

Jackson Lake Draw-down Project

An Annotated Bibliography and Database

Prepared for

**Grand Teton National Park
and the
University of Wyoming National Park Service
Research Center**

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Jackson Lake Draw-down Project

Annotated Bibliography and Database of Primary Research

Introduction

The Jackson Lake Draw-down project is a multi-year venture intended to gather research on the effects of drawing down, seasonally or permanently, the waters of Jackson Lake, Grand Teton National Park, Wyoming. Jackson Lake is a large reservoir within the Park that can store up to 624,000 acre-feet of water and is formed by the Snake River. Much of the water retained in Jackson Lake is used for agricultural and consumptive purposes downstream in both Wyoming and Idaho. Although the reservoir is currently located within the boundaries of Grand Teton National Park, Jackson Lake Dam is managed by the Bureau of Reclamation. However, any decisions involving water storage and releases of water below Jackson Lake Dam are of great importance to the National Park Service since these activities may directly or indirectly affect the natural and cultural resources of the Grand Teton National Park.

The Jackson Lake Draw-down project will encompass research from a wide variety of subject areas. Research will likely be conducted in the areas of hydrology, geomorphology, vegetation, vertebrates, and invertebrates. Researchers involved in this project are not only Park scientists, but researchers from many universities in the Rocky Mountain Region as well as the nation. Other government agencies such as the United States Geological Survey and the Bureau of Reclamation will also be involved. In April of 2004, a meeting was held among Grand Teton National Park scientists and administrators as well as current and potential researchers from universities and government agencies. The National Park Service addressed the need for research to be done on reservoir draw-down and the possible effects it may have on surrounding natural resources. Many attendees of the meeting were unsure as to what research had been previously conducted in Grand Teton National Park. A consensus was made that a preliminary project needed to be established that had a sole purpose to obtain literature and data. The data and information gathered in this project would be used to help future researchers and scientists working in or near the proposed Jackson Lake Draw-down research study area. The study area

proposed primarily covers the region of the Snake River at Flagg Ranch in the northern portion of Grand Teton National Park downstream to Moose, Wyoming. Jackson Lake and several tributaries to the Snake River are located within this area. With this information, Grand Teton National Park Scientists and outside researchers can fill in the gaps and better recognize areas that need further research. At the end of the project, the National Park Service and Bureau of Reclamation will be better prepared to make management decisions concerning the draw-down of Jackson Lake and flow regimes in the Snake River.

Purpose of Project

This project is intended to provide the National Park Service as well as outside researchers from other agencies and universities with an annotated bibliography and database of primary literature and data pertaining to Grand Teton National Park, particularly in the areas of the Snake River and Jackson Lake. Any literature relating specifically to the topic of reservoir draw-down is of utmost importance. This project is designed to aid future researchers by providing background literature and a knowledge of research that has been previously conducted in Grand Teton National Park. This document provides research in wide range of topics which are outlined in the next section. Additional literature is provided throughout the document that relates to draw-down and other research topics covered in this project; however, this supplementary literature was conducted outside of Grand Teton National Park. Even though this supplementary research does not directly involve Grand Teton National Park and Jackson Lake, the methods used and subsequent findings may be useful to researchers and park managers in their own studies in the region. This research is also helpful in areas where relevant studies in Grand Teton National Park are unavailable.

Organization of Literature and Database

This project is organized into a matrix of subject areas pertaining to the impacts of a possible drawdown of Jackson Lake. It begins with references to literature that can provide the park and other researchers with basic definitions and descriptions of river and lake ecosystems. The remainder of the annotated bibliography is organized into the broad categories of hydrology, vegetation, vertebrates, invertebrates, and fungi. Many of these broad categories are then broken

down into subcategories. For example, the category of Hydrology is divided into 6 subcategories: general water resources, channel migration, draw-down and dams, flow regimes, groundwater, and water quality. Individual research articles can be found in these subcategories. There are a total of 19 subcategories which are outlined in the Table of Contents. Users of this bibliography will find that many articles cross-reference more than one topic. For example, an article by Marston (1991) (see pages 12 and 46) is applicable to both vegetation and channel migration. This reference is therefore included in both research categories for user ease.

Contents of Database

The database is located on the CD accompanying the literature portion of this document. It contains 4 categories of data:

Indicators of Hydraulic Alteration: This database contains additional references to literature that encompass hydraulic research, ecological research, and environmental flow recommendations. This database may contain literature of interest for many different types of research along the Snake River, Jackson Lake, and the surrounding environment. The database also contains literature explaining how hydraulic alterations such as reservoir draw-down may impact these environments.

Bureau of Reclamation Hydromet Data: This database includes Snake River and Jackson Lake data at five major stations within Grand Teton National Park. Stations include the following: Snake River at Flagg Ranch, Pacific Creek, Snake River Station, Snake River below Flat Creek, and Jackson Lake Dam. Specific locations (latitude and longitude) and time span of the data are included. This file provides data such as stream gage height, discharge, unregulated flow, water, and air temperatures, precipitation, reservoir storage, etc. Availability of data varies by individual station.

Environmental Protection Agency STORET Data: This database contains water quality data for 55 stations along the Snake River and Jackson Lake within Grand Teton National Park.

Examples of data include phosphorus, nitrogen, dissolved oxygen, fecal coliform, metals, and pH readings of water samples taken at each station. Availability of data again varies by individual station. The majority of this data was obtained in the last two decades. This database was organized into 2 different queries, based on sheer size of the results. An index to individual station IDs and page location is provided in a separate file. ***It is important to use this index to guide the user to individual STORET stations of interest, as it will save time and limit frustration in navigating through these large files.***

United States Geological Survey Gage Data: This file contains USGS gage data for 4 stations within Grand Teton National Park: Snake River at Jackson Lake at Flagg Ranch, WY; Snake River near Moran, WY; Pacific Creek near Moran, WY; and Snake River at Moose, WY. USGS gage data contains discharge readings in cubic feet per second.

The CD also includes all files and introductory information included in the hardcopy of this document, so it can be reproduced for anyone who may find it useful in their research.

Jackson Lake Draw-down Project

Summary of Findings and Gaps in Literature/Data

The specific goal of this project was to data “mine” and search for literature pertaining to draw-down of Jackson Lake in Grand Teton National Park and the effects reservoir draw-down may have on both the Lake and Snake River ecosystems above and below the Jackson Lake Dam. Upon completion of this project, I have come to the conclusion that insufficient research that *specifically* targets the Jackson Lake/ Snake River Region of Grand Teton National Park in the subject of reservoir draw-down exists. Therefore, I consider the absence of geographically specific literature to be the most important gap to be filled in further studies and research investigations. On the other hand, I found abundant literature addressing draw-down in many other portions of the United States as well as other parts of the globe. This literature has been included in the draw-down/dams portion of the document (see pages 15-26). The draw-down/dams portion of this document may be the most useful to the resource managers at Grand Teton National Park as the literature in this section may serve as an aid in future management decisions concerning water releases at the Jackson Lake Dam.

River and Lake Ecosystem Definitions

I came across only a few sources that provided definitions of river and lake ecosystems beyond the scope of those found in a basic biology or ecology textbook. These sources better defined stream and lake ecosystems in terms of classification of their different components and are better oriented toward natural resource management. In particular, I found the manual by Cowardin et al, 1979 (U.S. Fish and Wildlife Service) to be rather thorough and applicable to the project (see pages 2 & 5). A University of Wyoming Zoology professor, who is very familiar with the standards and practices of the United States Fish and Wildlife Department, also recommended this work to me. I was told that many other state and federal agencies have adopted the guidelines and definitions outlined in this manual.

Hydrology

The hydrology section of this document is divided into 6 subcategories, and of these subcategories, channel migration and water quality contain the majority of research directly related to study area in Grand Teton National Park. Literature of great importance includes Marston (1990), Mills (1991), and Wrazien, (1993) (see pages 12 and 14). All three of these articles are studies that investigate horizontal channel migration and other geomorphic processes taking place in the Snake River below Jackson Lake Dam.

I came across many significant water quality related studies in the proposed study area within Grand Teton National Park. The National Park Service and U.S. Geological Survey conducted one of the most important studies. This study by Clark et al (2004) presented the results of routine water quality sampling of the Snake River (see pages 30-31). Farag (2001 and 2002) conducted studies which measured various hydrocarbons in lakes and sediment at several sites within the Park. Hall and Tank (1999 and 2003) also completed several studies concerning nitrogen reuptake and nutrient transport in streams within Grand Teton National Park (see pages 35-37). Finally, Miller (1995-1997) conducted several studies that evaluated the trophic state of several lakes, including Jackson Lake, within the Park boundaries. The water quality section of this document also includes other studies within GTNP and literature conducted in other regions of the world that may be applicable to further studies in the park.

One of the most important subtopics in this section is draw-down and dams. Again, very little draw-down specific research has been conducted in the study area, so this section is supplemented by outside research. The literature included in this section, however, covers a wide selection of topics. Some articles look at the effects of drawdown on fish communities (see Northcote et al, 1985 and Wik, 1995; pages 22 & 25). Others focus on the effects of reservoir drawn-down on various aspects of water quality. These aspects include ammonium and ion concentrations (Perrin et al 2000, page 23), suspended solids (Shantz et el, 2004, page 23), and water temperature (Webb and Walling, 1998, page 25) to name a few. Furthermore, research concerning the effects of draw-down on vegetation has also been provided (see Doyle and Smart, 2001, page 17 and Irwin and Noble, 1996, page 19). It is my hope that the research outlined in this subcategory will encourage new studies or serve as comparison tools for future researchers in the Jackson Lake Draw-down Project.

The remaining three subcategories, general water resources, flow regimes, and groundwater, have fewer research articles. Groundwater in particular is a sparse area of recent research in the park and may need to be addressed in future studies. The flow regimes section has one article that may be very helpful for researchers in need of historical information on flood patterns and seasonal flows. This study was conducted by Schmidt and White (2003) (see page 28), and it examines the hydrologic regime of the Snake River pre and post 1957.

Vegetation

Overall, I believe vegetation research in the riparian areas of the Snake River and Jackson Lake could be improved. In my searches for vegetation literature in the study area, I was disappointed to see that much of the literature in the Grand Teton National Park was outside the study area or somewhat irrelevant to draw-down. Much of the research I found was conducted in sagebrush or high alpine regions of the Park, and they are therefore not included in this bibliography. Much of the most relevant vegetation literature in this section of the document consists of articles previously mentioned in the hydrology section above (e.g, Marston, Mills, and Wrazien). Other studies that may be useful are those in which vegetation in Grand Teton/Yellowstone region is mapped. For example, Weber (2000) assesses land cover changes in the Greater Yellowstone Ecosystem as well as the upper Snake River Plain (see pages 49-50). The large woody debris subcategory consists of several studies by Marston, Gray, and others that examine the distribution and characterization of large woody debris in the Snake River below Jackson Lake Dam (see pages 51-53). The macrophyte subcategory of this section of the bibliography contains research more relevant to reservoir draw-down. Carol Brewer (see pages 54-56) conducted a series of studies that focused on macrophytes and other submersed plant communities and found that they were significantly reduced by draw-down occurring in Jackson Lake in 1985 to facilitate repair of the dam.

It is my belief that significant research may need to be performed in the future that specifically tackles riparian vegetation. I found no articles that focus upon vegetation such as reeds, tubers, grasses, or other types of lakeshore and riverbank vegetation. In my visits to the park, I also became aware of the large cottonwood community along the Snake River. With this knowledge, I believe additional studies concentrating on riparian trees should also be considered.

Wetland areas such as swamps and marshes should also be another topic of research interest, as these areas are likely to be impacted above and below the Jackson Lake Dam in a draw-down.

Vertebrates

This section contains a number of references and is categorized in the following subjects: general wildlife, amphibians, beavers/otters, birds, fish, and small mammals. Overall, I was most successful in finding literature in the proposed study area for vertebrates than in any other category. The strongest subcategories are beavers/otters and fish. Users of this bibliography will find decades of work by Joseph Hall devoted to otter research (see pages 67-68.) Thomas Collins and Bill Gribb have also provided ample research on beavers (see pages 62-66). Fish research ranges from creel surveys (see Gipson, pp 75-76) to the habitat and density of Cutthroat Trout. It is my observation, however, that little research has been done on Snake River fish species other than trout and little research addresses the effects of draw-down on fish. Future studies may need to focus on a wider variety of species that may be affected changing water levels or increases/decreased in discharge from dams.

Several articles were found concerning amphibians with the primary researcher being Charles Peterson (see pages 59-60). Many of these articles note the decline of amphibians on Grand Teton National Park. With this knowledge, it may be important to conduct a study that aims to identify the relationship of draw-down and seasonal water levels to amphibian decline.

Much research has been conducted on various bird species in Grand Teton National Park over the last couple of decades. Most of the research I found concentrates on species identification, population densities, and habitat use. Again, little bird research within the park addresses the impacts of drawdown on various species of birds. With this in mind, I included and outside reference by LaPerle (1974) (see page 74) that discusses the effects of water fluctuation on duck breeding success. After my visit to the park in June of 2005, I also became aware of current research being conducted on songbirds. To my knowledge, much of the songbird habitat seems to be away from riparian areas (e.g. sagebrush or forest). Therefore, I am also inclined to think much of the bird research I found for this project may also be located away from the riparian areas of the Snake River and Jackson Lake. Perhaps additional investigations of riparian/wetland birds need to be established (e.g. swans, geese, and other species of ducks) and how they may be affected by changes in water levels.

Small mammal research findings were a bit sparse with the exception of beavers and otters of course. Again, I feel that what research has been conducted is probably located outside the proposed study area or away from riparian and wetland habitats. I often found research on small mammals such as voles or marmots, which seemed to be outside the scope of this project and were therefore omitted from this document. Perhaps a study may be needed that simply identifies other types of small mammals whose habitat may be impacted by draw-down.

One of the major gaps in vertebrate research I have come across is literature on large mammals that utilize wetland and riparian areas along the Snake River and Jackson Lake. What about moose and deer? Could grizzlies or other bears potentially be impacted by draw-down? Furthermore, I would have liked to have come across more reptile research. I found no research in the park concerning snakes, turtles, or related species. Are these species even found in Grand Teton National Park? I am not sure if these would be viable studies or not concerning draw-down, but there is indeed an absence of literature pertaining to their activity specifically around Jackson Lake and the Snake River.

Invertebrates

This section of the document has been split into 2 subcategories: aquatic invertebrates and insects and terrestrial invertebrates. I came across quite a few research references pertaining to aquatic invertebrates; however, there are large time gaps between research dates. Much of the early research in Grand Teton National Park was done by Good and Kroger in the 1970's (see pages 92-94 and 97-98). More recent research has been performed by Gustafson (2000-01), Hall and Tank (2001 and 2004), and Hawkins (2002) (see pages 94-97). The more recent research primarily focuses on snails, where research from several decades ago covers a number of different invertebrate species. This section is also supplemented with literature from outside the study area.

The insects/terrestrial invertebrate section contains research focusing on butterflies, moths, and mosquitoes. Although I am unsure as to whether these references pertain to drawdown, I included them to give the park managers an idea of what other types of invertebrate research has been completed.

Fungi

Much of the fungi research in Grand Teton National Park pertains to simple identification and classification rather than specific studies on individual species. Kent McKnight and others have done the majority of the fungi work within the park and would be likely sources for obtaining information for future researchers. McKnight et al (1982) state that fungi tend to be highly productive in cool and wet weather; therefore, it may be possible that fungi could be negatively impacted by drawdown. Perhaps park managers may want to consider a future project that investigates the effect of drawdown on soil moisture and wetland areas that may provide habitat for many fungal species.

Conclusion and Acknowledgements

Over the past year I discovered a vast amount of literature and research that has been conducted throughout Grand Teton National Park. In this process I was introduced to a few new research techniques and learned a great deal of new information in so many different areas of study and expertise. I enjoyed the opportunity to be exposed to literature and research outside of my field. With this exposure, I was able to get an overall idea of the research that exists which may help park managers gain insight for making decisions on further research projects as well as the possible implications of drawing down Jackson Lake.

I believe Grand Teton National Park has a great deal of worthwhile research in many different study areas and academic specialties. It is my recommendation that park managers urge future research to relate specifically to draw-down. I have found many examples of research related to reservoir draw-down in other parts of the United States as well as the rest of the world. I hope that these studies can give resource managers an indication of the impacts found in other realms as well as information as to how to design future studies that pertain to Jackson Lake and the Snake River. Park managers may want to initiate further studies that fill in gaps in the other subject areas I have suggested above, in particular missing vertebrate and invertebrate species that are likely to be affected by draw-down. Furthermore, studies should be extended to vegetation as well, as the prominent literature generally relates to large woody debris and macrophytes.

I would like to thank the National Park Service, in particular Susan O’Ney for giving me this research opportunity and introducing me to National Park research avenues of which I was previously unaware. I also want to thank Dr. Bill Gribb and Dr. Hank Harlow for allowing me to participate in this project and inviting me to the AMK ranch, an opportunity I would not have ever had otherwise. I really enjoyed my stay at the park and hope to return in the near future. I also thank Karen Noland for her help in managing the account for this project and introducing me to all of the University of Wyoming NPS Annual Reports, which served as a large component of the literature in this project.

Jackson Lake Draw-down Project Annotated Bibliography

River/Lake Ecosystem Definitions

River Ecosystems (pp 2-4)

Lake Ecosystems (pp 4-7)

**Jackson Lake Draw-down Project
River Ecosystem Defined Annotated Bibliography**

Articles Pertaining to Riverine/Terrestrial Classification

Cowardin, L.M, Carter, V., Golet, F.C., & LaRoe, E.T. 1979. Classification of wetlands and deepwater habitats of the United States. (FWS/OBS-79/31). Washington D.C: U.S. Government Printing Office.

This manual is intended to describe ecological taxa, arrange them in a system useful to resource managers, furnish units for mapping, and provide uniformity for concepts and terms. Riverine ecosystems are among the highest classification hierarchy. Riverine ecosystems have four subsystems: tidal, lower perennial, upper perennial, and intermittent. Systems and subsystems also include classes and subclasses, which describe the substrate material, flooding regime, and vegetative life form present in the ecosystem. Modifiers are also utilized in further description of classes and subclasses. Categories of modifiers include the following: water regime, water chemistry, salinity, pH, soil, and special modifiers.

Frissell, C.A., Liss, W.J., Warren, C.E., & Hurley, M.D. 1986. A hierarchical framework for stream classification: viewing streams in a watershed context. *Environmental Management*, 10:199-214.

This article presents a framework for a hierarchical classification system, entailing an organized view of spatial and temporal variation among and within stream systems. Stream habitat systems, defined and classified on several spatiotemporal scales, are associated with watershed geomorphic features and events. Variables selected for classification define relative long-term capacities of systems, not simply short-term states. Streams and their watershed environments are classified within the context of a regional biogeoclimatic landscape classification. The framework is a perspective that should allow resource managers a more systematic interpretation of and description of watershed-stream relationships.

Lotspeich, F.B. & Platts, W.S. 1982. An integrated land-aquatic classification system. *North American Journal of Fisheries Management*, 2:138-149.

Responsible resource use depends largely on accurate inventories, which implies the creation of a land classification system because an inventory without classification is mainly an unorganized list. This paper develops a simple classification system based on causes of differences between classes, and it integrates the riverine with the terrestrial to form the basic ecological system. Within, this concept, diverse users of the system such as fishery managers, timber harvesters, and livestock grazers have a common classification base form which to

operate. Thus, this land-water classification system will help managers meet increasing demands placed on all resources while giving the fishery the optimum input into the decision-making process.

Pennak, R.W. 1971. Toward a classification of lotic habitats. *Hydrobiologia*, 38:321-34.

A world-wide system for classifying brooks, streams, and small rivers is proposed, using the following criteria: width, flow, current speed, substrate, summer temperatures, winter temperatures, turbidity, total dissolved organic matter, total dissolved inorganic matter, water hardness, dissolved oxygen, rooted aquatic plants, streamside vegetation. Some of these criteria have much greater biological implications than others. It is contended that widely separated lotic habitats that are similar in the above features have biotas consisting of ecologically similar and parallel clusters of species. There are, nevertheless, many kinds of "atypical" polluted and unpolluted lotic habitats that cannot be classified with respect to these criteria.

Savage, N.L. & Rabe, F.W. Stream types in Idaho: An approach to classification of streams in natural areas. *Biological Conservation*, 15:301-315.

Five types among small streams are described: ephemeral streams, spring streams, and three types of permanent streams. Key features used to designate stream types are order, gradient, pattern of flow, and substrate which are readily identifiable, non-variable characteristics. Type designation is supported on an ecological basis by analysis of extensive collections of aquatic plants and invertebrates.

Walker, E.H. 1954. Glacial terraces of the upper Snake River, Wyoming-Idaho. [Abstract] *Geological Society of America Bulletin*, 65:1318.

Four terraces are identified along the Snake River valley. A prominent terrace, which rises 65-90 feet above the river in 90 miles downstream, heads at the Pinedale 1 (late Wisconsin) moraine 4 miles south of Jackson Lake. A lower terrace, about 40 feet above the river, heads at the Pinedale 2 moraine, which holds Jackson Lake. This terrace can be traced 40 miles downstream before its position becomes uncertain. Both terraces have less slope than the 10 feet per mile average of the Snake River. Another 8-12 foot terrace is found at many places along the river. An outwash surface 220 feet above river level begins in the Snake River canyon south of Jackson Hole.

Articles Pertaining to Stream Habitat Evaluation

Platts, W.S., Megahan, W.F. & Minshall, G.W. 1983. Methods for evaluating stream, riparian, and biotic conditions. USDA Forest Service General Technical Report INT-138.

The purpose of the report is to help standardize the way that physical and biological attributes are measured and quantified and to shed light on the strengths and weaknesses of these attributes. Only through constant refinement of present methods, incorporation of additional attributes, and standardization will we ever develop a practical means of obtaining information of use to resource managers. This report presents standard techniques for measuring the aquatic, riparian, and biotic attributes and stresses the precision and accuracy that can be expected for each measurement. Its purpose is to provide the field specialist with a method of building on and evaluating the methodology chosen to measure a particular aquatic habitat.

Platts, W.S., Armour, C. Booth, G.D., Bryant, M., Bufford, J.L., Culpin, P. et al. 1987. Methods for evaluating riparian habitats with applications to management. USDA Forest Service General Technical Report INT-221.

This report is a continuation and update of Platts et al 1983 (listed above). This report is an attempt to compile a comprehensive set of the latest methods for resource specialists to use in managing, evaluating, and monitoring riparian conditions adjacent to streams, lakes, ponds, and reservoirs. The emphasis is on streams. The report covers topics such as sampling, measuring vegetation, riparian community classification and riparian soils, remote sensing, water column measurements, streambanks, measuring organic debris, and others.

Rabe, F.W. & Savage, N.L. A methodology for selection of aquatic natural areas. *Biological Conservation*, 15:291-300.

A methodology is presented for selection of aquatic natural areas based on numerical ranking of sites. Non-weighted points are assigned to 24 physical and biological characteristics of the aquatic and terrestrial components of a proposed natural area. Cumulative score reflects both natural diversity and occurrence of unusual species or conditions. A systematic selection procedure is described which can be utilized by land managers or natural area organizations to arrive at and support objective decisions involving natural area selection.

**Jackson Lake Draw-down Project
Lake Ecosystem Defined Annotated Bibliography**

Biological Definitions of a Lake Ecosystem

Cowardin, L.M, Carter, V., Golet, F.C., & LaRoe, E.T. 1979. Classification of wetlands and deepwater habitats of the United States. (FWS/OBS-79/31). Washington D.C: U.S. Government Printing Office.

This manual is intended to describe ecological taxa, arrange them in a system useful to resource managers, furnish units for mapping, and provide uniformity for concepts and terms. Lacustrine ecosystems are among the highest classification hierarchy. Lacustrine ecosystems have two subsystems, littoral and limnetic. Systems and subsystems also include classes and subclasses, which describe the substrate material, flooding regime, and vegetative life form present in the ecosystem. Modifiers are also utilized in further description of classes and subclasses. Categories of modifiers include the following: water regime, water chemistry, salinity, pH, soil, and special modifiers.

WOW. 2005. Water on the Web. - Monitoring Minnesota lakes on the internet and training water science technicians for the future - A national on-line curriculum using advanced technologies and real-time data. University of Minnesota-Duluth, Duluth, MN 55812. Biological Lake Ecology Primer.
http://www.waterontheweb.org/under/lakeecology/10_biological_lakeszones.html. 12 Jan 2005.

A typical lake has distinct zones of biological communities related to the physical structure of the lake. Major zones are littoral, limnetic, euphotic, and benthic. The littoral zone is near the shore area where sunlight can penetrate to the sediment and allow aquatic plants to grow. Light levels of about 1% or less of the surface values usually define this depth. The euphotic zone is the layer from the surface down to the depth where light levels become too low for photosynthesis. The limnetic zone is the open water area of a lake where light does not penetrate all the way to the bottom. The benthic zone is a bottom layer of sediment that is usually abundant with organisms.

Thermal Definitions of a Lake Ecosystem

WOW. 2005. Water on the Web. - Monitoring Minnesota lakes on the internet and training water science technicians for the future - A national on-line curriculum using advanced technologies and real-time data. University of Minnesota-Duluth, Duluth, MN 55812. Density Stratification Lake Ecology Primer.
http://www.waterontheweb.org/under/lakeecology/05_stratification.html. 12 Jan 2005.

Deep lakes tend to become stratified into three identifiable layers known as the epilimnion, metalimnion, and the hypolimnion, which are related to the density and temperature of the water. The epilimnion is the upper, warm layer of water and is well mixed. The metalimnion, or thermocline region is a layer of water in which temperature declines rapidly with depth. The hypolimnion is the bottom layer of coldwater. The density change that occurs at the metalimnion acts as a physical barrier that prevents the mixing of the upper and lower layers for several months during the summer.

Lake Ecotones and General Lake Ecology

Moss, Brian. 1980. The Ecology of Fresh Waters. New York: John Wiley and Sons.
(Accessible at AMK research library)

This book addresses a variety of topics in freshwater systems. The first two chapters give an overview of basic terms and ideas in lake ecosystems and discuss components such as light, water chemistry, nutrients, vertical stratification, lake fertility, the role of sediment, and the distribution of organisms. Tropic classification of water bodies is also addressed. Subsequent chapters address aquatic plant habitats, invertebrates, vertebrates, palaeolimnology, and fisheries.

Pieczynska, Ewa. 1990. Lentic aquatic-terrestrial ecotones: Their structure function and importance. In: The Ecology and Management of Aquatic-terrestrial Ecotones (R.J. Naiman and H. Décamps, eds). Park Ridge, New Jersey: Parthenon Publishing Group. pp 103-140.

Boundaries between water bodies and adjacent terrestrial patches (lentic ecotones) form extremely differentiated biotypes with respect to their spatial and temporal variability. Ecotone size and configuration depend on shore slope and water level fluctuations, as well as depositional and erosional processes. Lentic ecotones are colonized by diverse species of plants and animals, characterized by a shifting proportion of aquatic and terrestrial species. There are various

sources of autochthonous and allochthonous organic matter in lentic ecotones. These materials vary considerably in decomposition dynamics; however, material resistant to decomposition (plant litter) dominates the standing stock of detritus. Macrophytes have a central position in nutrient cycling, determining most of the important physical and biological characteristics of lentic ecotones. Responses of lentic ecosystems to pollution, as well as their protection and restoration, are also discussed, and specific suggestions are made for their management.

Hydrology

General Water Resources (pp 9-10)

Channel Migration (pp 11-14)

Draw-down and Dams (pp 15-26)

Flow Regimes (pp 27-28)

Groundwater (p 29)

Water Quality (pp 30-41)

General Water Resources Articles Pertaining to GTNP and Jackson Lake Draw-down

Cox, E.R. 1974. Water resources of Grand Teton National Park, Wyoming. U.S. Geological Survey Open-File Report: OF 74-1019. United States Department of the Interior, Geological Survey. (Retrieved February 11, 2005 from <http://pubs.er.usgs.gov/pubs/ofr/ofr741019>.)

The study described in this report is an appraisal of water resources in Grand Teton National Park where hydrologic data are needed for planning water supplies for public use. Water is used in the park for public water supplies at National Park Service facilities, for commercial and domestic use at guest ranches and private residences, and for irrigation. Public water supplies in the park utilize both surface and ground water. Some of the surface-water sources are in areas of heavy use by park visitors. Public-health requirements are that only ground water, if adequate in quantity and quality, should be used for public water supplies in such areas.

Marston, R.A. & Anderson, J.E. 1991. Watersheds and vegetation of the Greater Yellowstone Ecosystem. *Conservation Biology* 5:3 p. 338.

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 can be geographically defined as the Yellowstone Plateau and elevations in the 14 surrounding mountain ranges above the 2130-meter (7000-foot) contour: certain lower elevations need to be included to account for some ecological processes. 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 attendant 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.

Mott, D.N. 1998. Grand Teton National Park, Wyoming water resources scoping report. (Technical Report NPS/NR WRS/NRTR-98/154). United States Department of the Interior, National Park Service. (Retrieved January 13, 2005 from http://www.nature.nps.gov/water/management_plans/grte_final_press.pdf.)

This report describes hydrologic and related physical processes in and around Grand Teton National Park, how these processes interact with biological resources, and issues potentially affecting water resources. Specific issues discussed in this document include the following: water rights/irrigation, road aggregate mining, hazardous materials and wastewater management, oil and gas development, hydrologic modifications, livestock and ungulate grazing, fish stocking, fish restoration/enhancement, floodplain management, and recreation. Issues of major concern are the protection and management of cutthroat trout spawning habitat, safeguarding groundwater resources, and proper management and disposal of wastewater and hazardous materials. Additionally, stream flow alterations resulting from the operation of Jackson Lake Dam continue to change the character of the Snake River channel and adjoining riparian landscape.

Jackson Lake Draw-down Project Channel Migration Annotated Bibliography

Assani, A.A. & Petit, F. 2004. Impact of hydroelectric power releases on the morphology and sedimentology of the bed of the Warche River (Belgium). *Earth Surface Processes and Landforms* 29:2 133-143.

The Butgenbach dam on the Warche River was built in 1932 in order to maintain a sufficient supply of water to the Robertville reservoir situated 7 km downstream, for the production of hydroelectricity. During winter months, releases are made almost every day from the Butgenbach dam. From a hydrological point of view, this has resulted in significantly reducing the number of discharges that are higher than bankfull. Despite the reduction in peak discharge, there is a significant increase in the number of efficient discharges (0.6 bankfull). The impacts of these hydrological modifications on the bed morphology and sedimentology below the Butgenbach dam have been studied and the following geomorphological modifications have been identified: a doubling of the width of the channel in 45 years, a reduction in the number of riffles and pools, an increase in the number of gravel bars and islets and an increase in bedrock outcrops in the channel. Moreover, the finest bed particles are mobilized by the almost daily releases, inducing a significant increase in bed-material size sorting. The reduction of sinuosity and the disappearance of bed differentiation and riffle/pool sequences have produced a diminution of bed roughness and an increase of the competence of the river. Thus relatively small floods can remove the armoured layer.

Link, R., Piety, L. & Randle, T. 1997. Technical Findings Report, Pilgrim Creek Maintenance Program, Jackson Lake Dam, Minidoka Project, Wyoming/Idaho. National Park Service Investigator's Annual Report, GTNP.
<http://science.nature.nps.gov/research/ac/iars/search/iarView?reportId=4207>. 1 July 2005.

The objective of the study is to determine the geologic history and active geologic processes at Pilgrim Creek and its alluvial fan, including measuring stream discharge and sediment load and identifying upstream sediment sources, and to assess present stream channel stability and evaluate any potential risk to Jackson Lake Dam and the Teton Park Road downstream of the dam. Additionally, we would like to develop a hydrologic model of sediment load transport in Pilgrim Creek and assess the threat of future channel migrations that could endanger local infrastructure. Finally, we intend to provide technical recommendations to USBR and NPS management regarding alternate courses of action to manage the creek and protect infrastructure.

