazing and climate change. Meanwhile, alpine communities are influenced by human trampling and livestock use. Although the threats to alpine cushion plant communities are not yet critical, degradation of these systems will cause a decrease in diversity; regrowth in alpine areas can take decades.

Proposed Metric: To measure this indicator, methods generally include belt transects and/or quadrat studies, including total species present and percent cover in relation to expected species present. However, in some cases (i.e. sage grouse and bird species in riparian areas), the indicator measured will be a vertebrate species or the soil structure (in alpine areas) of the ecosystem.

Workshop Score: NEW Vital Sign

Current Monitoring: Riparian: The EPA's Exposure Research Laboratory, Environmental Sciences Division, has used the USGS National Hydrography Dataset (NHD) in conjunction with remote-sensing data from the National Land Cover Dataset (NLCD), to classify land cover within 100 feet of streams and rivers. The NHD is available at http://nhd.usgs.gov. Shrub-steppe: Monitoring of grassland and shrubland communities inside and outside of wild ungulate exclosures has taken place in the Pryor Mountain Wild Horse Range (PMWHR) in BICA (contact: James Detling). Also, plant biomass and composition was recorded in the PMWHR (contact: Troy Gerhardt and John Gross). The distribution of grassland and shrubland communities in GRTE was recorded (contact: Darold Sabinske). Plant frequency in transects has been measured in the low winter range of the Northern Range of YELL (contact: Michael Coughenour). Vegetation classification through LANDSAT TM files at 30m resolution have been created for the western end of the GYA for mixed conifer, lodgepole pine, Douglas-fir, sage, grass, aspen, wet meadow, willow and clear-cut (contact: Roland Redmond). Grazing transects have been created in YELL to measure effects of Bighorn in Tom Miner Basin (contact: Kristin Legg). Research is occurring to determine the effects of grazing on aboveground and belowground grassland productivity in plots in YELL (contact: Doug Frank). Also see: Frank, D.A., and S.J. McNaughton. 1992. the ecology of plants, large mammalian herbivores, and drought in Yellowstone National Park. Ecology. 73(6):2043-2058 and Hadly-Barnosky, E.A. 1994. Grassland change over 2,000 years in Northern Yellowstone Park. Pp. 319 in plants and their environments: Proceedings of the First Biennial Scientific Conference on the

Greater Yellowstone Ecosystem, D. Despain ed. Tech. Rep, NPS/NRYELL/NRTR, denver, CO: U.S. Department of the Interior, National Park Service, Natural Resources Publication Office and Knight, D.H., G.P. Jones, Y. Akashi, and R.W. Myers. 1987. Vegetation ecology in the Bighorn Canyon National Recreation Area. Final Rept. To U.S. Natl. Pk. Serv. And Univ. of WY, Natl. Pk. Serv. Res. Ctr. Dept. Botany, Univ. of WY, Laramie. 114 pp.
Aspen: Aspen regeneration inside and outside of current wolf pack territories and comparisons with historic aspen recruitment are being measured in YELL (contact: William Ripple). Aspen regeneration, as a function of fire intensity, is being studied in YELL (contact: John Burger). Aspen mortality, possibly due to fungal infection or injury was investigated in GRTE (contact: J.H. Hart). Vegetation classification through LANDSAT TM files at 30m resolution have been created for the western end of the GYA for mixed conifer, lodgepole pine, Douglas-fir, sage, grass, aspen, wet meadow, willow and clear-cut (contact: Roland Redmond). A current study created permanent belt transects for long-term monitoring of aspen stands in YELL, as a function of elk and wolf interactions (contact: Doug Smith). Some trailside surveys of aspen and seedling exclosures on aspen have also been conducted in YELL (contact: William Romme). Some browsing effects on aspen due to unmanaged ungulate populations as compared with historic aspen communities was conducted in YELL (contact: C.E. Kay). many other works of the same nature can be found in the GRYN literature review.
Alpine: Some monitoring of the influence of goat populations on alpine vegetation has taken place in GRTE (contact: John Laundre). Some modeling of alpine vegetation changes due to climate change in the GYA have been performed (Romme and Turner). See also: Billings, W.D. (1989). Alpine Vegetation, in North American Terrestrial Vegetation, W.D. Billings and R.K. Peet, Editors. Paragon Books. p. 392-420. Most research or monitoring of alpine plan communities has focused on plant-animal interactions, vegetation classification or plant responses to fire, with animals and fire being the focal point of the research. No ongoing monitoring of alpine plant community structure and its interaction with climate change and human use is currently taking place.

Relative Cost of Monitoring: $-$$ for each community of concern

Comments:

- Direct costs: The GRYN should focus on data analysis of already existing datasets or adapting current monitoring to fit the needs of long-term monitoring.
- Costs that can possibly be subsidized: Many datasets are already available.

Technical Note Author: Anne Schrag

FIRE, FUELS AND CARBON STORAGE

What is this vital sign and why is it important?: Fire, fuels and carbon storage refers to the cyclical relationship between these three ecosystem components and their interrelated effects on each other. Fire is often described as a "keystone" process in Western forests. In fact, many species that comprise these forests are known to be dependent on fire for germination. The carbon that forest species intake to create cell walls that maintain their structure is released into the atmosphere when the species, also known as fuels in relation to fire, burn. This creates what is known as the carbon cycle. In addition to these natural processes, humans release carbon into the atmosphere through fossil fuel burning, making more carbon available for storage in fuels, increasing fuel loads (through increases in small fuels) and causing fires to burn hotter. Moreover, land-use change that results in cutting down large areas of forests releases carbon into the atmosphere, leading to an increase in greenhouse gases and climate change. Large-scale modeling of the effect of fire on carbon storage and fuel loads, using remote sensing techniques, will allow for the creation of models that indicate the link between carbon levels, land-use change and climate change.

Proposed Metric: Remote sensing techniques can identify areas of carbon "sources" and "sinks", as well as identifying land-use change. Modeling is required to understand the interrelatedness of these processes. Academics, such as Steve Running (University of Montana) are involved in carbon cycling research.

Workshop Score: 0.92 (GRYN)

Current Monitoring: The following agencies are actively involved in carbon cycle research programs (however, not all have a fire and carbon cycle focus): U.S. Department of Energy, NASA, NOAA, NSF, USDA-ARS, USDA-Forest Service.

Relative Cost of Monitoring: $-$$ for analysis of current datasets, data management and reporting

Comments:

- Direct costs: The GRYN can probably only fund data analysis, as new remote sensing data is very costly.
- Costs that can possibly be subsidized: Many opportunities for collaboration with other agencies and academics working on carbon cycling are available.

Technical Note Author: Anne Schrag

LAND BIRD DISTRIBUTION AND ABUNDANCE

What is this vital sign and why is it important?: Most bird species, other than those selected as "sensitive" are included in this vital sign, such as colony nesting birds, song birds and migratory birds. Birds are important to ecosystem function through eating insects, caching seeds and pollinating plants. Many times, as is the case with migratory bird species, birds are absent in areas where quality habitat is rare. Their presence or absence is so significant, in fact, that such varied agencies as the USGS-BRD, FWS and Audobon Society conduct annual surveys of their distribution and abundance across the US.

Proposed Metric: They should be monitored closely for abundance and distribution using distance sampling (line transect or variable circular plot [VCP] sampling or double-observer [DO] methods) and nest productivity using constant-effort mist netting and banding (such as that used by the MAPS [Monitoring Avian Productivity and Survival] program) (Fancy 2003).

Workshop Score: NEW Vital Sign

Current Monitoring: Some monitoring has occurred in YELL, such as monitoring of nesting success of select nesting, migratory and breeding birds (contact: Terry McEneaney). GRTE does a Colter Bay breeding bird survey each year and a great blue heron survey and has historical data on neotropical migratory birds.

