



Multi-Metric Watershed Condition Model for Glacier National Park

Natural Resource Report NPS/GLAC/NRR—2015/944



ON THE COVER

Glacier National Park

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A Multi-Metric Watershed Condition Model for Glacier National Park

Natural Resource Report NPS/GLAC/NRR—2015/944

William J. Kleindl¹

F. Richard Hauer^{1, 2}

Bonnie Ellis¹

Shannon Kimball¹

Kyran Kunkel³

Phil Matson¹

Clint Muhlfeld^{4, 1}

Jared Oyler⁵

Ellen Porter⁶

Chris Servheen⁵

Kristina Smucker⁷

¹Flathead Lake Biological Station, University of Montana, Polson, MT 59860-6815

²Montana Institute on Ecosystems, University of Montana, Missoula, MT 59812

³1875 Gateway S. Dr., Gallatin Gateway, MT 59730

⁴Northern Rocky Mountain Science Center, Glacier National Park, West Glacier, Montana 59936

⁵College of Forestry and Conservation, University of Montana, Missoula, MT 59812

⁶Air Resource Division, National Park Service, Denver, CO 80225

⁷Division of Biological Sciences, University of Montana, Missoula, MT 59812

This report was prepared under Task Order J2380060105
(Cooperative Agreement H1200040001)

April 2015

U.S. Department of the Interior
National Park Service
Natural Resource Stewardship and Science
Fort Collins, Colorado

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Please cite this publication as:

Kleindl, W. J., F. R. Hauer, B. Ellis, S. Kimball, K. Kunkel, P. Matson, C. Muhlfeld, J. Oyler, E. Porter, C. Servheen, and K. Smucker. 2015. A multi-metric watershed condition model for Glacier National Park. Natural Resource Report NPS/GLAC/NRR—2015/944. National Park Service, Fort Collins, Colorado.

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Executive Summary

This natural resource multi-metric condition assessment for Glacier National Park (hereafter referred to as GLAC or the park) is made up of six chapters, the first of which is this executive summary. The second chapter is a general description of the park and surrounding areas. The third addresses purpose and need for this condition assessment and a summary of threats to the park's ecological condition that extend beyond boundaries of the park. The fourth chapter describes the philosophical foundations of watershed-scale multi-metric assessment approaches and their application in areas of limited human disturbance, as well as the general methods used to develop multi-metric indices that form the bases of this project. The fifth chapter describes each of the watershed-scale multi-metric indices used to assess condition of the park's ecological focal areas of concern. This chapter includes specific methods and results for each metric and assessment index. The final chapter provides these results in the context of the park's pre-existing management boundaries. The document's first appendix is a detailed summary of the park's meteorological attributes and potential climate change scenarios. The second appendix is an overview of the GIS models used in the analysis. The final appendix includes the background maps used to inform the metrics then employed in the multiple indices.

The intention of this document is to provide GLAC a watershed-scale prioritization tool to assist with finer scale monitoring or management decisions. This document relies on existing data to provide a comprehensive overview of the ecosystem condition of Glacier National Park's watersheds. The models within this document may be used to assess the success of conservation measures directed at protecting the park's resources, or to analyze the vulnerability of the system to specific threats. As new information is obtained or updated, the metrics and indices can be reanalyzed repeatedly over time to gauge changes in management activities and/or threat status.

This document provides a baseline ecological assessment of Glacier National Park's HUC 10 watersheds from the perspective of seven major focal areas selected collaboratively with the GLAC resource management team:

- Streams: The condition of alpine, mid-elevation and lowland streams within the park's watersheds.
- Large Rivers: The condition of the North and Middle Forks of the Flathead River including their floodplains within and adjacent to the park.
- Lakes: Potential risks to the condition of the park's lakes.
- Fish: The condition of native and non-native salmonid species within the park's watersheds.
- Avian: The condition of biotic and abiotic ecosystem attributes that support a diverse avian population within the park's watersheds.
- Mammal: The condition of biotic and abiotic ecosystem attributes that support a diverse mammalian population within the park's watersheds.