Status: All fieldwork and laboratory testing have been completed. Data analysis and report writing are ongoing with a final report transmittal date currently scheduled for May 15, 1998. Copies will be furnished to the National Park Service. Findings: Significant portions of the fan surface have well-developed soil profiles up to 1800 years old indicating long-term stability. The present Pilgrim Creek channel permits significant sediment transport, which appears to have been aided by channel incision initiated by the USBR Safety of Dams drawdown

of Jackson Lake from 1978 to 1989. The present channel appears to be stable and is likely to be stable for the next 50 to several hundred years. A channel avulsion can only occur through aggradation of the streambed and would require several years for completion once the avulsion process begins. The probability of Pilgrim Creek adversely affecting either Jackson Lake Dam or the Teton Park Road is considered very low and low, respectively. Construction of a structural alternate to control the creek is not warranted at the present time. A monitoring program will be recommended and will consist of annual field inspections at peak runoff, periodic surveying of channel profiles on 3-years intervals, and aerial reconnaissance of the upstream basin. Aerial reconnaissance of the basin will follow extensive forest fires and unusually high snow pack or spring runoff or large earthquakes, which could trigger increased stream sediment loads through landslides, increased erosion, etc.

Marston, R.A. 1990. Changes in geomorphic processes in the Snake River following impoundment of Jackson Lake and potential changes due to the 1988 fires in the watershed. In: University of Wyoming National Park Service Research Center 1990 Semiannual Report, (H.J. Harlow and M. Harlow, eds.)
(Note: Also found in 1991 Annual Report)

This report summarizes the objectives and preliminary results of a three year study designed to describe, explain, and predict changes in the geomorphology of the Snake River from Jackson Lake to Moose. It also aims to describe the related changes in riparian vegetation due to Jackson Lake Dam and 1988 fires in the watershed. Specific objectives are to determine changes over time and space in the following: 1) sediment mobilization on hillslopes from rainsplash and overland flow; 2) sediment delivery to streams for slope failures; 3) equilibrium condition and relative stability of the Snake River; and 4) extent of various riparian vegetation communities in the Snake River floodplain. Overall, the 1988 fires have increased sediment mobilization on hillslopes due to rainsplash and overland flow. Sediment supplied to streams from rainsplash and overland flow will be too small to cause persistent changes in channel morphology. The closure of Palisades Reservoir initiated changes in the reservoir release schedule of Jackson Lake Dam. Lack of peak flows cause the braided sections of the Snake River to revert to a compound pattern and eventually to single meandering channels. Five riparian communities have been tentatively identified which include: unvegetated channel deposits, shrub-swamp community dominated by willow and mountain alder, open forest dominated by cottonwood, mixed forest, and closed forest.

Mills, John D. 1991. Wyoming's Jackson lake dam, horizontal channel stability and floodplain vegetation dynamics. M.A. Thesis: Department of Geography and Recreation. University of Wyoming.

The stream channel and floodplain vegetation along the Snake River immediately below the Jackson lake Dam in GTNP, Wyoming have responded to changes in the operation of the dam. Flood flows decreased after Palisades Reservoir was closed downstream in 1957. As a

result, horizontal channel stability increased except immediately below tributaries and cutbacks where the added sediment load could no longer be readily transported. The diversity of floodplain vegetation, as measured by the Shannon-Weiner function, increased after 1957 because the increased horizontal stability of the Snake River allowed forested communities to expand.

Mills, Jack. 1983. GIS-based spatial analysis of channel and vegetation responses to dynamic and below river dam flows. Papers and Proceedings of Applied Geography Conferences. State University of New York at Binghamton.

In this study, a GIS was used to spatially analyze a randomly selected section of the Snake River floodplain between Jackson Lake Dam and Moose, Wyoming in Grand Teton National Park. Its goal was to determine what influence, if any, a finer spatial scale might have on results obtained from an earlier study of the same floodplain conducted at the landscape scale. The imported data for each year, consisting of boundary arcs and topology points, were converted into polygons which were classified into RIVER, UNVEGetated deposits, GRASS-covered deposits, WILLOW-alder shrubs, COTTONwood, MIXED cottonwood-blue spruce and Blue SPRuce. After colors were assigned to each class, images of both maps were created and displayed. Results indicate that 48% of the 1945 RIVER remained as RIVER in 1989, while 27% became UNVEGetated deposits, 5% went to GRASS, 11% to willow, 5% to COTTONwood, and 4% to MIXED cottonwood-blue spruce. In the MIXED cottonwood-blue spruce community, 57% remained as MIXED while 36% reverted to willow. This information substantiates the conclusion that, while the study area as a whole had experienced stabilizing conditions between 1945 and 1989, the selected section had become more unstable. This dichotomy of conclusions suggests that scale differences must be taken into account when reporting this type of research.

Mott, D.N. 1998. Grand Teton National Park, Wyoming water resources scoping report. (Technical Report NPS/NR WRS/NRTR-98/154). United States Department of the Interior, National Park Service. (Retrieved January 13, 2005 from http://www.nature.nps.gov/water/management_plans/grte_final_press.pdf.)

This report describes hydrologic and related physical processes in and around Grand Teton National Park, how these processes interact with biological resources, and issues potentially affecting water resources. Specific issues discussed in this document include the following: water rights/irrigation, road aggregate mining, hazardous materials and wastewater management, oil and gas development, hydrologic modifications, livestock and ungulate grazing, fish stocking, fish restoration/enhancement, floodplain management, and recreation. Issues of major concern are the protection and management of cutthroat trout spawning habitat, safeguarding groundwater resources, and proper management and disposal of wastewater and hazardous materials. Additionally, stream flow alterations resulting from the operation of

Jackson Lake Dam continue to change the character of the Snake River channel and adjoining riparian landscape.

Wrazien, David R. 1993. GIS investigations of horizontal channel migration and floodplain vegetation development: Snake River, Wyoming. M.A. Thesis: Department of Geography and Recreation.

Changes in the release schedule of Jackson Dam in Grand Teton National Park, Wyoming since 1957 have altered flow conditions on the Snake River. Altered flow conditions have affected channel stability and vegetation diversity. A geographical information system (GIS) explains and predicts spatial and temporal variations in floodplain vegetation development, relative to trends in horizontal channel migration.

Jackson Lake Draw-down Project

Drawdown and Dam Literature Annotated Bibliography

Assani, A.A. & Petit, F. 2004. Impact of hydroelectric power releases on the morphology and sedimentology of the bed of the Warche River (Belgium). *Earth Surface Processes and Landforms* 29:2 133-143.

The Butgenbach dam on the Warche River was built in 1932 in order to maintain a sufficient supply of water to the Robertville reservoir situated 7 km downstream, for the production of hydroelectricity. During winter months, releases are made almost every day from the Butgenbach dam. From a hydrological point of view, this has resulted in significantly reducing the number of discharges that are higher than bankfull. Despite the reduction in peak discharge, there is a significant increase in the number of efficient discharges (0.6 bankfull). The impacts of these hydrological modifications on the bed morphology and sedimentology below the Butgenbach dam have been studied and the following geomorphological modifications have been identified: a doubling of the width of the channel in 45 years, a reduction in the number of riffles and pools, an increase in the number of gravel bars and islets and an increase in bedrock outcrops in the channel. Moreover, the finest bed particles are mobilized by the almost daily releases, inducing a significant increase in bed-material size sorting. The reduction of sinuosity and the disappearance of bed differentiation and riffle/pool sequences have produced a diminution of bed roughness and an increase of the competence of the river. Thus relatively small floods can remove the armoured layer.

Benson, N.G. & Hudson, P.L. 1975. Effects of a reduced fall drawdown on benthos abundance in Lake Francis Case. *Transactions of the American Fisheries Society* 104: 526-528.

Lake Francis Case, a 356-km² Missouri River reservoir, is drawn down each fall to hold water released from upstream for winter power generation. The customary drawdown of 10-12 m in 1953-70 was reduced to 6-7 m in 1971-73. Benthos samples collected from 1966 to 1973 indicated that abundance of benthic organisms in May along two transects (to depths of 10.5 and 15 m) increased more than threefold after the drawdown was reduced; abundance in September did not increase. May increases were most evident for five burrowing forms: chironomids, *Hexagenia*, *Caenis*, *oligochaetes*, and *ceratopogonids*.

Casas, J.J.; Zamora-Munoz, C.; Archila, F.; & Alba-Tercedor, J. 2000. The effect of a headwater dam on the use of leaf bags by invertebrate communities. *Regulated Rivers: Research and Management* 16: 577-591.

Breakdowns rates and colonization of leaves from four tree or scrub species differing in quality are studied upstream and downstream of the Canales Reservoir, a dam located in the headwater of the River Genil, Sierra Nevada, in southern Spain. This dam, with hypolimnetic

release, displays short-term fluctuations of discharge and nutrient enrichment in the tailwaters during the study period. Breakdown rates of the four leaf species studied do not differ between sites, despite the higher dissolved nutrient concentration in the tailwater. This lack of differences is attributed to the potentially high physical breakage of leaves during peak flows that are of higher magnitude at the upstream site. The invertebrate density in leaf bags does not differ between sites, and Chironomidae and Ephemeroptera are numerically dominant taxa at both sites. With regard to functional feeding groups, the scarcity and lack of significant differences between sites for shredders do not match the trend dictated by the Serial Discontinuity Concept in relation to the effect of a headwater dam. Possibly, the discharge fluctuations at both sites cause excessive instability of the natural substrate (leaf litter) for the shredder guild. However, as expected, the biomass of collectors colonizing leaf bags is significantly higher than the tailwater, which might not be explained in terms of quantity, but as a consequence of the higher nutritional quality of the fine particulate matter (FPOM) accumulated in leaf bags at this site, owing to the eutrophication caused by the dam. Despite the scarcity of functional shredders at both sites, at the community level, the leaf material is significantly more ingested at the upstream site, suggesting the importance of this source of nutrition for the trophic web at this site in contrast with the tailwater, as predicted by the Serial Discontinuity Concept. This also suggests that caution is needed in using functional feeding groups as trophic guilds to infer system-level trophic drawdown and maximizing the flood duration and flood dry season areas or volumes. However, experiences from dams and other hydraulic engineering projects suggest that these predictions should be treated with caution until we better understand the influence of hydrology on spawning behavior, system primary production, and critical habitat availability.

Christensen, V.G.; Payne, G.A.; & Kallemeyen, L.W. 2004. Effects of changes in reservoir operations on water quality and trophic state indicators on Voyageurs National Park, Northern Minnesota, 2001-03. United States Department of the Interior, USGS Scientific Investigation Report 2004-5044. <http://pubs.usgs.gov/sir/2004/5044/pdf/2004-5044Book.pdf>.

Implementation of an order by the International Joint Commission in January 2000 has changed operating procedures for dams that regulate two large reservoirs in Voyageurs National Park in northern Minnesota. These new procedures were expected to restore a more natural water regime and affect water levels, water quality, and trophic status. Results of laboratory analyses and field measurements of chemical and physical properties from May 2001 through September 2003 were compared to similar data collected prior to the change in operating procedures. Rank sum tests showed significant decreases in chlorophyll-a concentrations and trophic state indices for Kabetogama Lake ($p=0.021$) and Black Bay ($p=0.007$). There were no significant decreases in total phosphorus concentration, however, perhaps due to internal cycling of phosphorus. No sites had significant trends in seasonal total phosphorus concentrations, with the exception of May samples from Sand Point Lake, which had a significant decreasing trend ($\tau=-0.056$, probability=0.03). May chlorophyll-a concentrations for Kabetogama Lake showed a significant decreasing trend ($\tau=-0.42$, probability=0.05). Based on mean chlorophyll trophic-state indices (2001-03), Sand Point, Namakan, and Rainy Lakes would be classified oligotrophic to mesotrophic, and Kabetogama Lake and Rainy Lake at Black Bay would be classified as

mesotrophic. The classification of Sand Point, Namakan, and Rainy Lakes remain the same for data collected prior to the change in operating procedures. In contrast, the trophic classification of Kabetogama Lake and Rainy Lake at Black Bay has changed from eutrophic to mesotrophic.

Doyle, R.D. & Smart, R.N. 2001. Effects of drawdowns and dessication on tubers of hydrilla, an exotic weed. *Weed Science* 49:1 pp135-140.

Subterranean turions (tubers) of hydrilla lose viability when desiccated. Experimental data showed that freshly collected tubers had a moisture content between 50 and 60% and more than 90% viability. When desiccated, there was an approximate 2% increase in tuber mortality with each percent decline in moisture content. However under field conditions, the tuber bank within the exposed sediments of a northern Texas reservoir showed no decline in number or tuber viability throughout a 12-mo continuous drawdown. Apparently, the buried tubers were never subject to sufficient dessication to damage them. Finally, an experimental pond with an extensive hydrilla tuber bank was manipulated through six flood/drawdown cycles to determine the effects of short-term drawdowns on tuber survival and quiescence. Initially, the pond had a tuber bank of about 676 and 305 tubers m^{-2} in the shallow and deep zones, respectively. Although the tuber number was reduced to fewer than 15 to 30 tubers m^{-2} by these repetitive drawdowns, hydrilla tubers were not eradicated from the pond.

Fabre, André. 1988. Experimental Studies on some factors influencing phosphorus solubilization in connection with the drawdown of a reservoir. *Hydrobiologia* 159:2 153-158.

The periodical drawdown of reservoirs affects the phosphorus cycle. During the dry period the sediments are in immediate contact with the atmosphere, while part of them are resuspended when the water rises again. Experimental studies on the sediments of the Puyvalador reservoir (Pyrenees, France), which is subjected to a considerable drawdown every year, show that the quantity of phosphorus solubilized after resuspension of these sediments varies according to the speed with which the water rises, the preceding desiccation of the sediments and the origin of the water used in the experiments. The intensity with which the sediments are stirred depends on the refilling rate. The observed differences related to the origin of the water of the affluent streams are attributed to their initial ortho-phosphate content and their difference in pH. These variations related to drawdown make it necessary to take this important phenomenon into account when studying the solubilization of phosphorus in reservoirs.

Halls, A.S. & Welcomme, R.L. 2004. Dynamics of river fish populations in response to hydrological conditions: a simulation study. *River Research and Applications* 20:8 985-1000.

Increasing multi-sectoral demands on water resources have led to water abstraction and transfer activities, and the construction of dams and embankments that have significantly altered the flood regimes of rivers throughout the world resulting in the loss of fish production and biodiversity. The current emphasis on sustainable development and biodiversity conservation is leading efforts to mitigate these impacts by means of interventions such as the release of artificial floods downstream of dams and the manipulation of water levels within impounded floodplains.

Whilst much work has been done to determine the hydrological requirements for the maintenance of salmonid populations, few equivalent studies are available from which to develop criteria for the management of hydrological regimes for fishes and fisheries in large floodplain-river systems such as the Mekong. The population dynamics of fish in such rivers are believed to respond to hydrological conditions in a density-dependent manner. An age-structured population dynamics model incorporating sub-models describing density-dependent growth, mortality and recruitment was used to explore how hydrological conditions within a theoretical floodplain-river system affect the dynamics of a common floodplain-river fish species.

Graphical summaries of the response of exploitable biomass to a range of different drawdown rates, dry and flood season areas and volumes, and flood season durations are presented under five different model assumptions concerning density-dependent processes. Optimal flooding patterns are also described for the model species and theoretical river system.

The patterns of predictions that emerge from the simulations provide guidelines for managing or manipulating hydrological conditions in river systems for both fixed and variable volume hydrological scenarios. As a general rule of thumb, exploitable biomass is maximized by minimizing the rate of drawdown and maximizing the flood duration and flood and dry season areas or volumes. However, experiences from dam and other hydraulic engineering projects suggest that these predictions should be treated with caution until we better understand the influence of hydrology on spawning behavior, system primary production, and critical habitat availability.

Hauer, R.F. & Lorang, M.S. 2004. River regulation, decline of ecological resources, and potential for restoration in a semi-arid lands river in the western USA. *Aquatic Sciences—Research Across Boundaries* 66:4 pp 388-401.

Societal needs for power generation, water management/use, and land uses (e.g., urban and agricultural) have often resulted in a significant departure from the natural processes of hydrologic regimes and material transport and deposition throughout most of the rivers flowing through arid and semi-arid landscapes of the western USA. We examine the compromised ecosystem integrity of one such river, the upper Snake River in eastern Idaho, below a large irrigation and power dam that has altered hydrologic regimes and reduced channel sediment supply. We review the ecological structure and function of gravel-bed rivers as they vary across

a hierarchy of landscape scales with different spatial and temporal dimensions. Major linkages within the large, alluvial river systems of the western USA include exchange of water and materials along longitudinal connections from streams to rivers, lateral connections between river and floodplain systems, and vertical surface and subsurface (hyporheic) water exchanges. Longitudinal linkages dominate confined (canyon) river reaches while unconfined (floodplain) reaches show strong affinities for lateral and vertical exchange. Hydrogeomorphic processes, driven by river power and cut and fill alluviation, produce a dynamic landscape in floodplain reaches, which we refer to as a Shifting Habitat Mosaic (SHM). The SHM fosters high physical and ecological diversity of habitats, biotic communities, and ecosystem complexity. In this case study, we examine the dynamics of a series of floodplains along a 90 km river landscape, employing an airborne spectrophotometer, producing georeferenced hyperspectral imagery, coupled with ground truth measures of river hydraulics, river depth, riparian vegetation and other surface characteristics. From these data we derived estimates of the hydraulics and hydrographic regimes necessary to mobilize channel and riparian sediments, thus reestablishing the dynamics of the river SHM. We also evaluated subsequent variation in aquatic and riparian habitat characteristics. Evaluation of these factors, which affect interactions between the river channel and the surrounding river-riparian corridor, permitted us to develop a restoration strategy focused on normative variation among the various physical and biotic processes contributing to ecosystem integrity.

Irwin, E.R. & Noble, R.L. 1996. Effects of reservoir drawdown on littoral habitat: Assessment with on-site measures and geographic information systems. American Fisheries Society Symposium.

<http://www.csa.com/partners/viewrecord.php?requester=gs&collection=ENV&recid=4026633&q=&uid=787055022&setcookie=yes>. 23 Nov 2005.

Effects of reservoir drawdown on littoral habitats in two reservoir embayments were quantified using on-site measures and remotely sensed data entered into geographic information systems (GIS). Habitat characteristics (slope, substratum, and cover) were measured at three water levels (65.8, 64.6, and 64.0 m above mean sea level) at 15 10 x 2-m fixed sites in Little Beaver Creek (LBC) and White Oak Creek (WOC) embayments of B. E. Jordan Reservoir, North Carolina. Additional fixed sites were analyzed to more precisely characterize habitats in each embayment. Differences in habitat between the two embayments were detected with sample sizes of 55-57 sites. Habitat databases that included bathymetric and dominant substratum data were incorporated into GIS. Both GIS and on-site measures indicated that slope characteristics remained stable as water level declined. The GIS indicated that LBC was steeper than WOC, whereas on-site measures did not detect these differences. Significant decreases in total cover with decreasing water levels were detected in both embayments via on-site habitat measures. Incorporation of cover into GIS at the embayment scale was not feasible. Amounts of gravel substratum decreased in both embayments as water level declined. The GIS allowed large-scale assessment of changes in size and configuration of habitat patches, whereas on-site measures provided finer resolution of habitat characteristics. Because some littoral habitats support higher densities of fish, differences in habitat on embayment-wide scales should be considered when

managing water levels. Geographic information systems are powerful tools that provide reservoir managers the ability to visually and analytically assess habitat data.

Jansson, R.; Nilsson, C.; Dynesius, M.; & Andersson, E. 2000. Effects of river regulation on river margin vegetation: A comparison of eight boreal rivers. *Ecological Applications* 10:1 pp 203-224.

Regulation and fragmentation by dams belong to the most widespread deliberate impacts of humans on the world's rivers, especially in the Northern Hemisphere. We evaluated the effects of hydroelectric development by comparing the flora of vascular plants in 200-m-long reaches of river margin distributed along eight entire rivers in northern Sweden. Four of these rivers were free-flowing, and four were strongly regulated for hydroelectric purposes. First, we compared species diversity per site between entire free-flowing and regulated rivers. To reduce the effects of natural, between-river variation, we compared adjacent rivers. One regulated river had lower plant species richness and cover than two adjacent free-flowing ones, whereas two other parallel rivers, one regulated and another free-flowing, did not differ significantly. Second, river-margin vegetation responded differently to different types of regulated water-level regimes. Both along run-of-river impoundments, with small but daily water-level fluctuations, and along storage reservoirs, with large fluctuations between low water levels in spring and high levels in late summer and fall, the number of species and their cover per site were lower than along the free-flowing rivers. Regulated but unimpounded reaches were most similar to free-flowing rivers, having lower plant cover per site, but similar numbers of species. For reaches with reduced discharge, evidence was mixed; some variables were lower compared to free-flowing rivers whereas others were not. However, for the last two types of regulation, statistical power was low due to small sample sizes. Third, we classified all plant species according to their dispersal mechanisms and tested whether they respond differently to different types of regulated water-level regimes. Three out of four types of regulation had higher proportions of wind-dispersed species, and two out of four had lower proportions of species without specific mechanisms for dispersal, compared to free-flowing rivers, suggesting that dispersal ability is critical for persistence following regulation. Run-of-river impoundments had higher proportions of long-floating species and species with mechanisms for vegetative dispersal, suggesting that water dispersal may still be important despite fragmentation by dams. Fourth, plant species richness and cover varied with both local factors, such as water-level regime, and regional factors, such as length of the growing season. Presence of clay and silt in the river-margin soil, preregulation position of the contemporary river margin, nonreservoir sites, low altitudes, and long growing seasons were associated with high plant species richness and cover.

Kadlec, J.A. 1962. Effects of a Drawdown on a Waterfowl Impoundment. *Ecology* 43:2 267-281.

A pilot drawdown on the Backus Lake flooding project in north-central lower Michigan was evaluated during the summer of 1958 along with its effect on vegetation, waterfowl, soil, water, and bottom fauna. Plant species composition was not notably affected. Common

perennials were able to survive drainage for one growing season. Many submerged and floating-leaf species were reduced in abundance. Water lilies were little affected except in severely dried areas. Water smartweed and bushy pondweed grew luxuriantly after the drawdown. Most emergents spread and increased in abundance. Sedges and woolgrass were most abundant on dry portions of the study area. Cattail, bulrush, and burreed were more abundant where soil moisture was returned throughout the drawdown. Rice cutgrass and mannagrasses were generally distributed. Waterfowl utilization of the area increased in late summer 1959. Abundant food attracted ducks, and increased cover caused increased use by breeding waterfowl in 1960. Soil and water analyses indicated a definite increase in plant nutrients, especially soil nitrates due to aerobic nitrification. Invertebrate populations were considerably reduced after the drawdown.

Lessard, J.L. & Hayes, D. B. 2003. Effects of elevated water temperature on fish and macroinvertebrate communities below small dams. *River Research and Applications* 19:7 721-732.

Many studies have investigated the ecological changes that occur below dams that release cold, hypolimnetic water, but very few studies have looked at the effects of the release of warm, surface waters. The effect of small, surface release dams on downstream thermal regimes is a major habitat concern for many cold-water systems, however. The objective of this study was to examine the effects of summer temperature increases due to impoundment on downstream fish and macroinvertebrate communities in cold-water streams. We sampled fish, macroinvertebrates and habitat upstream and downstream of dams on ten rivers during the summers of 1998 and 1999. Changes in mean summer temperature downstream varied from a cooling of 1 °C to an increase of more than 5 °C. Increasing temperatures downstream coincided with lower densities of several cold-water fish species, specifically brown trout (*Salmo trutta*), brook trout (*Salvelinus fontinalis*) and slimy sculpin (*Cottus cognatus*) while overall fish species richness increased downstream. Density of mottled sculpin (*Cottus bairdi*), another cold-water species, was not related to temperature changes below the dams. Macroinvertebrates showed shifts in community composition below dams that increased temperature. This study provides information useful for determining the extent of impact of these small, surface release dams, which are abundant across the country.

Link, R., Piety, L. & Randle, T. 1997. Technical Findings Report, Pilgrim Creek Maintenance Program, Jackson Lake Dam, Minidoka Project, Wyoming/Idaho. National Park Service Investigator's Annual Report, GTNP.
<http://science.nature.nps.gov/research/ac/iars/search/iarView?reportId=4207>. 1 July 2005.

The objective of the study is to determine the geologic history and active geologic processes at Pilgrim Creek and its alluvial fan, including measuring stream discharge and sediment load and identifying upstream sediment sources, and to assess present stream channel stability and evaluate any potential risk to Jackson Lake Dam and the Teton Park Road downstream of the dam. Additionally, we would like to develop a hydrologic model of sediment load transport in Pilgrim Creek and assess the threat of future channel migrations that could

endanger local infrastructure. Finally, we intend to provide technical recommendations to USBR and NPS management regarding alternate courses of action to manage the creek and protect infrastructure.

Status: All fieldwork and laboratory testing have been completed. Data analysis and report writing are ongoing with a final report transmittal date currently scheduled for May 15, 1998. Copies will be furnished to the National Park Service. Findings: Significant portions of the fan surface have well-developed soil profiles up to 1800 years old indicating long-term stability. The present Pilgrim Creek channel permits significant sediment transport, which appears to have been aided by channel incision initiated by the USBR Safety of Dams drawdown of Jackson Lake from 1978 to 1989. The present channel appears to be stable and is likely to be stable for the next 50 to several hundred years. A channel avulsion can only occur through aggradation of the streambed and would require several years for completion once the avulsion process begins. The probability of Pilgrim Creek adversely affecting either Jackson Lake Dam or the Teton Park Road is considered very low and low, respectively. Construction of a structural alternate to control the creek is not warranted at the present time. A monitoring program will be recommended and will consist of annual field inspections at peak runoff, periodic surveying of channel profiles on 3-years intervals, and aerial reconnaissance of the upstream basin. Aerial reconnaissance of the basin will follow extensive forest fires and unusually high snow pack or spring runoff or large earthquakes, which could trigger increased stream sediment loads through landslides, increased erosion, etc.

Northcote, TG; Arcifa, MS, & Froehlich, O. 1985. Effects of impoundment and drawdown on the fish community of a South American River. *Verhandlung Internationale Vereinigung Limnologie* 22:4 pp 2704-2711.
<http://mdl.csa.com/partners/viewrecord.php?requester=gs&collection=ENV&recid=8600978&q=&uid=787055022&setcookie=yes>. 3 Nov 2005.

The Americana Reservoir (Brazil) was formed by a 25 m high dam constructed on the Atibaia River, some 500 km above its confluence with the middle Parana. Limnological characteristics of the eutrophic and polymictic reservoir are well documented as are general effects of pollution from sewage and industrial outfalls. The Atibaia River prior to impoundment had a moderately rich fish community probably composed of some 90 species, mostly characoids and siluroids. Of the 65 species apparently no longer present 30 years after impoundment, over two-thirds were siluroids whereas a lower reduction occurred in the characoids, leaving a post-impoundment fish community dominated by this latter group. Not all the changes in the fish community following impoundment of the Atibaia River can be related to changes associated with the shift from lotic to lentic conditions. During this same period there also has been marked eutrophication of the system as well as severe pollution by heavy metals, phenols, herbicides and other materials. The recent and sudden drawdown of Americana Reservoir apparently did not produce major changes in relative abundance of many fish species. The reduction in conditions for the planktivorous *Astyanax* following drawdown may be a food chain effect related to the concomitant decline in phytoplankton and zooplankton abundance.

Perrin, C.J.; Ashley, K.I.; & Larkin, G.A. 2000. Effect of drawdown on ammonium and iron concentrations in a coastal mountain reservoir. *Water Quality Research Journal of Canada* 35:2 231-244.

Part way through a year-long water quality field survey, the Capilano Reservoir, located in the Greater Vancouver Water District, was drawn down to accommodate earthquake reinforcement work on the Cleveland Dam. This paper reports observations of the effect of drawdown on water quality in the reservoir, in the context of the original study. The drawdown exposed a large zone of deltaic material through which the Capilano River eroded a path up to 2.5 m deep. The deltaic material contained substantial amounts of nitrogen and iron (TKN, 4,470 mg times kg super(-1); total iron, 21,800 mg times kg super(-1)). During drawdown, turbidity in the reservoir increased up to 25 times as compared to prior conditions. Ammonium (NH sub(4) super(+)-N) and dissolved and particulate iron concentrations in the drawdown zone were up to two orders of magnitude higher than concentrations upstream. Both NH sub(4) super(+)-N and dissolved iron were observed to travel the length of the reservoir. Persistence of NH sub(4) super(+)-N in the highly oxygenated conditions may be explained by the presence of factors that inhibit nitrification. Persistence of NH sub(4) super(+)-N and particularly dissolved iron may be due to adsorption and complexation reactions. Seasonally high concentrations of iron and ammonium at the water intake corresponded to the timing of complaints of taste, odor, turbid water, and staining in the distribution system. Observations made during this extreme drawdown suggest that transport of N and Fe from exposed deltaic sediments may play a role in the periodic increase in ammonium and iron observed in the Capilano Reservoir. Further understanding of the impacts associated with changing reservoir elevation should lead to the development of appropriate management strategies to maintain the high quality of GVWD water.

Shantz, M.; Dowsett, E.; Canham, E.; Tavernier, G.; Stone, M.; & Price, J. 2004. The effect of drawdown on suspended solids and phosphorus export from Columbia Lake, Waterloo, Canada. *Hydrological Processes* 18:5 865-878.

This study examines the effect of drawdown on the timing and magnitude of suspended solids and associated phosphorus export from a 12 ha reservoir located in an urbanized watershed in southern Ontario, Canada. Water level in Columbia Lake was lowered by 1.15 m over a 2-week period in November 2001. The total phosphorus (TP) concentrations ranged from 63 to 486 $\mu\text{g L}^{-1}$ in Columbia Lake and 71 to 373 $\mu\text{g L}^{-1}$ at its outflow. All samples exceeded the Provincial Water Quality Objective of 30 $\mu\text{g TP L}^{-1}$. Outflow concentrations of suspended solids and TP increased significantly with decreasing lake level and were attributed to the resuspension of cohesive bottom sediments that occurred at a critical threshold lake level (0.65 m below summer level). Suspended solids at the outflow consisted of flocculated cohesive materials with a median diameter (D_{50}) of *c.* 5 μm . Particulate organic carbon accounted for 8.5% of the suspended solids export by mass. A total mass of 18.5 t of suspended solids and 62.6 kg TP was exported from Columbia Lake, which represents a significant pulse of sediment-associated P to downstream environments each autumn during drawdown. The downstream impacts of this release can be minimized if the water level in Columbia Lake is lowered no more than 0.5 m below summer levels.

Stevens, L.E.; Shannon, J.P.; & Blinn, D.W. 1998. Colorado River benthic ecology in Grand Canyon, Arizona, USA: dam, tributary, and geomorphological influences. *Regulated Rivers: Research and Management* 13:2 129-149.

The serial discontinuity concept (SDC; Ward and Stanford, in *Ecology of River Systems*, 1983) predicts that recovery of large regulated rivers over distance downstream from a dam is limited by relative tributary size; however, channel geomorphology may also influence the recovery process. We examined the spatial variation in water quality, benthic composition and ash-free dry standing biomass (AFDM) among the bedrock-defined geomorphological reaches in three turbidity segments of the Colorado River between Glen Canyon Dam and Diamond Creek, Arizona, including most of the Grand Canyon. This 387-km long study area supported virtually no Ephemeroptera, Plecoptera or Trichoptera, probably because cold, stenothermic, hypolimnetic releases limited maximum aestival warming to 17·1°C. The benthos displayed abrupt, physically related decreases in AFDM over distance from the dam and in the varial zone. The 26-km long clear water segment between the dam and the Paria River supported a depauperate *Cladophora glomerata*/epiphyte/chironomid/*Gammarus lacustris*/lumbricine/*Physella* sp. assemblage, and ooze-dwelling oligochaetes. This segment contained 6·9% of the aquatic habitat below the 140 m³/s (normal minimum) discharge stage of the Colorado River study area, but supported 63·5% of the benthic primary producer AFDM and 87% of the benthic consumer AFDM in the entire study area. Turbidity increased and light penetration decreased immediately downstream from the confluence of the small, turbid Paria River, and further downstream from the Little Colorado River confluence. The benthos downstream from the Paria River was abruptly replaced by an *Oscillatoria*/*Simulium* assemblage with a mean AFDM of <0·12 g C/m².