Relative Cost of Monitoring: $-$$

Comments:

- Direct costs: The GRYN will most likely need to provide additional employees in order to expand the monitoring ongoing in YELL to the necessary level and to add monitoring in GRTE and BICA.
- Costs that can possibly be subsidized: The GRYN will need to make use of existing data from the USGS, NPS and USFWS.

Technical Note Author: Anne Schrag

LARGE CARNIVORE POPULATION PRESENCE AND DISTRIBUTION

What is this vital sign and why is it important?: Large carnivore abundance refers to the number of large carnivores at selected sites to be resampled, while large carnivore distribution refers to locations of the large carnivores across park landscapes. Abundance data are initially collected at chosen sites throughout the parks and resampled, and distribution measurements should include GPS data points of where abundance data were collected to show a landscape distribution of large carnivores. It is well known that the most sensitive wildlife species are often those that have specific habitat requirements or require large amounts of area; therefore, as top predators and highly mobile animals with large home ranges, large mammalian carnivores are particularly susceptible to the impacts of habitat fragmentation (Spowart and Samson 1986). Large carnivores are umbrella species, flagship species, habitat quality indicators and wilderness quality indicators. Though often habitat generalists, large carnivores are important focal species in determining areas of contiguous wildlands in a heterogeneous landscape. Carnivore populations, their guilds and the trophic levels they affect, are highly susceptible to the constraints imposed by barriers such as roads, park infrastructure, urbanization and other human processes that destroy and alter habitat, introduce pollutants and exotic plants and animals, alter hydrologic regimes and fragment remaining natural areas. For these reasons, and the fact that the GRYN has one of the highest large-mammal prey bases of any large North American wildland ecosystem, it is essential to continue monitoring these species in the GRYN. Given the complement of predators in the GRYN, and the relatively slow rate of growth of many predator/scavenger populations, it is possible that some predator populations are still recovering from the combined effects of predator control programs earlier in the century and the ungulate control practiced throughout the 1960's (YNP 1997). This possibility, plus the recent reintroduction of wolves, seem to warrant further investigations of predator ecology and predator-prey relationships, which include the complex interactions caused by the presence of meso-carnivores (the ecology of which remains virtually unknown at this time), surplus killing, additive predation between predators, enhancement and interference between predator species and switchover between prey species (Boutin 1992). Additionally, because of the diverse ways carnivores exploit their environments, it is important that unique habitat preferences of individual species are considered in the study of carnivores.

Proposed Metric: Presence, relative density, absolute density, relative abundance by habitat area, and demographic parameters, distribution, spatial ecology, movement patterns, survival and mortality.

VSM Workshop Score: 0.60 (GRYN)

Current Monitoring: Both YELL and GRTE biological staff are active in large carnivore management and monitoring. Current activities at YELL include: wolf-lion-bear interactions (Dr. Robert Garrot, MSU, (406) 994-2270), wildlife disease monitoring, cougar-wolf relationships (Hornocker Institute), lynx presence and distribution, spring carcass surveys at Firehole, Norris, Heart Lake, and the Northern Range, roadkill studies, rare mammal monitoring, wolf population and distribution monitoring, genetic study of wolves, grizzly bear population monitoring, human-bear conflict report, grizzly & black bear genetic diversity, bear management plan implementation, bear attractant storage, IGBST activities, army cutworm moth survey,

mountain lion management, Natural History Field Observation cards. There are many other universities and state and federal game and agricultural management agencies involved in carnivore management/monitoring (parks and the Montana, Idaho and Wyoming Departments of Fish, Wildlife and Parks (or similar agencies)). Another contact is Steve Primm, M.A., who is the field director of the Gravelly Range Grizzly Project and author of "Predator Conservation in the Greater Yellowstone Ecosystem".

Relative Annual Cost of Monitoring: As such monitoring is already occurring in YELL and GRTE and to a limited extent in BICA, costs of monitoring to the GRYN should be minimal. $.

Comments:

- Direct costs to the GRYN: Direct costs to the GRYN will be in the form of salaried time of the data manager for the network. Substantial work will be needed from this position to remain apprised of current datasets and their analysis.
- Costs that can possibly be subsidized: As there are not many specific direct costs to the network, it is difficult to define costs that may be subsidized. There will be substantial data management needed and it is possible that students at MSU could assist with this for free or in exchange for credit hours.

Technical Note Author: Laura Gianakos

MESO CARNIVORE POPULATION PRESENCE AND DISTRIBUTION

What is this vital sign and why is it important?: Meso-carnivore population, presence and distribution is the population status and trends of small to mid-sized carnivores throughout the GRYN such as lynx, wolverine, fisher, marten, bobcat, Swift fox, and river otters. This vital sign is quantified by calculating the Presence/absence, relative abundance (density), and absolute abundance (density) of these species using lure stations with remote cameras, snow tracking transects and visual indices. The mammal species of concern in the West today are mostly meso-carnivores. Mid-sized forest carnivores, especially from the Mustelidae family, are umbrella, flagship, wilderness and habitat quality indicators, wide-ranging predators, habitat specialists, and dispersal limited species. Owing to their secretive behavior and the expense of studying small populations of wide-ranging mammals inhabiting remote wilderness, small carnivores have often been overlooked in biodiversity and conservation management studies (Bourne 1997). They are important barometers of ecosystem health, contributing to competition, resource partitioning and the overall structure of carnivore guilds. Even though predator loss has been shown to lead to biodiversity loss, very little is known about the numbers and ecology of meso carnivores (Spowart and Samson 1986). While conservationists have focused much attention on restoring wolves and grizzlies to the GRYN and northern Rockies, the midsized forest and basin carnivores (fisher, marten, wolverine, lynx, swift fox, and aquatic species such as the Yellowstone River otter) are becoming scarce and relegated to remote roadless areas and remaining pockets of old growth, primarily on public lands, due to logging, trapping, burgeoning development, water development, conversion of grasslands for agriculture, incidental poisoning by bait intended for wolves and coyotes, and poisoning of food sources such as prairie dogs and ground squirrels. Yet despite their extremely low numbers and shrinking habitat, many of these species, such as the wolverine and fisher, have been denied protection under the Endangered Species Act because of lack of scientific information.

Proposed Metric: Presence/absence, relative abundance (density), and absolute abundance (density) using lure stations with remote cameras, snow tracking transects and visual indices.

VSM Workshop Score: 0.60 (GRYN)

Current Monitoring: Both YELL and GRTE have very limited meso-carnivore monitoring; both are attempting to determine the status and distribution of lynx and wolverines so as to establish a baseline for future trend monitoring. Other meso-carnivore (Yellowstone River otter, marten, fisher, mountain lions, badger, skunk, weasel, fox, etc.) work has occurred at GRTE and YELL but has consisted primarily of inventory and research efforts that may eventually lead to monitoring recommendations. Other names: Bill Zielinski, USFS, Pacific Southwest Research Station, Arcata, CA. Wild Things Unlimited, founded by Steve Gehman and Betsy Robinson currently conducts programs and activities in the Yellowstone Ecosystem. The research program consists of the Rare Carnivore Surveys project, a 10-year study designed to gather needed information on the distributions and abundance of Yellowstone's three rarest mammalian carnivores: fisher, wolverine, and lynx. The Yellowstone to Yukon Initiative is a joint Canadian-US network of over 80 organizations, institutions, and foundations, plus individual scientists, conservationists, economists, and environmental advocates who have recognized both the

necessity and the advantages of coordinating their efforts transnationally, on a scale that mirrors the area they seek to conserve. Their area of focus includes the Rocky Mountains from the Grand Tetons (Wyoming) north to the Yukon border. Lastly, the Predator Conservation Alliance (PCA), founded in 1991, is dedicated to conserving, protecting, and restoring native predators and their habitats in the Northern Rockies and Northern Plains.

Relative Annual Cost of Monitoring: Depends upon the species chosen to monitor. Costs are widely variable. The greatest expense will be salaried time (over 50% of total budget). Per fiscal year, per watershed or subbasin chosen to survey/monitor, and with no matching dollars or in-kind donation of time or equipment, the cost will be approximately $70,000.