- Vegetation: Impacts to the vegetation condition in terms of non-native plants, illegal grazing, and human disturbance within the assessment watersheds.

Specifically, this study evaluates a subset of the biotic and abiotic structural components that describe a natural ecological range of variation in areas of limited disturbance. These are referred to as ‘significance metrics’. This study also assesses the range of impacts to these structural components in areas of the park with increased human interaction. These are referred to as ‘stressor metrics’. Additionally, a small subset of metrics for the lake assessment measure abiotic components that could potentially threaten lake condition. These are referred to as ‘risk metrics’ (See Chapter 4 for more details).

To create a metric, measurable system attributes are presented as continuous ratios or percentages, or as descriptive categories. These measurements are then normalized by applying a sub-index to each metric which standardizes the variables by transforming them to a dimensionless scores that use the same scale (0-1). The scores provide a means of qualifying the conditions related to that metric; 0 being poor and 1 being excellent. Chapter 4 describes the methods for metric and index development in detail.

The assessment of the park’s focal areas is conducted through a series of multi-metric indices that combine, in some cases, multiple significance, risk, and stressor metrics. Significance metrics generally measure ecosystem diversity, habitat diversity, and species distribution. Risk metrics, only used in the lake model, generally measure exposure of an ecosystem to potential or future detrimental elements. Stressor metrics generally measure contemporary anthropogenic perturbations. The ecological condition of a watershed within the park is determined by a combination of metrics that measure the natural range of ecological significance as they interact with metrics that measure the human threats or risk of threats. Ultimately the ecological condition of a park’s watershed is relative only to other watersheds within the park. In other words, the quality of the ecological condition of a watershed may be much better or worse than another watershed within the park, but very likely the ecological condition is very high compared to watersheds outside the park. These outside of park, watershed comparisons are beyond the scope of this model. Therefore, watershed by watershed comparisons should be restricted to those within GLAC due to the focused reference domain of the model.

Below is a brief summary of results for each focal area that includes 1) a watershed scale map of each index and 2) a table of the 0-1 scores for each metric and final index. Each metric, as well as the multi-metric index provided in the tables and figures below and in greater detail in Chapter 5, can be used as a prioritization tool. For instance, if a management group is only interested in valley bottom stream buffer condition or Alpine Stream diversity the separate metrics of the stream assessment would provide insight to these areas of interest.

Please refer to Chapter 2 for specific details of methods and Chapters 5 and 6 for results and details concerning application to the park’s preexisting management zones.

Stream Condition

Six metrics: alpine, subalpine and valley bottom stream significance, and three buffer stressor metrics for each zone were combined to provide an assessment index of stream condition in the park's watersheds (Table E.1). The significance metrics measure the diversity of stream types relative to each watershed in the park. For instance, the watershed with the highest alpine aquatic land cover diversity will score the highest; however, these scores may change in future assessments as land cover changes due to climate change. Additionally, the stressor metrics measure likely impacts to stream buffers due to proximity to park infrastructure. Here, Lake McDonald watershed scored the lowest (index score of 0.92) due predominately to buffer impacts in each zone.