Dam-related effects on water clarity, varial flow and water temperature overrode geomorphological influences on habitat availability. These results generally support the SDC, in that recovery of the benthos did not take place over distance in this large river ecosystem; however, geomorphological differences in substratum availability between reaches mediated dam and tributary effects on water clarity and benthic AFDM. Interactions between flow regulation and geomorphology produce a pattern of circuitous recovery of some physical river ecosystem characteristics over distance from the dam, but not of the benthos. Improving discharge management for endangered native fish populations requires detailed understanding of existing and potential benthic development, and trophic interactions, throughout the geomorphological reaches and turbidity segments in this river.

United States Department of the Interior, Bureau of Reclamation, Pacific Northwest Region.
2004. Banks Lake drawdown final environmental impact statement. Upper Columbia Area Office, Ephrata Field Office. Ephrata, WA.
http://www.usbr.gov/pn/programs/bankslakeeis/pdf/1BL_Summary.pdf. 6 Oct 2004.

The Action Alternative describes the resource conditions that would occur with Banks Lake water surface elevations between 1570 feet and 1560 feet, while the No Action Alternative describes the conditions that would occur without the action, with water surface elevation between 1570 feet and 1565 feet. Both the No Action and Action Alternatives include four potential operational scenarios that could occur annually within their respective ranges,

depending upon the hydrology of any given year. Both alternatives include refilling the reservoir to elevation 1570 feet by September 22. The No Action Alternative is the preferred alternative. The final environmental impact statement provided Reclamation's determination that the Action Alternative "may affect but is not likely to adversely affect" the federally listed bald eagle (*Haliaeetus leucocephalus*) and would have no effect on the federally listed pygmy rabbit (*Brachylagus idahoensis*) or Ute ladies'-tresses (*Spiranthes diluvialis*). The U.S. Department of the Interior's Fish and Wildlife Service concurred with this assessment in a letter dated April 3, 2003, as part of the consultation process in compliance with section 7(a)(2) of the Endangered Species Act of 1973 as amended and codified in 50 CFR 402. This analysis was done in compliance with Action 31 of the Reasonable and Prudent Alternative under the December 2000 Biological Opinion issued by the National Marine Fisheries Service (NMFS) (currently National Oceanic Atmospheric Administration [NOAA] Fisheries) for operation of the Federal Columbia River Power System. Therefore, additional ESA consultation with NOAA Fisheries is not necessary.

Webb, B.W., & Walling, D.E. 1998. Complex summer water temperature behaviour below a UK regulating reservoir. *Regulated Rivers: Research and Management* 13:5 463-477.

Detailed monitoring over a 15-year period has revealed considerable complexity in summer water temperature behaviour below Wimbleball Lake, a large regulating reservoir in south-west England. Continuous records of water temperature in the regulated River Haddeo and the neighbouring unregulated River Pulham, coupled with information on flow in the tailbay of the dam and on the thermal structure of the impounded water body, reveal that the nature and extent of the thermal modification below the reservoir varies from day to day, month to month and year to year. This complexity largely reflects changes in the balance between a springflow and a direct reservoir release component of the compensation runoff, which arise in response to variations within and between summers in hydrometeorological conditions and in the way the reservoir is operated to regulate downstream flows. Temperature behaviour in the regulated river is made more complicated by progressive warming of the springflow during the summer months, the thermal inertia of the stored water, the development of thermal stratification within the reservoir and the alteration of release depth, although the detailed effect of some of these factors depends on weather conditions, the use of destratification equipment and the rapidity of reservoir drawdown.

Wik, S. J. 1995. Reservoir drawdown: Case study inflow changes to potentially improve fisheries. *J. Energy Engrg*, 121:89-96.

Salmon populations in the Columbia River Basin have declined, and several species are now protected under the Endangered Species Act. Many factors have contributed to the decline, including overharvest, loss of habitat, degradation of water quality, and construction of dams. Many measures have been implemented to reduce the impact of the dams, but additional measures are being considered. Lowering water-surface elevations behind four lower Snake

River dams has been proposed as a measure to improve juvenile salmonid survival. The Corps of Engineers has determined preliminary costs, schedules, and required modifications for several drawdown alternatives. Initial estimates of the ability of this type of operation to improve salmonid survival are controversial.

Wulforst, J.M., Parkinson, S., Annandale, G.W., Butler, T., and Gordon-Laborde. Monitoring and evaluation of local erosion downstream of CJ Strike Dam on the Snake River, Idaho. *Wetlands*, 110:31.

The Snake River in Idaho is exhibiting localized bank erosion downstream of the CJ Strike Dam. Multiple tools were used to investigate the cause of the erosion and predict the potential for future erosion. Two of these tools were GoldSize and side-scan sonar. GoldSize software converts digital images of earth material into grain size distributions. Side-scan sonar produces a plan view image of the riverbed by emitting and receiving acoustic pulses from a towfish. These tools revealed armor layer protects a large percentage of the streambed. The existing armor layer was compared to a theoretical pre-development armor layer generated with Gessler's approach. Pre-development discharges and the existing substrate particle sizes (beneath the existing armor layer) were used to calculate a theoretical armor layer distribution. The theoretical armor layer has a smaller particle size distribution than the existing armor layer, indicating that the current armor layer is more stable than what would exist under pre-development discharges.

Jackson Lake Draw-down Project Flow Regime Annotated Bibliography

Annear, T.C. 1989. Snake River Instream Flow Studies. Wyoming Game and Fish Department Fish Division Administrative Report. Project: IF-1088-09-8701
(Document can be accessed at AMK research Library and UW Science Library)

Instream flow studies were initiated by the Wyoming Game and Fish Department in the fall of 1987. These studies were designed to address the impacts of various reservoir release rates on the physical habitat for trout during the winter (Annear, 1987). These preliminary instream flow studies were further limited in scope to address impacts only in the 4.3 mile long segment of the river between Jackson Lake Dam and Pacific Creek. Impacts to this segment were regarded as potentially more severe than downstream segments since no other tributaries enter this segment of the river, which might help sustain the fishery during periods of extremely low reservoir releases. Subsequent consideration and input from interested groups suggested that fishery impacts in more downstream segments of the river are also important. To address these concerns, additional studies were designed and implemented in 1988 to evaluate stream flow/fish habitat dynamics in other segments of the river.

Studies were designed to 1) evaluate incremental changes in physical habitat with change in stream flow for adult Snake River cutthroat trout, 2) determine the stream flow that will maintain hydraulic criteria which are important for trout passage and aquatic insect survival in the main channel of the river, and 3) identify the stream flow that will maintain hydraulic criteria in side channels of the Snake River. The results and recommendations of all studies were applied to the time period between October 1 and March 31 only.

Larson, R.K. & Spinazola, J. 2000. Conjunctive management analyses for endangered species flow augmentation alternatives. *Watershed Management*: 105: 56.

The U.S. Bureau of Reclamation's (Reclamation) Pacific Northwest Region is working to enhance the ability to integrate surface and ground water hydrological and institutional modeling capabilities for use in the Snake River Basin and other river systems in the Pacific Northwest. The MODSIM model is a generalized river basin network flow model which is capable of distinguishing between natural flow and various storage contract arrangements for water entitlement accounting, including storage ownership, water service contracts, and rent pool/water banking. The USGS MODFLOW groundwater model is applied to the vast East Snake River Plain Aquifer to analyze the long term impacts to groundwater discharge to the Snake River. MODSIM and MODFLOW are applied to the Upper Snake basin to quantify how much water reallocation is needed to accomplish flow augmentation objectives. River and reservoir operation simulation analysis is used to quantify impacts to irrigation water supply, river and reservoir recreation, resident fish and wildlife, and other local water uses from various proposed storage rental and reallocation scenarios for satisfying instream flow requirements for endangered species.

Schmidt, J.C. & M.A. White. 2003. The Hydrologic Regime of the Snake River in Grand Teton National Park. Draft Report: Utah State University.
<http://www.forestry.umt.edu/research/cesu/NEWCESU/Assets/Individual%20Project%20Reports/NPS%20Projects/Utah/2003/Schmidt03/Snake%20River%20hydrology.pdf>. 26 June 2005.

The hydrologic regime of the modern Snake River is substantially different from the estimated natural flow regime and from the regulated flow regime that existed prior to 1957, based on analysis of the record of stream flow near Moran, immediately downstream from Jackson Lake Dam, and comparison with the unregulated flow regime, as estimated by the Bureau of Reclamation. Today's late spring floods are much lower and late summer flows are much higher than if the dam did not exist. Today's fall and winter flows are approximately what they would be if there were no dam, and they are much higher than prior to 1957 when base flows were very low. Today's flood regime is much lower than those prior to 1957, but occur in a more "natural" season. Analyses were based on three techniques: traditional comparison of mean daily and instantaneous stream flow, continuous wavelet analysis, and analysis using the Indicators of Hydrologic Alteration software. The utilization of mean daily discharge data and the Bureau of Reclamation's estimated unregulated stream flow represent new contributions to the study of stream flow alteration in Grand Teton National Park.

Jackson Lake Draw-down Project Ground Water Annotated Bibliography

McGreevy, L.J. & Gordon, E.D. 1964. Ground water east of Jackson Lake Grand Teton National Park, Wyoming. Geological Survey Circular 494. Washington: USGS. Retrieved Feb 11, 2004, from <http://pubs.er.usgs.gov/pubs/cir/cir494>.

Report investigates results of test wells that were drilled in five locations in and around GTNP to evaluate the deposits of Quaternary age rock as possible sources of groundwater for National Park facilities. Test wells yielded 30-200 gallons per minute. Unconsolidated deposits of Quaternary age rock were the most promising sources of additional ground water; however, these deposits vary greatly in permeability and fluctuate seasonally. Chemical analyses of water samples from twelve wells indicate that the water is of generally good quality.

Young, H.W., Parlman, D.J., Jones, M.L. & 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 91-56. U.S. Department of the Interior, Geological Survey. (Retrieved February 10, 2005 from <http://pubs.er.usgs.gov/pubs/ofr/ofr9156>.)

This report presents data collected from thirteen observation and ten production wells in and near Grand Teton National Park, Wyoming, from September 1988 to September 1990. The data include measurements of depth of well, depth to water, 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.

Jackson Lake Draw-down Project Water Quality Annotated Bibliography

Christensen, V.G.; Payne, G.A.; & Kallemeyn, L.W. 2004. Effects of changes in reservoir operations on water quality and trophic state indicators on Voyageurs National Park, Northern Minnesota, 2001-03. United States Department of the Interior, USGS Scientific Investigation Report 2004-5044. <http://pubs.usgs.gov/sir/2004/5044/pdf/2004-5044Book.pdf>. 3 November 2005.

Implementation of an order by the International Joint Commission in January 2000 has changed operating procedures for dams that regulate two large reservoirs in Voyageurs National Park in northern Minnesota. These new procedures were expected to restore a more natural water regime and affect water levels, water quality, and trophic status. Results of laboratory analyses and field measurements of chemical and physical properties from May 2001 through September 2003 were compared to similar data collected prior to the change in operating procedures. Rank sum tests showed significant decreases in chlorophyll-a concentrations and trophic state indices for Kabetogama Lake ($p=0.021$) and Black Bay ($p=0.007$). There were no significant decreases in total phosphorus concentration, however, perhaps due to internal cycling of phosphorus. No sites had significant trends in seasonal total phosphorus concentrations, with the exception of May samples from Sand Point Lake, which had a significant decreasing trend ($\tau=-0.056$, probability=0.03). May chlorophyll-a concentrations for Kabetogama Lake showed a significant decreasing trend ($\tau=-0.42$, probability=0.05). Based on mean chlorophyll trophic-state indices (2001-03), Sand Point, Namakan, and Rainy Lakes would be classified oligotrophic to mesotrophic, and Kabetogama Lake and Rainy Lake at Black Bay would be classified as mesotrophic. The classification of Sand Point, Namakan, and Rainy Lakes remain the same for data collected prior to the change in operating procedures. In contrast, the trophic classification of Kabetogama Lake and Rainy Lake at Black Bay has changed from eutrophic to mesotrophic.

Clark, M.L., Sadler, W.J., & O'Ney S.E. 2004. Water quality characteristics of the Snake River and five tributaries in the upper Snake River Basin, Grand Teton National Park, Wyoming, 1998-2002. U.S. Department of the Interior, U.S. Geological Survey Scientific Investigations Report 2004-5017. <http://water.usgs.gov/pubs/sir/2004/5017/>. 24 Jan 2005.

To address water-resource management objectives of the National Park Service in Grand Teton National Park, the U.S. Geological Survey in cooperation with the National Park Service has conducted water-quality sampling in the upper Snake River Basin. Routine sampling of the Snake River was conducted during water years 1998-2002 to monitor the water quality of the Snake River through time. A synoptic study during 2002 was conducted to supplement the routine Snake River sampling and establish baseline water-quality conditions of five of its eastern tributaries—Pilgrim Creek, Pacific Creek, Buffalo Fork, Spread Creek, and Ditch Creek. Samples from the Snake River and the five tributaries were collected at 12 sites and analyzed for field measurements, major ions and dissolved solids, nutrients, selected trace metals, pesticides,

and suspended sediment. In addition, the eastern tributaries were sampled for fecal-indicator bacteria by the National Park Service during the synoptic study.

Major-ion chemistry of the Snake River varies between an upstream site above Jackson Lake near the northern boundary of Grand Teton National Park and a downstream site near the southern boundary of the Park, in part owing to the inputs from the eastern tributaries. Water type of the Snake River changes from sodium bicarbonate at the upstream site to calcium bicarbonate at the downstream site. The water type of the five eastern tributaries is calcium bicarbonate. Dissolved solids in samples collected from the Snake River were significantly higher at the upstream site ($p\text{-value} < 0.001$), where concentrations in 43 samples ranged from 62 to 240 milligrams per liter, compared to the downstream site where concentrations in 33 samples ranged from 77 to 141 milligrams per liter. Major-ion chemistry of Pilgrim Creek, Pacific Creek, Buffalo Fork, Spread Creek, and Ditch Creek generally did not change substantially between the upstream sites near the National Park Service boundary with the National Forest and the downstream sites near the Snake River; however, variations in the major ions and dissolved solids existed between basins. Variations probably result from differences in geology between the tributary basins.

Concentrations of dissolved ammonia, nitrite, and nitrate in all samples collected from the Snake River and the five eastern tributaries were less than water-quality criteria for surface waters in Wyoming. Concentrations of total nitrogen and total phosphorus in samples from the Snake River and the tributaries generally were less than median concentrations determined for undeveloped streams in the United States; however, concentrations in some samples did exceed ambient total-nitrogen and total-phosphorus criteria for forested mountain streams in the Middle Rockies ecoregion recommended by the U.S. Environmental Protection Agency to address cultural eutrophication. Sources for the excess nitrogen and phosphorus probably are natural because these basins have little development and cultivation.

Concentrations of trace metals and pesticides were low and less than water-quality criteria for surface waters in Wyoming in samples collected from the Snake River and the five eastern tributaries. Atrazine, dieldrin, EPTC, or tebuthiuron were detected in estimated concentrations of 0.003 microgram per liter or less in 5 of 27 samples collected from the Snake River. An estimated concentration of 0.008 microgram per liter of metolachlor was detected in one sample from the Buffalo Fork. The estimated concentrations were less than the reporting levels for the pesticide analytical method.

Suspended-sediment concentrations in 43 samples from the upstream site on the Snake River ranged from 1 to 604 milligrams per liter and were similar to suspended-sediment concentrations in 33 samples from the downstream site, which ranged from 1 to 648 milligrams per liter. Suspended-sediment concentrations in 38 samples collected from the tributary streams ranged from 1 to 286 milligrams per liter. Seasonal variations were observed in suspended-sediment concentrations. Concentrations were highest in samples collected during late spring and lowest in samples collected during the fall in response to variations in streamflow. Concentrations of fecal coliform in samples collected from the five eastern tributary streams ranged from less than 1 colony per 100 milliliters to greater than 200 colonies per 100 milliliters. A microbial source-tracking method determined that ribotype patterns for *Escherichia coli* isolates generally were matched to wildlife sources. Avian, bovine, and deer and elk sources were most frequently identified. Human sources were matched in 6 percent or less of the isolates for each basin.

Fabre, André. 1988. Experimental Studies on some factors influencing phosphorus solubilization in connection with the drawdown of a reservoir. *Hydrobiologia* 159:2 153-158.

The periodical drawdown of reservoirs affects the phosphorus cycle. During the dry period the sediments are in immediate contact with the atmosphere, while part of them are resuspended when the water rises again. Experimental studies on the sediments of the Puyvalador reservoir (Pyrenees, France), which is subjected to a considerable drawdown every year, show that the quantity of phosphorus solubilized after resuspension of these sediments varies according to the speed with which the water rises, the preceding desiccation of the sediments and the origin of the water used in the experiments. The intensity with which the sediments are stirred depends on the refilling rate. The observed differences related to the origin of the water of the affluent streams are attributed to their initial ortho-phosphate content and their difference in pH. These variations related to drawdown make it necessary to take this important phenomenon into account when studying the solubilization of phosphorus in reservoirs.

Farag, Aida. 2001. Evaluation of PAHs in Jackson and Jenny Lakes, Grand Teton National Park, Wyoming. National Park Service Investigator's Report, Grand Teton National Park. <https://science1.nature.nps.gov/research/ac/iars/search/iarView?reportId=20974>. 6 June 2005.

The objective of this study is to investigate the presence/absence of polycyclic aromatic hydrocarbons (PAHs) in Jackson Lake and Jenny Lake in Grand Teton National Park, and determine the sources of any PAHs present. Water and sediment collected from these lakes will be analyzed to determine the presence of priority pollutant PAHs defined by the Environmental Protection Agency, and identify patterns of PAH contamination consistent with two and four stroke internal combustion engines. Ratios of three, four, and five ring PAHs will be evaluated to determine if contamination is present because of local activity or long-range deposition. These results will develop an understanding of water and sediment quality and establish a baseline for long-term monitoring of water and sediment quality in the park's lakes. Additionally, information from this study will be used to identify the possibility of PAH accumulation in fish and other aquatic organisms. Water and sediment samples were collected from Jackson, Jenny and Taggart Lakes on August 13 and 14, 2001. Taggart Lake will serve as a reference site for this study because of its "pristine" characteristics and lack of internal combustion engine use. Water was taken from seven locations on Jackson Lake and sediment was collected at five of the locations. Water was collected at two sites on Jenny Lake and sediment was taken from one site. Water and sediment were collected from one site on Taggart Lake. Water and sediment samples are currently being analyzed using gas chromatographic/mass spectrometry and HPLC and GC/FID screening at the Columbia Environmental Research Center in Columbia, Missouri. Additional sample collection is planned for the spring of 2002 to identify the potential for PAH contamination from surface ice. A sampling plan for the summer of 2002 will be determined with data from year 2001 results.

Farag, Aida. 2002. The presence of hydrocarbons in water and sediment of lakes in Grand Teton National Park. National Park Service Investigator's Annual Report, Grand Teton National Park.

<https://science1.nature.nps.gov/research/ac/iars/search/iarView?reportId=24022>.

6 June 2005.

The objective of this study is to determine the presence/absence of polycyclic aromatic hydrocarbons (PAHs) in Jackson Lake and Jenny Lake, and attempt to determine the sources of any PAH's present. Water and sediment collected from these lakes will be analyzed to determine the presence of priority pollutant PAH's defined by the Environmental Protection Agency, and identify patterns of PAH presence consistent with two and four stroke internal combustion engines. With this information, managers will be provided with an understanding of the current water and sediment quality in Jackson Lake and Jenny Lake, and these data will be used to establish a baseline for long-term monitoring. Additionally, information from this study will be used to identify the possibility of PAH accumulation in fish and other aquatic organisms.

Water and sediment were collected from Jackson, Jenny, and Taggart Lakes on August 13 and 14, 2001 and July 23 and 24, 2002. Water was taken from seven locations and sediment was taken from five locations from Jackson Lake during each year. Water was collected from two sites and sediment from one site on Jenny Lake in 2001 and in 2002 six water samples and four sediment samples were collected from Jenny Lake. One sample of water and one of sediment were collected from Taggart Lake each year. Positive control samples of water were collected after allowing a two stroke or a four stroke boat engine to run approximately one minute and collecting the water near the motor. Snow was collected from Jackson Lake (two samples) and Taggart Lake (one sample) on March 22, 2002 along with a positive control of snow where a snowmobile was allowed to run before the snow was collected from the immediate area. Two samples of water were collected from Jackson Lake and one water sample was collected from Taggart Lake on May 13, 2002, soon after the ice on the lakes melted. Taggart Lake will serve as a reference site for this study because of the pristine characteristics and lack of internal combustion engine use. Analyses for water and sediment samples from 2001 and spring snow and water from 2002 are complete and currently being interpreted. Analyses of water and sediment collected in July 2002 are ongoing and additional samples of snow, water, and sediments will be collected in 2003. Ten lake trout were collected from Jenny Lake in October 2002 and are currently being stored frozen until lake trout from Jackson Lake, and cutthroat trout from Jackson Lake and Jenny Lake are collected during 2003. When all of the trout samples are collected, decisions will be made to analyze trout tissues for organics and/or metals based on results gathered data from the water and sediment samples collected during this study.

The preliminary water data suggest that trace levels of organics, naphthalene and acenaphthylene were found in Jenny Lake and at Signal Mountain, swimmer's beach, Sargent's Bay, and Leek's Marina in Jackson Lake during August 2001. Furthermore, some alkylated naphthalenes (2-methyl naphthalene and 1-methyl naphthalene) were found in Jenny Lake and (1-methyl naphthalene) at the three locations on Jackson Lake stated above. All of the concentrations are low and will be interpreted more fully when the data are finalized. No PAHs were found in summer waters collected from Taggart Lake (the reference site) in 2001. Data compilation and interpretations will continue in 2003.

Gooseff, M.; Baker, M.; Haggerty, R.; Wondzell, S. 2004. Controls on hyporheic nitrate retention - Discriminating among transport, reaction-rate, and substrate limitation. National Park Service Investigator's Annual Report, Grand Teton National Park. <https://science1.nature.nps.gov/research/ac/iars/search/iarView?reportId=31324>. 4 October, 2005.

The transport and fate of nitrogen in stream networks is critical to understanding watershed exports of nitrogen. Nitrate (NO_3^-) retention, and denitrification in particular, is known to be dependent upon a variety of factors: geochemical conditions (chiefly RedOx potential), substrate (largely availability of NO_3^- and dissolved organic carbon (DOC)), and transport of nitrate and DOC to favorable locations for denitrification. We will examine the controls of nitrate retention in the hyporheic zones of streams in Wyoming: 2 forested stream reaches, 2 agricultural streams, and 2 urban streams. Each reach will be the subject of $^{15}\text{NO}_3^-$ injections in partnership with the Lotic Interbiome Nitrogen eXperiment II (LINX II) project which is using nitrogen-15 (^{15}N) techniques to study uptake and retention. Collaborating with LINX II allows synergistic and cost-effective examination of stream and hyporheic nitrogen cycling. The objectives of our research are to examine the factors controlling nitrate retention and denitrification in hyporheic zones of small streams and to quantify the fraction of nitrate retention in these streams due to hyporheic exchange. We will test the following hypotheses: (1) hyporheic denitrification in headwater, forested streams will be low because of substrate and rate limitations, yet biotic assimilation will be high, relative to agricultural and urban streams, because of inorganic N-limitation; (2) hyporheic denitrification will be greatest in mid-network locations where surrounding land use is predominantly agricultural, however, total loss of NO_3^- will be transport-limited and biotic assimilation will be reduced because nitrogen is less limiting; and (3) potential rate of denitrification in the hyporheic zone will be high in the urban stream reaches, but total nitrate retention in the hyporheic zone will be low because both denitrification and biotic assimilation will be severely transport-limited.

Elevation surveys of the longitudinal profiles of the stream reaches will be used to quantify channel morphology and provide a base for groundwater flow and reactive transport simulations. We have successfully used this technique to model groundwater flow and calculate hyporheic residence time distributions. We will use tracer tests based on new understanding of their use for measuring residence time distributions in the hyporheic zone. Please note: for Grand Teton streams, we will not follow the exact protocol in the attached proposal (24 hr. continuous release of rhodamine WT dye tracer), instead we will perform a discrete gulp injection (an instantaneous application of dye into the stream). We will collect dye concentration data downstream. We will also perform a short term (< 24 hr) dissolved salt tracer experiment (see proposal). We plan to temporarily deploy 12-15 (not 19-26 as stipulated in the proposal) wells and piezometers in the streambed. These will be deployed to a level that will be difficult to see from any distance, and well/piezometer tops will be cut to a length that is 1-2" above the water surface. Dark colored materials will be used such that they will not be obvious. Deployment time will be 1 week and then all materials will be removed from the streambed. Locations will be dictated by our collaborations with Drs. Hall and Tank.

Findings and Status:

During the summer of 2004, we continued our research on the hydrologic controls on stream nutrient cycling by performing stream bed and stream water surface topographic surveys, and stream tracer experiments in 3 streams in Jackson Hole. One stream was set in an urban landscape (Teton Pines Stream), one in an agricultural setting (Headquarters Stream), and the third in a reference setting in Grand Teton National Park (Two Ocean Creek). Similar to our findings in 2003, our results suggest that reference streams demonstrate the greatest potential for stream water transient storage (the retention of stream water in in-channel dead zones like pools, or in the hyporheic zone, where water moves slower than bulk channel water), while agricultural streams have moderate potential for transient storage, and urban streams have very little. Further, our topographic surveys also suggest that reference streams are the most complex, with numerous channel-spanning changes in slope, and urban streams were the least complex.

The findings from our research over the past 2 years suggest that reference streams, such as those found within GTNP, are more likely to be able to process biogeochemical constituents of streams, because increased transient storage residence time indicates the potential for interactions between streamwater and subsurface biofilms.

Findings from this work were reported at the American Geophysical Union Fall Meeting, 2004 in San Francisco, CA:

Gooseff, MN, RO Hall Jr., JL Tank. 2004. Stream transient storage as a function of land use in Jackson Hole, Wyoming. [Poster H21B-1001] American Geophysical Union Fall Meeting, San Francisco, CA.

Hall, R.O.; Tank, J.L.; & Marshall, M. 1999. Physical and biological control of nutrient transport in streams. National Park Service Investigator's Annual Report, Grand Teton National Park. <https://science1.nature.nps.gov/research/ac/iars/search/iarView?reportId=4269>. 15 September, 2005.

One objective of this study was to estimate physical and biological controls on nutrient (nitrogen and phosphorus) uptake rates in streams. Streams do not simply transport nutrients to downstream ecosystems, but rather microbes in the stream will take up nutrients. Hence, we related stream metabolic activity, stream geomorphology with nutrient uptake in order to develop a predictive model to understand controls on nutrient transport. The other objective was to relate patterns of shallow groundwater invertebrates with whole-stream metabolism, because distribution and abundance of these organisms may be related to oxygen consumption in stream sediments

Findings and Status:

We measured whole stream metabolism and nutrient uptake in eight streams. Six were on the east side of the Park (2 reaches of Pilgrim Creek, Two Ocean Lake Creek, Lizard Creek, Bailey Creek and Ditch Creek), and two were on the west side of the park (unnamed creeks near North Moran Bay and Moose-Wilson Rd.) Initial findings are: (1) Some streams have extremely low nitrogen concentrations, thus high demand for N. (2) 88 % of the variation in total nitrogen uptake on an areal basis is predicted based on stream respiration and primary production, suggesting that biological processes may control nitrogen transport in streams within the Park. (3) Streams in the park have abundant hyporheic invertebrate taxa. Some taxa had higher biomass in streams with higher respiration.

Hall, R.O. & Tank, J.L. 2003. Ecosystem metabolism controls nitrogen uptake in streams in Grand Teton National Park, Wyoming. *Limnology and Oceanography*. 48:1120-1128.

Streams and rivers regulate nitrogen transport (N) to downstream ecosystems. Rates of N uptake can be high in streams, but controls on the variation in uptake rates of N among streams are not known. We measured ammonium (NH_4^+) and nitrate (NO_3^-) uptake velocities (V_f) and compared these with whole-reach estimates of gross primary production (GPP) and community respiration (CR) in 11 low-nitrogen streams in Grand Teton National Park, Wyoming. We predicted that increased metabolism would positively relate to higher N demand because of stoichiometric N requirements associated with carbon fixation. Rates of GPP and CR explained 82% of variation in NH_4^+ V_f . Nitrate V_f was controlled by GPP, not CR, with GPP explaining 75% of variation in NO_3^- V_f . Nitrate concentrations did not increase downstream during NH_4^+ addition in all streams, including streams with zero NO_3^- uptake, suggesting low nitrification rates relative to NH_4^+ uptake. Using a stoichiometric model, we show that areal N uptake estimated from microbial and algal production was similar to measured areal N uptake. High primary production could be a prerequisite for streams exhibiting high NO_3^- uptake rates.

Hall, R.O. & Tank, J.L. 2003. Nitrate uptake and retention in streams: mechanisms and effects of human disturbances from stream reaches to landscapes. National Park Service Investigator's Annual Report, Grand Teton National Park.
<http://science.nature.nps.gov/research/ac/iars/search/iarView?reportId=28050>. 30 June 2005.

We propose an intensive, inter-site study of the fate of nitrate in streams. Our research will evaluate whether streams are indeed important sites of N retention in the landscape and, more importantly, how human disturbances affect that retention. We will use field ^{15}N -tracer experiments to determine the rates and factors controlling nitrate uptake and retention in relatively pristine streams and in streams that have been altered by agriculture or urban development and have elevated nitrate levels. These experiments and associated measurements will allow us to test a variety of hypotheses dealing with the impacts of human disturbances on streams, including effects on channel morphology, hydraulics, biological activity, and N retention. At each of eight sites distributed across diverse biomes throughout the U.S., we will perform tracer-level ^{15}N -nitrate addition experiments to trace the fate of nitrate in nine streams: 3 reference, 3 agricultural and 3 urban streams (for a total of 72 streams across all sites). Each experiment will consist of a 24-h addition of ^{15}N -nitrate and longitudinally distributed measurements of ^{15}N in water and in various benthic organic matter pools to determine in-situ rates of nitrification, assimilatory uptake of nitrate, and denitrification in each stream. We will use our experimental results to develop a general, process-based model of nitrate retention in stream reaches. We then will extend our results to much larger spatial scales by combining our stream model with GIS-based information on hydrography and land use to predict nitrate retention in 5th or 6th order river basins at each of the eight study sites. We will test these

predictions with synoptic field measurements of stream nitrate concentrations within each basin. The validated river basin model will be an important land-use planning and management tool for controlling the N loading of lakes and coastal ecosystems. In summer 2003 we measured nitrate uptake and storage in Ditch Creek as part of this project. We also used 2 streams outside of the park in agricultural and suburban land use. Ditch Creek represents a relatively pristine stream from which to compare the other 2. The tracer nitrate was taken up relatively quickly in Ditch Creek, with about 1/3 of the nitrate taken up in the 350 m study reach. Almost none of this nitrate was denitrified (i.e. turned into N₂ gas), but rather it was taken up by benthic microbes and algae. Although Ditch Creek was a reference stream for the other land uses, its rate of nitrate uptake was actually lower because primary production was much lower there relative to an agricultural spring stream and an irrigation ditch. In summer 2004 we will repeat this study using 3 new streams.

Miller, Woodruff. 1995. Trophic state evaluation of selected lakes in Grand Teton National Park. In: University of Wyoming National Park Service Research Center 19th Annual Report (H.J. Harlow and M. Harlow, eds.). pp 39-44.