Comments:

- Direct costs to the GRYN: While species identification is easy, and seasonal employees may do the field work, overall monitoring may involve significant amounts of salaried time. Equipment costs should be minimal.
- Costs that can possibly be subsidized: There are good possibilities of interagency cooperation with state and federal wildlife management agencies as well as regional research groups and universities. MSU, UW, UM, USGS, USFWS, Montana Parks and Rec, Wyoming Game and Fish, USFS.

Technical Note Author: Laura Gianakos

NATIVE INSECT DIVERSITY AND DISTRIBUTION IN RIPARIAN AND MESIC MEADOWS

TBA

SELECTED SENSITIVE BIRD SPECIES ABUNDANCE, DISTRIBUTION AND PRODUCTIVITY

What is this vital sign and why is it important?: Selected sensitive bird species include, but are not limited to, trumpeter swans, harlequin ducks, loons, American dippers and kingfishers. These species have similar qualifying life histories and thus their role in tracking ecosystem habitat quality and availability is essential. By definition, sensitive species will likely be the first ones to respond to environmental perturbation and may therefore make good indicators. If the park populations represent populations that are critical to species survival, they should be monitored closely for declining trends, survivorship, nest success and productivity, response to management actions, loss of genetic diversity and loss of tradition and migratory behaviors. Many bird species rely on diverse habitats of high quality.

Proposed Metric: Abundance and distribution (for example, using helicopter transect surveys and ground-truthing) and nest productivity (for example, using constant-effort mist netting and banding such as used by the MAPS [Monitoring Avian Productivity and Survival] program).

Workshop Score: 0.87 (GRYN)

Current Monitoring: YELL has ongoing bird monitoring for the following species: bald eagles, loons, peregrine falcons, osprey, trumpeter swans and migratory birds (contact: Terry McEneaney) that generally include aerial surveys to monitor the number of active nests (or, in the case of migratory birds, a one day count).

Relative Cost of Monitoring: $-$$

Comments:

- Direct costs: The GRYN will most likely need to provide additional employees in order to expand the monitoring ongoing in YELL to the necessary level and to add monitoring in GRTE and BICA.
- Costs that can possibly be subsidized: The GRYN will need to make use of existing data from the USGS, NPS and USFWS.

Technical Note Author: Anne Schrag

UNGULATE POPULATION DISTRIBUTION AND ABUNDANCE

What is this vital sign and why is it important?: Ungulate abundance refers to the number of ungulates at selected sites to be resampled, while ungulate distribution refers to locations of the ungulates across park landscapes. Abundance data are initially collected at chosen sites throughout the parks and resampled, and distribution measurements should include GPS data points of where abundance data were collected to show a landscape distribution of ungulates. Wild ungulates are among the most prized wildlife groups and inventory and monitoring of wild ungulates and their habitat is one of the most important tasks of wildlife biologists. As ungulates, in general, are adaptable, regular monitoring is imperative; ungulates are relatively long-lived and response to habitat change may be apparent many years later (Boyd et. al. 1986). Environmental variability, therefore, has a fundamental effect on herbivore population dynamics. Alternately, wild ungulates can cause short-term ecological changes (via grazing, browsing, wallowing and trampling) such as altered biogeochemical cycles, increased erosion and enhancing opportunities for invasive plants. Alpine and arid areas are especially susceptible to such damage (Saether 1997). Additionally, there are species of ungulates, such as mountain goats, which do not appear in the paleontological, archeological or historical records of the GRYN, further complicating how much overlap and competition can be tolerated in an ecosystem where the NPS is mandated to preserve native species (YNP 1997). Predation, disease and hunting limit ungulate dynamics. Still, even though ungulates have been intensively managed, overall management techniques and understanding are still primitive (Boyd et al. 1986), and continued inventory and monitoring efforts are necessary for parks and the public to identify broad-scale issues and problems related to ungulate management.

Proposed Metric: Migration and movements, presence/absence, relative density or relative abundance, density (total counts, sample counts, ration methods, indirect methods), animal condition, population structure and productivity, behavioral indicators, recent browse intensity and longer term browse intensity. This is already being performed to some degree by the parks and the Montana, Idaho and Wyoming Departments of Fish, Wildlife and Parks (or similar agencies).

VSM Workshop Score: 0.78 (GRYN)

Current Monitoring: Much monitoring already occurs within YELL and GRTE and to a limited extent in BICA (wild horses, bighorn sheep). Typical activities and studies in YELL and GRTE (in conjunction with cooperators and researchers) include: elk-predator-herbivory interactions; the sustainability of grazing ecosystems (Dr. Doug Frank, Syracuse, 315-443-4529); bighorn sheep population monitoring; mountain goat population monitoring; Northern Range elk population monitoring; elk classification; bison population monitoring; recreationist conflicts; elk reduction; moose management; mule deer management; and pronghorn antelope monitoring and management. Multiple other agencies, universities, and research groups are involved with ungulate monitoring (Wyoming Game and Fish Department, Bureau of Land Management, etc.). Another contact is Harold Picton, Ph.D., emeritus professor of wildlife at Montana State University, who is currently involved in herbivore and carnivore studies as well as the history of wildlife management and is the author of "Plant Eaters of Yellowstone" and "The Bison of Yellowstone".

Relative Annual Cost of Monitoring: Much of this monitoring already occurs and should not represent a direct cost to the GRYN. $.

Comments:

- Direct costs to the GRYN: Direct costs to the GRYN will be the data managers' time and effort needed to stay apprised of studies and their analysis.
- Costs that can possibly be subsidized: There are great possibilities of interagency cooperation, especially with state game and fish agencies that may also provide scientific oversight.

Technical Note Author: Laura Gianakos

ALGAL SPECIES COMPOSITION AND BIOMASS

What is this vital sign and why is it important?: Algal species composition refers to the kinds of species present in a body of water, while algal biomass is the combined mass of these species. Certain species can indicate changes in the water column, such as increased nutrient input or water temperature. "On a fundamental level, the productivity and diversity of algae in a system is an indicator of its condition. Increased nutrients and changes to the food web (e.g. Carpenter et al. 1985) may change algal biomass, water clarity and species composition. Research in Yellowstone Lakes has shown that diatom species compositions predictably respond to slight changes in nutrients according to their physiology (Interlandi et al. 1999), and these changes in assemblages may be sensitive indicators to nutrient inputs and associated climate change (Kilham et al. 1996). Algal species in high-elevation lakes can also signal changes in nutrient concentrations (Wolfe et al. 2001)" (Hall 2003). Periphyton are useful indicators of environmental condition because they respond rapidly and are sensitive to a number of anthropogenic disturbances, including habitat destruction, contamination by nutrients, metals, herbicides, hydrocarbons and acidification. Benthic algae (periphyton or phytobenthos) are primary producers and an important foundation of many stream food webs. These organisms also stabilize substrata and serve as habitat for many other organisms. Because benthic algal assemblages are attached to substrate, their characteristics are affected by physical, chemical, and biological disturbances that occur in the stream reach during the time in which the assemblage developed. In addition, an increase in algal biomass can be the result of nutrient runoff or deposition and can lead to an increase in bacterial production (for algal decomposition), causing the depletion of available oxygen (Heinz 2002).

Proposed Metric: Chlorophyll a concentrations of algae in lakes. The three methods for determination of chlorophyll a in phytoplankton are: spectrophotometric, fluorometric and high-performance liquid chromatography (HPLC). Fluorometry is more sensitive than spectrophotometry requires less sample and can be used for in-vivo measurements. These optical methods can significantly under- or overestimate chlorophyll a concentration due to overlapping absorption and fluorescent bands (APHA 1992). Secchi disk measurements (a measure of water clarity). Algal (mostly diatoms and some cyanobacteria) assemblage structure.

Workshop Score: 0.95 (GRYN)

Current Monitoring: Some research has taken place in YELL to determine algal biomass in the ponds of the Lamar Valley (contact: Wendy Roberts).