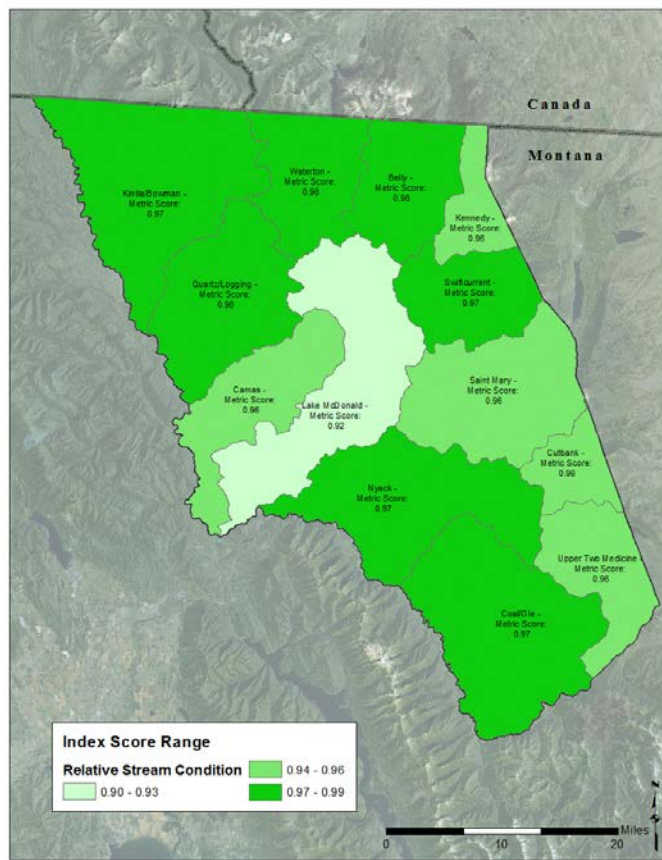


Table E.1. Stream condition score for all watersheds with GLAC.

Watershed	Metric Scores						Index Score
	Alpine Stream	Alpine Buffer	Subalpine Stream	Subalpine Buffer	Valley Bottom Stream	Valley Bottom Buffer	
Belly	1.00	1.00	0.98	0.98	0.99	0.93	0.98
Camas	0.90	1.00	0.98	0.97	0.97	0.93	0.96
Coal/Ole	0.97	1.00	0.99	0.97	0.96	0.95	0.97
Cut Bank	0.94	0.98	0.97	0.98	0.96	0.91	0.96
Kennedy	0.94	1.00	0.96	0.98	0.98	0.91	0.96
Kintla/Bowman	0.99	0.99	0.97	0.98	0.93	0.94	0.97
Lake McDonald	0.98	0.94	0.98	0.94	0.94	0.74	0.92
Nyack	1.00	0.99	1.00	0.98	0.95	0.93	0.97
Quartz/Logging	0.99	1.00	0.97	0.99	0.95	0.96	0.98
Saint Mary	0.99	0.99	0.98	0.96	0.96	0.91	0.96
Swiftcurrent	0.96	0.99	0.99	0.96	0.99	0.91	0.97
Upper Two Medicine	0.95	1.00	0.97	0.96	1.00	0.91	0.96
Waterton	1.00	0.99	1.00	0.98	0.96	0.94	0.98

Flathead River Riparian Condition

The Flathead River condition scores represent a combination of two significance metrics that measure the range of natural vegetation patch connectivity and floodplain cover, and four stressor metrics that measure human alterations within the riparian area and buffers of the Middle and North Forks of the Flathead River. For instance, Middle Fork Site 2 is a confined channel with a limited floodplain and thereby limited habitat diversity. Middle Fork Site 1 has a broad floodplain but it has been impacted by the urban activities of the town of West Glacier. Both of the scores of these two sites represent the departure from floodplain conditions that provide a diverse native habitat. In the North Fork, Sites 2 and 5 scored the lowest due to high road densities in the buffer and floodplain. All scores represent a departure from an unaltered floodplain condition resulting from concentrated human use (Table E.2).