This report summarizes the 120 page complete report describing trophic status evaluation of seventeen lakes located in Grand Teton National Park, Wyoming. The study was motivated by concern that the water quality of the lakes within the park may be declining due to increased human usage over the past several years. The trophic status evaluation, which consists of nutrient and chlorophyll-a analyses, was chosen because it is believed to be a sound indicator of the lakes' overall water quality. Given that no other trophic status studies have been conducted on the Teton lakes, this report should be used as a guideline for comparison for future studies. The report describes the main categories of trophic states (oligotrophic, eutrophic, mesotrophic, and hyper-eutrophic) as well as three trophic state models (Carlson, Vollenweider, and Larsen). The seventeen lakes are divided into groups based on their physiographic and/or geographic location and classified into trophic status categories. Coliform analysis and nutrient limitations were also conducted on various lakes as part of the study.

Miller, Woodruff. 1996/97. Trophic state evaluation of Jackson Lake in Grand Teton National Park. In: University of Wyoming National Park Service Research Center 20th Annual Report (H.J. Harlow and M. Harlow, eds.). pp 63-67.

This report is a continuation of the study above in which the trophic state of Jackson Lake is specifically evaluated. Jackson Lake trophic states were examined under the Carlson, Vollenweider, and Larsen-Mercier models. Temperature, dissolved oxygen, nitrogen, and specific conductivity measurements were also taken. Trophic states vary seasonally in Jackson Lake. Phosphorus concentrations are high in June at the inflow to the lake, which causes data for this month to yield a slightly mesotrophic state. July and August were found to be slightly oligotrophic and the month of October strongly mesotrophic. Overall, the lake is determined to be slightly mesotrophic by the three trophic state models.

Maret, T.; MacCoy, D.; & Ott, D. 2003-2004. Upper Snake National Water-Quality Assessment Program. National Park Service Investigator's Annual Report, Grand Teton National Park. <https://science1.nature.nps.gov/research/ac/iars/search/iarView?reportId=25236>. 15 September, 2005.

The objective of this project is to assess the status and trends of the nation's waters. Specific sampling will include water quality, habitat and ecological indicators. Ecological sampling will take place at the Snake River at Flagg Ranch (nr the USGS gage) during fall (September) low-flow period.

Findings and Status:

Algae, macroinvertebrates, and fish were collected from a representative reach (immediately below USGS, gage ID 13010065) to assess biological integrity of aquatic life. Associated habitat conditions were also measured that included measures of substrate, channel morphology, and instream cover. Data will be assessed as part of the National Water-Quality Assessment Program. A few vouchered fish specimens were collected and are deposited in the Orma J. Smith Museum of Natural History, Caldwell, Idaho. Results for macroinvertebrate and algae samples are pending taxonomic processing by the USGS National Water Quality Laboratory Biological Group, Denver.

Miller, Woodruff & Bellini, Mark. 1996. Trophic State Evaluation of Selected Lakes in GrandTeton National Park. Provo, UT: Brigham Young University.

The following report contains an evaluation of the trophic status of seventeen lakes located in GTNP, Wyoming. The study was motivated by concern that the water quality of lakes within the Park may be declining due to increased human usage of the Park in the past several years. The trophic status evaluation, featuring nutrient and chlorophyll-a analyses, was chosen because it is believed to be a sound indicator of the lakes's overall water quality.

The literature review proved unsuccessful in finding any trophic status studies which had been previously conducted on the Teton lakes. As a result, it was not possible to identify any changes in water quality over time. Therefore, this report may serve as a guideline with which future studies may be compared.

The seventeen lakes selected for the study were grouped according to their elevation and location within the park. The groups and their respective lakes are as follows:

Mountain Lakes: Amphitheatre, Lake of the Crags, Delata, Holly, Solitude, Surprise
Moraine Lakes: Bradley, Jenny, Leigh, Phelps, String, Taggart
Valley Lakes: Christian pond, Emma Matilda, Two Ocean
Colter Bay Lakes: Cygnet Pond, Swan Lake.

Nanus, Leora. 2004. Developing screening procedures and sampling protocols for assessment of deposition-sensitive surface waters in the Rocky Mountains. National Park Service Investigator's Annual Report, Grand Teton National Park.
<http://science.nature.nps.gov/research/ac/iars/search/iarView?reportId=32272>. 30 June, 2005.

Atmospheric deposition of pollutants threaten pristine environments around the world. High-elevation ecosystems in the Rocky Mountains are particularly vulnerable because of the storage and release of acids and nutrients in snowmelt runoff combined with steep slopes, granitic bedrock, and limited soils and biota. Land use managers have limited resources for sampling and thus need direction on how best to design monitoring programs. The primary objective of this project is to develop screening procedures and sampling protocols for the assessment of alpine and subalpine lakes sensitive to atmospheric deposition of pollutants in National Parks of the Rocky Mountains, including Glacier National Park, Grand Teton National Park, Great Sand Dunes National Park and Preserve, Rocky Mountain National Park, and Yellowstone National Park. Relationships between water quality and basin characteristics derived from GIS including topography, geology, vegetation, and soils will be explored. Water quality including acid neutralizing capacity, nitrate, sulfate, and other constituents will be collected from alpine and subalpine lakes in each Park. Multivariate logistic regression analysis will be used to develop predictive models for each park. These models will predict the probability of detecting ANC below a specified sensitivity threshold, and nitrate and sulfate above a specified sensitivity threshold for over 800 alpine and subalpine lakes. Lakes with a high probability of being sensitive to atmospheric deposition of nitrate, sulfate, and acidity will be identified. Each of the five parks will first be studied individually, then as a group to determine if a regional approach is appropriate for identifying deposition-sensitive lakes in the Rocky Mountains for focused attention. Screening procedures developed for this project are based on terrain and landscape information available to all participating parks. Because the screening procedure is based on available data, this is a pilot project that may be applicable to other National Parks with potentially sensitive surface waters. The sensitivity of 106 lakes in Grand Teton National Park to acidification from atmospheric deposition of nitrogen and sulfur was estimated based on statistical relations between acid-neutralizing capacity concentrations and basin characteristics to aid in the design of a long-term monitoring plan for Outstanding Natural Resource Waters. Acid neutralizing capacity concentrations that were measured at 52 lakes in Grand Teton during synoptic surveys were used to calibrate the statistical models. Basin-characteristic information (45 for Grand Teton National Park) was derived from Geographic Information System data sets. A logistic regression model was developed and applied to lake basins greater than 1 hectare. For Grand Teton, the elevation of the lake outlet and the area of the basin with northeast aspects were determined to be statistically significant and were used as the explanatory variables in the multivariate logistic regression model. The lakes that exceeded 60-percent probability of having an acid neutralizing capacity concentration less than 100 microequivalents per liter, and therefore had the greatest sensitivity to acidification from atmospheric deposition, are located at elevations greater than 2,790 meters in Grand Teton. Modeling results were cross validated through lake sampling in Grand Teton National Park during Fall 2004. Water samples were collected at alpine and subalpine lakes greater than 1 hectare during mid September 2004. Lake selection was based on the results of the GIS and statistical model to represent both sensitive and non sensitive lakes and due to logistical

constraints. In Grand Teton National Park, samples were collected at 14 lakes between 09/08/2004 and 09/15/2004 including Arrowhead Lake, Bear Paw Lake, Bradley Lake, Holly Lake, Lake of the Craggs, No name 44, Noname 44A, Noname 48, Noname 49, Noname 57, Noname 89, Ramshead Lake, Taggart Lake, and Trapper Lake. Samples were analyzed for dissolved inorganic constituents (chloride, sulfate, acid neutralizing capacity), dissolved nutrients (nitrate, inorganic nitrogen), dissolved organic nitrogen, pH, and conductivity. Complete chemical analysis including dissolved inorganic constituents (calcium, magnesium, sodium, potassium) and dissolved organic carbon will be completed within the next 4 months. Multivariate logistic regression will be used to develop models that estimate probabilities for nitrate and sulfate concentrations in deposition-sensitive lakes. Spatial variability in water quality and basin characteristics, and predicted probabilities will be explored. The utility of this approach for predictive modeling will be evaluated for acid neutralizing capacity, nitrate, and sulfate.

Perrin, C.J.; Ashley, K.I.; & Larkin, G.A. 2000. Effect of drawdown on ammonium and iron concentrations in a coastal mountain reservoir. *Water Quality Research Journal of Canada* 35:2 231-244.

Part way through a year-long water quality field survey, the Capilano Reservoir, located in the Greater Vancouver Water District, was drawn down to accommodate earthquake reinforcement work on the Cleveland Dam. This paper reports observations of the effect of drawdown on water quality in the reservoir, in the context of the original study. The drawdown exposed a large zone of deltaic material through which the Capilano River eroded a path up to 2.5 m deep. The deltaic material contained substantial amounts of nitrogen and iron (TKN, 4,470 mg times kg super(-1); total iron, 21,800 mg times kg super(-1)). During drawdown, turbidity in the reservoir increased up to 25 times as compared to prior conditions. Ammonium (NH sub(4) super(+)-N) and dissolved and particulate iron concentrations in the drawdown zone were up to two orders of magnitude higher than concentrations upstream. Both NH sub(4) super(+)-N and dissolved iron were observed to travel the length of the reservoir. Persistence of NH sub(4) super(+)-N in the highly oxygenated conditions may be explained by the presence of factors that inhibit nitrification. Persistence of NH sub(4) super(+)-N and particularly dissolved iron may be due to adsorption and complexation reactions. Seasonally high concentrations of iron and ammonium at the water intake corresponded to the timing of complaints of taste, odor, turbid water, and staining in the distribution system. Observations made during this extreme drawdown suggest that transport of N and Fe from exposed deltaic sediments may play a role in the periodic increase in ammonium and iron observed in the Capilano Reservoir. Further understanding of the impacts associated with changing reservoir elevation should lead to the development of appropriate management strategies to maintain the high quality of GVWD water.

Shantz, M.; Dowsett, E.; Canham, E.; Tavernier, G.; Stone, M.; & Price, J. 2004. The effect of drawdown on suspended solids and phosphorus export from Columbia Lake, Waterloo, Canada. *Hydrological Processes* 18:5 865-878.

This study examines the effect of drawdown on the timing and magnitude of suspended solids and associated phosphorus export from a 12 ha reservoir located in an urbanized watershed in southern Ontario, Canada. Water level in Columbia Lake was lowered by 1.15 m over a 2-week period in November 2001. The total phosphorus (TP) concentrations ranged from 63 to 486 $\mu\text{g L}^{-1}$ in Columbia Lake and 71 to 373 $\mu\text{g L}^{-1}$ at its outflow. All samples exceeded the Provincial Water Quality Objective of 30 $\mu\text{g TP L}^{-1}$. Outflow concentrations of suspended solids and TP increased significantly with decreasing lake level and were attributed to the resuspension of cohesive bottom sediments that occurred at a critical threshold lake level (0.65 m below summer level). Suspended solids at the outflow consisted of flocculated cohesive materials with a median diameter (D_{50}) of *c.* 5 μm . Particulate organic carbon accounted for 8.5% of the suspended solids export by mass. A total mass of 18.5 t of suspended solids and 62.6 kg TP was exported from Columbia Lake, which represents a significant pulse of sediment-associated P to downstream environments each autumn during drawdown. The downstream impacts of this release can be minimized if the water level in Columbia Lake is lowered no more than 0.5 m below summer levels.

Webb, B.W., & Walling, D.E. 1998. Complex summer water temperature behaviour below a UK regulating reservoir. *Regulated Rivers: Research and Management* 13:5 463-477.

Detailed monitoring over a 15-year period has revealed considerable complexity in summer water temperature behaviour below Wimbleball Lake, a large regulating reservoir in south-west England. Continuous records of water temperature in the regulated River Haddeo and the neighbouring unregulated River Pulham, coupled with information on flow in the tailbay of the dam and on the thermal structure of the impounded water body, reveal that the nature and extent of the thermal modification below the reservoir varies from day to day, month to month and year to year. This complexity largely reflects changes in the balance between a springflow and a direct reservoir release component of the compensation runoff, which arise in response to variations within and between summers in hydrometeorological conditions and in the way the reservoir is operated to regulate downstream flows. Temperature behaviour in the regulated river is made more complicated by progressive warming of the springflow during the summer months, the thermal inertia of the stored water, the development of thermal stratification within the reservoir and the alteration of release depth, although the detailed effect of some of these factors depends on weather conditions, the use of destratification equipment and the rapidity of reservoir drawdown.

Vegetation

General Vegetation (pp 43-50)

Large Woody Debris (pp 51-53)

Macrophytes (pp 54-56)

**Jackson Lake Draw-down Project
Annotated Bibliography of Articles on General Vegetation**

Doyle, R.D. & Smart, R.N. 2001. Effects of drawdowns and dessication on tubers of hydrilla, an exotic weed. *Weed Science* 49:1 pp135-140.

Subterranean turions (tubers) of hydrilla lose viability when desiccated. Experimental data showed that freshly collected tubers had a moisture content between 50 and 60% and more than 90% viability. When desiccated, there was an approximate 2% increase in tuber mortality with each percent decline in moisture content. However under field conditions, the tuber bank within the exposed sediments of a northern Texas reservoir showed no decline in number or tuber viability throughout a 12-mo continuous drawdown. Apparently, the buried tubers were never subject to sufficient dessication to damage them. Finally, an experimental pond with an extensive hydrilla tuber bank was manipulated through six flood/drawdown cycles to determine the effects of short-term drawdowns on tuber survival and quiescence. Initially, the pond had a tuber bank of about 676 and 305 tubers m⁻² in the shallow and deep zones, respectively. Although the tuber number was reduced to fewer than 15 to 30 tubers m⁻² by these repetitive drawdowns, hydrilla tubers were not eradicated from the pond.

Jansson, R.; Nilsson, C.; Dynesius, M.; & Andersson, E. 2000. Effects of river regulation on river margin vegetation: A comparison of eight boreal rivers. *Ecological Applications* 10:1 pp 203-224.

Regulation and fragmentation by dams belong to the most widespread deliberate impacts of humans on the world's rivers, especially in the Northern Hemisphere. We evaluated the effects of hydroelectric development by comparing the flora of vascular plants in 200-m-long reaches of river margin distributed along eight entire rivers in northern Sweden. Four of these rivers were free-flowing, and four were strongly regulated for hydroelectric purposes. First, we compared species diversity per site between entire free-flowing and regulated rivers. To reduce the effects of natural, between-river variation, we compared adjacent rivers. One regulated river had lower plant species richness and cover than two adjacent free-flowing ones, whereas two other parallel rivers, one regulated and another free-flowing, did not differ significantly. Second, river-margin vegetation responded differently to different types of regulated water-level regimes. Both along run-of-river impoundments, with small but daily water-level fluctuations, and along storage reservoirs, with large fluctuations between low water levels in spring and high levels in late summer and fall, the number of species and their cover per site were lower than along the free-flowing rivers. Regulated but unimpounded reaches were most similar to free-flowing rivers, having lower plant cover per site, but similar numbers of species. For reaches with reduced discharge, evidence was mixed; some variables were lower compared to free-flowing rivers whereas others were not. However, for the last two types of regulation, statistical power was low due to small sample sizes. Third, we classified all plant species according to their

dispersal mechanisms and tested whether they respond differently to different types of regulated water-level regimes. Three out of four types of regulation had higher proportions of wind-dispersed species, and two out of four had lower proportions of species without specific mechanisms for dispersal, compared to free-flowing rivers, suggesting that dispersal ability is critical for persistence following regulation. Run-of-river impoundments had higher proportions of long-floating species and species with mechanisms for vegetative dispersal, suggesting that water dispersal may still be important despite fragmentation by dams. Fourth, plant species richness and cover varied with both local factors, such as water-level regime, and regional factors, such as length of the growing season. Presence of clay and silt in the river-margin soil, preregulation position of the contemporary river margin, non-reservoir sites, low altitudes, and long growing seasons were associated with high plant species richness and cover.

Jones, G.; Ehle, D.; Bollin, C.; Lee, E.; Dardy-McGee, L.; & Kurth, V. 2002. Vegetation Mapping of Grand Teton National Park. National Park Service Investigator's Annual Report Grand Teton National Park.
<https://science1.nature.nps.gov/research/ac/iars/search/iarView?reportId=24045>. 4 October 2005.

The National Park Service, NatureServe, the Bureau of Reclamation, and Natural Heritage Programs are collaborating to create new or improved vegetation maps and inventories of plant associations present in National Parks. As a result, there will be two products of the Grand Teton National Park Vegetation Mapping Project: a list of plant associations and a park-wide vegetation map derived from aerial photo interpretation. Vegetation composition and cover data generated from field sampling will be used to create a list of plant associations in the Park, and will be used by Bureau of Reclamation personnel to aid interpretation of aerial photos. Plant association names usually indicate both the dominant overstory and understory species. The vegetation map will likely indicate overstory plants species only, as understory species composition and cover will usually not be identifiable across the landscape in aerial photographs. Field work for the Grand Teton National Park Vegetation Mapping Project is to be conducted over 3 summers. The first two summers are dedicated to vegetation data collection, and the third summer will be dedicated to on-the-ground accuracy assessment of the preliminary vegetation map created by the photo interpreters. The summer of 2002 was the first year of vegetation data collection.

Three different sampling methods were used: Modified-Whittaker sample plots, Detailed Descriptions, and Observation Points. Modified-Whittaker plots and Detailed Descriptions of vegetation were used to define vegetation types (associations). Observation Points, along with the results of the other two methods, will be used by the photointerpreters to increase the accuracy of the vegetation map created from aerial photographs. The Wyoming Natural Diversity Database employees conducted the vegetation sampling during 2002, along with 2 Park-hired employees. The additional employees were hired by the Park to help sample fuels at the same locations where vegetation was sampled for the vegetation mapping project. Fuels sampling methodology was directed by the Park, and fuels data will be analyzed by personnel in the GTNP Fire Program.

Findings and Status:

A total of 163 plots were sampled using Modified-Whittaker plots, and 3 wetland sites were sampled using Detailed Descriptions. Seventy-three Observation Points were sampled. A total of about 5,400 plant specimens were collected from the plots.

When possible, vegetation types were assigned a provisional association name from the list of associations in the National Vegetation Classification System. Ninety vegetation types were assigned an association with confidence, 36 were assigned an association with uncertainty, and 41 could not be assigned an association. Whenever possible, associations named in the National Vegetation Classification System (NVCS) was considered the final authority, although other sources were used when appropriate.

It is recommended by NatureServe that approximately three plots be sampled within each association. Primary emphasis for the 2003 field season should be placed on sampling the remaining 1-2 plots within associations sampled during 2002 and locating and sampling associations thought to occur or likely occur in Grand Teton National Park.

Kadlec, J.A. 1962. Effects of a Drawdown on a Waterfowl Impoundment. *Ecology* 43:2 267-281.

A pilot drawdown on the Backus Lake flooding project in north-central lower Michigan was evaluated during the summer of 1958 along with its effect on vegetation, waterfowl, soil, water, and bottom fauna. Plant species composition was not notably affected. Common perennials were able to survive drainage for one growing season. Many submerged and floating-leaf species were reduced in abundance. Water lilies were little affected except in severely dried areas. Water smartweed and bushy pondweed grew luxuriantly after the drawdown. Most emergents spread and increased in abundance. Sedges and woolgrass were most abundant on dry portions of the study area. Cattail, bulrush, and burreed were more abundant where soil moisture was returned throughout the drawdown. Rice cutgrass and mannagrasses were generally distributed. Waterfowl utilization of the area increased in late summer 1959. Abundant food attracted ducks, and increased cover caused increased use by breeding waterfowl in 1960. Soil and water analyses indicated a definite increase in plant nutrients, especially soil nitrates due to aerobic nitrification. Invertebrate populations were considerably reduced after the drawdown.

Kurtz, D.; Hanson, K.; Aspinall, R. 1998. Geographic Characterization of Exotic Plant Species in Grand Teton National Park, Wyoming. National Park Service Investigator's Annual Report, Grand Teton National Park.

<https://science1.nature.nps.gov/research/ac/iars/search/iarView?reportId=4228>.

15 September, 2005.

Objectives of this study included: 1) to map and sample a distribution of Priority-1 exotic plant species in Grand Teton National Park; 2) to analyze the environmental factors underlying these distributions; 3) to determine the associations of the distributions with the environmental factors; 4) to determine the probability of other areas to be suitable habitat for Canada thistle (*Cirsium arvense*) and musk thistle (*Carduus nutans*) based on present distributions of these two species.

Findings and Status:

201 sites were visited in the south-eastern portion of Grand Teton National Park. Canada thistle was present in 7% of the sites visited. Musk thistle was present in 16% of the sites visited. Chi square tests determined elevation, geology, soil, grazing allotments, and distance from hydrography to be significantly associated with musk thistle; and geology, soil, grazing allotments, and distance from roads to be significantly associated with Canada thistle. By combining conditional probabilities of these environmental factors with Bayes probability theorem and GIS, a map has been produced to show the probability of suitable habitat for these two species, based on the present distribution and the associated environmental factors, in areas beyond the sampled sites.

Marston, R.A. 1990. Changes in geomorphic processes in the Snake River following impoundment of Jackson Lake and potential changes due to the 1988 fires in the watershed. In: University of Wyoming National Park Service Research Center 1990 Semiannual Report, (H.J. Harlow and M. Harlow, eds.)
(Note: Also found in 1991 Annual Report)

This report summarizes the objectives and preliminary results of a three year study designed to describe, explain, and predict changes in the geomorphology of the Snake River from Jackson Lake to Moose. It also aims to describe the related changes in riparian vegetation due to Jackson Lake Dam and 1988 fires in the watershed. Specific objectives are to determine changes over time and space in the following: 1) sediment mobilization on hillslopes from rainsplash and overland flow; 2) sediment delivery to streams for slope failures; 3) equilibrium condition and relative stability of the Snake River; and 4) extent of various riparian vegetation communities in the Snake River floodplain. Overall, the 1988 fires have increased sediment mobilization on hillslopes due to rainsplash and overland flow. Sediment supplied to streams from rainsplash and overland flow will be too small to cause persistent changes in channel morphology. The closure of Palisades Reservoir initiated changes in the reservoir release schedule of Jackson Lake Dam. Lack of peak flows cause the braided sections of the Snake River to revert to a compound pattern and eventually to single meandering channels. Five riparian communities have been tentatively identified which include: unvegetated channel deposits, shrub-swamp community dominated by willow and mountain alder, open forest dominated by cottonwood, mixed forest, and closed forest.

Marston, R.A. & Anderson, J.E. 1991. Watersheds and vegetation of the Greater Yellowstone Ecosystem. *Conservation Biology* 5:3 p. 338.

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 can be geographically defined as the Yellowstone Plateau and elevations in the 14 surrounding mountain ranges above the 2130-meter (7000-foot) contour: certain lower elevations need to be included to account for some ecological processes. 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 attendant 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.

Martinson, Greg. 2002. Ecological genetics of cottonwood hybrid trees. National Park Service Investigator's Annual Report, Grand Teton National Park.
<http://science.nature.nps.gov/research/ac/iars/search/iarView?reportId=24553>. 30 June 2005.

We address the basic premise that genetic variation in a dominant plant structures communities and significantly affects ecosystem processes. To address the above hypothesis, we have been focusing on cottonwood gallery forests, one of the most productive and sensitive components of riparian ecosystems in western North America. Just as sites within a hybrid zone vary in genetic structure, the genetic structures of entire hybrid zones vary among rivers. Different hybrid zones vary greatly in genetic structure such that some rivers are composed of many backcrosses and few F₁s, whereas other rivers are composed of many F₁s and few or no backcrosses (Martinsen et al. 2001). Cottonwoods have hybridized in every river system of the West (Eckenwalder 1984a,b). Hybrid cottonwoods ~12 million years old have been recorded in the fossil record, and hybridization events have probably occurred many times as glaciers retreated (Eckenwalder 1984c). By examining different river systems we have an opportunity to examine the landscape level implications of hybridization on the arthropod community and on ecosystem-level processes. Our first efforts to utilize this biogeographic perspective were highly successful. Genetic analyses are now complete on 5 rivers and samples taken from 12 more rivers await processing. Once these genetic analyses are completed, we can census arthropods on these same trees to determine how the underlying genetic structure of the pure and hybrid zones affects arthropod biodiversity. In our efforts to catalog the genetic diversity of hybrid zones

along rivers throughout the western U.S., we collected leaf samples from 20 trees each along the Snake River and Cottonwood Creek in the Teton National Park. The DNA from these trees has been extracted and is awaiting analysis. We have begun to identify SNPs (single nucleotide polymorphism markers) from 35 RFLP (restriction fragment length polymorphism) markers that are distributed across the *Populus* genome. These markers are extremely important because we have used them to determine the patterns of hybridization and the occurrence of introgression in natural populations (Keim et al. 1989; Martinsen et al 2001). Because specific RFLP markers introgress far across the hybrid zone, any gene in the region or fragment of the genome surrounding the RFLP markers introgresses. Once SNPs have been identified from the RFLP markers, we can place these markers on a detailed genetic map constructed using a synthetic backcross population (Woolbright et al. 2002). Previous QTL analyses revealed the location of genes influencing traits such as tannin concentration, internode length, phenology and even fitness traits such as seed production and cloning ability (Schweitzer et al. 2002). Combining our knowledge of the introgression of the RFLP markers in natural hybrid zones with that of the QTL analysis in our synthetic backcross population may reveal adaptive genes that naturally introgress from Fremont to narrowleaf cottonwood.

Mills, Jack. 1983. GIS-based spatial analysis of channel and vegetation responses to dynamic and below river dam flows. Papers and Proceedings of Applied Geography Conferences. State University of New York at Binghamton.

In this study, a GIS was used to spatially analyze a randomly selected section of the Snake River floodplain between Jackson Lake Dam and Moose, Wyoming in Grand Teton National Park. Its goal was to determine what influence, if any, a finer spatial scale might have on results obtained from an earlier study of the same floodplain conducted at the landscape scale. The imported data for each year, consisting of boundary arcs and topology points, were converted into polygons which were classified into RIVER, UNVEGetated deposits, GRASS-covered deposits, WILLOW-alder shrubs, COTTONwood, MIXED cottonwood-blue spruce and Blue SPRuce. After colors were assigned to each class, images of both maps were created and displayed. Results indicate that 48% of the 1945 RIVER remained as RIVER in 1989, while 27% became UNVEGetated deposits, 5% went to GRASS, 11% to willow, 5% to COTTONwood, and 4% to MIXED cottonwood-blue spruce. In the MIXED cottonwood-blue spruce community, 57% remained as MIXED while 36% reverted to willow. This information substantiates the conclusion that, while the study area as a whole had experienced stabilizing conditions between 1945 and 1989, the selected section had become more unstable. This dichotomy of conclusions suggests that scale differences must be taken into account when reporting this type of research.

Mills, John D. 1991. Wyoming's Jackson Lake Dam, horizontal channel stability and floodplain vegetation dynamics. M.A. Thesis: Department of Geography and Recreation. University of Wyoming.

The stream channel and floodplain vegetation along the Snake River immediately below the Jackson lake Dam in GTNP, Wyoming have responded to changes in the operation of the dam. Flood flows decreased after Palisades Reservoir was closed downstream in 1957. As a result, horizontal channel stability increased except immediately below tributaries and cutbacks where the added sediment load could no longer be readily transported. The diversity of floodplain vegetation, as measured by the Shannon-Weiner function, increased after 1957 because the increased horizontal stability of the Snake River allowed forested communities to expand.

Wallen, Rick. 1992. The status and distribution of exotic plants in Grand Teton National Park. National Park service Investigator's annual Report. Grand Teton National Park. <https://science1.nature.nps.gov/research/ac/iars/search/iarView?reportId=4166>. 15 September 2005.
(Note: this project began in the 1991 field season.)

The objective of this project is to Document the distribution and quantify the abundance of exotic plants throughout the park. At this juncture, Canadian thistle is the most abundant exotic plant species in GTNP, while spotted knapweed and musk thistle also are found in large numbers.

Weber, Keith. 2000. Assessment of land cover changes in the upper Snake River plain and Greater Yellowstone Ecosystem. National Park Service Investigator's Annual Report, Grand Teton National Park. <http://science.nature.nps.gov/research/ac/iars/search/iarView?reportId=19611>. 30 June 2005.

Changes in the landscape affect everyone. Loss of native vegetation reduces the biodiversity, vigor, and viability of the ecosystem, and landcover changes can alter hydrologic cycles, induce or accelerate soil erosion, and impact wildlife populations. To quantitatively assess the rate and extent of landscape changes we will use GIS and remotely sensed imagery. This information will be invaluable to land use managers and planners on the INEEL as well as land managers in the community. RESULTS: A total of 24 sets ($n = 48$) of points were sampled in 2000. A difference threshold of 5 percent change between points in a pair was used for creating error matrices (Weber 2001). LUCCAS estimated a change where as little as 1 percent change in cover occurred, but due to small sample size and a large amount of variability (environmental heterogeneity) we decided to be conservative when assigning an arbitrary threshold. No statistical differences were found in the total vegetative cover of points designated as no change versus those designated as change (t-test; $t = -0.738$, $df = 22$, $p = 0.468$). However, the error matrices suggest that LUCCAS is accurately detecting changes in grass and woody

cover. We expected differences in the percentage of bare ground between pairs of points to be most indicative of LUCCAS accuracy but this was not the case. Percent bare ground had a lower producer's accuracy (54.17 percent) than percent grass (79.17 percent) or percent woody species (83.33 percent).

Wrazien, David R. 1993. GIS investigations of horizontal channel migration and floodplain vegetation development: Snake River, Wyoming. M.A. Thesis: Department of Geography and Recreation. University of Wyoming.

Changes in the release schedule of Jackson Dam in Grand Teton National Park, Wyoming since 1957 have altered flow conditions on the Snake River. Altered flow conditions have affected channel stability and vegetation diversity. A geographical information system (GIS) explains and predicts spatial and temporal variations in floodplain vegetation development, relative to trends in horizontal channel migration.

Jackson Lake Draw-down Project Large Woody Debris Annotated Bibliography

Gray, Robin D., 2003. Distribution and characterization of large woody debris along the Snake River in Grand Teton National Park, WY. M.A. Thesis: Department of Geography and Recreation. University of Wyoming.

The purpose of this thesis is to understand the distribution and character of large woody debris within the Snake River. Furthermore, comparing the distribution and composition of LWD within the study area will provide insight on sources of LWD and formation of LWD accumulations. Understanding these processes will, in turn, provide a foundation for developing best management practices and to allow for management of natural river processes while maintaining or enhancing recreational opportunities. Field data was collected along the Snake River, GTNP, in the summer of 1999. The 42 km study section was divided into five reaches based on previous research differentiating channel morphology. Occurrences of LWD and associated characteristics were mapped and recorded. Bank vegetation and stability was noted and channel geomorphology data collected. Results indicate that occurrences of LWD are not distributed equally among study reaches. Detailed studies of 41 LWD accumulations showed that LWD containing rootwads must be present for the creation and stabilization of jams and that as channel gradient, sinuosity, and floodplain width increased, the total number of jams per km increased. Initial results also indicate that Jackson Lake Dam may effect the distribution of LWD within the study area by modifying the natural flow regime of the river.

Marcus, W.A., Marston R. A., Colvard, C.R., & Gray, R.D. 2002. Mapping the spatial and temporal distributions of woody debris in streams of the Greater Yellowstone Ecosystem, USA. *Geomorphology*. 44:3-4. pp 323-335.

The objectives of this study were: (1) to document spatial and temporal distributions of large woody debris (LWD) at watershed scales and investigate some of the controlling processes; and (2) to judge the potential for mapping LWD accumulations with airborne multispectral imagery. Field surveys were conducted on the Snake River, Soda Butte Creek, and Cache Creek in the Greater Yellowstone Ecosystem, USA. The amount of woody debris per kilometer is highest in 2nd order streams, widely variable in 3rd and 4th order streams, and relatively low in the 6th order system. Floods led to increases in woody debris in 2nd order streams. Floods redistributed the wood in 3rd and 4th order streams, removing it from the channel and stranding it on bars, but appeared to generate little change in the total amount of wood throughout the channel system. The movement of woody debris suggests a system that is the reverse of most sediment transport systems in mountains. In 1st and 2nd order tributaries, the wood is too large to be moved and the system is transport-limited, with floods introducing new material through undercutting, but not removing wood through downstream transport. In the intermediate 3rd and 4th order channels, the system displays characteristics of dynamic equilibrium, where the channel is able remove the debris at approximately the same rate that it is introduced. The spatial distribution and quantity of wood in 3rd and 4th order reaches varies widely, however, as wood

is alternatively stranded on gravel bars or moved downstream during periods of bar mobilization. In the 6th order and larger channels, the system becomes supply-limited, where almost all material in the main stream can be transported out of the central channel by normal stream flows and deposition occurs primarily on banks or in eddy pool environments. Attempts to map woody debris with 1-m resolution digital four-band imagery were generally unsuccessful, primarily because the imagery could not distinguish the narrow logs within a pixel from the surrounding sand and gravel background and due to problems in precisely coregistering imagery and field maps.