Relative Cost of Monitoring:

Comments:

- Direct costs:
- Costs that can possibly be subsidized:.

Technical Note Author: Susan O'Ney

CONTINUOUS WATER TEMPERATURE

What is this vital sign and why is it important?: Temperature of both water and air is a key field measurement at all monitoring sites and is essential information to water data collection. Temperature is measured because rates of biological and chemical processes are strongly influenced by temperature and numerous aquatic organisms are dependent on certain temperature ranges for optimal health. For example, temperature is a key parameter in assessing the suitability of a water body (e.g. stream) for particular fish species and thus in determining its appropriate beneficial use. Because temporal variation in temperature can be significant, intermittent temperature monitoring (stations) can be problematic and use of continuous recording devices is a preferred means of eliminating these sampling problems (MacDonald et al. 1991).

Proposed Metric: All temperature measurements should be made and reported in units of degrees Celsius (ºC). All temperature measurements should be reported to the nearest 0.2 ºC when using a thermistor thermometer and to the nearest 0.5 ºC when using a liquid-in-liquid thermometer.

Workshop Score: 0.95 (GRYN)

Current Monitoring: YELL currently has 71+ *in situ* temperature loggers in place in various locations throughout the park. The USGS has one real-time temperature probe in GRTE at the Snake River at Moose.

Relative Annual Cost of Monitoring: $

Comments:

- Direct costs to the GRYN:
    - Field personnel should be experienced in the use of the water quality probes and should have become familiar with the manufacturers instructions for calibration and utilization of the specific equipment planned for use in the monitoring/sampling effort. Experience in equipment handling, calibration, and use/field deployment of the sondes/probes is best obtained through a combination of apprenticeship, vendor workshop training, and through testing of and gaining some familiarity with the equipment at the office prior to entering the field.
    - Cost of HOBO type data logger <$200 each; battery lasts up to 6 years.
    - *In situ* multi parameter probes $5-7,000 ea..
- Costs that can possibly be subsidized:
    - Continuous, real-time temperature monitoring can be added to existing USGS gauging stations for approximately $12,000/year (includes DO, conductivity and pH).

Technical Note Author: Susan O'Ney

E. COLI

What is this vital sign and why is it important?: *Escherichia coli* (*E. coli*) is one type of fecal bacteria that is used for predicting gastrointestinal illness in swimmers based on the density of the indicator organism in bathing and contact recreational waters. In BICA, the Shoshone River is listed as a 303d stream due to its high levels of *E. coli*. Fecal indicator bacteria are used to assess the quality of water because they are not typically disease causing, but are correlated to the presence of several waterborne disease-causing organisms (pathogens). The concentration of indicator bacteria (the term "indicator bacteria" is used synonymously with fecal indicator bacteria) is a measure of water safety for body contact recreation or for consumption. Wastes from warm-blooded animals contribute a variety of intestinal bacteria that are pathogenic to humans. The presence of *Escherichia coli (E. coli)* in water is direct evidence of fecal contamination from warm-blooded animals and indicates the possible presence of pathogens (Dufour 1977). The EPA estimates that no more than a geometric mean of 126 *E. coli* per 100 ml of fresh water should be present to be protect people from gastrointestinal illness.

Proposed Metric: The freshwater criterion for *E. coli* in bathing water is a geometric-mean concentration of 126 col/100 mL. (EPA 1986). For potable waters, the detection of 1 col/100 mL of *E. coli* warrant concern for public health.

VSM Workshop Score: 0.38 (BICA)

Current Monitoring: Selected backcountry and front-country streams of GRTE are being monitored for *E. coli* during the summer months, along with DNA source tracking to determine the mammalian source of the bacteria. There is currently no fecal monitoring program in place at BICA.

Relative Annual Cost of Monitoring: $

Comments:
Direct costs to the GRYN: All water quality data collectors should have had formal training and some period of field apprenticeship in order to correctly calibrate and operate field equipment, implement sampling procedures, and document the field protocols used and sampling results with the necessary metadata. The GRYN may choose to initiate monitoring with GRYN/Park staff or transition water quality monitoring responsibilities from contractors/cooperators or USGS personnel to permanent GRYN staff as the program evolves. Training and apprenticeship for Park Service technicians should be planned and budgeted prior to execution of monitoring activities by NPS staff. The USGS regularly offers a course entitled *Field Water Quality Methods for Groundwater and Surface Water* held at the USGS National Training Center in Denver, Colorado. NPS staff and cooperators may attend on a space-available basis. Some level of coordination or cooperative effort with the local USGS-NAWQA water resources office and other federal/state/local water quality district offices and monitoring organizations should also prove highly beneficial and allow for maximum use of limited monitoring resources.
Costs that can possibly be subsidized: Possible collaboration with state monitoring programs and USGS-NAWQA.

Technical Note Author: Susan O'Ney and Laura Gianakos

GROUNDWATER QUANTITY AND QUALITY

What is this vital sign and why is it important?: Groundwater quantity and quality refers to the groundwater level and chemistry (including contamination). Data collected in the monitoring of groundwater includes groundwater level and volume, pH, temperature, conductivity and trace organic compounds and metals (MT DEQ 1995). According to NOAA (2000), groundwater hydrology is "the branch of hydrology that specializes in groundwater, its occurrence and movements, its replenishment and depletion, the properties of rocks that control groundwater movement and storage, and the methods of investigation and utilization of groundwater." The American Institute of Hydrology lists groundwater hydrology as a basic hydrological measurement; monitoring is important in spatial and temporal comparisons, as well as the interpretation of overall water quality. In stream, spring, and wetland ecosystem structure and function, interactions between surface water and groundwater play an important role (Gibert et al. 1994). For example, the hyporheic zone (>10% stream water), lying underneath and adjacent to riverbeds and an important component of stream ecosystem metabolism, connects the stream and groundwater ecosystems. Subsurface flowpaths transport water and stream nutrient retention is determined by the extent of surface-groundwater exchange and subsurface chemical transformation rates. Similarly, riparian vegetation diversity is inextricably coupled to natural groundwater hydrologic processes and wetlands. In addition to improving water quality through filtering and helping to maintain stream flow during dry periods, both are replenished by and replenish groundwater. The parameters and processes within shallow groundwaters develop their own gradients, varying with space and time. Therefore, since 1983, the objectives of many shallow groundwater investigations have been to obtain more detailed information about hydrologic processes such as the occurrence, movement and quality of groundwater (Lindner-Lunsford and Wilson 1992). Likewise, stream, spring and wetland protection programs and studies are most effective and informative when integrated with other groundwater protection programs and studies. It would be beneficial to the GRYN to develop a network of groundwater monitoring wells in strategic locations throughout the parks.

Proposed Metric: water level, pumping rate, pumping period, well depth, depth to top of sample interval, depth to bottom of sample interval, geologic unit, core physical and chemical parameters, nutrients, organics, major inorganics, minor and trace inorganics, and radiochemicals. ESRI GIS software is available to monitor and model groundwater hydrology.

Workshop Score: 1.00 (GRYN)

Current Monitoring: USGS-WRD (and NOAA) does some monitoring of groundwater levels and hydrology in the GYA. There is no groundwater monitoring at BICA.

Relative Cost of Monitoring: $-$$$$$ (highly variable depending on current data collection)

Comments:

- Direct costs: If the GRYN can use USGS data from the GYA, the only expense would be analysis.
- Costs that can possibly be subsidized: Interagency cooperation with the USGS.