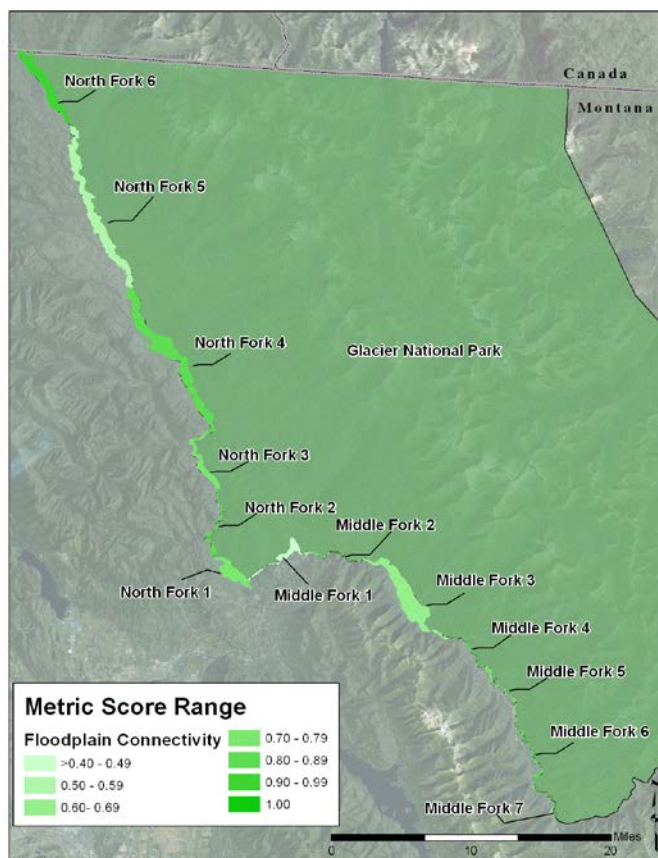


Table E.2. The metric and index scores for each floodplain assessment area in Glacier National Park.

Riparian Reach Name	Buffer		Floodplain			Index
	land Use	Road Density	Land Use	Connectivity	Road Density	
Middle Fork 1	0.94	0.00	0.77	0.50	0.43	0.58
Middle Fork 2	0.95	0.43	0.90	0.77	0.39	0.71
Middle Fork 3	0.98	0.77	0.86	0.72	0.65	0.79
Middle Fork 4	0.96	0.38	1.00	0.81	0.99	0.89
Middle Fork 5	0.97	0.37	0.97	0.81	1.00	0.89
Middle Fork 6	0.97	0.38	0.98	0.87	0.70	0.83
Middle Fork 7	0.97	0.52	0.96	0.89	0.82	0.87
North Fork 1	0.97	0.54	0.93	0.78	0.83	0.84
North Fork 2	1.00	0.45	1.00	0.80	0.88	0.87
North Fork 3	1.00	0.40	0.96	0.75	0.55	0.77
North Fork 4	0.99	0.55	0.94	0.82	0.78	0.85
North Fork 5	0.95	0.55	0.81	0.59	0.42	0.66
North Fork 6	1.00	0.33	1.00	0.95	0.83	0.89

Lake Risk

The GLAC lake condition (vulnerability) scores represent a combination of risk metrics that measure the range of natural variability of attributes that buffer lakes from potential acidification or increased eutrophication and potential human degradation resulting from the introduction of aquatic nuisance species. These are the only risk metrics in the project. Lake McDonald, Saint Mary and Upper Two Medicine watersheds scored the lowest (i.e., at highest risk) primarily because of potential exposure to non-native, non-fish aquatic species (Table E.3).

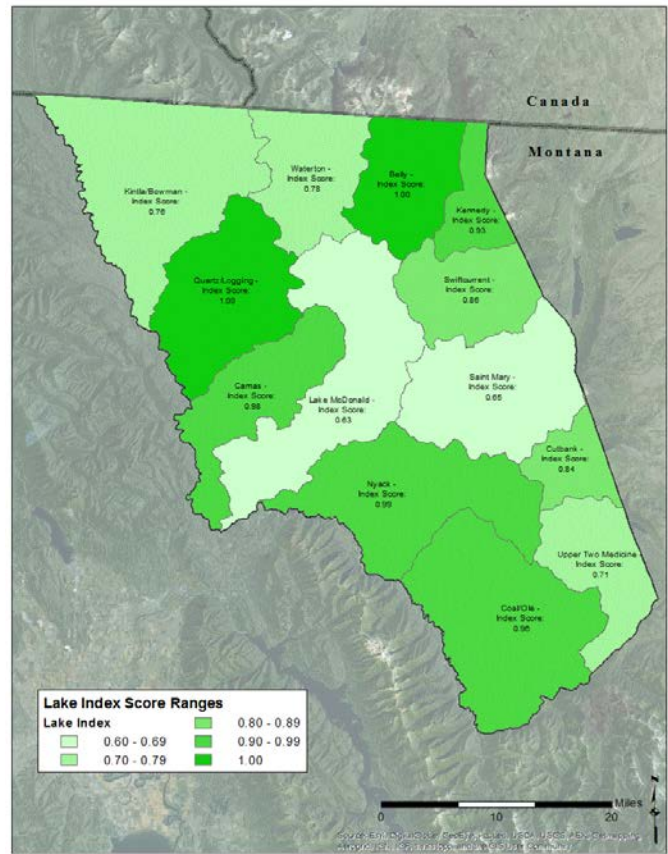


Table E.3. The lake metric and index scores in each watershed in Glacier National Park.