Marston, R.A. & Gray, R.D. 1999. Spatial Distribution of large woody debris on the Snake River, Grand Teton National Park. University of Wyoming National Park Service Research Center 23rd Annual Report (H.J. Harlow and M. Harlow, eds.) pp119-123.

Large woody debris plays a key role in controlling the ecology and geomorphology of streams. Woody debris traps coarse particulate matter and sediments. This study documents the distribution of LWD jams on the Snake River in Grand Teton National Park, WY in an attempt to understand the effects of LWD on channel morphology in large river systems. The study area encompasses the Snake River from Jackson Lake to Moose, Wyoming. Forty-one in channel jams were measured and the total number of LWD pieces ranged from 3 to 75 with a mean of 12. Jam sizes ranged from 18.36m^2 to 693m^2 , averaging 165m^2 . Jackson Lake Dam plays an important role in LWD distribution, preventing LWD from entering the system from Jackson Lake. Transport by stream flow and geomorphic factors as well as channel shifting may play an important role in the size and location of jams.

Marston, R.A. & Gray, R.D. 2000. Spatial Distribution of large woody debris on the Snake River, Grand Teton National Park. (unpublished--Copy received from Dr. Bill Gribb, Professor of Geography, University of Wyoming).

The purpose of this study is to document the distribution of large woody debris jams on the Snake River in GTNP, Wyoming in order to understand the effects of LWD on channel morphology in large river systems. The study area encompassed the Snake River from Jackson Lake to Moose, Wyoming. Detailed measurements on 41 in-channel LWD accumulations at ten locations were performed. Mapping and recording several streamside vegetation and bank geomorphology variables also determined LWD recruitment potential. For the 41 in-channel jams measured, the total number of LWD pieces ranged from 3 to 75, with a mean of twelve. Jam sizes ranged from 18.36m^2 to 693m^2 , averaging 165m^2 . More than 500 occurrences of in-channel LWD were identified on the 42.0 km long study section. Rootwads were found to act as an anchor for developing LWD jams, and bank undercutting provides the primary means of recruitment for these rootwads. Jackson Lake Dam plays an important role in LWD distribution by preventing LWD from entering the system from Jackson Lake. Consequently, LWD jams are expected to increase as the distance from the dam increases. Data

also indicates that streamside vegetation recruitment and channel morphology play a significant role in LWD jam size and distribution.

Obedzinski, R.A.; Shaw C.G.; & Neary, D.G. 2001. Declining woody vegetation in riparian ecosystems of the western United States. *Western Journal of Applied Forestry* 16:4 pp 169-181.

Riparian ecosystems serve critical ecological functions in western landscapes. The woody plant components in many of these keystone systems are in serious decline. Among the causes are invasion by exotic species, stress-induced mortality, increases in insect and disease attack, drought, beaver, fire, climatic changes, and various anthropogenic activities. The latter include agricultural development, groundwater depletion, dam construction, water diversion, gravel mining, timber harvesting, recreation, urbanization, and grazing. This article examines the factors implicated in the decline and discusses the importance of interactions among these factors in causing decline. It also clarifies issues that need to be addressed in order to restore and maintain sustainable riparian ecosystems in the western United States, including the function of vegetation, silvics of the woody plant species involved, hydrologic condition, riparian zone structure, and landscape features, geomorphology, and management objectives.

Jackson Lake Draw-down Project Macrophyte Annotated Bibliography

Brewer, Carol & Parker, Michael. 1983. Distribution of littoral macrophytes in Jackson Lake, Wyoming. In: University of Wyoming National Park Service 7th Annual Report (K. Diem, Director). pp 73-76.

The research described here is part of a 2-year study to characterize the structure and function of the littoral macrophyte community in Jackson Lake, Grand Teton National Park. The objectives for the first year were: 1) to identify the plant species occurring in the lake; 2) to quantify their relative abundances; 3) to characterize the littoral habitat, and; 4) to construct a detailed map of macrophyte distribution. Data collected during the first field season will be used to help evaluate results of experiments conducted during year two on mechanisms affecting macrophyte segregation.

Brewer, Carol & Parker, Michael. 1985. Distribution and composition of substrate in the littoral zone in Jackson Lake, Grand Teton National Park, Wyoming. In: University of Wyoming National Park Service 9th Annual Report (K. Diem, Director). pp 56-62.

The composition of sediments varies both horizontally and vertically in a lake. The distribution of sediment types is related not only to basin geomorphology, but also to the effect of turbulent water as it moves substrate particles in the littoral zone. Definite patterns of erosion and deposition in lakes have been described by many limnologists (e.g. Hutchinson, 1957; Spence, 1982; Keddy, 1982-84.) Sedimentation and the quality of sediments as a nutrient source affect the ability of macrophytes to colonize and persist in the littoral habitat. The ability to root in a particular area is directly related to the extent which a substrate can anchor the potentially large plants (Spence, 1982). On erosional shores, suspended sediments abrade rooted plants and may cause damage and breakage. On the other hand, the macrophyte community stabilizes bottom sediments and their presence leads to increased water clarity as particulates settle out due to reduced water currents within plant beds.

Since the relationship between plants and sediments is well known, our objective was to measure the distribution and composition of the sediments in the littoral zone of the lake. Then we could relate the distribution of the substrate to the distribution we had measured for macrophytes in the littoral zone.

Brewer, Carol A. 1986. An investigation of the aquatic macrophyte community in Jackson Lake Wyoming: distribution, effect of moving water, and species-specific tensile properties. M.S. Thesis Department of Zoology and Physiology. University of Wyoming.

The thesis was initiated to gain baseline information on the aquatic macrophyte community in Jackson Lake in an effort to evaluate several management questions including the effect renovation of the Jackson Lake Dam would have on the biological communities in the lake and how to reduce the formation of floating mats. Submergent macrophytes were identified and a species list compiled. The distribution of the various species was also mapped and factors controlling their distribution were also identified. Plant breakage and water movement experiments were also conducted. Water levels related to drawdown seem to be related to macrophyte mat formation as well as changes in the distribution of macrophytes. Drawdown effects on macrophytes appear to be of great importance as these aquatic plants serve as a food source and habitat for invertebrates, fish and waterfowl.

Brewer, Carol A. & Parker, Michael. 1990. Adaptations of macrophytes to life in moving water: upslope limits and mechanical properties of stems. *Hydrobiologia*: 194. pp 133-142.

Structural properties of vascular aquatic macrophyte stems were studied from a mechanical perspective using data from Jackson Lake, Grand Teton National Park, Wyoming. Stem tensile strength, extensibility and cross sectional width were measured for seven vascular freshwater species. Mean values for these properties were significantly different when all species were compared. Moreover, tensile strength and extensibility were significantly different when deep water species were compared with shallow water species. Extensibility was significantly different when species duplicating by clone production were compared with species switching between clonal and sexual duplication, but tensile strength was not statistically different. Force to break a stem was modeled as a significantly increasing power function of stem cross sectional area ($R^2 = 86.0\%$). Species specific tensile properties are considered as factors that can regulate the upslope distribution of macrophytes in moving water.

Brewer, Carol A. 1991. Assessment of the aquatic plant community in Jackson Lake, Grand Teton National Park, Wyoming: 1991 Status Report. In: University of Wyoming National Park Service Research Center 15th Annual Report (H.J. Harlow and M. Harlow, eds.), pp 139-143.

Changing water levels, a consequence of reservoir drawdown schedules, alter plant community species composition over time. From the perspective a plant, water level changes present a challenge to growth and community persistence. The most recent perturbations to the littoral habitat in Jackson Lake began in 1978, when the water level was lowered from 2065m to

approximately 2060m. It was further lowered in 1985 to facilitate repair and modification of Jackson Lake Dam. The entire lakebed was seriously impacted during the time that the dam was being restored, in particularly the shallow littoral zone that was exposed. Because of severe impacts to the littoral habitat and significant reduction of the submergent plant community caused by the restoration of the dam, the status of the aquatic plant community was monitored during the summers of 1989-1991. This report summarizes the status of the aquatic plant community three years after the repair of the dam was completed.

Brewer, Carol A. 1995. The submersed aquatic plant community in Jackson Lake, Grand Teton National Park, Wyoming. In: University of Wyoming National Park Service Research Center 19th Annual Report (H.J. Harlow and M. Harlow, eds.), pp 14-18.

Water level fluctuations are a challenge to plant growth. Disturbances associated with changing water levels include ice scour during winter drawdown, abrasion due to increased erosion along the lake shore, and wave action. The magnitude and timing of water level fluctuations may be the most important factor regulating macrophyte community processes at shallower depths in reservoirs. Twelve species of rooted aquatic macrophytes were collected in Jackson Lake in 1995, and species richness remained low when compared to the time period before the dam was repaired. Peak cover was found at depths of 3-6 meters. Most species at Jackson Lake have patchy, disjunct distributions. Data and observations suggest that Jackson Lake is organized by physical processes acting along the vertical gradient. Downslope, it is possible that the bottom limit of macrophytes in the lake depends on light penetration and possibly temperature.

Brewer, Carol A. 1996. Seed bank viability in Jackson Lake Grand Teton National Park, Wyoming. University of Wyoming National Park Service Research Center 20th Annual Report, (H.J. Harlow and M. Harlow, eds.) pp 31-34.

Since the early 1900's, Jackson Lake has been influenced by a series of drawdowns of varying magnitude that influenced the composition of and extent of the macrophyte community in the littoral zone. Initial work on plant community dynamics in Jackson Lake has shown that the aquatic plant community in Jackson Lake has been exposed to a varied disturbance regime that has impacted recolonization, species diversity and peak biomass development. Drawdown schedules and resulting fluctuating water levels may be selecting for a plant community characterized by low diversity and patchy distribution. This study attempts to establish protocols and collect preliminary data on potential for recruiting macrophytes from the littoral seed bank by measuring germination of seeds from the lake sediments. Lake bed sediments were collected from shallow shelf and sheltered bay habitats in the area of Third Creek drainage. Few seedlings were germinated from sediments collected from depths less than 4m. The greatest germination occurred from samples collected at depths greater than 6m. Many seeds tend to fall and accumulate in deeper water after drawdown.

Vertebrates

General Wildlife (pp 58-59)

Amphibians (pp 60-62)

Beavers/Otters (pp 63-70)

Birds (pp 71-76)

Fish (pp 77-85)

Small Mammals (pp 86-89)

Jackson Lake Draw-down Project General Wildlife Annotated Bibliography

Gerhart, W.A., & Olson, R.A. 1982. Handbook for evaluating the importance of Wyoming's riparian habitat to terrestrial wildlife. Wyoming Game and Fish Department.

In 1978, the Wyoming Game and Fish Department took on the task of developing a habitat evaluation system for determining the importance and relative value of riparian habitat to the maintenance and well-being of the State's terrestrial wildlife resources. The system was designed to provide biologists, resource managers, and administrators with an additional tool for assessing the potential wildlife impacts of contemplated land-use changes in riparian areas. In addition, the technique was designed to preclude the initiation of a complete wildlife survey at each individual site. The impetus behind the project was and is concern over the potential loss and alteration of riparian habitats to development and industrialization together with a lack of knowledge regarding the basic ecology of these disproportionately valuable ecosystems to wild animals.

The entire evaluation scheme was designed around basic wildlife-habitat relationships and each species relative dependence on riparian systems for survival from information obtained from the literature and the expertise of Department biologists. Criteria for determining animals potentially present in an area and their preference for a specific habitat or combination of habitats were based on each species geographic distribution patterns, Kuchler potential natural vegetation zone occurrence and use, habitat type occurrence and use, life form classifications, and special habitat requirements. The relative value of riparian habitats to terrestrial vertebrates was based on the number of species potentially present within a specific riparian community type and on the biological status, riparian affinity status, and overall habitat value index scores assigned to each animal. Biological status scores ranging from 1 to 3 were assigned to each animal on the basis of their current statewide population status and trend. Riparian affinity status scores were assigned to each species on the basis of their statewide relative degree of dependence on riparian habitat for survival during all physiological life stages and seasons other than water available for consumption. Riparian affinity scores ranged from 0 to 3 with a value of 0 representing an animal with "complete independence" of riparian habitat for survival and a score of 3 representing "complete dependence" on riparian systems for survival. The habitat value index scores ranging from 0 to 6 for each species was determined by summing the biological status and riparian affinity status scores. In those instances where the riparian affinity status was equal to 0, the corresponding habitat value index score was 0 under the assumption that the species is not dependent on riparian habitat for survival. Greater habitat value index scores reflect a more critical dependence on riparian habitat for survival and a correspondingly higher biological status value.

On the basis of riparian affinity status scores, 37 to 43 percent of the terrestrial species in the state prefer and are to some degree dependent on and require riparian habitat for survival. Of the 445 species in the state rated, 21 percent prefer riparian habitats exclusively, 39 percent prefer non-riparian types exclusively, and the remaining 40 percent prefer a combination. Even though the vast majority of Wyoming consists of non-riparian habitat, only 20 percent of the species rated had riparian affinity scores of 0, which reflects "complete independence" from riparian systems for survival while approximately 18 percent of all animals evaluated had scores

of 3 which indicates complete dependence on riparian habitats for survival. The remaining 62 percent had scores of 0-1, 0-2, 0-3, 1, 1-2, 1-3, 2, and 2-3. The apparent contributions of riparian habitat to the maintenance and well-being of the State's terrestrial wildlife is significant particularly when compared to the small amount of riparian habitat present.

The technique developed can be used to evaluate the relative terrestrial wildlife value of riparian areas anywhere in the State given the location and type of riparian habitat present by merely checking or marking those species potentially present in the geographic area or degree block under investigation, those species, associated with the appropriate Kuchler vegetation zone and those species which prefer or favor the specific type of riparian habitat present. The number, the biological status, riparian affinity status, and overall habitat value index scores are calculated by summing the values for the species marked. The final values represent the relative wildlife value of the specific riparian habitat type present in that particular Kuchler potential natural vegetation zone within the degree block or geographic area being evaluated.

Harry, B. & Dilley, W.E. 1972. Wildlife of Yellowstone and Grand Teton National Parks. Salt Lake City: Wheelwright Press.

This book lists all vertebrate animals, with the exception of birds, that have been recorded in Grand Teton and Yellowstone National Parks. It includes pictures and text to aid in identification of specific species. The text also suggests likely locations and habitats to find common animals. Common and scientific names are included in an index.

Schroeder, R.L., Allen, A.W. 1992. Assessment of habitat of wildlife communities on the Snake River, Jackson, Wyoming. United States Department of the Interior—Fish and Wildlife Service Resource Publication 190. Washington D.C.

The composition of the wildlife community in western riparian habitats is influenced by the horizontal and vertical distribution of vegetation, the physical complexity of the channel, and barriers to movement along the corridor. A model was developed to evaluate the wildlife community along the Snake River near Jackson, Wyoming. The model compares the conditions of the current or future years with conditions in 1956, before construction of levees along the river. Conditions in 1956 are assumed to approximate the desirable distribution on plant cover types and the associated wildlife community and are used a standard of comparison in the model. The model may be applied with remotely sensed data and is compatible with a geographic information systems analysis. The model also evaluates floodplain and channel complexity and assesses anthropogenic disturbance and its potential effect on the quality of wildlife habitat and movement of wildlife in the riparian corridor.

Jackson Lake Draw-down Project Amphibian Annotated Bibliography

Harlow, M. & Harlow, T.S. 2000. Movements and habitat use of boreal toads in the Snake River Quarry Area. University of Wyoming National Park Research Service Center 24th Annual Report. (H.J. Harlow and M. Harlow, eds.) pp 38-50.

Nine boreal toads (*Bufo boreas*) were captured during the summer of 1999 at the Snake River Quarry and fitted with telemetry transmitters. Locations were determined approximately once each week. Females may be leaving the quarry site around mid-summer while males remain in the area throughout the summer. Toads prefer two aquatic sites until around mid-July then dispersed to dryer terrestrial areas with a preference for three sites characterized by loose soil, which provided good burrow shelter. This quarry is to undergo major reclamation efforts. It is recommended to: 1) stay major construction disturbance until the females undertake their seasonal departure from the area, 2) preserve the breeding and preferred aquatic habitat, and 3) capture male toads from the preferred terrestrial areas and reintroduce them back after reclamation is completed.

Hawk, J.E., & Peterson, C.R. 1997. Amphibian declines in the Greater Yellowstone Ecosystem: Toads with protection from bacterial disease. University of Wyoming National Park Service Research Center 21st Annual Report. (H.J. Harlow and M. Harlow eds.) pp 81-98.

Boreal Toads have declined in the Greater Yellowstone Ecosystem. In summer of 1997, twelve breeding and fifteen non-breeding sites were sampled. Water samples were collected for determining bacterial densities and chemical analysis. The results of the study verified that the remaining Boreal Toad breeding sites found in the GYE are predominately found in areas with high conductivity in comparison to historical sites where breeding no longer occurs and other amphibian breeding sites where toad breeding has not been detected. Densities of *Aeromonas hydrophila*, a causative agent of redleg, were found to be positively correlated with conductivity, alkalinity, pH, and temperature and are opposite of previous predictions.

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

This is a general guidebook to amphibians and reptiles of these national parks including species description, approximate location, etc.

Peterson, Charles. 1997. (multiple projects) 1. The Distribution of Amphibians and Reptiles in Grand Teton National Park. (continuation) 2. Monitoring Amphibian Populations in the Greater Yellowstone Ecosystem. (continuation) 3. Adaptive Management Component of Amphibian and Reptile Surveys, Monitoring, and Research. (continuation) 4. Amphibian Declines in the Greater Yellowstone Ecosystem: Do Geothermally Influenced Waters Provide Boreal Toads with Protection from Bacterial Disease? National Park Service Investigator's Annual Report, GTNP.
<http://science.nature.nps.gov/research/ac/iars/search/iarView?reportId=4209>. 1 July 2005.

Objectives of this study include the following: 1) Determine the distribution of amphibians and reptiles in Grand Teton National Park; 2) Monitor amphibian populations to determine status and trends; 3) Contribute to adaptive management through conducting surveys, compiling information, and formulating recommendations for the conservation of amphibian and reptile populations in areas that may be affected by development projects or other human activities; 4) Test hypotheses concerning the causes of changes in amphibian and reptile populations. Current project investigates relationships among water chemistry, toad breeding, and densities of the bacterium *Aeromonas hydrophila*, the causative agent of redleg disease.

Findings and status of the project are as follows: 1) Distribution: We have continued to increase the amount of distribution information for amphibians and reptiles in Grand Teton National Park (GTNP). Employing experienced volunteers, we conducted surveys in backcountry areas: Berry, Owl, and Moose Creeks, west of Jackson Lake. This was a pilot effort for mapping distribution in remote areas. We are compiling survey results into our database and GIS. We are planning to continue this type of survey in 1998. We also conducted an amphibian training session for interested Park naturalists/volunteers. Their observations from this summer will be included in the amphibian/reptile database. 2) Monitoring: We continued monitoring at two amphibian breeding sites in GTNP, with field assistance from Resources Management. Results of our six years of monitoring at these sites are being compiled for a report and publication. We are expanding our monitoring program to include a network of sites across the Greater Yellowstone Ecosystem. In 1997, we designed and tested a system for randomly selecting potential monitoring areas. Five of the selected test areas are in GTNP. In the future, we plan to apply this system for increasing the number of monitoring sites and the effectiveness of monitoring in GTNP. The expanded monitoring program will enable us to detect declines in amphibian populations across the Greater Yellowstone Ecosystem. 3) Adaptive management: As requested by Resources Management, we surveyed wetlands at the Snake River gravel quarry area, which is targeted for restoration. We found Boreal Toads and Boreal Chorus Frogs breeding in the area. Because Boreal Toads are a species of special concern due to suspected population declines, we continued monitoring at this site throughout the summer. We submitted a report describing amphibian use of the quarry area to GTNP, with recommendations for protecting toads and enhancing habitat.; Responding to an observation from a Resources Management employee, we surveyed for Bullfrog tadpoles in a warm-water ditch that flows from Kelly Warm Springs and eventually reaches Ditch Creek. Bullfrog tadpoles in late stages of development were observed at several sites along the ditch near Blacktail Butte. The Bullfrog is an introduced species, which has had adverse effects on native amphibians elsewhere in the western U.S. We plan to continue surveys in the Kelly Warm Springs area to determine if

Bullfrogs are successfully colonizing new areas through ditches and natural drainages. 4)
Research: Boreal Toad (*Bufo boreas boreas*) populations have declined and disappeared throughout much of the Grand Teton/Yellowstone area over the past 40 years, but populations have persisted in many geothermally influenced wetlands. At many sites where toads continue to breed, there is unusual water chemistry, including high conductivity and high acid neutralizing capacity. We hypothesized that toads may be protected from a common bacterial disease, known as redleg, by the unusual water chemistry found at these sites. In 1997, we sampled 28 sites. Contrary to expectations, we found that bacterial densities increased with conductivity, and that the occurrence of toad breeding was positively related to bacterial densities. We are preparing a report of this study for the University of Wyoming National Park Service Research Center. In 1998, we will continue the laboratory portion of this study, testing for relationships among water chemistry, water temperature, bacterial densities, and Boreal Toad tadpole resistance to redleg disease.

Woodward, B. & Mitchell, S. 1992. Temperature variation and species interactions in aquatic systems in Grand Teton National Park. University of Wyoming National Park Service Research Center 16th Annual Report. (G.E. Plumb and H.J. Harlow, eds.) pp. 140-145.

Temperature variation and species interactions were examined in small montane ponds in Grand Teton National Park during summer 1991. Temperature variation was pronounced, both over time and from place to place within one pond or across ponds. The magnitude of the temperature variation is such that it is likely to lead to large differences in the growth rates of poikilotherms that occupy these ponds. Growth rates determine body sizes at any one point in time. Tadpole body size influenced the probability of predation by salamander larvae in these montane ponds in GTNP. Given the natural body size ratios of predator and prey (observed in 1991), salamanders biased predation towards smaller tadpoles. Other predation experiments revealed that the salamander larvae biased predation towards tadpoles and away from damselfly naiads. This suggests that damselflies may experience lower predation by salamanders when in the presence of tadpoles than when in the absence of tadpoles. Several species, including snails, caddisfly larvae, and tadpoles were very abundant in some ponds, but could be essentially absent from others. These three taxa appear to share similar diets. A simple experiment revealed the *Pseudoeurycea* tadpoles and the snails compete, and that presence of salamander larvae had no effect on the strength of their competitive interaction.

Jackson Lake Draw-down Project Beavers and Otters Annotated Bibliography

Collins, T. C. 1976. Population characteristics and habitat relationships of beavers, *Castor Canadensis*, in Northwest Wyoming. Ph.D Thesis, Department of Zoology and Physiology, University of Wyoming.
(note: hard copy can be accessed only through UW Dept of Zoology or on Microfiche in UW Science Library)

Unexploited beaver populations of GTNP in northwest Wyoming were investigated from 1974 through 1976 to assess population characteristics and habitat relationships. Data were obtained on 103 beaver colonies, 51 of which were located on the Snake River floodplain, the largest habitat source for beavers in the Park. The sample of 174 beavers examined included 91 live trapped and 83 carcasses, the latter obtained from throughout Wyoming. In GTNP, the beaver populations appear at carrying capacity.

Beaver abundance on the major streams was 0.9 colonies/km with an average of 5.2 beavers/colony. Eighty percent of adult females live-trapped between May and July were lactating. Parturition usually occurred between mid-May and mid-June. The first age of breeding was usually three years, though some individuals bred in their second and possibly fourth year. There were 2.1 kits and 2.0 yearlings per colony for those colonies with these age classes, suggesting low realized fertility. Adult mortality appeared low, the major observed causes appearing damage control on private lands within the Park, road kill, and disease. Most offspring dispersed from family groups at age two, though some individuals were suspected to have delayed dispersal to age three.

Age/weight regression analyses demonstrated that beavers grow rapidly early in life and reach adult proportions by age three or four. The percent of adults, yearlings, and kits in the carcass and live trapped samples were 51, 24, 25, and 49, 29, 22 respectively. Significant differences in sex ratios were obtained only for live trapped adults with a preponderance of adult males.

Colonies on the major streams in GTNP exhibited territorial packing with no home range overlap unless vacant habitat separated colonies. There were no expansions and contractions of territories, and active marking of territorial boundaries appeared related to the potential for encountering beavers from neighboring colonies or transients. Pond colonies isolated from stream courses and other colonies seldom marked territories.

Analyses of annual cutting rates of woody vegetation and seasonal food selection demonstrated that beavers are broad-niched animals with respect to forage utilization but show strong preferences for certain plant species and size classes. The distance beavers will travel to cut woody vegetation correlated with species size and class preference. Fecal analysis of food habits demonstrated a seasonal change in selectivity correlated positively with availability of alternate food resources. Forbs and graminoids constituted 50 percent of the summer diet. Beavers and moose demonstrated food resource overlap, but moose were the broader niched animal with respect to forage utilization. Habitat degradation and shrub decadency appeared to be affected to a greater extent by beavers when their home ranges were small and the habitat had

a low plant species diversity index. Data are presented which suggest that in some localities the beavers' cutting of woody vegetation enhanced plant succession to climax vegetation.

Beaver populations on one impaired and two unimpaired streams were studied to assess the influence of seasonal flow regimes on population abundance, distribution, and movements. Seasonal movements caused by fluctuations in stream flow were typical for beaver populations in GTNP. Reduction in habitat and scarcity of dwelling sites at low flow rates restricted potential colony density and dictated beaver carrying capacity. Most colonies forced to abandon at low stream flows re-established in precariously eroding stream banks while other abandoning colonies left their territories in search of suitable denning sites. Most new and re-establishing colonies cut food caches regardless of stream conditions or previous experience, suggesting that building of dwellings during the fall months releases caching behavior. Other behavioral and faunal relationships are discussed.

Collins, T.C. 1977. Instream flows for beaver populations: Effects of a midwinter drawdown of the Snake River and drought in Grand Teton National Park. Asst. Prof., Department of Wildlife Technology, Penn State University, DuBois Campus, and the University of Wyoming.

Beaver colonies in Grand Teton National Park were studied between June and October of 1977 to determine the effects of drought and a mid-winter drawdown of the Snake River on beaver abundance, distribution, movements and mortality. Abundance of colonies in the first several miles below the Jackson Lake Dam remained the same before and after the drawdown though one colony of seven individuals was lost and its position on the floodplain taken by another colony. Distribution and territorial boundaries remained unchanged and there was a total loss of 54 percent (13 of 24) of the known individuals to dispersal and mortality, probably related to midwinter drawdown. The drawdown did not effect reproduction of the colonies in the first several miles below the Jackson Lake Dam as all colonies produced as many or more young as in 1976. The maintenance of high water levels on the Snake River in the summer of 1977 combined with the depleting flows on adjacent streams swelled colony abundance on the Snake River floodplain to 49 colonies, the largest number observed since censuses began in 1974. Drought conditions and reduced Snake River flows in the late summer forced abandonment of 28 percent of the colonies under study (28 of 101) colonies representing at least 140 beavers. The effects of the drought were more severe for colonies other than those on the Snake River floodplain with 31 percent (16 of 52) of the colonies abandoning in response to low water levels. The carrying capacity of the Snake River Floodplain was at its lowest level in four years by the fall of 1977. Where sufficient flow was available, the availability of denning sites within established territories was the major limiting factor. Drought-related habitat abandonment combined with natural dispersal of young has resulted in the loss of 67 percent (67 of 101) of the ear tagged population in the study area since 1974. Beaver adaptability, management implications, and recommendations are discussed.

Gribb, Bill. 2002. Development of a potential beaver habitat model for the Snake River Basin in Grand Teton National Park. Grand Teton National Park Investigator's Annual Report. <https://science1.nature.nps.gov/research/ac/iars/search/iarView?reportId=24683>. 15 June, 2005.

There has not been a complete analysis of beavers (*Castor Canadensis*) in Grand Teton National Park since 1976. During this period two major events may have changed elements of the Park's beaver ecosystem: the major fires in 1988 and 2000 and the major drawdown of Jackson Lake dam in 1998. Thus, to understand the location and distribution of beavers and inventory and environmental analysis has been conducted. This project has six primary objectives. These objectives are: 1.) evaluate the Allen habitat model for beavers adjusting its parameters to the Greater Yellowstone Ecosystem and specifically Grand Teton National Park; 2.) obtain current remote sensed images, mainly aerial photography, of potential beaver habitats and identify distinguishable evidence of beaver activity; 3.) establish a field observation and measurement strategy for determining beaver activity and locations in the upper portions of the Snake River basin from Jackson Lake dam to Moose; 4.) utilizing GPS and GIS technologies, map the location of beaver activities and habitat characteristics; 5.) test the Allen modified beaver habitat model to the observed beaver habitat; and, 6.) identify modifying factors that would influence beaver distribution and habitat. Three different research techniques were employed in this study to analyze the potential beaver habitats: field research; statistical analysis; and, GIS/remote sensing tools and techniques. The field research involved locating beaver dens and lodges adjacent to the main course of the Snake River from Flagg Ranch to Moose. Overall, a distance of 48km was field surveyed along the banks of the Snake River, finding only seven bank dens and lodges, producing a density of .14dens/km. This is comparable to the densities found in Yellowstone National Park in the late 1980s averaging .16/km. Aerial photo interpretation (scale 1:1600) produced another 16 locations of beaver activity, though their age and activity level was not field checked. The beaver Habitat Suitability Index (HSI) model is built on vegetation and hydrologic data. Vegetation data focuses on three components: percent shrub cover, percent tree crown, and shrub height. At each of the seven den and lodge locations, the three vegetation components were collected using six 900 sq.m. grid sites. The percent shrub cover averaged 52.9%, the percent tree crown averaged 18%, while the average height of the shrubs were 1.6m, dominated by willow. The hydrologic data focused on stream width and stream gradient. The average stream width along the Snake River was 33.2m while the gradient averaged .64%. Because of the number of bank dens, bank height was also collected averaging 1.2 m. This figure is misleading because of the regulation of the Snake River. In June, 2002 this was the bank height, unfortunately the water level can vary almost .79m in June, the field collection month. A quadrat analysis was performed to determine if the distribution of bank dens/lodges was random, the VMR (-.46) demonstrated that our distribution is more dispersed ($p=.021$). However, bank dens/lodges were only examined along the main course of the Snake River and not the side tributaries and branches. A different pattern of density and results of the quadrat analysis could be calculated if a broader extent of the Snake River was investigated. The sample size also influenced the HSI results which were inconclusive and not statistically significantly. The literature suggests more information maybe needed on hydrology and vegetation indicators above the basic HSI model. In conclusion, more field research will be needed to determine the location and densities of bank dens/lodges, and an expansion of the

vegetation and hydrologic factors will need to be collected to test the HSI model for Grand Teton National Park.

Gribb, Bill. 2003. Expanded search for beavers in Grand Teton National Park and development of a Habitat Suitability Index Model (HSI) integrating field research, GIS, and satellite imagery. Grand Teton National Park Investigator's Annual Report.
<http://science.nature.nps.gov/research/ac/iars/search/iarView?reportId=28524>. 30 June 2005.