Technical Note Author: Laura Gianakos

WATER CHEMISTRY

What is this vital sign and why is it important?: Fundamental knowledge of natural and human processes that control natural water composition is required for sound management of water quality, the protection of aquatic life and the attainment of water quality criteria, standards, guidelines (Hem 1992). In order to develop long-term consistent and comparable information on streams and ground water in the GRYN and to foster rational management decisions, the GRYN, in support of both Vital Signs and Water Quality planning efforts, will consider the following questions: What is the condition of our park's waterbodies, how are these conditions changing temporally, and how do natural features and human activities affect these conditions? Assessing the chemical and physical quality and characteristics of our waters in relation to hydrologic conditions, sources, and transport will involve investigations of selected park waters following standardized protocols and will include the fundamental water quality topics of:
Core Field Parameters (dissolved oxygen, pH, specific conductance, water temperature, and discharge) provide instant information about the condition of a water body and also provide the metadata from which all other water quality parameters may be scientifically interpreted
Major Ions, which provide important geochemical data, include the dissolved cations of calcium, magnesium, sodium, and potassium and the major anions of sulfate, chloride, fluoride, nitrate, and those contributing to alkalinity.
Nutrients (nitrogen, ammonia, phosphorus, and potassium), while essential for animal and plant growth, can, in excess, indicate undesirable eutrophication or the presence of animal wastes in water bodies. Pesticides (chemicals applied to control weeds, insects, fungi, nematodes, rodents or other "pests.") and volatile organic compounds (components of gasoline, fuel oils, and lubricants, organic solvents, fumigants, some inert ingredients in pesticides, and some by-products of chlorine disinfection) are measured in water and sediment due to their carcinogenicity, tendency to bioaccumulate, and toxicity to wildlife.
and
Trace Elements (including arsenic, cadmium, chromium, copper, lead, mercury, nickel, and zinc) occur naturally only in minor amounts but easily become toxic to biota if their concentrations in water and sediments are increased due to anthropogenic activities.

Proposed Metric: Specific metrics will depend upon parent material, water body type, and stressor evaluation, selected from the following list of parameters: alkalinity, Acid Neutralizing Capacity (ANC), Ca, Mg, Na, K, H^+, ANC, Cl, NO_3, SO_4, SRP, TNP, Si, DOC, NH_4, TKN, TSS measured in micro or milligrams per liter. Concurrent discharge measurements would allow data to be flow rated. All of the listed anions and cations need to be measured to allow for quality assurance checks using ion balances.

Workshop Score: 0.95 (GRYN)

Current Monitoring: The USGS-NAWQA program measures major ion chemistry in GRTE on the Snake River at Flagg and Moose; in YELL at Soda Butte Creek at the park boundary, Blacktail Deer Creek and on the Yellowstone River near Yellowstone Lake outlet.

Relative Cost of Monitoring: $-$$ depending upon number of sampling sites and numbers of samples per site.

- Direct costs: Analysis costs $85/sample.
- Costs that can possibly be subsidized: Much of this monitoring is currently ongoing in GRTE and YELL through the USGS-NAWQA program. This monitoring could be combined with monitoring of geothermal water chemistry. To add on chemical analyses at existing USGS gaging stations would cost approximately $1000 per station for a one-time, low-flow sampling with published, QA/QC'd data. Quarterly sampling could range from $4000-$7000.

Technical Note Author: Susan O'Ney

NATIVE AQUATIC COMMUNITY STRUCTURE AND COMPOSITION

What is this vital sign and why is it important?: Native aquatic community structure, composition, stability and genetic integrity refers to the overall health of the fish communities in water bodies of interest. In order to measure native aquatic health, species richness and composition metrics, trophic composition metrics, fish abundance and condition metrics and genetic purity analysis must be performed. Fish are especially good indicators of long-term environmental effects and broad habitat conditions because they are relatively long-lived and mobile, life history information is extensive for many species, fish distribution information is commonly available, and the environmental requirements of most fish are well known. Fish assemblages generally include a range of species that represent a variety of trophic levels (omnivores, insectivores, planktivores, and piscivores) and they tend to integrate the effects of lower trophic levels, thus reflecting integrated environmental health. Fish are at the top of the aquatic food web and are consumed by humans, making them important for assessing tissue contamination. Similarly, aquatic life uses (water quality standards) are typically characterized in terms of fisheries (coldwater, coolwater, warmwater, sport, forage) and monitoring fish provides direct evaluation of "fishability", which emphasizes the importance of fish and their ecology to anglers. Lastly, fish account for nearly half of the endangered vertebrate species and subspecies the United States; therefore, it is extremely important to maintain genetic integrity in native populations. In general, fish are easy to collect, easy to identify to the species level and most specimens can be sorted and identified in the field by experienced fisheries professionals and subsequently released unharmed.

Proposed metric(s): species richness and composition metrics, trophic composition metrics, fish abundance and condition metrics and genetic purity analysis.

Workshop Score: 1.00 (GRYN)

Current Monitoring: Both Yellowstone and Grand Teton National Parks are actively involved in inter-agency research on fish ecology, angler catch, and restoration and preservation of native species, subspecies, and genotypes, and major revisions in fisheries regulations and management. More specifically, Yellowstone NP is undertaking ongoing monitoring of the zebra mussel invasion of Yellowstone and Lewis lakes, native Montana grayling populations, Yellowstone cutthroat trout populations, Lake trout in Yellowstone lake, fish populations in backcountry lakes, fish populations in streams, Whirling disease monitoring, New Zealand mud snail populations, Westslope cutthroat trout populations, anglers and angler success, and is currently developing an empirical model for predicting the stream invertebrate fauna of the GYE.

Relative Annual Cost of Monitoring: Genetic analysis can be expensive.

Comments:

- Direct costs to the GRYN: Where important, most such studies are already occurring. The GRYN data manager will need to spend time in the management, analysis and reporting of such data sets.

- Costs that can possibly be subsidized: There are many opportunities for inter-agency cooperation/cost subsidies through USGS, USFWS, WY Game & Fish, MTFW&P, universities, etc.

Technical Note Author: Laura Gianakos

RESERVOIR ELEVATION

What is this vital sign and why is it important?: Lakes that are hydrologically managed (e.g. Jackson Lake, Bighorn lake) have fluctuating water levels that affect lake food webs, ecosystem function, water quality and downstream attributes and, therefore, need to be monitored for elevation changes, reservoir storage, inflow and outflow. Dramatically fluctuating lake levels change the environmental conditions for all riparian and aquatic organisms in the standing water body as well as in the flowing water. For example, as levels change, the physico-chemical and nutrient balance in the reservoir water and in the downstream river changes. Changing stratification of the water column and nutrient enrichment of the reservoirs may lead to eutrophication problems, therefore impacting ecological communities, drinking water treatment and downstream water quality. Lastly, lakes are linked to their shoreline and receive a fraction of their energy inputs from allochthonous inputs, inputs that may control terrestrial predator interactions with the lake (Schindler and Scheuerell 2002). Changing water levels may decrease allochthonous inputs and may limit access of the lake by terrestrial predators such as otters (Hall 2003). The Bureau of Reclamation measures the reservoir elevation of both Jackson Lake and Bighorn Lake (Yellowtail Dam) on a daily basis and provides information such as pool elevation (in feet), reservoir storage (in acre-feet), inflow and outflow (in cfs) on its website.

Proposed Metric: pool elevation (in feet), reservoir storage (in acre-feet), inflow and outflow (in cfs).

Workshop Score: 1.00 (BICA and GRTE)

Current Monitoring: The Bureau of Reclamation measures the reservoir elevation of both Jackson Lake and Bighorn (Yellowtail Dam). The information is available online at Jackson Lake: http://mac1.pn.usbr.gov/hydromet/ and at Yellowtail Dam: http://water.gp.usbr.gov/gp/rflow.htm

Relative Cost of Monitoring: $

Comments:

- Direct costs: If the GRYN uses the USBR data, the only direct cost is data analysis.
- Costs that can possibly be subsidized: Interagency cooperation with the USBR would greatly reduce the time and effort spent to monitor this candidate vital sign.