Watershed	Acid Sensitive Lakes	Enhanced Algal		Lake Condition Index
		Production Sensitivity	Non-Fish Exotic Species Risk	
Belly	1.00	1.00	1.00	1.00
Camas	0.97	0.99	1.00	0.98
Coal/Ole	0.94	0.98	1.00	0.96
Cut Bank	0.71	0.96	1.00	0.84
Kennedy	0.85	1.00	1.00	0.93
Kintla/Bowman	1.00	1.00	0.76	0.76
Lake McDonald	1.00	1.00	0.63	0.63
Nyack	0.97	1.00	1.00	0.99
Quartz/Logging	1.00	1.00	1.00	1.00
Saint Mary	0.99	1.00	0.65	0.65
Swiftcurrent	0.99	1.00	0.86	0.86
Upper Two Medicine	0.96	0.92	0.76	0.71
Waterton	1.00	1.00	0.78	0.78

Park Salmonid Condition

The distributions of salmonid populations are used to calculate a ratio of native to non-native salmonids in GLAC lakes and streams. Metrics derived from these ratios are averaged to provide an overall index of salmonid condition for each watershed (Table E.4). The Cut Bank Creek watershed has no native salmonids in either its lakes or streams and therefore scored a 0.00 for condition. Upper Two Medicine has no native salmonids mapped in its lakes and therefore scored low. Lake McDonald and the Belly watersheds have the highest ratio of native fish relative to the non-native fish occupancy in its lakes and Kintla/Bowman in its streams and therefore scored the highest for this index. However all watersheds have been impacted by non-native fish species.

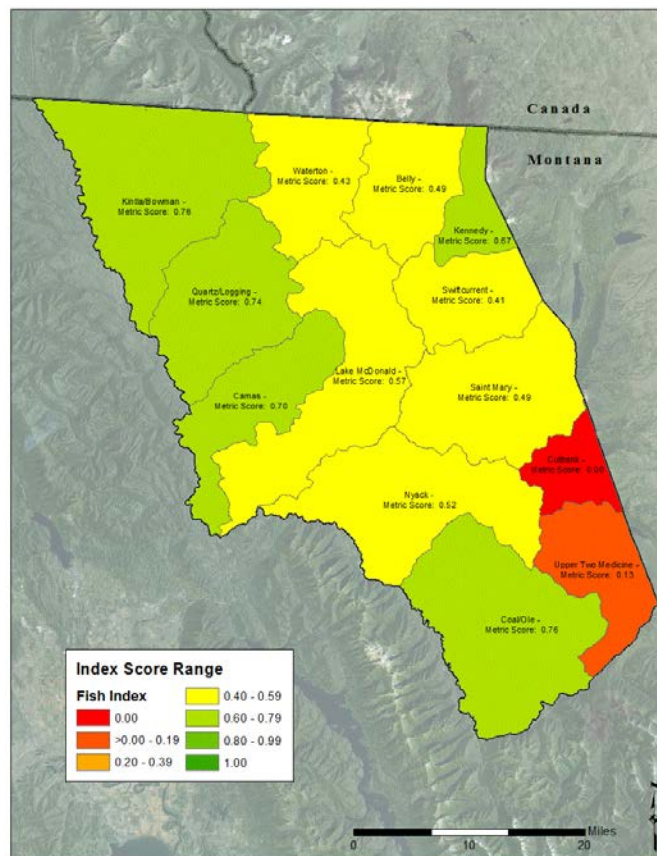


Table E.4. The fish metric and index scores in each watershed in Glacier National Park.