In the 1976 beaver study by Collins, he identified more than 86 beaver dens and lodges either on or adjacent to the Snake River from Jackson Lake to Moose. In an initial inventory conducted in summer 2002, only 17 beaver dens and lodges were identified of which only 8 were active. The beaver (*Castor Canadensis*) is an integral part of the Greater Yellowstone ecosystem, yet it appears that there is a major fluctuation in their population. Allen (1983) has constructed a model of the beaver's habitat needs and constraints so that it is possible to define potential locations of beavers and for beaver reintroduction. Incorporating GIS and remote sensing technologies, Johnson and Naiman (1990) have tried to identify those habitats and examine the role of the beaver in the overall ecosystem. The work of Collins (1976) provides a baseline knowledge of beaver habitat and distribution in the GTNP. But, with the changing characteristics of the landscape due to controlled water flow from Jackson Lake Dam and the 25 years since his study, that knowledge base may be out-dated. A complete update of their current location and habitat is needed, along with knowledge of their potential habitat areas.

This project will have the following objectives:

1. Evaluate the Allen habitat model for beavers adjusting its parameters to Grand Teton National Park.
2. Obtain current satellite images of GTNP to identify potential beaver habitats.
3. Establish a field observation and measurement strategy for determining beaver activity and locations in the upper portions of the Snake River basin specifically Pacific Creek and Spread Creek tributaries.
4. Utilizing GPS and GIS technologies, map the location of beaver activities and habitat characteristics.
5. Test the Allen modified beaver habitat model to the observed beaver habitat.
6. Identify potential beaver habitats using remote sensing techniques adopting the modified Allen model.

There are four different objectives in this proposal with each requiring different research techniques. GIS will be used to develop the Allen (1983) beaver habitat model. To populate the different model factors digital data will be acquired from available sources or captured from mapped and remote sensed images (Johnston, 1998; Johnston, Pastor and Naiman, 1993). Use aerial photography to identify locations of potential beaver lodges in willow groves and meadows. Field inspection of identified potential and active beaver areas will have to be conducted to test the efficiency of the identification keys and interpretive factors. Finally, computer modeling and statistical testing is the last of the techniques that will be employed to

obtain the research objectives. The model will produce a probability matrix of beaver location based on the modified-HSI factors. The model will then be tested against the found locations.

The overall intent of this research is to inventory the beaver population in Grand Teton NP, survey their habitat, and attempt to determine their distribution. In the period 1976-1977 Collins (1976) completed his survey of *Castor canadensis* along the Snake River and found between 37-49 colonies inhabiting the area from Jackson Lake dam to Moose. This 43.4km stretch of the Snake River thus had a density of approximately 1.0 colony per km along the river. Collins only surveyed along the Snake River and some of its tributaries in flat terrain. There are a multitude of areas that he did not survey completely. This project involved the survey of Buffalo Fork and Pacific Creek from the Snake River upstream to the Park boundary.

The ground survey information recorded the location and type of beaver colony along with information on habitat characteristics as defined by Allen (1982). This project contends that by combining the field information into the habitat suitability index (HSI) model and incorporating the data into a GIS, it will be possible to identify potential beaver habitat areas. The critical element in this study is to identify a significant number of active beaver colonies to record the habitat conditions for the model as it applies to GTNP.

Between the two surveyed creeks, Buffalo Fork and Pacific Creek over 22.9km of stream bank and side channels were inventoried for active beaver lodges or dens. In this portion of GTNP only one active lodge was located and no active bank dens. The habitat surrounding the lodge was dominated by willows (*Salix* spp.) on tufts of land separated by stream rivulets.

In the two previous years of study, Gribb (2002, 2003) has not found the same density of dens or lodges as Collins. In fact, the densities are dramatically less in the areas that have been surveyed. On the Snake River, of the 34.4km that have been surveyed only 7 active dens and lodges have been found, producing a density of .2 colonies per km. This density is even less than those calculated by Breck, Wilson and Anderson (2001) for beaver colonies along the Yampa and Green Rivers, .35 colonies/km and .5-.6 colonies/km respectively.

Overall, the study was inconclusive and incomplete for collecting data on beaver habitat and distribution. The location of only one lodge in this drainage provided too small of a sample of habitat to complete any modeling for the remainder of GTNP. The short field period (10 days August, 2003) was not enough time to complete the inventory along the west flowing streams into the Snake River.

Gribb, Bill. 2005. A Survey of Beaver Location and Habitat to Model their Distribution in Grand Teton National Park, Wyoming. Grand Teton National Park Investigator's Annual Report. <http://science.nature.nps.gov/research/ac/iars/search/iarView?reportId=32550>. 15 June 2005.

There is inadequate information on the distribution and habitat of beavers (*Castor canadensis*) in Grand Teton National Park (GTNP) since 1977. This project will complete a survey of the Snake River and its side-channels for beaver colonies and record their location and adjacent habitat.

Methodology: This project proposes to complete the field survey along that portion of the Snake and to employ the use of aerial survey in estimating colony location and density and its relationship to bank den density. Overall, the Snake River floodplain from the southern

Yellowstone boundary to Moose is 44.3km long, and encompasses over 1500 sq. km., to survey that entire area is too time consuming. If an aerial survey can be employed to identify lodges and infer bank dens, this would drastically reduce the time and financial burden to determine the health of the beaver population in GTNP. The field survey of beaver den and lodge locations was completed for the following areas: the portion of the Snake River from Deadman's Bar to Ranch Bar BC; the following tributaries into Jackson Lake: Lizard Creek, Arizona Creek, Spread Creek, Three Mile Creek, Pilgrim Creek, and the west branch of Spring Creek; and Cottonwood Creek into the Snake River. In addition, the complete shorelines of Christian Pond, Two Ocean Lake, Swan Lake, Heron Pond, and the southwestern one-quarter of the shoreline of Emma Matilda Lake were inventoried. The combined efforts of the beaver locations the similar research in 2002 and 2003 have revealed the following. Of the 137.5 km of river banks surveyed, a total of 126 bank dens and lodges were found. Of this group, 85 (67%) were inactive and only 41 (33%) displayed activity. Similar statistics were found along the lakes/ponds, a total of 20.3km of shoreline were surveyed and a total of 13 lodges were found, with only 5 active (38%) and 8 (62%) inactive. The use of aerial inventory was proposed to compare to the field inventory results, however, because of logistical problems was not completed this year.

Hall, J.G. 1984. Ecological study of River Otters in Grand Teton National Park. In: University of Wyoming National Park Research Center 8th Annual Report (K. Diem, ed.), pp 39-41. (Note: This study continues in the 9th and 10th Annual Reports, 1985-86)

The objectives of this study are to obtain information about habitat preferences, movements, activity patterns, social interactions, distribution and density of otters within the park, primarily on the Snake River between the Jackson Lake Dam and Moose. This type of information is valuable as a basis of comparison with what is known about otters elsewhere and also could guide the NPS in altering policies or managing habitats to the benefit of otters, should this be desired in the future.

Hall, J.G. 1995. Activity patterns of river otters in the Oxbow Bend vicinity, Grand Teton National Park. In: University of Wyoming National Park Service Research Center 19th Annual Report (H.J. Harlow and M. Harlow, eds.), pp 31-32.

Goals of the project were to obtain information on daily movements and activity of river otters, particularly nocturnal activity. Of special interest was to determine whether or not nocturnal peaks in activity occur which is similar to those seen by day. Any evidence of fidelity to specific habitat sites was also documented. Twenty-five photographs of otters were obtained while only ten of those photographs qualified as independent visits to specific habitats. Given the small sample size of otters photographed, peaks in nocturnal activity could not be determined. Another conclusion, which would need more future data to support, is that a group of otters have a habitual circuit that is run in the same direction (southerly in this case). Focal

points of otter activity were observed in the northwest corner of the main island and the western end of the northern border of the Oxbow Bend region of the park. These locations were determined to be focal points of activity over a decade ago.

Hall, J.G. 1996. Behavior of river otters in the Oxbow Bend vicinity, Grand Teton National Park. In: University of Wyoming National Park Service Research Center 19th Annual Report (H.J. Harlow and M. Harlow, eds.) pp 50-51.

This report is a continuation of a study begun in 1995—to obtain information on movements, sociability, and activity patterns of river otters in the Oxbow region of the Snake River within GTNP. Particularly emphasis was on nocturnal patterns as documented by automatic cameras activated by buried treadle-switches in places otters are known to frequent, such as latrines, resting sites, and feeding sites. Daytime activities were monitored by cameras and canoe patrols. A strong social bond was observed in otters, with only one occasion having a lone otter spotted. This season was considerably less productive for unknown reasons. Overall, fewer otter visits were recorded and animal “vandalism” increased.

Hall, J.G. 1997. Behavior of river otters in the Oxbow Bend vicinity, Grand Teton National Park 1997 season. In: University of Wyoming National Park Service Research Center 19th Annual Report (H.J. Harlow and M. Harlow, eds.), pp 26-27.

This report covers the third and final season devoted to obtaining information on otter behavior. Twenty-one otter visits were recorded with seventeen by day and four by night. Overall, otters were determined to be more diurnal rather than nocturnal, perhaps due to visibility and accessibility of food. The south spit of an island upriver turned out to be visited most by otters. Frequent “vandalism” of equipment by the otters occurred frequently in this area.

Hall, J.G. 2001. Summer habitat preferences and activity patterns of river otters in Grand Teton National Park. In: University of Wyoming National Park Service Research Center 25th Annual Report (H.J. Harlow and M. Harlow, eds.), pp 63-70.

The natural history of river otters (*Lontra canadensis*) was studied during the summers of 1982-1986 and 1995-1997 in GTNP, Wyoming. Habitat preferences were analyzed by tallying sightings on 5 types of habitat along 16 km of the Snake River. Otters were seen on all 5 habitat types and exhibited a strong preference for the log-jam/beaver lodge category. Beavers and otters sometimes occupied a lodge simultaneously. Daytime activity was recorded directly in 1982 and a large peak was noted in mid-morning as well as a small one in late afternoon. Camera monitors and treadle switches were used to monitor round-the-clock activity. Pooled

records for three summers showed almost two and a half times higher activity by day than by night, a finding opposite of what was expected. It is hypothesized that diurnal activity exceeds nocturnal activity because of the habituation of otters to humans over half century's tradition of frequent exposure and non-harassment in the national park. Observations of river otters were made along the Snake River from Flagg Ranch near the north boundary of the park to the north end of Jackson Lake and from Pacific creek to Deadman's bar. The 3-km stretch of river just below Jackson lake dam was the site of most intensive study.

Jackson Lake Draw-down Project Annotated Bibliography of Birds

Buhler, Matt L. 1998. Avian Habitat Ecology within the Riparian Corridor along the Snake River in Grand Teton National Park, Wyoming. M.S. Thesis Department of Zoology and Physiology, University of Wyoming.

Avian surveys were conducted during the summers of 1996 and 1997 on 56 transects within the riparian corridor of the Snake River, Grand Teton National Park, Wyoming. Comparisons were made between bird utilized and non-utilized habitat components in six habitat types. Habitat use was determined for three scales of resolution, microhabitat, intermediate (0.04 ha), and landscape. Activity patterns were separated to more accurately determine vegetation requirements of each activity.

Habitat utilization was then related to extrinsic factors to determine alteration in community composition. Human use of the area was extensive during the breeding season. Of the 77 avian species observed within the riparian corridor, 68 (88%) decreased in abundance due to human influence. Avian species composition and relative abundance were analyzed to ascertain interspecific interactions and influence on habitat utilization. Predatory and nest parasitic species have increased in abundance throughout the region. Detrimental effects from those species from habitat alteration and attraction could seriously effect songbird populations. Dynamic structure of the Snake River from periodic flooding also influenced avian assemblages. Flooding during 1996 and 1997 altered channel morphology and habitat composition through erosion and deposition. No single avian species was favored due to multi-aged habitat stands. This thesis addressed the ecology of avian assemblages and their role within the system.

Cody, M.L. 1991. Population Densities and Community Structure of Birds in Jackson Hole: A Reassessment After 25 Years. National Park Service Investigator's Annual Report, Grand Teton National Park.

<http://science.nature.nps.gov/research/ac/iars/search/iarView?reportId=4132>. 30 June, 2005.

Note: Study continues in the 1992 field season.

The study aims to compare bird community structure (species diversity, density and distribution) within two habitat sites in Grand Teton National Park. Determine if any changes have occurred since this study was performed in 1966-68. Though the basic structures of both habitat types have not changed in 25 years, some differences in species composition have been identified. In grass-sage habitat an overall reduction in emberizidae species was identified. However, starlings and chipping sparrows were identified in 1991 but not 25 years ago.

Cody, M.L. 1997. Monitoring breeding bird populations in Grand Teton National Park: 1995-1997. University of Wyoming National Park Service Research Center 21st Annual Report. (H.J. Harlow and M. Harlow, eds.) pp 13-25.

This project instigates a system for monitoring the densities of breeding bird species by establishment of fixed sites as a basis for a long term monitoring plan and of census protocols that can detect changes of breeding species and their densities over successive years. The project emphasizes the need for long-term and on-going studies on breeding bird species and densities and their importance as a tool for evaluating the impact of both local and distant influences on breeding bird populations. The project established a total of 30 monitoring sites within (28 sites) or immediately adjacent to (2 sites) GTNP, covering all of the major habitat types within GTNP. Sites are located over various types of vegetative cover and were censused using a combination of territory mapping, transect counts, and point counts. Approximately 270 bird species have been recorded in GTNP and 21 of these species are considered rare.

Craighead, Derek. 2002. Ecology studies in Grand Teton National Park. Grand Teton National Park Investigator's Annual Report.
<https://science1.nature.nps.gov/research/ac/iars/search/iarView?reportId=24015>. 15 June, 2005.

We documented abundance and diversity of raptors in a relatively undisturbed landscape in Grand Teton National Park, Wyoming, from February through August 2002. Within a 31.1 km² study area we located 46 nesting pairs that consisted of 9 raptor species. The American kestrel (*Falco sparverius*) and the Common raven (*Corvus corax*) were the two most abundant species on the study area. We considered Common ravens as an ecological and trophic level equivalent of raptors. Six of nine species fledged at least one young, and the mean number of young fledged per occupied nest for all species was 1.0 (sd = 1.0, range = 0 to 3.0). We observed complete nesting failure for Swainson's hawks (n=4 nests), Bald eagle (n=1 nest), and the Long-eared owl (n = 1 nest). We located the territory but not a nest for two Great horned owl (*Bubo virginianus*) adults, and two Sharp-shinned hawk adults. Six of the nine species observed in 2002 migrate, and two of the nine species are known neotropical migrants. Cold and wet weather conditions along with a high wind storm during the early incubation period appeared to have a negative effect on the breeding success of stick-nest breeders on the study area.

Debinski, D., Kindscher, K., & Jakubauskas, M. 2000. A Remote Sensing and GIS-Based Model of Habitat as a Predictor of Biodiversity. National Park Service Investigator's Annual Report. <http://science.nature.nps.gov/research/ac/iars/search/iarView?reportId=18920>. 30 June 2005.

Note: This is a multi-year study that was started in 1997 and is continuing into the 2005 season.

The major objectives of the research were to: 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; and 3. Test the spectrally-based spatially explicit model developed in Objective 2 for predicting plant and animal species diversity; patterns in montane meadows. We sampled birds, butterflies, and plants for four years (1997-2000) in two regions of the Greater Yellowstone ecosystem: the Gallatin National Forest and northwestern portion of Yellowstone National Park and Grand Teton National Park. We used satellite imagery to classify two types of wetland meadows and four sagebrush communities. In Grand Teton National Park, our overall accuracy of mapping sagebrush communities was 65 percent, and highest for the mixed big sagebrush/low sagebrush community at 86 percent. Abundance of habitat specialist bird species was highly correlated with both meadow type and landscape variables. Butterfly species abundance and distribution was even more strongly correlated with meadow type (butterfly distribution was used to predict meadow type with a 92-96 percent accuracy in the Tetons). Voucher plants are housed at the University of Kansas McGregor Herbarium; vouchers butterflies are housed at Iowa State University.

Diem, K.L. 1980-83. Bird populations in a narrowleaf cottonwood community, Grand Teton National Park, Wyoming. In: University of Wyoming National Park Service Research Center 4th Annual Report. (K.Diem, Director). pp 40-43.

The Wyoming Game and Fish Department are developing an avian atlas for the State of Wyoming. Baseline information on the avifauna of the riparian communities is especially sparse. Consequently, the objective of this study is to collect information on the composition, density, distribution, and habitat of the bird species inhabiting a portion of the narrowleaf cottonwood, *Populus angustifolia*, community in GTNP. The study was initiated in June 1980 on a portion of the western floodplain of Pilgrim Creek. The Dark-eyed Junco and the American Robin were essentially present over the entire study area. The Warbling Vireo and the Dusky Flycatcher were mostly in the large cottonwood trees. Several species were confined to restricted habitat. McGillivray's Warbler, Wilson's Warbler, White-crowned Sparrows, and the song Sparrows only occurred in the limited willow patches. The Yellow Warbler used both the willows and the alders.

Diem, K.L. 1981. Bird Populations in a black cottonwood community, Grand Teton National Park. In: University of Wyoming National Park Service Research Station 5th Annual Report. (K. Diem, Director). pp 54-55.

Baseline information on the avifauna of the riparian communities in Grand Teton National Park is sparse. Consequently, the objective of this project is to collect information on the composition, density, distribution, and habitat of bird species inhabiting a portion of the black cottonwood, *Populus trichocarpa*, community in Grand Teton National Park. The study was initiated in June 1980 on a portion of the western floodplain of Pilgrim Creek. The southeast corner of this 300m x 400m (12ha) plot is identified by a metal post. This post can be located on a bearing line of 4° E of N. 77mm from the fiducial center of the infrared aerial photo N 31 (U.S. Bur. of Reclamation Series B/R17, 7-16-1979). This floodplain community is

predominately black cottonwood with scattered trees of quaking aspen *Populus tremuloides*, engelmann spruce *Picea engelmannii*, and lodgepole pine *Pinus contorta*. In restricted moister areas several small patches of alder, *Alnus incana* occur under the larger trees and a few patches of willow, (*Salix, sp.*) are located in the moist openings of the woodland.

Eng, R. L., Harmata, A., & Alt, K. 1980. Banding of nestling bald eagles in Yellowstone and Grand Teton National Parks and vicinity. In: University of Wyoming National Park Service Research Station 4th Annual Report (K. Diem, Director). pp 44-47.

A significant population of nestling Bald Eagles (*Haliaeetus leucocphalus*) occurs in and adjacent to Yellowstone National Park and Grand Teton National Park. Alt (1980) and Swenson (1975) located 30 Bald Eagle territories within an approximate 15,000 km² area encompassing both parks and the surrounding area of southwestern Montana and northwestern Wyoming, designated here as the Yellowstone-Teton area of influence (YTAI). Although this population is probably essential in producing recruits for the remaining depressed western populations, little is known of the movements and dynamics of this population outside of the breeding season. As a result, a nestling banding project was initiated in the summer of 1979, and expanded to include colormarking in 1980, to determine post fledging movements and population dynamics of Bald Eagles produced in the YTAI. Through band recoveries, returns, and resightings of color-marked eagles, attempts were made to determine: 1) juvenile dispersal patterns, 2) immature survival rates, 3) longevity, 4) wintering areas of YTAI Bald Eagles, 5) mortality factors, 6) migration routes, 7) fidelity to the natal area in successive years, 8) importance of the YTAI population in relation to producing recruits for other population, and 9) assessment of banding activities on subsequent productivity.

LaPerle, M. 1974. Effects of water fluctuation on duck breeding success. In: Canadian Wildlife Service Waterfowl Studies in Eastern Canada, 1969-73. (H.Boyd, editor). Report Series 29, Canadian Wildlife Service. pp 18-30.

Searching and examination of nests were reduced from 1968 to 1970 and this reduced disturbance of hens by observers. Nevertheless, the American black duck's (*Anas rubripes*) nesting success declined from 64% in 1968 to 53% in 1969 and 44% in 1970. The nesting success of mallards (*A. platyrhynchos*), however was 36%, 73%, and 61% in the same years. The low in 1968 was attributed to the intensive effort of capturing mallard hens on nests.

Montopoli, G. & Anderson, D.A. 1988. A mathematical and statistical analysis of the cumulative effects model. Laramie, WY: University of Wyoming.

In June, 1986, the Greater Yellowstone Ecosystem Bald eagle Working Team requested research assistance in the development of a cumulative effects model (CEM) to quantitatively evaluate the cumulative effects of human disturbance on bald eagles (*Haliaeetus leucocephalus*) in their natural habitat. Basic approach and underlying mathematics that were used in the development of the model are discussed. To demonstrate one way in which the model may be used, an analysis of the bald eagle habitat on a 27-mile segment of the Snake River in GTNP is presented using primary and secondary data. This analysis can be further used as an aid to validate and calibrate the CEM.

Raynes, B. 1984. Birds of Grand Teton National Park and the surrounding area. Jackson, Wyoming: Grand Teton Natural History Association.

This book is intended to help the casual or intense birdwatcher identify many of the birds that are present in Grand Teton National Park and the surrounding areas. Habitat is the basis for the recommendations of where to see the birds featured in the book. A full-page map keyed to the specific sites and habitats described is provided at the end of the habitat section. Each page in the bird section has a small map which is color-coded to the habitats in which the species is likely to be found. The seasons during which some species may be expected in a region are suggested along with a written description. Also described are birds similar in size, plumage, or habitat selection that could possibly be confused for the species sought. A photo representing each species accompanies its description.

Ruszkowski, T.A. 1996. Songbird and small mammal diversity and habitat use of the riparian zone in the John D. Rockefeller Jr. Memorial Parkway. M.S. Thesis, University of Wyoming, Department of Zoology and Physiology.

Songbird and small mammal surveys were conducted in 1994 and 1995, on fifty-five 25 meter radius plots in the Snake River riparian zone in the John D. Rockefeller Jr. Memorial Parkway, Grand Teton National Park. Comparisons of wildlife relative abundance and community composition were made between seven distinct vegetation types (tall shrub/dry grassland, tall shrub, tall shrub/wet meadow, wet meadow, marsh/fen, marsh/fen/wet meadow, and moist forb meadow).

Relationships between wildlife and vegetation structure were also examined. Several species of small mammals and songbirds showed affinities to particular habitat characteristics and vegetation types within the riparian zone. Common yellow throats and Lincoln's sparrows were predominately observed in moist habitats containing dense vegetation, while savannah sparrows were most abundant in the wet meadow. Deer mice were predominately captured in the tall shrub/dry grassland, which was characterized by habitat, while western jumping mice were most abundant in the moist forb meadow.

Each vegetation type within the riparian zone had a unique species composition depending on the level of structural complexity found in each. Relative abundance and vegetation structure were related.

Stauffer, D.F. & Best, L.B. 1980. Habitat selection by birds of riparian communities: Evaluating effects of habitat alterations. *Journal of Wildlife Management* 44(1):1-15.

Avifaunas of riparian communities were studied in Iowa during late spring and early summer. Birds were censused on 28 study plots representing a habitat gradient from hayfields to closed canopy woodlands. An index of nesting niche breadth was determined for 18 open-nesting bird species on the basis of vegetation life form(s) used for nesting, and for 10 cavity-nesting bird species on the basis of type(s) of nest-cavity support. Cavity-nesters preferred soft snags as nest sites. Floodplain woodlands supported higher densities of breeding birds than upland woodland or herbaceous habitats. Bird species richness increased ($P < 0.01$) with the width of wooded riparian habitats. Wooded habitats supported a maximum of 32 species; herbaceous habitats, 8. Observation frequencies of 41 bird species in 6 general habitat types were used to calculate indices of tolerance to habitat alteration. Microhabitat characteristics selected by each species were determined by comparing bird observation frequencies with 36 vegetation variables, using stepwise multiple regression. The potential effects of 6 alterations to wooded riparian habitats on the 41 species are predicted.

Wallen, R.L. & Eng, R.L. 1986. Habitat utilization of Harlequin Ducks. In: University of Wyoming National Park Service 10th Annual Report (K.Diem, Director). pp 147-155.

During the 1986 field season, 89 Harlequin Ducks (*Histrionnicus histrionicus*) were individually identified on four backcountry streams and the Snake River. Forty-eight birds were banded (15 adults and 33 young of the year). Twelve adults and one young of the year banded in 1985 returned to the study area. Eight broods were found. Hatch dates ranged from the 15th of July to the 1st of August with a mean brood size of 5.4. An estimate of age span at different plumage subclasses was determined through repeated observations. Age at first flight was found to be 42 days. Moose Creek produced most birds (4). Insect samples were taken at feeding sites along four streams on a monthly basis to give some insight into food resources. Eight measurements of habitat were taken at points where ducks were observed and at 200 m intervals along the streams which they were found. Five hens which showed up in late June 1985 as unpaired birds returned to the same streams this season with mates. None of the marked hens with broods found in 1985 were seen in the area in 1986.

Wallen, R.L. 1987. Habitat Utilization by Harlequin Ducks in Grand Teton National Park. M.S. Thesis, Montana State University.

(Abstract unavailable)

Jackson Lake Draw-down Project Fish Annotated Bibliography

Farag, Aida & Harper, David. 2004. Bioenergetics modeling of stocked and naturalized lake trout (*Salvelinus namaycush*) populations in Jackson Lake, Grand Teton National Park, Wyoming. National Park Service Investigator's Annual Report, Grand Teton National Park. <https://science1.nature.nps.gov/research/ac/iars/search/iarView?reportId=29308>. 6 June 2005.

For the last 30 years, extensive field data have been collected on fish populations of Jackson Lake, Grand Teton National Park, Wyoming. There is a need to compile the data into a database format suitable for investigation of fishery trends of Jackson Lake. The objective of this study is to compile the data and begin development of a bioenergetics model. The expectation is that the bioenergetics model will be a useful tool for assessing the current status and predicting future trends of the lake trout (*Salvelinus namaycush*) population in Jackson Lake. Initially, the bioenergetics model will be used to help define data gaps. The bioenergetics model developed will also provide a framework for future investigations of the status of native fishes within Jackson Lake, including Yellowstone cutthroat trout (*Oncorhynchus clarki bouvieri*).

Annual trend gill-netting was performed at Jackson Lake in cooperation with the Wyoming Game and Fish Department. Samples were collected on July 15-18 and September 22. Lake Trout, Cutthroat Trout and Brown Trout were collected for age, growth and food habits data. Specifically, stomachs were removed and frozen under dry ice. Otoliths (ear bones) were removed and stored in scale cards. A total of 52 lake trout, 25 brown trout, and 13 cutthroat trout were collected during July, and 22 lake trout, 8 brown trout and 8 cutthroat trout were collected during September. Water temperature profiles were collected on August 22 and September 22.

Stomach content samples were analyzed in the laboratory during August and October. The stomachs contents were weighed and the contents identified. Contents were classified as zooplankton, aquatic invertebrate, terrestrial invertebrate, or fish. Identification of family and species macroinvertebrates and fish was attempted when possible. Zooplankton was the most frequently observed item in stomachs for all species during summer and fall samples, except for brown trout in summer. In the July sample, lake trout most frequently consumed zooplankton, a combination of zooplankton/aquatic macroinvertebrates, fish, and aquatic macroinvertebrates. Brown trout most frequently consumed terrestrial macroinvertebrates, aquatic macroinvertebrates, a combination of zooplankton/aquatic macroinvertebrates, a combination of zooplankton/terrestrial macroinvertebrates and fish. Cutthroat trout most frequently consumed zooplankton, terrestrial macroinvertebrates, and combinations of zooplankton/aquatic macroinvertebrates and zooplankton/terrestrial macroinvertebrates. Fall stomach contents were restricted to zooplankton, except for lake trout, which of which a small proportion contained fish or macroinvertebrates.

Gipson, Rob. 1993. Jackson Lake Creel Survey, 1991. Wyoming Game and Fish Department Fish Division Administrative Report. Project: 410-320-20.
(Document can be accessed at AMK research station library)

A creel survey was conducted on Jackson Lake during the winter and summer fishing seasons of 1991. During the winter season (January-April), an estimated 6,548 anglers spent 31,238 hours on the ice. During the summer season (May-September), an estimated 20,560 anglers fished 75,662 hours on Jackson Lake. Lake trout dominated the creel for both survey periods. Lake trout were caught at a rate of 0.39 fish per hour during the winter season and 0.34 fish per hour during the summer season. Catch rates have declined since the late 1970's; however, angler satisfaction remains high due to an increase in the mean size of fish harvested. Thirty-two percent of all fish caught in the winter were released, and 20% of all fish caught in the summer were released. Hatchery-reared lake trout comprised 16.3% of the total catch for both surveys combined. Analysis of the fin clips indicated that growth of hatchery-reared lake trout was highly variable within and between cohorts. Jackson Lake can support current fishing pressure. However, as pressure continues to increase, a reduction in creel limit, an increase of stocking, or eyed-egg plants may be necessary to maintain present catch rates.

Gipson, Rob. 1993. Snake River Creel Census, 1990. Wyoming Game and Fish Department Fish Division Administrative Report. Project: 01-00-001.
(Document can be accessed at AMK research station library)

The Snake River cutthroat trout is indigenous in Wyoming to the Snake River drainage between Jackson Lake and Palisades Reservoir on the Idaho-Wyoming line. The Snake River is presently managed under the unique species concept. In 1990, special regulations were implemented from 1,000 feet below Jackson Lake Dam to Wilson Bridge (Sections 1-3). The limit is 6 trout of which only one may exceed 18 inches, all trout 11-18 inches must be released, and fishing is restricted to artificial flies or lures. In sections 4-6, general statewide regulations apply. This report summarizes data obtained during the 1990 creel census of the Snake River and compares these data to similar surveys conducted in 1980 and 1985. In 1990, the overall catch rate for sections 2-6 was greater than in 1985. The stable flows enjoyed in 1990 were the first since the reconstruction of the dam, and they imparted a credible influence on the success enjoyed by all anglers.

Gipson, Rob. 1994. Snake River creel survey, 1994. Wyoming Game and Fish Department Fish Division Administrative Report. Project: 01-00-001.
(Document can be accessed at AMK research station library)

A creel survey was conducted on the Snake River between July and October, 1994. An estimated 26,783 anglers fished 82,271 hours. The catch was comprised of 68,285 Snake River cutthroat trout, of which 63,559 (93.1%) were released. Catch rates fell below the management objective of one cutthroat trout per hour for sections 2-4. Releases from Jackson Lake Dam could have contributed to decreased catch rates. Harvest rates continue to decline and can be attributed to the strong catch and release ethic of the area and the general trend toward non-

consumptive use of wildlife resources. An attitude survey revealed that anglers preferred a reduced creel limit, more tackle restrictions, an 11-18 inch slot, a trout season closure from November 1 through March 31, and a year-round mountain whitefish season.

Gipson, Rob. 1997. Jackson Lake winter creel survey, 1996. Wyoming Game and Fish Department Fish Division Administrative Report. Project: 401-320-20.

A creel survey was conducted on Jackson Lake during the 1996 winter season. Between January and April, an estimated 6,170 anglers spent 33,034 hours on the ice. Lake trout *Salvelinus namaycush* dominated the creel and were caught at a rate of 0.72 fish per hour. A harvest rate of 0.40 lake trout per hour surpasses the management objective of 0.35 lake trout per hour. Snake River cutthroat trout *Onchorhynchus clarki* spp. and brown trout *Salmo trutta* were incidental to the creel. Forty-four percent of all fish caught were released. Hatchery-reared lake trout comprised 13% of the total catch. Analysis of the fin clips indicated that growth of hatchery reared lake trout was highly variable within cohorts and between cohorts. Anglers generally prefer a 6-fish limit, 1 fish over 24 inches, and no tackle restrictions. Excluding the no opinion response, 93% of anglers were satisfied with the size of the fish, 92% were satisfied with the number of fish, and 98% were satisfied with the overall fishing experience.

Goldstein, J., Farag, A., & Woodward, D. 1997. Fall and winter movements and habitat selection by Snake River Cutthroat Trout in the Upper Snake River, below Jackson Lake Dam, Wyoming. National park Service Investigator's Annual Report, GTNP.
<http://science.nature.nps.gov/research/ac/iars/search/iarView?reportId=4202>. 1 July 2005.