Technical Note Author: Laura Gianakos

RIVER INVERTEBRATE ASSEMBLAGES

What is this vital sign and why is it important?: Benthic macroinvertebrate assemblages in streams reflect overall biological integrity of the benthic community. Monitoring these assemblages is useful in assessing the status of the water body and detecting trend in ecological condition. Benthic invertebrates inhabit the sediment or live on the bottom substrates of streams. Benthic communities respond to a wide array of stressors in different ways so that it is often possible to determine the type of stress that has affected a macroinvertebrate community (Klemm et al. 1990). They are sensitive indicators of change and they can integrate physical stressors that might otherwise be difficult to measure, and these changes can relate to changes in ecosystem function (Wallace et al. 1996). Because many macroinvertebrates have relatively long life cycles of a year or more and are relatively immobile, macroinvertebrate community structure is a function of present or past conditions. Long-term monitoring of invertebrates may detect change in response to exotic mud snails, and new, unforeseen invasions (Hall 2003).

Proposed Metric: There are several approaches to using invertebrates to measure water quality; two current methods either develop a set of additive metrics (Kerans and Karr 1994), a local examples is Wyoming index of biotic integrity (WYIBI) (Stribling), Another method uses multivariate approaches to estimate predicted invertebrate assemblages which can be compared to measured assemblage structure (e.g. Hawkins et al. 2000).

Workshop Score: 0.95 (GRYN)

Current Monitoring: A current study by Dr. Chuck Hawkins of Utah State University, entitled "Development of an empirical model for predicting the stream invertebrate fauna of the Greater Yellowstone Ecosystem", looks at creating a model to predict river and stream invertebrate assemblages in the GYE (contact: 435-797-2280). Some limited macroinvertebrate sampling is ongoing at the fisheries sampling sites and backcountry lake monitoring sites in YELL (contact: Todd Koel). The State of Wyoming Reference Stream Database contains macroinvertebrate surveys for twelve streams in YELL (contact: Kurt King). A crude list of macroinvertebrates found in BICA in 1985 is available (contact: Terry Peters). Pre-New Zealand mud snail invasions macroinvertebrate abundance is available from Bob Hall in GRTE.

Relative Cost of Monitoring:

Comments:

- Direct costs:
- Costs that can possibly be subsidized:

Technical Note Author: Susan O'Ney

SPRINGS AND SEEPS DISTRIBUTION AND HYDROLOGY

What is this vital sign and why is it important?: Springs and seeps distribution and hydrology includes the location and the volume, duration and seasonality of flow of springs and seeps located primarily within BICA and somewhat within the boundaries of GRTE. This vital sign is quantified by calculating the physical/geometric measurements (maximum, minimum, and average depth, length and width of the surface water) and discharge (flow duration, peak flows and flow quantity) at each spring or seep. Additional data collected at spring monitoring sites include bio-physical characteristics and occurrence of special status and indicator species. Springs are places where water flows out of the ground under its own volition; some springs are seeps, in which the water flows out of sand, soil or gravel with no discernable outlet. Both seeps and springs are common along the highly fractured limestones and dolomites of BICA and numerous springs emerge along the Snake River floodplain south of the Buffalo Fork confluence and in the limestone areas in the northwest and southwest portions of GRTE. Both YELL and GRTE also maintain within their boundaries numerous thermal springs. Although they cover a small percentage of the land area, the riparian zones and wetlands fed by springs and seeps play an integral role in sustaining diverse ecosystems of the surrounding areas and uplands (Bourgeron and Engelking 1994). Plant and animal life are highly dependent on water and surrounding vegetation from the springs for sustenance (especially during winter, when other water sources are dry or frozen). These habitats often maintain the highest densities of biological diversity, including insects and songbirds. The permanent water of springs provide critical habitat for amphibians, including breeding grounds, forage and winter cover. Additionally, some reptile species frequent the springs, where prey abundance is high. Springs are also important supplies of water for human consumption. Many of the conditions that make riparian areas rare and valuable, particularly in a semiarid landscape, also make them sensitive to disturbance and change. Potential water loss from diversions in and near BICA is a danger to base flows in seeps and springs. Characterizing the hydrology (the volume, duration, and seasonality of flow) (Riggs 1972) of springs in the GRYN are a first step toward developing a plan to protect and manage the parks' springs; ensure water resources are available to wildlife, aquatic organisms, and plants; promote efforts to reduce erosion and sediment production; initiate wetland delineation studies as required by Section 404 of the Clean Water Act; and manage water rights (Jacobs et. al. 1996).

Proposed Metric: Physical/geometric measurements: maximum, minimum, and average depth, length and width of the surface water, discharge (flow duration, peak flows and flow quantity), water quality, vegetation maps, bio-physio characteristics and occurrence of special status and indicator species.

VSM Workshop Score: NEW Vital Sign

Current Monitoring: Multiple agencies and organizations are involved with spring, seep, and wetland research and classifications including: the Bureau of Land Management (BLM), U.S. Fish and Wildlife Service, U.S. Geological Survey, National Park Service, USDA Forest Service, Smithsonian Institution, The Nature Conservancy and the Smithsonian Institution. Outside of thermal spring biotic inventories in YELL, there are no current spring/seep monitoring activities in the GRYN.

Relative Annual Cost of Monitoring: $$ for inventory stages, $ for annual monitoring thereafter.

Comments:

- Direct costs to the GRYN: It is recommended that professionals monitor these resources, especially if habitat is to be considered. Otherwise, once trained, seasonal employees can handle the physical measurements. The GRYN data manager will need to spend time in the management, analysis and reporting of such data sets.
- Costs that can possibly be subsidized: The greatest possibility of cooperation is with the USGS Water Resources Division in Wyoming, who may also provide scientific oversight.

Technical Note Author: Laura Gianakos

STREAMFLOW

What is this vital sign and why is it important?: Streamflow at any point in time is an integration of the streamflow generation and routing mechanisms in a watershed. This integration also defines the water quality at that time, including land use activities, point source discharges and natural sources (NPS 1998). Thus streamflow measurement should be considered an essential component of water quality monitoring. Streamflow measurements are useful for water quality data comparisons over time, interpretation of water quality data, and calculation of parameter loads.

Proposed Metric: Stream discharge is defined as the unit volume of water passing a given point on a stream or river over a given time. Stream discharge (Q) is typically expressed in cubic feet per second (cfs) or cubic meters per second (cms) and is based on the equation Q = A * V, where A is the cross sectional area of the stream at the measurement point and V is the average velocity of water at that point. No single method for measuring discharge is applicable to all types of stream channels. The preferred procedure for obtaining discharge data is based on "velocity-area" methods (e.g. Rantz et al. 1982; Linsley et al. 1982). For streams that are too small or too shallow to use the equipment required for the velocity-area procedure, two alternative procedures are recommended by the EPA (Lazorchak et al. 1998). One procedure is based on timing the filling of a volume of water in a calibrated bucket. The second procedure is based on timing the movement of a neutrally buoyant object (e.g. an orange) through a measured length of the channel, after measuring one or more cross-sectional depth profiles within that length.

Workshop Score: 1.00 (GRYN)

Current Monitoring: The USGS has streamflow gauging stations in YELL on Blacktail Deer Creek, Yellowstone River near Yellowstone Lake Outlet, Madison River, Firehole River, Gibbon River, Gallatin River, Soda Butte Creek (two locations), Gardner River, Boiling River, and Yellowstone River at Corwin Springs; in GRTE on Snake River at Flagg Ranch Snake River at Moose, Pacific Creek, Buffalo Fork and Spread Creek; in or near BICA on Bighorn at Kane, Shoshone River near Lovell, Shoshone River at Kane and Crooked Creek near Lovell. YELL is monitoring streamflow on Reese Creek.