Watershed	Stream Fish Metric	Lake Fish Metric	GLAC Fish index
Belly	0.47	0.52	0.49
Camas	0.87	0.53	0.70
Coal/Ole	0.86	0.66	0.76
Cut Bank	0.00	0.00	0.00
Kennedy	0.75	0.59	0.67
Kintla/Bowman	1.00	0.51	0.76
Lake McDonald	0.53	0.60	0.57
Nyack	0.67	0.38	0.52
Quartz/Logging	0.87	0.60	0.74
Saint Mary	0.65	0.33	0.49
Swiftcurrent	0.60	0.23	0.41
Upper Two Medicine	0.25	0.00	0.13
Waterton	0.38	0.48	0.43

Flathead River Salmonid Condition

The salmonid condition assessment of Flathead River is a stand-alone metric. This system is different in its size and extent of human disturbance than other stream systems in the park. The cumulative percent occupancy of all native and non-native in North and Middle Forks Flathead River and the resulting condition scores are provided in Table E.5. Lake trout are present throughout the study area; however rainbow and cutthroat-x-rainbow hybrid do not extend to the upstream assessment areas of the North Fork. Therefore the assessment areas closer to the confluence generally have lower index scores than those further upstream.

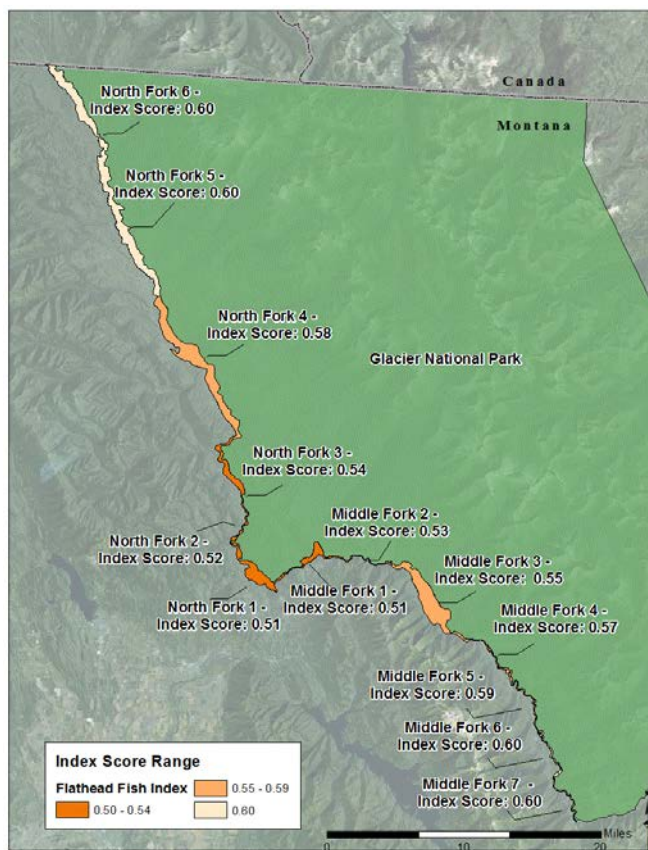


Table E.5. The percent occupancy of non-native salmonids in the North and Middle Forks of the Flathead River.

Flathead River Assessment Area	Native Sum	Non-Native Sum	Flathead Fish Index Score
Middle Fork 1	300	288	0.51
Middle Fork 2	300	270	0.53
Middle Fork 3	300	248	0.55
Middle Fork 4	300	227	0.57
Middle Fork 5	300	209	0.59
Middle Fork 6	300	200	0.60
Middle Fork 7	300	200	0.60
North Fork 1	300	292	0.51
North Fork 2	300	277	0.52
North Fork 3	300	256	0.54
North Fork 4	300	220	0.58
North Fork 5	300	200	0.60
North Fork 6	300	200	0.60

Avian Condition

Avian condition index is comprised of three significance metrics that measure habitat and bird diversity and one stressor metric that measures proximity of bird habitat to human infrastructure. Metrics were combined to provide an assessment index of avian condition in the park's watershed (Table E.6). Birds are very mobile and, although these metrics measure the range of natural variability of contemporary habitat in the park, for metrics like fire habitat bird species can travel long distances to locate preferable areas. Given that, Kennedy and Upper Two Medicine watersheds scored the lowest predominantly due to a combination of low post fire habitat and high corvid habitat. Waterton, St. Mary, and Quartz/Logging scored the highest amongst all watersheds.