The objective of this study is to determine movement patterns and habitat selection by cutthroat trout in the upper Snake River. Thirty fish were tracked to examine the effects of winter conditions and flow manipulations on movement and habitat use. A high rate of post-tagging mortality occurred and was attributed to the combined effects of electroshocking and carbonic acid anesthesia during the tagging procedure. Reliable data on movements and habitat selection were collected on only five (17%) of the radiotagged fish. Fish were not displaced following fall flow reductions from Jackson Lake Dam (2,200 cfs to 500 cfs, October 1996); however, it appeared that two of the fish were displaced up to 7 km downstream during January 1997 after several frazil ice events had occurred and winter conditions were prevalent. Radiotagged fish were observed using shelf ice as protective cover during this period. Throughout the study period, radiotagged fish selected locations where multiple types of stream habitat were present. Additional study is needed to determine how habitat availability and flow manipulations interact to affect winter distribution and survival of cutthroat trout.

Halls, A.S. & Welcomme, R.L. 2004. Dynamics of river fish populations in response to hydrological conditions: a simulation study. *River Research and Applications* 20:8 985-1000.

Increasing multi-sectoral demands on water resources have led to water abstraction and transfer activities, and the construction of dams and embankments that have significantly altered the flood regimes of rivers throughout the world resulting in the loss of fish production and biodiversity. The current emphasis on sustainable development and biodiversity conservation is leading efforts to mitigate these impacts by means of interventions such as the release of artificial floods downstream of dams and the manipulation of water levels within impounded floodplains.

Whilst much work has been done to determine the hydrological requirements for the maintenance of salmonid populations, few equivalent studies are available from which to develop criteria for the management of hydrological regimes for fishes and fisheries in large floodplain-river systems such as the Mekong. The population dynamics of fish in such rivers are believed to respond to hydrological conditions in a density-dependent manner. An age-structured population dynamics model incorporating sub-models describing density-dependent growth, mortality and recruitment was used to explore how hydrological conditions within a theoretical floodplain-river system affect the dynamics of a common floodplain-river fish species.

Graphical summaries of the response of exploitable biomass to a range of different drawdown rates, dry and flood season areas and volumes, and flood season durations are presented under five different model assumptions concerning density-dependent processes. Optimal flooding patterns are also described for the model species and theoretical river system.

The patterns of predictions that emerge from the simulations provide guidelines for managing or manipulating hydrological conditions in river systems for both fixed and variable volume hydrological scenarios. As a general rule of thumb, exploitable biomass is maximized by minimizing the rate of drawdown and maximizing the flood duration and flood and dry season areas or volumes. However, experiences from dam and other hydraulic engineering projects suggest that these predictions should be treated with caution until we better understand the influence of hydrology on spawning behavior, system primary production, and critical habitat availability.

Harper, D.D. 1998. Winter habitat use by Snake River Cutthroat in the upper Snake River, below Jackson dam, WY. National Park Service Investigator's Annual Report, Grand Teton National Park.

<https://science1.nature.nps.gov/research/ac/iars/search/iarView?reportId=4246>.

15 September 2005.

Objectives of the project are to determine the winter habitat use of Snake River Cutthroat and to monitor movements in response to changing temperatures and spawning migrations using radio telemetry. Microhabitat variables such as water depth, cover, water velocity and substrate are recorded at fish locations. Locations are recorded using the GPS. Snake River Cutthroat are

using a variety of habitats, with deep runs, pools, and backwater habitats the most frequently used areas. Several backwater areas used by SRCT have ground water influence and are 1-4 degrees warmer than the main river channel. Depth, large boulders, and shelf ice are the most frequently used cover during winter. Fish implanted with radio transmitters do not appear to be making long distance migrations.

Harper, D.D. & Farag, A. M. 2004. Winter habitat use by cutthroat trout in the Snake River near Jackson, Wyoming. Transactions of the American Fisheries Society 133:15-25.

Winter habitat use by Yellowstone cutthroat trout *Oncorhynchus clarki bouvieri* was monitored with radiotelemetry during November-March 1998-2001 in channelized and unaltered sections of the Snake River near Jackson, WY. The use of run and off-channel pool habitat was significantly correlated to water temperature; run use was most frequent when mean water temperature exceeded 1.0°C, and off-channel pool use was greatest when mean water temperature was below 1.0°C. Available habitat was surveyed during winter 1999-2000 and was compared with actual habitat use. This comparison indicated that cutthroat trout avoided riffle habitat, selected deep runs, and strongly selected off-channel pool habitat. Large, deep, off-channel pools with groundwater influence were uncommon in the study area but were frequently selected as over-wintering habitat in the channelized section during all three of these study years. During 2000-2001, main-stem water temperatures were significantly colder than in previous years, and anchor ice was observed more frequently. Mean water temperatures in off-channel pools were not significantly different among years. Depth and shelf ice were most frequently identified as cover elements in the channelized section. Run habitat was more common and selected more frequently as cover in the unaltered section than in the channelized section.

Kiefling, J.W. 1972. An analysis of stock densities and harvest of the cutthroat trout of the Snake River, Teton County, Wyoming. M.S. Thesis Department of Zoology. University of Wyoming.

The cutthroat trout, *Salmo clarki* Richardson is native to the Snake River drainage area. The Snake River cutthroat is well adapted to the large, swift stream habitat, and is presently maintaining itself by natural reproduction in the Wyoming portion of the Snake River. This thesis is the fifth segment in a series of comprehensive studies dealing with the ecology of the Snake River cutthroat trout and has been given the objective of determining the stock density and age structure in the Snake River proper and continuing the analysis of the harvest. Five study sections were established starting at Jackson Lake Dam and ending at Astoria Hot Springs. Research methods included a creel census, harvest, and marking. Results of the thesis include population estimates, harvests, size and condition of cutthroat trout, harvest success rate, tackle efficiency, movement of tagged cutthroat trout, and harvest of non-cutthroat species.

Kiefling, J. W. 1986. Snake River creel census, 1985. Wyoming Game and Fish Department Fish Division Administrative Report. Project: 01-00-001.
(Document can be accessed at AMK Research Station Library)

Current fisherman use patterns and catch statistics are a necessity in evaluating management of the Snake River Fishery. Creel census updates have been programmed on a 5 year basis in order to follow use levels and evaluate new regulations implemented in 1986. The previous programmed census was conducted from July through October of 1980 and will be used for comparison. Increased numbers of catch and release fisherman and changes in flow releases from Jackson Lake waters have affected the harvest of cutthroat trout in recent years. Although such changes have not been detrimental to the fishery, continued harvest trend data will have to be collected in order to monitor the well being of this nationally important "blue-ribbon" trout stream. The 1985 creel census was conducted from July through October on the 63 miles of river between Pacific Creek and Elbow. Methods included the random scheduling of aerial flights to establish fisherman counts as well as interviews being conducted with fisherman on the ground. The 1985 census data indicates that an estimated 16,482 fisherman spent over 56,341 hours angling for Snake River cutthroat trout. In general, the overall harvest of cutthroat trout continues to decline as catch and release becomes more popular.

Lessard, J.L. & Hayes, D. B. 2003. Effects of elevated water temperature on fish and macroinvertebrate communities below small dams. *River Research and Applications* 19:7 721-732.

Many studies have investigated the ecological changes that occur below dams that release cold, hypolimnetic water, but very few studies have looked at the effects of the release of warm, surface waters. The effect of small, surface release dams on downstream thermal regimes is a major habitat concern for many cold-water systems, however. The objective of this study was to examine the effects of summer temperature increases due to impoundment on downstream fish and macroinvertebrate communities in cold-water streams. We sampled fish, macroinvertebrates and habitat upstream and downstream of dams on ten rivers during the summers of 1998 and 1999. Changes in mean summer temperature downstream varied from a cooling of 1 °C to an increase of more than 5 °C. Increasing temperatures downstream coincided with lower densities of several cold-water fish species, specifically brown trout (*Salmo trutta*), brook trout (*Salvelinus fontinalis*) and slimy sculpin (*Cottus cognatus*) while overall fish species richness increased downstream. Density of mottled sculpin (*Cottus bairdi*), another cold-water species, was not related to temperature changes below the dams. Macroinvertebrates showed shifts in community composition below dams that increased temperature. This study provides information useful for determining the extent of impact of these small, surface release dams, which are abundant across the country.

Northcote, TG; Arcifa, MS, & Froehlich, O. 1985. Effects of impoundment and drawdown on the fish community of a South American River. *Verhandlung Internationale Vereinigung Limnologie* 22:4 pp 2704-2711.
<http://mdl.csa.com/partners/viewrecord.php?requester=gs&collection=ENV&recid=8600978&q=&uid=787055022&setcookie=yes>. 3 Nov 2005.

The Americana Reservoir (Brazil) was formed by a 25 m high dam constructed on the Atibaia River, some 500 km above its confluence with the middle Parana. Limnological characteristics of the eutrophic and polymictic reservoir are well documented as are general effects of pollution from sewage and industrial outfalls. The Atibaia River prior to impoundment had a moderately rich fish community probably composed of some 90 species, mostly characoids and siluroids. Of the 65 species apparently no longer present 30 years after impoundment, over two-thirds were siluroids whereas a lower reduction occurred in the characoids, leaving a post-impoundment fish community dominated by this latter group. Not all the changes in the fish community following impoundment of the Atibaia River can be related to changes associated with the shift from lotic to lentic conditions. During this same period there also has been marked eutrophication of the system as well as severe pollution by heavy metals, phenols, herbicides and other materials. The recent and sudden drawdown of Americana Reservoir apparently did not produce major changes in relative abundance of many fish species. The reduction in conditions for the planktivorous *Astyanax* following drawdown may be a food chain effect related to the concomitant decline in phytoplankton and zooplankton abundance.

Novak, M. & Young, M. 2002. Snake River and Yellowstone cutthroat trout subspecies distribution mapping. National Park Service Investigator's Annual Report, GTNP.
<http://science.nature.nps.gov/research/ac/iars/search/iarView?reportId=25198>.
1 July 2005.

The purpose of this inventory is to document the geographic distributions of Yellowstone cutthroat trout, *Oncorhynchus clarki bouvieri* (YSC), and Snake River cutthroat trout, *O. c.* subsp. (SRC), in the Snake River headwaters of Wyoming.

Objectives are to: 1) Systematically sample all fish bearing streams between Palisades Reservoir and Jackson Lake, on lands administered by federal land management agencies; 2) Document the distributions of YSC and SRC, and provide a comprehensive survey of all game and non-game fishes in the streams surveyed; 3) Spatially display (map) geographic distribution of cutthroat trout subspecies and areas of subspecies overlap using a Geographic Information System (GIS). Maps are updated annually, and final maps will be produced; and 4) Provide land and resource managers with information to facilitate informed management of aquatic biota.

Our goal is to document the geographic distributions of Yellowstone cutthroat trout, *Oncorhynchus clarki bouvieri* (YSC), and Snake River cutthroat trout, *O. c.* subsp. (SRC), in the Snake River headwaters of Wyoming. These taxa are distinguishable based largely on spotting patterns.

Streams surveyed in Grand Teton National Park (GTNP) during 2002 were grouped as

tributaries to the Snake River from the east and west. West-side streams and their tributaries included Lake Creek, Stewart Draw, and Cottonwood Creek. East-side streams and their tributaries included Ditch Creek, Lost Creek, and Brush Creek. Eastside streams were surveyed throughout the length of perennial flow in GTNP and on the Bridger-Teton National Forest.

Surveys were completed on 69.9 km in 17 perennial named streams within GTNP. Salmonids occupied 13 of the 17 streams surveyed, and 4 streams were fishless. No Yellowstone cutthroat trout were captured in GTNP streams during 2002. Snake River cutthroat trout were present in 7 of the 13 streams occupied by trout, and 11.1 km of the stream length surveyed. Cutthroat trout <150 mm (positively identified as cutthroat trout, but unable to distinguish as either YSC or SRC) were captured in 3.30 km of 4 additional streams.

Stephens, T.J. 1994. Inventory of Fish in Alpine Lakes in Grand Teton National Park, Wyoming. National Park Service Investigator's Annual Report. Grand Teton National Park. <https://science1.nature.nps.gov/research/ac/iars/search/iarView?reportId=29520>. (Note: Study began in the 1992 field season.)

Fish in alpine lakes in Grand Teton National Park have not been widely surveyed and only a few anecdotal reports are found in the literature (Hazzard 1931). These lakes will be surveyed over three short field seasons. The goal of this study is to expand the species list within the alpine lakes of Grand Teton National Park. The baseline information gathered through this study will provide a means to make better management decisions to ensure no impairment of fish populations in alpine lakes and determine future monitoring activities.

Stephens, T.J. & Gipson, R.D. 2004. Summary of Jackson Lake fishery investigations 1971-2003 with management implications. Wyoming Game and Fish Department Fish Division Administrative Report.

Jackson Lake provides a unique angling resource in the Snake River drainage of Wyoming, and management has varied considerably over time. Trend netting, trophy lake trout (LAT) *Salvelinus namaycush* netting, LAT tagging, programmed and spot creel, and productivity data were summarized for Jackson Lake from 1971-2003. The decrease in relative weight (W_r) for LAT less than 20 in, low numbers of stocked LAT in the creel, and no apparent correlation between numbers stocked and trend netting catch per unit effort for LAT indicate that LAT stocking in Jackson Lake should be phased out. The other game species in Jackson lake, Snake River cutthroat trout *Oncorhynchus clarki* spp., brown trout *Salmo trutta*, and mountain whitefish *Prosopium williamsoni*, also exhibited a decrease in W_r with increased length and discontinued LAT stocking may benefit these species as well. Zooplankton volumes have fluctuated over recent years and increased monitoring may provide insight into food availability for game and non-game fish species. Bioenergetics modeling for Jackson Lake LAT will provide further insight into the reasons for the trends in W_r . Monitoring of angler numbers, catch rates, and harvest rates should be continued due to changes in the winter use plan for Grand Teton National Park.

Woodward, D.F., Farag, A.M., Mueller, M.E., Little, E.E. Vertucci, F.A. 1989. Sensitivity of endemic Snake River Cutthroat Trout to acidity and elevated aluminum. Transactions of the American Fisheries Society. 118:630-643.

Acidic episodes in waters of the western USA, do not last as long and are not as intense as those in the eastern USA, but we found that the native western cutthroat trout *Oncorhynchus clarki* is sensitive to even brief reductions in pH. In laboratory studies, fish were exposed to acidity (pH 4.5–6.5) alone or in the presence of aluminum during the first 7 d of the freshly fertilized egg, eyed embryo, alevin, or swim-up larva stages of development. Following exposure to acidity and aluminum, eggs and fish were held under control water quality conditions to 40 d posthatch to assess effects of the exposure on subsequent development. Reductions in pH from 6.5 to 6.0 in low-calcium water (1.4 mg/L) did not affect survival, but reduced growth of fish in the early life stages. The presence of as little as 50 $\mu\text{g Al/L}$ at low pH further decreased growth and reduced survival. The most sensitive indicators of stress were loss of ions (determined from whole-body sampling) and reduced swimming in alevins, reduction in the ratio of RNA:DNA, feeding inhibition, and pathology of gill tissue in swim-up larvae. A pH of 6.0 and 50 $\mu\text{g Al/L}$ reduced whole-body sodium by 72% and potassium by 50% in alevins. Reductions in the RNA:DNA ratio, correlated with lower growth rates, were observed in swim-up larvae exposed to pH 5.5 and 50 $\mu\text{g Al/L}$. Exposure to 50 $\mu\text{g Al/L}$ at pH 6.0 reduced swimming activity of alevins by 68% and feeding rates of swim-up larvae by 67%. In the presence of 50 $\mu\text{g Al/L}$, pathological changes in gill tissue were observed in swim-up larvae exposed to pH 6.0 or less. Although acidification is not widespread in the western USA, cutthroat trout have a narrow margin of safety between conditions that currently exist and those at which pH and aluminum reduce survival and growth.

Jackson Lake Draw-down Project Small Mammals Annotated Bibliography

Geier, A.R. & Best, L.B. 1980. Habitat selection by small mammals of riparian communities: evaluating effects of habitat alterations. *Journal of Wildlife Management*. 44(1): 16-24.

Small mammals of riparian communities in Iowa were studied during the summer using live- and snap-trapping techniques. Six general habitat types were identified from the herbaceous vegetation on 28 study plots selected to represent a range of habitats from open fields to deciduous forest. Predominant habitat alterations were grazing, timber removal, and stream-channel realignment. Small-mammal species diversity was highest in channelized habitats and lowest in dry floodplains. An index of breadth of habitat usage was calculated for 9 species of mammals; white-footed mice (*Peromyscus leucopus*) exhibited the most generalized habitat usage. With the use of stepwise multiple regression relationships were determined between small-mammal species abundances and 1 variables describing microhabitat features. In many instances, small-mammal numbers also were correlated significantly with each other. The potential effects of 6 habitat alterations on the 9 small-mammal species are predicted.

Miller, B. & Harlow, H. 2000. Monitoring selected species of mammals in Grand Teton National Park in 2000. In: University of Wyoming National Park Research Station 24th Annual Report, (H. J. Harlow, and M. Harlow, eds.). pp 60-65.

Note: This study continues through the 2004 field season. Additional information on all field seasons can be obtained in the following National Park Service Investigator's Annual Reports: 21119, 25036, 26177, and 31542.

Our objective is to establish a long-term monitoring project that will assess the abundance and densities of selected species of mammals at sites representing five defined vegetation types found in GTNP. The term monitoring implies data collection over multiple years. Taking long-term estimations of population composition before, during, and after biotic and abiotic changes provides needed information to assess the impacts of such changes and furnishes useful options for management decisions. This standardized monitoring plan will provide information on small and medium-sized mammals that will (1) assess species use of habitat, (2) monitor changes in species composition as a result of environmental change, such as precipitation and temperature, (3) produce predictive models of small and medium-sized mammal distribution based on vegetation type, and (4) analyze the impact of wolf colonization on the mammal (and plant) community.

2000 Field Season: We were able to estimate populations of small mammals in a dry sage plot, a lodgepole pine plot, mixed grass-forb plot, damp sedge-grass meadow, and a sedge-grass swamp. All trapping plots were one hectare grids, and we also recorded indices of medium-sized mammals on those grids. Capture-recapture data were analyzed by the Jolly Seber technique. On

the sage plot, we estimated a population of 18 *Peromyscus maniculatus* and we also captured four individuals of the genus *Microtis*. In the lodgepole pine grid, sample size was not sufficient to estimate either *Clethrionomys gapperi* or *Eutamias amoenus*, the two most common small mammals trapped. In the mixed grasses and forbs, we estimated a population of 55 *Microtis* and 24 *P. maniculatus*. In the sedge-grass damp meadow, we estimated a population size for *Microtis* as 136 individuals. In the sedge-grass swamp, we estimated a population size of 78 *Microtis* on the 1 ha grid. We recorded indices for medium-sized mammals present on all one hectare grids (in 1999, *Tamiasciurus hudsonicus*, *Thomomys talpoides*, *Spermophilus* spp., *Taxidae taxus*, *Martes americana*, *Canis latrans*, and mouse/vole holes). In year 2000, we will expand our efforts, trapping 7 habitat types with 2 replicates in each type. The 1999 data will be beneficial, but only in the context of repeated sampling over time to demonstrate trends that can be correlated with environmental changes.

2001 Field Season: We sampled small mammals through standard capture recapture techniques on two replicate grids in each of the five habitat types. Data were recorded as number of unique captures per 1000 trap-nights and as densities per hectare using Lincoln-Peterson. We trapped a total of 11,000 trap-nights. Densities for deer mice were 9/ha in sage, 3/ha in lodgepole pine, and 7/ha in grass/forb meadows. *Tamias* densities were 5/ha in lodgepole pine. *Microtis* densities were 2/ha in grass/forb meadow, 38/ha in damp grass/willow meadows, and 31/ha in wet grass/sedge/willow meadows. Because we have collected data from the sites for three years we were able to show a weak relationship between species abundance and rainfall (as of June in each year) for all the above species except deer mice in sage and *Tamias* in lodgepole pine. We also walked 96 kilometers of trails through the five habitat types on two occasions separated by three weeks. We collected a total of 80 coyote scats, which a geneticist is now analyzing to identify individuals. Her recovery rate thus far is about 50%. We hope that identification of individuals allows a population estimate of coyotes in the 100 sq. km study area via Lincoln-Peterson. The three years have now given a reasonable baseline for the five habitat types in areas without wolves. While continuing in the areas without wolves, we would also like to add similar estimates in the same habitat types, but in areas with wolves.

2002 Field Season: We continued to trap the same plots as we had since 1999. These included sage, mixed grass/forbs, damp meadow, wet meadow, and lodgepole pine. Estimates of rodent abundance via the Peterson technique correlated with unique number of captures per 1000 trap-nights ($p = 0.01$, $r\text{-squared} = 0.54$). Across years, abundances of rodents were less affected by rainfall differences in drier habitats (e.g. sage) than in wetter habitats. Abundances of *Microtis* and *Clethrionomys* correlated more closely with level of rainfall than *Peromyscus* and *Tamias*. We found only 1/3 the number of coyote scats in 2002 than we found in 2001. This may be due to increasing numbers and activity of wolves in the Park, but more data are needed.

2003 Field Season: We captured rodents across 5 habitat-types. Unique number of captures per 1,000 trap nights correlated to estimates of abundance for each species. When we compared the estimates of abundance across a given habitat type over the five years to level of precipitation, we found that abundance of *Microtis* in grass/forb meadows ($r^2 = 0.69$, $p = 0.08$) and red-backed voles in mature forest ($r^2 = 0.74$, $p = 0.06$) were somewhat related to level of precipitation. At this point genetic analyses of coyote scat are still in progress. We walked the same trails in the Pacific Creek area during 2001 - 2003, but we collected 68 fresh coyote scats in 2001, 22 in

2002, and 34 in 2003 ($X^2 = 27.5$, d.f. = 2, $p < 0.001$). Number of scats has declined significantly in 2002 and 2003. Those two years saw a fast expansion of wolves in the Teton Pack. There was no significant difference in the number of scat collected around the Elk Ranch when we compared 2002 and 2003. During 2002 and 2003, there were no significant differences in the number of scats located in the Pacific Creek area as opposed to the Elk Ranch Reservoir area (adjusted for differences in total transect length at each site). The Elk Ranch area is near the wolf denning site. The lack of difference could indicate that wolves are affecting coyotes evenly over both areas.

2004 Field Season: If a system that evolved with large carnivores finds those apex predators extirpated, the system changes. Yet we know relatively little about such changes across trophic levels. Nearly all of such studies from Yellowstone National Park examined the interaction pathway of wolves to ungulates to plants. This study examines the interaction pathway of wolves to coyotes to mice. Coyotes generally avoided areas near the wolf den, and they chose different habitats when they were near to the wolf den as compared to when they were away from the wolf den. We saw higher numbers of mice and voles on plots that were near the wolf den as opposed to away from the wolf den. Predation by coyotes seems to be regulating numbers of small mammals more strongly in areas away from the wolf den, whereas level of annual rainfall seemed to be a stronger factor in regulating mice and voles near the wolf den (where there were fewer coyotes). Taken together, these factors may indicate a top-down effect by wolves on coyotes and subsequently on the mice and voles of the area.

Ruszkowski, T.A. 1996. Songbird and small mammal diversity and habitat use of the riparian zone in the John D. Rockefeller Jr. Memorial Parkway. M.S. Thesis, University of Wyoming, Department of Zoology and Physiology.

Songbird and small mammal surveys were conducted in 1994 and 1995, on fifty-five 25 meter radius plots in the Snake River riparian zone in the John D. Rockefeller Jr. Memorial Parkway, Grand Teton National Park. Comparisons of wildlife relative abundance and community composition were made between seven distinct vegetation types (tall shrub/dry grassland, tall shrub, tall shrub/wet meadow, wet meadow, marsh/fen, marsh/fen/wet meadow, and moist forb meadow).

Relationships between wildlife and vegetation structure were also examined. Several species of small mammals and songbirds showed affinities to particular habitat characteristics and vegetation types within the riparian zone. Common yellow throats and Lincoln's sparrows were predominately observed in moist habitats containing dense vegetation, while savannah sparrows were most abundant in the wet meadow. Deer mice were predominately captured in the tall shrub/dry grassland, which was characterized by habitat, while western jumping mice were most abundant in the moist forb meadow.

Each vegetation type within the riparian zone had a unique species composition depending on the level of structural complexity found in each. Relative abundance and vegetation structure were related.

Villalobos, B.C. & Keller, B.L. (1991). The influence of riparian and adjacent habitats on small mammal distributions in Grand Teton National Park, Wyoming. In: University of Wyoming National Park Service Research Center 15th Annual Report (H.J. Harlow and M. Harlow, eds.) pp 175-179.

(Note: study continued in 16th annual report, 1992)

The principle objective of the study is to understand the environmental and landscape factors in which the riparian edge habitat or ecotone influences small mammals. Four sub-objectives are required to accomplish the main objective. Three study sites were used to trap small mammals from June to October, 1991. During 3,207 live-trap nights, 473 individuals were captured, including eight species of rodents and one species of shrew. A difference in species diversity of the rodent species is apparent among areas. Riparian areas appear to have the highest species diversity, whereas the edge usually contains the greatest abundance of small mammals. At the edge, animals have access to both riparian and upland areas and may utilize benefits available in both habitats. Among the sites, seasonal changes were observed in species composition and relative density. These changes were accounted for in the reproductive patterns of the deer mouse (*Peromyscus maniculatus*) and the southern red-backed vole (*Clethrionomys gapperi*).

Invertebrates

Aquatic Invertebrates (pp 91-101)

Insects/Terrestrial Invertebrates (pp 102-105)

Jackson Lake Draw-down Project Aquatic Invertebrates Annotated Bibliography

Benson, N.G. & Hudson, P.L. 1975. Effects of a reduced fall drawdown on benthos abundance in Lake Francis Case. *Transactions of the American Fisheries Society* 104: 526-528.

Lake Francis Case, a 356-km² Missouri River reservoir, is drawn down each fall to hold water released from upstream for winter power generation. The customary drawdown of 10-12 m in 1953-70 was reduced to 6-7 m in 1971-73. Benthos samples collected from 1966 to 1973 indicated that abundance of benthic organisms in May along two transects (to depths of 10.5 and 15 m) increased more than threefold after the drawdown was reduced; abundance in September did not increase. May increases were most evident for five burrowing forms: chironomids, *Hexagenia*, *Caenis*, oligochaetes, and ceratopogonids.

Casas, J.J.; Zamora-Munoz, C.; Archila, F.; & Alba-Tercedor, J. 2000. The effect of a headwater dam on the use of leaf bags by invertebrate communities. *Regulated Rivers: Research and Management* 16: 577-591.

Breakdown rates and colonization of leaves from four tree or scrub species differing in quality are studied upstream and downstream of the Canales Reservoir, a dam located in the headwater of the River Genil, Sierra Nevada, in southern Spain. This dam, with hypolimnetic release, displays short-term fluctuations of discharge and nutrient enrichment in the tailwaters during the study period. Breakdown rates of the four leaf species studied do not differ between sites, despite the higher dissolved nutrient concentration in the tailwater. This lack of differences is attributed to the potentially high physical breakage of leaves during peak flows that are of higher magnitude at the upstream site. The invertebrate density in leaf bags does not differ between sites, and Chironomidae and Ephemeroptera are numerically dominant taxa at both sites. With regard to functional feeding groups, the scarcity and lack of significant differences between sites for shredders do not match the trend dictated by the Serial Discontinuity Concept in relation to the effect of a headwater dam. Possibly, the discharge fluctuations at both sites cause excessive instability of the natural substrate (leaf litter) for the shredder guild. However, as expected, the biomass of collectors colonizing leaf bags is significantly higher than the tailwater, which might not be explained in terms of quantity, but as a consequence of the higher nutritional quality of the fine particulate matter (FPOM) accumulated in leaf bags at this site, owing to the eutrophication caused by the dam. Despite the scarcity of functional shredders at both sites, at the community level, the leaf material is significantly more ingested at the upstream site, suggesting the importance of this source of nutrition for the trophic web at this site in contrast with the tailwater, as predicted by the Serial Discontinuity Concept. This also suggests that caution is needed in using functional feeding groups as trophic guilds to infer system-level trophic drawdown and maximizing the flood duration and flood dry season areas or volumes. However, experiences from dams and other hydraulic engineering projects suggest that these predictions should be treated with caution until we better understand the influence of hydrology on spawning behavior, system primary production, and critical habitat availability.

Fisher, S.G. & Lavoy, A. 1972. Differences in littoral fauna due to fluctuating water levels below a hydroelectric dam. J. Fish Res Board Canada 29:10 pp 1472-1476.
<http://mdl.csa.com/partners/viewrecord.php?requester=gs&collection=ENV&recid=7400463>. 23 Nov 2005.

Water level fluctuations below a hydroelectric dam on the Connecticut River produce a freshwater 'intertidal' zone. Along a transect, in this zone from high to low water mark benthic invertebrates increased markedly in density and taxonomic diversity. Community composition shifted from chironomid-oligochaete predominance on the most exposed sites to mollusk predominance on the least exposed sites.

Good, W.R. 1971. Downstream Drift of Aquatic Invertebrates in the Snake River, Grand Teton National Park. Unpublished Report, Department of Zoology and Physiology, University of Wyoming.
(Document accessible in AMK research library)

Downstream drift of stream invertebrates was measured on five dates during the summer of 1967 at the Cattleman's Bridge on the Snake River, Grand Teton National Park. Relative abundance of the various taxa in the drift was mostly similar to their relative abundance in the standing population as reported by Kroger (1967). The two most abundant mayfly nymphs in the drift were *Ephemerella inermis* Eaton and *Tricorythodes minutus* Traver. Both drifted mostly at night. *Ephemerella inermis* was most abundant on the nights of July 21-22 and August 6-7. It exhibited a decline in drift rate on nights with a full moon. *Tricorythodes minutus* was most abundant on the nights of August 19-20 and September 4-5. Sub-images of *T. minutus* contributed heavily to the drift during emergence periods. Chironomidae were abundant in the drift on all sampling dates. Daytime decrease in the drift rate of the larvae may have been due to selective removal of larger larvae by feeding fish. Chironomidae emerging pupae, virgin adults, and spent adults occurred mostly at dusk and dawn. Simuliidae larvae were abundant in the drift on all five dates and occurred mostly at night. The sum of Ephemeroptera and Diptera biomasses was 70-92% of the total drift. Drifting organisms were distinguished as belonging to five groups: 1) benthos, 2) emerging forms, 3) spent adults, 4) terrestrials, and 5) lake plankton. The very abundant lake plankton was not tabulated. The sum of the benthos and emerging forms biomasses was 93-98% of the remaining drift.

Drift data obtained from the sampling point could not be used to make quantitative estimates of drift rate across the remainder of the river's width. A model of downstream drift was suggested for purposes of discussion. Use of downstream drift rate measurements to estimate excess production rate after the method of Waters (1966) was found unfeasible due, in part, to feeding on drift by fish.

Good, W.R. 1974. Some effects of spring snowmelt runoff on aquatic invertebrate populations in a high mountain stream. PhD Thesis University of Wyoming, Department of Zoology and Physiology.
(Hard copy of document accessible at AMK research station library)

This study was an investigation of the abiotic and biotic factors acting on a community of benthic invertebrates in a high mountain stream during the spring snowmelt runoff period. All data used were collected in 1970. This study area was a 1 km section of Nash Fork Creek near 3,000 m in the Snowy Range, Wyoming. The runoff began in mid-May when the discharge was at 6 cfs (.17 cms), rose erratically to a peak of June 25, at 125 cfs (3.54 cms), then dropped through the rest of the summer. Water temperatures increased through the runoff from 0°C in mid-May to 4.5-11.5°C on June 25 and to 7-16°C by July 21. The general snow cover over the stream present in mid-May was gone by June 4. For each invertebrate species in the study area which could be separated, population estimates were made, size ranges were recorded, and when possible, hatching and breeding periods were noted. Of 30 species of which the life cycle could be defined, 6 were non-seasonal, 12 were slow seasonal, and 12 were fast seasonal, based on the system of Hynes (1970).