Relative Annual Cost of Monitoring: $ (per existing gauging station if operated by USGS)
$ (new gauging station set-up)
$ (per station if using pressure transducer/stage discharge set-up)

Comments:

- Direct costs to the GRYN: All water quality data collectors should have had formal training and some period of field apprenticeship in order to correctly calibrate and operate field equipment, implement sampling procedures, and document the field protocols used and sampling results with the necessary metadata. The Networks may

choose to initiate monitoring with Network/Park staff or transition water quality monitoring responsibilities from contractors/cooperators or USGS personnel to permanent Network staff as the program evolves. Training and apprenticeship for Park Service technicians should be planned and budgeted prior to execution of monitoring activities by NPS staff. The USGS regularly offers a course entitled *Field Water Quality Methods for Groundwater and Surface Water* held at the USGS National Training Center in Denver, Colorado. NPS staff and cooperators may attend on a space available basis. Field training is necessary to ensure field sampling tasks are performed safely, achieve the most representative measurements possible, and data is consistent and comparable service wide. All Network staff involved in the water quality component of the Vital Signs program and the sampling technicians in particular, should have a thorough understanding of the program objectives. Some level of coordination or cooperative effort with the local NAWQA/USGS water resources office and other federal/state/local water quality district offices and monitoring organizations should also prove highly beneficial and allow for maximum use of limited monitoring resources.

- Costs that can possibly be subsidized: Interagency cooperation is possible with the USGS. Cost of operating existing USGS gauging station is $12,500/year, which includes QA/QC and publishing of data and real-time web availability. Some stations are funded through local or state agencies. Costs for installing pressure transducer systems

Technical Note Author: Susan O'Ney

WATERSHED BUDGETS

What is this vital sign and why is it important?: Watershed budgets are a compilation of water, nutrient, sediment and chemical inputs and outputs for a particular watershed and represent a methodology for monitoring water quality in the GRYN. These budgets are variable depending on the study area; however, most sample for concentration of major ions and isotopes, streamflow, groundwater hydrology and continuous temperature. Allowing for truly multi-faceted ecosystem study, watershed budgets, by design, incorporate and integrate many individual ecosystem indicators that regulate ecosystem functions and services. Watershed characteristics such as size, slope, geological composition, biota and climate all influence a watershed's quantity and quality of water resources, forest production, landscape diversity, trace gas fluxes, soil C storage, erosion and biodiversity. Therefore, the goal of a "watershed budget" is to understand processes (snow accumulation, atmospheric deposition, snowmelt, hydrologic flowpaths, ground-water/surface-water interactions, rainfall runoff, fluxes of carbon and nitrogen, cation exchange and mineral weathering and streamflow generation) controlling water, energy, sediment and other biogeochemical fluxes, within the context of atmospheric and climatic variables and within a specified drainage basin. An understanding of controls on spatial and temporal variations on such processes and fluxes is needed to predict ecosystem response to natural and anthropogenic stresses (the most common of which are erosion, toxic chemicals, and sewage waste) and to link ecosystem science with public policy.

Proposed metric(s): Stream chemistry (major ions, nutrients, DIC, DOC, and selected isotopes including $^{2}H/H$, $^{18}O/^{16}O$, $^{15}N/^{14}N$ and $^{18}O/^{16}O$ in nitrate ion, ^{35}S, $^{34}S/^{32}S$, $^{87}Sr/^{86}Sr$, ^{13}C, and ^{12}C); precipitation; stream discharge; spring discharge, conductance, and temperature; spring water chemistry; soil lysimeters; snowpack amount and chemistry (depth, snow-water equivalent); selected microenvironment runoff (e.g., rock outcrop, talus fields); meteorology (wind speed, wind direction, air temperature, incoming and outgoing radiation, relative humidity); gas flux (CO_2 and CH_4) in wetland, forest, and talus soils; CO2 concentrations in surface waters; snowmelt lysimeter discharge and chemistry; load (discharge, tonnes/year) or yield (tonnes/km^2/year) of sediment, suspended sediment (mg/L), and turbidity.

Workshop Score: 0.90 (GRYN)

Current Monitoring: Watershed studies are being conducted in Rocky Mountain National Park (Colorado), Big Bend National Park (Texas), Great Smoky Mountains National Park (North Carolina and Tennessee), Isle Royale National Park and Lake Superior Basin (Michigan), Glacier National Park, MT, Noatak National Preserve (Alaska), Olympic National Park (Washington), Rocky Mountain National Park (Colorado), Sequoia and Kings Canyon National Parks (California) and Denali National Park (Alaska). The Hubbard Brook Ecosystem Study is classic, and other agencies involved with such watershed research are the National Science Foundation, U.S. Geological Survey-Biological Resources Division-WEBB Program, National Science Foundation, National Park Service, U.S. Department of Agriculture-Forest Service, Colorado Department of Public Health and Environment, U.S. Environmental Protection Agency, National Oceanic and Atmospheric Administration, University of Colorado, U.S. Geological Survey-Hydrologic Benchmark Network, National Atmospheric Deposition Network,

Niwot Ridge LTER Site, Institute of Arctic and Alpine Research (INSTAAR), Long-Term Ecological Research Network, and regional synoptic survey projects, such as the annual Rocky Mountain snowpack chemistry survey. Helpful planning publications include: Turk, J. T., N. E. Spahr, and D. H. Campbell, Planning document of water, energy, and biogeochemical-budget (WEBB) research project, Loch Vale watershed, Rocky Mountain National Park, Colorado, U.S. Geol. Surv. Open File Rep., 92-628, 18 pp., 1993; Hirsch, R.M., 1998, Small Watershed Investigations in the U.S. Geological Survey, [abs] EOS, Transactions American Geophysical Union, vol. 79, S124; Lins, Harry F. Recent Developments in Water, Energy, and Biogeochemical Budgets Research EOS, Transactions, American Geophysical Union, v. 75, no. 38, p. 433-439, 1994. Regional contacts of note include: University of Colorado, Boulder Diane McKnight and Mark Williams; University of Wyoming, Laramie Tim Drever; U.S. Geological Survey, Geologic Division Bob Rye and Cindi Kester; U.S. Geological Survey, Biological Resources Division Jill Baron, Steve Corn, Erin Muths, Alan Shiller and Bob Stottlemyer; National Park Service Kathy Tonnessen and Tamara Blett; and the U.S. Forest Service, Rocky Mountain Experiment Station Kelly Elder and Bob Musselmann.

Relative Annual Cost of Monitoring: $$-$$$$$ ($25,001 to over $100,000)/ per watershed. The costs on such studies are extremely variable; it completely depends on the types of analysis and the size of the watershed.

Comments:
Direct costs to the GRYN: Again, seasonal employees may be used under the tutelage of a professional. The installation of permanent weirs on large streams is also expensive.
Costs that can possibly be subsidized: There are many opportunities for inter-agency cooperation. The USGS is the agency with which the NPS will have the greatest chance of cost sharing.