The median values for the total standing crop biomass were 3,600 mg per m² for Junes 1-4 and 5,980 mg per m² for July 27-29. These values were not different at the 0.5 level using the Mann-Whitney u-statistic.

Drift samples were taken between the benthos sampling periods. From the drift samples of June 12-13, 17-18, and 22-24, drift rates for all vertebrates together increased with the increase in discharge. The same trend was found for the drift of oligochaetes and tipulid larvae considered separately. In the daytime drift, the percentage of drifting oligochaete biomass which fragments was correlated with discharge ($r = 0.9717$). The species which could be sorted with a live-sorting apparatus were considered as a group. The drift rates of this group increased with discharge through June 12-13 and 17-18 until the peak on June 22-24. They then decreased to lower levels on July 6-7 and 13-14, and finally increased, only at night, on 21-22 July. A net downstream loss of drifting invertebrates from the study area could not be confirmed.

A nocturnal drift index was correlated with water temperature (positive correlation) and discharge (negative correlation). For the multiple regression of the index on water temperature and discharge the coefficient of determination was .86. This was interpreted as showing an increase in behavioral drift with increasing water temperature, but an inhibition of behavioral drift with high discharge. Samples taken to determine the percentage of drifting invertebrates that were dead contained 11% dead invertebrates. Ratios of drift rate/benthos density were measured for a few species. The species most highly modified to resist current had the lowest drift/benthos ratios. Predation on drifting invertebrates by fish was assumed to be a source of mortality. Also, the rapid growth of the net-spinning *Arctopsyche* sp. Larvae was taken to indicate that it was a very effective live predator on drift during the runoff.

Adjustment of the life cycle was found to be a common means of adaptation to the runoff and was manifest in several ways:

- 1) The Diptera avoided exposing pupae to the peak of the runoff.

- 2) Many insect species were found to breed during the runoff. Of thirty selected species, 18 did breed, 4 (all fast seasonal species) were presumed not to breed, and the breeding period of 8 was not known.
- 3) Prolonged hatching of eggs, or avoidance of hatching, were recognized as runoff survival strategies. Of 48 selected species, 5 were hatching only on the rising (June 1-24) phase, 6 only in the falling (July 6-29) phase, and 21 species hatched in both phases, and 16 species did not hatch in either phase.

The co-existence of very similar congeneric species in the genera *Baetis*, *Alloperla*, *Nemoura*, *Paraleuctra*, and *Rhyacophila*, was proposed to be allowed because the congeners may have different runoff-survival strategies which vary in effectiveness due to largely yearly differences in the timing and severity of the runoff.

Gustafson, Daniel. 2000. Status of the Jackson Lake springsnail, *Pyrgulopsis robusta*. National Park Service Investigator's Annual Report, Grand Teton National Park.
<https://science1.nature.nps.gov/research/ac/iars/iarPrint?reportId=194662>). 7 June 2005.

The objectives of this study are to determine the current status of the native Jackson Lake springsnail, *Pyrgulopsis robusta* (Walker) in Polecat Creek, which is now invaded by the exotic New Zealand mudsnail, *Potamopyrgus antipodarum* (Gray), and to obtain a DNA sample that will be used in a major analysis of the western North American Species of *Pyrgulopsis* by Robert Hershler. As of June 26, 2000, *Pyrgulopsis robusta* remains in lower Polecat Creek, but is outnumbered by *Potamopyrgus antipodarum* by about 2,000 to 1. The survival of the native species in this area seems doubtful. A shell, body, and DNA sample were placed in the National Museum of Natural History (Smithsonian institution) and a few shells were returned to the park. (See also http://www.esg.montana.edu/dlg/alm/etc/teton_pr.html)

Gustafson, Daniel. 2001. Status of *Pyrgulopsis robusta*, 2001. National Park Service Investigator's Annual Report, Grand Teton National Park.
<https://science1.nature.nps.gov/research/ac/iars/search/iarView?reportId=21048>.
 15 June 2005.

The objective of the study is to evaluate the status of the only known population of *Pyrgulopsis robusta*, which is now under pressure from the invading New Zealand mudsnail *Potamopyrgus antipodarum*. This study repeats an initial evaluation that was done in 2000. On June 25 2001, I repeated my June 26, 2000 mollusk sample of Polecat Creek below the bridge near the mouth. The same nine mollusca taxa were found as last year. This year we did find one live *Pyrgulopsis robusta* in the field (none last year). However, only three were found more with lab sorting (54 total last year). There were also several dead shells that were not counted either year. The 2mm sieve works well to separate these species. The total number of the exotic *Potamopyrgus antipodarum* collected this year was about 80,000 but this actually reduced from last year's collection of nearly 110,000, but this may be more due to a larger average size and my

fixed collection volume (about 500 ml). The *Potamopyrgus* ratio is now about 1:20,000. This represents a 10 fold reduction since last year. The total catch reflects 13.5 fold decline. No small specimens of *Pyrgulopsis robusta* among the mass of *Potamopyrgus* shells were found. The common snail *Valata humeralis* has also dropped to barely detectable levels.

The situation does not look good at this site, however, On August 10, 2001 a better population was found upstream near the Yellowstone boundary. These populations were associated with springs and these may serve as refuges for native species. I have seen this situation in several other areas. The native species holds on near the spring source and the mudsnails dominate further downstream. There is no guarantee that this will be the case. The need to further monitor lower Polecat Creek is greatly lessened with knowledge of the upstream populations. The population in the lower creek cannot get much lower and still be detectable with reasonable samples. I now recommend that the upstream spring sites, as potential refuges, be identified and offered special protection. These areas may be very small and thus very venerable. The identity of the upstream snails should also be checked to insure they are the same species, but this does not seem most likely.

Hall, R.O., Tank, J.L., & Dybdahl, M.F. 2001. Exotic snails dominate nitrogen and carbon cycling in a highly productive stream. In: University of Wyoming National Park Service Research Center 25th Annual Report. (H.J. Harlow and M. Harlow, eds.), pp 72-77.

Individual animal species can impact ecosystem processes, but few exotic animal species have demonstrated ecosystem-scale impacts, in spite of large population sizes. We studied the role of the exotic New England Mud Snail, *Potamopyrgus antipodarum*, on carbon (C) and nitrogen (N) fluxes in Polecat Creek, Wyoming. We combined whole-stream measures of carbon and nitrogen fluxes with rates of consumption and ammonium excretion to show that *Potamopyrgus antipodarum* dominated carbon and nitrogen fluxes in a highly productive stream. Exotic snails consumed 75% of gross primary productivity, and their excretion accounted for two-thirds of ammonium demand. These large fluxes were due to high snail biomass rather than high per biomass rates of excretion or consumption. This snail may dramatically alter ecosystem function in rivers, with potential consequences for food web structure and element transport.

Hall, R.O. 2004. The spread and impact of exotic New Zealand mudsnails in the GYA . National Park Service Investigator's Annual Report, GTNP.
<http://science.nature.nps.gov/research/ac/iars/search/iarView?reportId=31327>. 1 July 2005.

Note: This is a multi-year study beginning in 2000. NPS Investigator Annual Repots pertaining to this study include the following: 19202, 21191, 23175, and 28051.

The New Zealand mudsnail has invaded Polecat Creek and the Snake River in Grand Teton National Park, and is achieving extremely high densities in Polecat Creek. Given the invasion capacity of the New Zealand mud snail, we expect that it is likely to be introduced into

other aquatic ecosystems in Grand Teton National Park, and become successful invaders in waters that are invulnerable to the mud snails. A goal of our research is to define the spread and impact of mud snails at invasion fronts. Additionally, because snail impacts will be mediated by consumption of their attached algal food resources, we will estimate the degree to which nitrogen excretion by snails alters primary production of attached algae. This will be part of a long-term study that we have recently initiated in GYE rivers. It is part of several ongoing collaborative studies by the two PIs that focus on measuring the factors that determine the invasiveness and ecological impact of mud snails, and of invaders in general.

Objectives for this specific study include:

1. Assess the rate of spread and impact of mud snails at invasion fronts.
2. Collect pre-invasion samples in GTNP streams at risk.
3. Assess the impact of mud snails on nitrogen cycling in Polecat Creek (JDR Parkway).

In this field season, we continued monitoring of snail population in Polecat Creek and have examined other streams at risk for snail invasion. We are processing the snail samples from Polecat Creek. Our search for *Potamopyrgus* in other streams turned up a new invasive snail, *Melanoides tuberculata*, from Kelly Warm Springs. It is a common aquarium escapee from Malaysia found throughout warm parts of the US. It has extremely high densities in Kelly Warm Springs.

Hawkins, Chuck. 2002. Development of an empirical model for predicting the stream invertebrate fauna of the Greater Yellowstone Ecosystem. National Park Service Investigator's Annual Report, Grand Teton National Park.
<http://science.nature.nps.gov/research/ac/iars/search/iarView?reportId=25103>. 30 June, 2005.

The purpose of this study is to expand upon previous work we have conducted, in which we developed empirical models that predict the stream invertebrate fauna in streams in both Yellowstone NP and the Pacific Northwest. These models use various multivariate statistical methods to predict the occurrence of individual taxa in a given stream based upon easily measured physical characteristics (e.g., slope, conductivity, elevation). This allows us to generate an expected species composition at each site. The models are constructed using data from a large set of unimpaired reference streams that encompass the full range of natural variability in a given area. By comparing the number of expected taxa actually observed at a new, or "test" site, with the number predicted to occur, we can assess the biological integrity of the stream. The ratio of observed to expected taxa, or O/E, provides an easily interpretable measure of biological integrity. Streams with O/E scores significantly less than 1 are inferred to be biologically impaired.

This work is part of a large-scale project, funded by the EPA, designed to assess the biological integrity of streams throughout the western US. Given the increasing anthropogenic pressure on, and the ecological importance of, the Greater Yellowstone Ecosystem, it is critical that we assess the degree to which human activity may be degrading stream ecosystems. The first step in that process is to collect data from a large number of unimpaired streams in the GYE. The

streams of Grand Teton National Park will be a crucial part of this effort. In addition, this study will provide valuable data regarding the state of stream ecosystems in the Park.

During 2002 we collected macroinvertebrates and periphyton from a number of streams in and around GTNP. We have used these data to build a predictive model for conducting bioassessments of streams and rivers in the Greater Yellowstone Ecosystem. We expect this model to be available to interested agencies via the Web within 6-8 months. In addition, we are using the periphyton data to examine the utility of biologically based classification schemes for partitioning the variability in ecosystem process rates such as primary productivity. This would allow us in principle to develop predictive models for stream ecosystem process rates, and allow the inclusion of ecosystem processes in bioassessments.

Kroger, R.L. 1967. A study of the classification and ecology of the aquatic invertebrates in the Snake River, Grand Teton National Park, Wyoming. M.S. Thesis, University of Wyoming, Department of Zoology and Physiology.

A study of the taxonomy and ecology of the aquatic invertebrates in the Snake River and tributaries in GTNP, Wyoming and surrounding areas was conducted during the summer and fall of 1965 and 1966. The principal objectives of the study were to determine the species composition of this ecosystem and the life histories of as many of the species as possible.

The life history data includes information on density, distribution, growth rates, maximum weights when mature, dates of emergence, lengths of life cycles, egg incubation periods, drift, food habitats and parasites of the major species. One-hundred and seventy species of invertebrates were collected from the river and tributaries, and these have been made into a reference collection for future researchers.

Additional data was collected during the study period. The effects of fluctuating water flow on the organisms, the identification of higher plants and algae of the river and tributaries, and the changes in standing crop of invertebrates at four arbitrarily selected stations were investigated. Primary emphasis was placed on taxonomy and life history data, but other data collected to serve to supplement these and to suggest areas that should be studied intensively in the future.

This study, which was sponsored by the National Park Service, is the first segment of a long range study to acquire knowledge about the ecology of the river with special reference to the fishery of the cutthroat trout, *Salmo clarki* Richardson. The study is needed because of the increasing use of the river for recreation and the need to determine the effects of the fluctuating flows on the ecology of the river.

Kroger, R.L. 1972. Underestimation of standing crop by the Surber Sampler. *Limnology and Oceanography*, 17:475-478.

Before the low flow of water from Jackson Lake into the Snake River was stopped by closure of the dam, invertebrates were collected in five Surber samples from a downstream riffle. After the water had receded from the riffle, five 0.093m² areas of the exposed streambed

substrate were hand-collected and the invertebrates removed. Predraw-down samples contained 4,286 invertebrates weighing 6.3g while postdrawn samples contained 15,490 weighing 13.6g. Large differences between submerged and exposed samples resulted from passage of smaller insects through fine mesh of the Surber sampler and from backwash created by the sampler.

Kroger, R.L. 1973. Biological effects of fluctuating water levels in the Snake River, Grand Teton National Park, Wyoming. *American Midland Naturalist*, 89: 478-481.

The effects of fluctuating water levels, which result from variation in the demand for irrigation water released through Jackson Lake Dam, on aquatic biota released in the Snake River in Grand Teton National Park were observed. Unnaturally low water levels and sudden decreases in water flow exposed the stream bed and destroyed algae, invertebrates, and some fish and probably limited the production of other fish occupying higher trophic levels. This is evidently the first published report, which shows that rapid changes in water levels leave aquatic invertebrates and some fish stranded on the exposed streambed.

Lessard, J.L. & Hayes, D. B. 2003. Effects of elevated water temperature on fish and macroinvertebrate communities below small dams. *River Research and Applications* 19:7 721-732.

Many studies have investigated the ecological changes that occur below dams that release cold, hypolimnetic water, but very few studies have looked at the effects of the release of warm, surface waters. The effect of small, surface release dams on downstream thermal regimes is a major habitat concern for many cold-water systems, however. The objective of this study was to examine the effects of summer temperature increases due to impoundment on downstream fish and macroinvertebrate communities in cold-water streams. We sampled fish, macroinvertebrates and habitat upstream and downstream of dams on ten rivers during the summers of 1998 and 1999. Changes in mean summer temperature downstream varied from a cooling of 1 °C to an increase of more than 5 °C. Increasing temperatures downstream coincided with lower densities of several cold-water fish species, specifically brown trout (*Salmo trutta*), brook trout (*Salvelinus fontinalis*) and slimy sculpin (*Cottus cognatus*) while overall fish species richness increased downstream. Density of mottled sculpin (*Cottus bairdi*), another cold-water species, was not related to temperature changes below the dams. Macroinvertebrates showed shifts in community composition below dams that increased temperature. This study provides information useful for determining the extent of impact of these small, surface release dams, which are abundant across the country.

Marshall, Michael. 2000. Hyporheic invertebrate grazing effects on nutrient cycling in streams. National Park Service Investigator's Annual Report, Grand Teton National Park. <http://science.nature.nps.gov/research/ac/iars/search/iarView?reportId=19387>. 30 June, 2005.

Our objective was to determine the effects of interstitial invertebrate grazing on hyporheic microbial processes (nitrogen uptake and respiration) and physical attributes of stream sediments. We manipulated interstitial invertebrate densities in sediment filled microcosms temporarily installed in the unstable alluvium directly beneath the streambed of Two Ocean Lake Creek, WY. After 1 to 2 weeks within stream sediments, nitrogen uptake and respiration were measured for each invertebrate density treatment to determine the effects of invertebrate grazing on ecosystem function. Average community respiration increased and modeled dispersion rate (a measure of solute mixing) generally decreased with increasing invertebrate density. These results suggest that hyporheic invertebrates may affect some physical and chemical properties of sediments and may provide potential links to ecosystem level processes in streams. Additional work is planned for Summer 2001.

Marshall, Michael. 2001. Hyporheic invertebrate effects on nutrient cycling in streams. National Park Service Investigator's Annual Report, Grand Teton National Park. <http://science.nature.nps.gov/research/ac/iars/search/iarView?reportId=21125>. 30 June, 2005.

The objective of this study is to determine the effects of interstitial invertebrates on nitrogen cycling and respiration in stream sediments. We manipulated interstitial invertebrate biomasses in sediment -filled flow-through microcosms in a laboratory at the UW/NPS Research Center. Average net nitrate regeneration/uptake increased with increasing invertebrate biomass, showing invertebrates stimulated in situ nitrate production or suppressed nitrate uptake. Invertebrates also stimulated ecosystem respiration and coarse particulate organic matter content in microcosms.

Meier, P.G. & Travers, D.F. 1997. The relationship between riparian vegetation and the trophic structure of aquatic macroinvertebrate communities within the Greater Yellowstone Area. University of Wyoming National Park Service Research Center 21st Annual Report. (H.J. Harlow and M. Harlow, eds.) pp 99-118.

This study investigated the effects of reduced vegetation cover on stream ecosystems within the Greater Yellowstone Area. The emphasis of the research concerned whether these effects express themselves within the aquatic macroinvertebrate community. Three general vegetation categories, each comprising three to four streams, were used to distinguish gradients of riparian vegetation: dense cover (control), moderate cover, and low cover. Within each site, five aquatic macroinvertebrate samples were collected from riffle areas with a Hess sampler.

The organisms were identified to the lowest practicable taxonomic level and assigned to trophic groups on the basis of gut content analysis. Riparian and in-stream variables were also measured. Statistical analyses were performed to elicit significant differences in the riparian, stream, and insect community indices among the streams and to relate the structure of the insect assemblage to the riparian and stream variables. The analysis of the data yielded no statistically significant differences in the vegetation categories with respect to embeddedness, bank overhang, and several physiochemical indices of water quality. Macroinvertebrate densities, biomass, and species richness did not differ among the categories. The trophic group analysis revealed that the abundance and biomass indices of the scraper community were significantly greater within the low cover sites than within the other streams. Conversely, the indices of the shredder community were significantly higher within the control streams than within the other sites. It is proposed that a shift from allochthonous to autochthonous food resources, corresponding to different vegetation gradients, accounted for these observations.

Mueller, Brad. 2002. Assessment of Aquatic Insects in the Snake River, Wyoming. National Park Service Investigator's Annual Report, Grand Teton National Park.
<https://science1.nature.nps.gov/research/ac/iars/search/iarView?reportId=23269>. 15 September, 2005.

The objective of this study will be to collect, identify, and photograph aquatic insects from various sites along the Snake River. Invertebrates will be collected at six sites above and below Jackson Lake during summer and fall, 2002 and spring, 2003. Aquatic insects will be identified and logged into a database including location and time of year, habitat-type, and other physical and water quality stream parameters. Photographs of the different genus/species will be collected. Insects will be kept at the USGS, Jackson Field Research Station and will serve as reference specimens for all client agencies and interested parties.

Summer and fall, 2002 collections have been completed along with habitat type (i.e. substrate), water quality (Temperature, DO, Conductivity, pH), and physical (current velocity and depth) parameter analysis. Insect identifications are presently ongoing. To date, approximately 10 different orders, 25 families, 35-40 genera, and 20 species have been identified from twelve sites on the Snake River above and below Jackson Lake. Reference specimens have been collected and are currently stored at the USGS, Jackson Field Research Station.

Waters T.F. 1965. Interpretation of invertebrate drift in streams. *Ecology*. 46:3 pp 327-334.

Various experiments were conducted in a small Minnesota trout stream to determine if data on the drift of stream invertebrates obtained with stationary nets set in the stream, may be interpreted as indication of permanent downstream displacement. A mayfly, *Baetis vegans* McDunnough, and the scud, *Gammarus limnaeaus*, Smith were the two species primarily involved in the drift. Drifting invertebrates were collected in arrays of several shallow nets stacked on their supporting rods to obtain the vertical distribution of the drift through the water column. Both species entered the drift nets, not only along the stream bottom, but in all water

strata. A comparison of the standing crops with drift net accumulations indicated that the drift was too large to be supplied only by standing crops in the vicinity of the drift nets and that the organisms must have drifted down from upstream areas. Measurement of the dispersal of organisms moving into a denuded stream bottom area, alternately open to movement from upstream and downstream, indicated that both species did so primarily at night and from upstream. Experimentally blocking the drift with nets set from bank to bank reduced daily drift rates downstream from the block position through a distance of 38 m, including two riffles and an intervening pool, indicating that the organisms normally drifted through at least this distance. In general, it appears that the accumulation of organisms in drift nets is the result of a permanent displacement of the organisms downstream, and not the result of non-directional activity in the immediate vicinity of the nets.

Jackson Lake Draw-down Project
Insects/Terrestrial Invertebrates Annotated Bibliography

Bagdonas, K., McGann, T. Rehg, M. Harrington, & Blanche, S. 1980. Lepidopteran survey of Grand Teton National Park. In: University of Wyoming National Park Service Research Station 4th Annual Report. (K. Diem, Director). pp 17-23.

Lepidopterans play an integral role in the high altitude ecosystems of the Rocky Mountain Region as larval herbivores and, more importantly as pollinating adults. Lepidopterans also constitute a major food source for many other invertebrates and vertebrates inhabiting these areas. However, very little is known about the lepidopteran fauna of Wyoming, particularly the Heterocera (moths), and especially in the national parks. It has therefore been impossible to accurately assess the degree to which lepidopterans affect the ecosystems.

Initiated in 1979-1980, a baseline study of the macro lepidopteran species and the formulation of a synoptic list of the lepidopteran species inhabiting Grand Teton National Park was continued and expanded in 1980-81. When this study and list are completed, we will have data directly applicable to making economic, ecological, and evolutionary data designations for the majority of the macro-lepidopteran species inhabiting the area.

Bagdonas, K., Carlisle, J., Davis, B., Bracewell, B., Harter, M., & Wills, B. 1981. Lepidopteran Survey of Grand Teton national park. In: University of Wyoming National Park Service Research Station 5th Annual Report. (K. Diem, Director). pp 40-45.

This article is a continuation of the study above. Objectives include the following: 1) Formulation of a synoptic list and voucher specimen collection of all macro lepidopteran species inhabiting GTNP, 2) Determination of Pleistocene "relict" or "marker" species which have survived in GTNP, and 3) determination of relative abundances, habitat preferences, seasonal flight periods, life histories, and other ecological data of Grand Teton lepidopterans. In the three-year survey, 95 species of butterflies and shippers were recorded in 7 families, and 226 species of macro- moths were likewise recorded in 17 families. Approximately 260 of 321 recorded lepidopterans in GTNP are relict species with scattered colonies and disjunct populations. Their abundance within the park and surrounding areas range from very common to extremely rare.

Debinski, D., Kindscher, K., & Jakubauskas, M. 2000. A Remote Sensing and GIS-Based Model of Habitat as a Predictor of Biodiversity. National Park Service Investigator's Annual Report. <http://science.nature.nps.gov/research/ac/iars/search/iarView?reportId=18920>. 30 June 2005.

Note: This is a multi-year study that was started in 1997 and is continuing into the 2005 season.

The major objectives of the research were to: 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; and 3. Test the spectrally-based spatially explicit model developed in Objective 2 for predicting plant and animal species diversity; patterns in montane meadows. We sampled birds, butterflies, and plants for four years (1997-2000) in two regions of the Greater Yellowstone ecosystem: the Gallatin National Forest and northwestern portion of Yellowstone National Park and Grand Teton National Park. We used satellite imagery to classify two types of wetland meadows and four sagebrush communities. In Grand Teton National Park, our overall accuracy of mapping sagebrush communities was 65 percent, and highest for the mixed big sagebrush/low sagebrush community at 86 percent. Abundance of habitat specialist bird species was highly correlated with both meadow type and landscape variables. Butterfly species abundance and distribution was even more strongly correlated with meadow type (butterfly distribution was used to predict meadow type with a 92-96 percent accuracy in the Tetons). Voucher plants are housed at the University of Kansas McGregor Herbarium; vouchers butterflies are housed at Iowa State University.

Lund, Richard. 2001-2004 (Multi-year study). Butterflies of Yellowstone and Grand Teton Park. National Park Service Investigator's Annual Report, Grand Teton National Park. <https://science1.nature.nps.gov/research/ac/iars/search/iarView?reportId=30466>. 15 September, 2005.

The objective of this multi year study is to produce field guides about the insects of Yellowstone and Grand Teton National Parks. Photographs need to be taken of all species in the Parks. Data and photos only need to be obtained. No specimens are collected. All specimens are safely netted, photographed and released live in the area of the Park where they were discovered by the researchers.

Moore, J.P. 2001. Inventory of mosquitoes of Grand Teton National Park and John D. Rockefeller, Jr., Memorial Parkway. National Park Service Investigator's Annual Report, Grand Teton National Park.
<https://science1.nature.nps.gov/research/ac/iars/search/iarView?reportId=20986>. 15 September, 2005.

The objective of the study is to record the occurrence, distribution, and bionomic factors of the mosquito fauna of Grand Teton National Park and John D. Rockefeller, Jr., Memorial Parkway. These bionomic factors include blood host preferences, biting periods, adult and larval habitat descriptions, and determination of the most efficient methods of monitoring pestiferous and disease-associated species.

Findings and Status:

1. Continuation of inventory effort started under NPS Permit No. GRTE-98-19.
2. Throughout study period (1998 to present), 25 mosquito species belonging to 3 genera and 5 subgenera were collected.
3. Research results published as:
Moore, J.P. 2001. Mosquitoes of Grand Teton National Park, Teton County, Wyoming, USA. *Journal of the American Mosquito Control Association* 17(4): 249-253.
4. Research results presented to 54th Annual Conference of the Utah Mosquito Abatement Association at Provo, UT, in October 2001, and to the 28th Annual Meeting of the Tennessee Entomological Society at Clarksville, TN, in October 2001.
5. Future efforts include:
 - a. Additional field collections to identify additional mosquito species.
 - b. Identification of additional larval habitats with co-existing populations of *Ochlerotatus nevadensis* and *Ochlerotatus communis*.

Opler, Paul. 1998-2002. (Multi-year study) Inventory of the moths and butterflies of Grand Teton National Park. National Park Service Investigator's Annual Report, Grand Teton National Park.
<https://science1.nature.nps.gov/research/ac/iars/search/iarView?reportId=24141>. 15 September, 2005.

The objective of this project is to determine a baseline list of the moths and butterflies found in Grand Teton National Park, and to determine their distribution by habitat, season, and altitude. This baseline will serve as a comparison against future changes due to factors such as global climate change, invasive exotic plants, grazing by ungulates, and fire. To alert Park Service resource management personnel of any management or conservation concerns relating to the Lepidoptera fauna. To describe newly discovered species in appropriate entomological journals. To keep up-to-date fauna list on U.S. Geological Survey on-line site, and to prepare complete report of findings at end of project or at such intervals as requested.

Findings and Status:

Study has just begun. To date a list of about 70 butterfly species for Grand Teton National Park has been prepared (more than 120 species expected) and will be served on-line at a U.S.G.S. site.

Moths collected in 1998 have not been labelled and identified, but a running list and database will be established. Up-to-date list will be served on-line at a U.S. Geological Survey site. Investigator will sample several days in 1999 during July and possibly in mid-May. During 1998 surveys it was discovered that 3 regional endemic butterflies, the Gillette's Checkerspot (*Euphydryas gillettei*), Relict Fritillary (*Boloria kriemhild*), and Hayden's Ringlet (*Coenonympha haydenii*) are found in the park. The last species is widespread and common, while the first two are restricted in the park and may require periodic monitoring. These two species are probably negatively affected by both fire and invasion by exotic plants. The widespread occurrence of Smooth Brome grass (*Bromus inermis*) in the park was noted; this grass would certainly be a negative influence on native moths and butterflies as almost none use it as caterpillar food source. ;Specimens collected in the park are stored in the C.P. Gillette Museum of Arthropod Diversity at Colorado State University.

Fungi

Jackson Lake Drawdown Project Fungi Annotated Bibliography

Blodgett, James. 2004. Distribution, Species, and Ecology of Armillaria-Fungi in Wyoming. National Park Service Investigator's Annual Report, Grand Teton National Park. <http://science.nature.nps.gov/research/ac/iars/search/iarView.jsessionid=DC43DBB19341B372DA4A845F8763B333?reportId=30062>. 30 June 2005.

A statewide investigation of Armillaria in Wyoming is proposed to: 1) collect and identify Armillaria species, 2) map species distributions, 3) record host relationships, 4) determine pathogenicity, and 5) identify soil and site associations.

Armillaria root disease is associated with various forest tree declines in the Rocky Mountain Region. Subalpine fir decline, for example, is one of the most widespread causes of mortality in high elevation spruce-fir forests. Armillaria root disease has been suggested to play a primary or contributing role in this malady, however, its importance in the decline has not been described. Armillaria root disease also has been suggested to play a role in tree mortality that is usually attributed only to bark beetles. Armillaria has been documented as a major forest pest in the states surrounding Wyoming, yet an evaluation of the significance of this root pathogen in Wyoming is lacking. Given the widespread tree mortality in Wyoming noted in previous FHM detection surveys, we propose to assess the spatial distribution and actual and potential impacts of this pathogen statewide. This study will be the first evaluation/monitoring study of Armillaria root disease in Wyoming.

McKnight, K.H., Harper, K.T. & McKnight, K.B. 1980. Mushrooms of Grand Teton National Park. In: University of Wyoming National Park Research Station 4th Annual Report. (K. Diem, Director). pp 58-61.
(Note: Study continues in 4th through 11th Annual Reports, 1982-87)

This study attempts to inventory the mushrooms and related fungi of the Park and to assemble correlative data useful in park resource management and utilization. It is directed towards 1) determining what species of higher fungi grow in and around Grand Teton National Park; 2) appraising their role in the ecosystem; and 3) preparing descriptions, illustrations, and where possible, keys for the common species. Fungi included are mostly Ascomycetes and Basidiomycetes with large or otherwise conspicuous fruiting bodies. Collecting is not confined to GTNP, but includes sites with similar ecology in the areas surrounding the park.

McKnight, K. H. 1982. Checklist of Mushrooms and Other Fungi of Grand Teton and Yellowstone National Parks. Grand Teton Library and Museum Association, University of Wyoming Natl. Park Ser. Research Center, Yellowstone Library and Museum Association.

The fungi listed here comprise 474 species and infraspecific taxa of Eumycota and Myxomycota in 162 genera and 55 families from Grand Teton and Yellowstone National Parks and their immediate vicinity. One collection from each included taxon is cited and the locations of exsiccati are given.

McKnight, K. H., Harper, K.T, & McKnight, K.B. 1982. Mushrooms of Grand Teton National Park. In: University of Wyoming National Park Research Station 6thth Annual Report. (K. Diem, Director). pp 69-80.

Collections of fungi and measurements of soil moisture were made in and around the Parks during the summer and early autumn of 1982 and directed to 1) adding to the total number of species known to occur there; 2) comparing the mushroom species fruiting on 11 different forest stands over a twelve-week period; and 3) elucidating possible correlations with mushroom fruiting and soil moisture. The 1982 season proved to be unusually productive due to relatively cool and wet weather. Sixty-two taxa not previously reported were identified and added to the compiled list, thus totaling 532 species.

McKnight, K.H. 1987. Taxonomy and ecology of ectomycorrhizal macrofungi of Grand Teton National Park. In: University of Wyoming National Park Service Research Station 11th Annual Report. (K. Diem, Director). pp 82-83.

This is a brief report describing the continuation of multi-year study aiming to inventory the fungal species of Grand Teton National Park. Forty-one new species were identified in the summer of 1987, bringing the total number of species known to occur in the park to 721. Report includes a list of the newly identified species.

Miller, Steven L. 1988. Hypogeous fungi occurrence, distribution and mycorrhizal hosts in Grand Teton National Park and John D. Rockefeller, Jr. Memorial Parkway. In: University of Wyoming National Park Service Research Center 12th Annual Report. pp 107-108.

Objectives of this research were to collect and identify the species of hypogeous fungi associated with the ectomycorrhizal vascular plant hosts occurring in Grand Teton National Park and the John D. Rockefeller Memorial Parkway over a three-year period and to document small mammal activity associated with sporocarps of the hypogeous fungi. Few fungi were encountered in the early portion of the summer season due to drought conditions. Late summer species collected included new records for GTNP. Less than half of the hypogeous fungi encountered in the first season were associated with small mammal digging activity. The ability of hypogeous fungi to complete their life cycle under drought conditions underscores their adaptation to extreme environmental conditions.