Technical Note Author: Laura Gianakos

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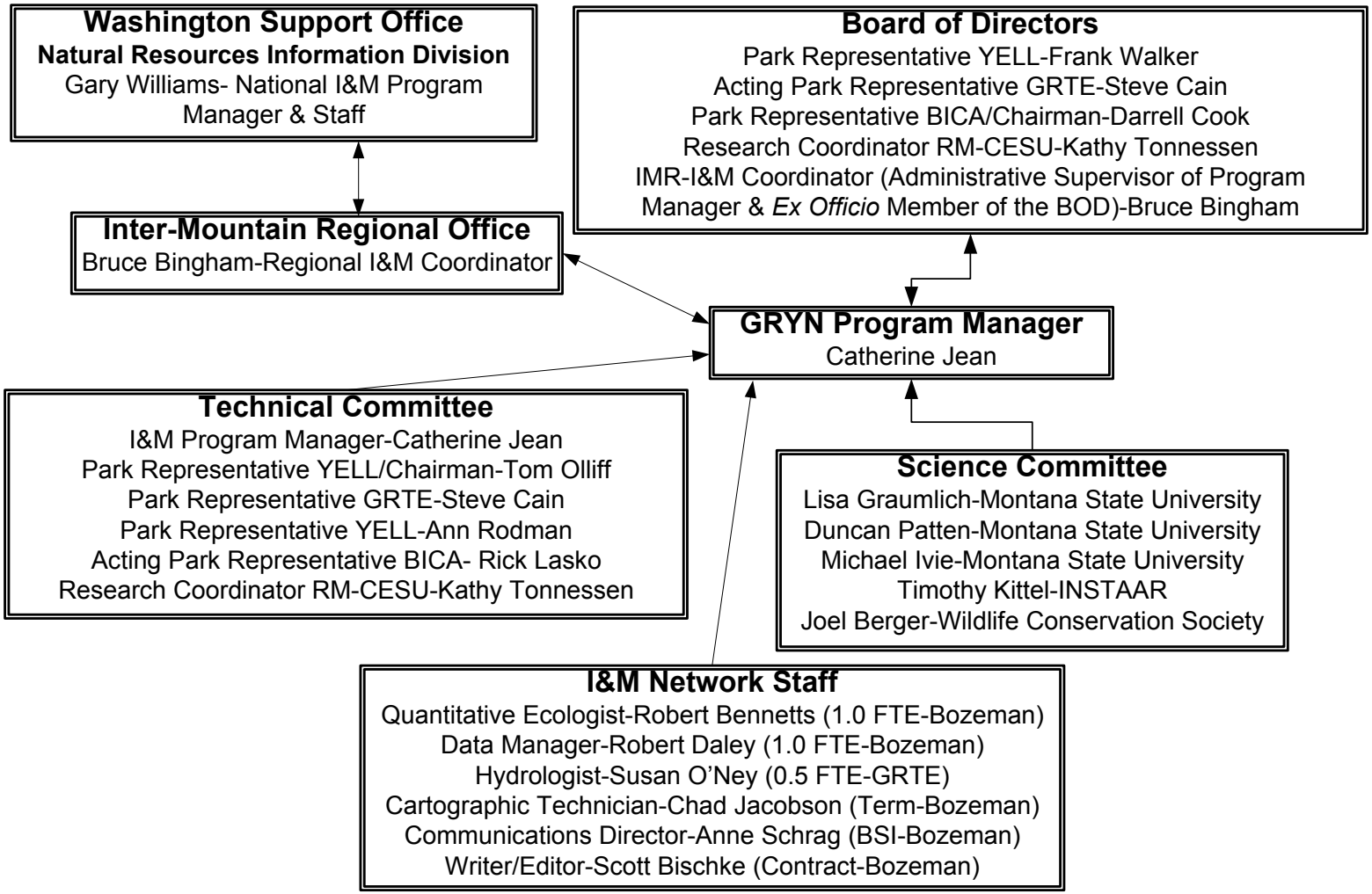
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IX. GRYN ORGANIZATIONAL CHART

Greater Yellowstone Network Organization Chart



X. GRYN WORKSHOP PARTICIPANTS

	Water Quality Meeting-June 5, 2001	Water Quality Meeting-December 5, 2001	Water Quality Meeting-June 25-26, 2002	Water Quality Meeting-October 2002	GRTE Workshop-March 10-11, 2003	YELL Workshop-March 19-20, 2003	Vital Signs Workshop-May 6-8, 2003	Technical Committee Meeting-June 17-19, 2003	Board of Directors Meeting-August 8, 2003
Adams, Mark			X		X				
Arnold, Jeff				X		X	X		X
Bear, Beth			X						
Bergsma, Brian					X				
Bevenger, Greg			X						
Bigelow, Pat						X			
Bischke, Scott								X	
Blair, Roger			X						
Brewster, Wayne						X			
Brooks, Myron							X		
Budge, Nancy							X		
Burgette, Dan					X		X		
Cain, Steve					X			X	X
Cameron, Lane	X	X	X						
Campbell, Don			X						
Consolo Murphy, Sue						X			
Cook, Darrell									X
Corbin, Jennifer		X	X						
Corn, Stephen							X		
Crabtree, Bob							X		
Creel, Scott							X		
Crowe, Elizabeth							X		
Debinski, Diane							X		
Despain, Don							X		
Doss, Paul	X								
Dunworth, Leigh Anne						X			
Fancy, Steve							X		
Farnes, Phil							X		

	Water Quality Meeting-June 5, 2001	Water Quality Meeting-December 5, 2001	Water Quality Meeting-June 25-26, 2002	Water Quality Meeting-October 2002	GRTE Workshop-March 10-11, 2003	YELL Workshop-March 19-20, 2003	Vital Signs Workshop-May 6-8, 2003	Technical Committee Meeting-June 17-19, 2003	Board of Directors Meeting-August 8, 2003
Flaherty, Patrick		X	X						
Gianakos, Laura			X	X			X	X	X
Gogan, Peter							X		
Graumlich, Lisa							X		
Gruber, Lori						X			
Guerrieri, Rick					X				
Hall, Bob					X		X		
Haynes, Steve					X		X	X	
Heasler, Hank						X	X		
Hektner, Mary						X	X		
Hendrix, Christie						X			
Herzog, Peggy					X	X	X		
Hudson, Tim	X								
Inskeep, Bill							X		
Ivie, Michael							X		
Jachowski, Richard							X		
Jackson, Bill		X	X						
Jacobson, Chad							X		
Jean, Cathie				X	X	X	X	X	X
Keniath, Doug							X		
Klukas, Tim						X			
Koel, Todd	X	X	X			X	X		X
Laidlaw, Tina							X		
Lasko, Rick	X	X							
Lewis, Suzanne						X			
Lindstrom, Peter					X				
Mahony, Dan						X			
Maj, Mary							X		
Manning, Mary							X		
Martin, Steve					X				

	Water Quality Meeting-June 5, 2001	Water Quality Meeting-December 5, 2001	Water Quality Meeting-June 25-26, 2002	Water Quality Meeting-October 2002	GRTE Workshop-March 10-11, 2003	YELL Workshop-March 19-20, 2003	Vital Signs Workshop-May 6-8, 2003	Technical Committee Meeting-June 17-19, 2003	Board of Directors Meeting-August 8, 2003
Mast, Alisa							X		
Matz, Mike		X							
Maxwell, Bruce							X		
McEneaney, Terry						X			
McGlynn, Brian							X		
Meyer, Marty					X				
Morstad, Suzanne		X							
Murphy, Kerry						X			
Nanus, Leora							X		
Nordstrom, D. Kirk							X		
Olliff, Tom		X				X	X	X	X
O'Ney, Sue	X	X	X	X	X		X	X	X
Patla, Susan							X		
Patten, Duncan					X	X	X		
Peterson, Chuck							X		
Pierce, Ken							X		
Plumb, Glenn					X	X	X	X	
Porter, Ellen							X		
Reinhart, Dan						X			
Remlinger, Brian			X						
Renkin, Roy						X	X		
Rew, Lisa							X		
Rodman, Ann	X		X			X	X	X	
Rosenlieb, Gary		X							
Schrag, Anne					X	X	X	X	X
Smith, Doug						X			
Smith, Wes			X						
Story, Mark			X						
Stottlemyer, Bob			X						
Swanson, Robert			X						

	Water Quality Meeting-June 5, 2001	Water Quality Meeting-December 5, 2001	Water Quality Meeting-June 25-26, 2002	Water Quality Meeting-October 2002	GRTE Workshop-March 10-11, 2003	YELL Workshop-March 19-20, 2003	Vital Signs Workshop-May 6-8, 2003	Technical Committee Meeting-June 17-19, 2003	Board of Directors Meeting-August 8, 2003
Tae, Michele					X	X	X		
Tinker, Dan							X		
Tonnessen, Kathy		X	X	X			X		X
Varley, John						X	X		
Villalobos, Brian					X				
Walker, Frank						X			X
Wallen, Rick						X			
Ward, Nancy	X								
Whipple, Jennifer							X		
White, P.J.						X			
Whitlock, Cathy							X		
Wolff, Sue		X			X		X		
Woods, Scott			X				X		
Zale, Alexander							X		
Zumberge, Jeremy			X						