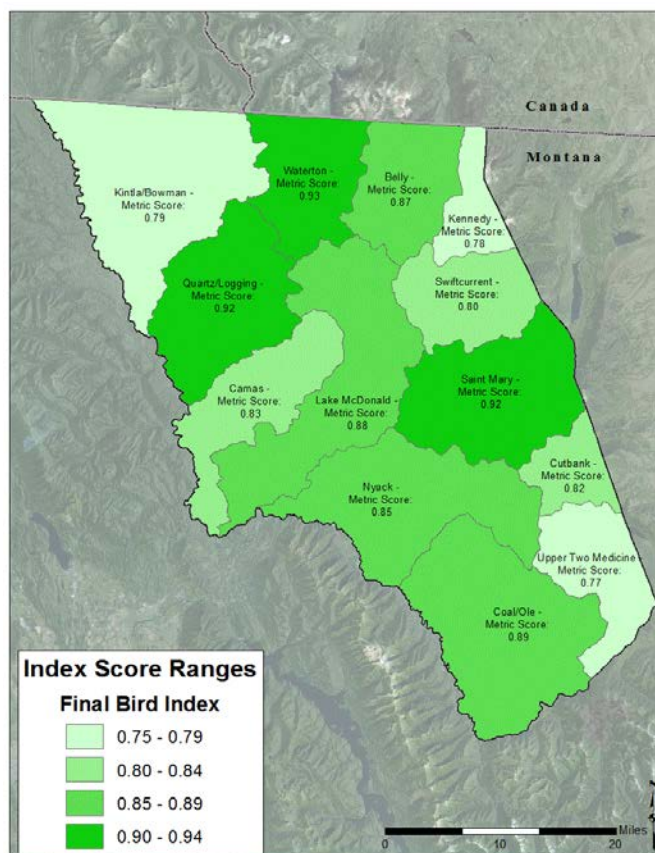


Table E.6. Each bird condition metric and index scores.

Watershed	Bird Diversity	Fire Habitat	Alpine Habitat	Human Impact	Bird Condition Index Score
Belly	1.00	0.10	1.00	0.97	0.87
Camas	1.00	1.00	0.33	0.82	0.83
Coal/Ole	1.00	1.00	0.66	0.86	0.89
Cut Bank	1.00	0.10	0.66	0.98	0.82
Kennedy	1.00	0.10	0.66	0.89	0.78
Kintla/Bowman	1.00	0.10	0.66	0.91	0.79
Lake McDonald	1.00	1.00	1.00	0.78	0.88
Nyack	1.00	0.50	0.66	0.91	0.85
Quartz/Logging	1.00	1.00	0.66	0.93	0.92
Saint Mary	1.00	1.00	1.00	0.85	0.92
Swiftcurrent	1.00	0.10	0.66	0.92	0.80
Upper Two Medicine	1.00	0.10	0.66	0.85	0.77
Waterton	1.00	0.50	1.00	0.99	0.93

Mammal Condition

The mammal index incorporates six significance metrics that measure habitat attributes within each watershed that are necessary to support a healthy population of mammals that the park has deemed important (e.g. bears, goat, sheep, wolves). Additionally, there are two stressor metrics that measures the proximity of these habitats to human infrastructure and the potential exposure of the various watersheds to illegal poaching. Collectively, this index provides an insight of the relative condition of a wide variety of mammals in each of the park's watersheds. The watersheds that scored the lowest generally had limited habitat in one or more of the metrics and increased potential pressure from illegal poaching within the park or harvesting adjacent to the park. The range of index scores by watershed is presented in Table E.7.

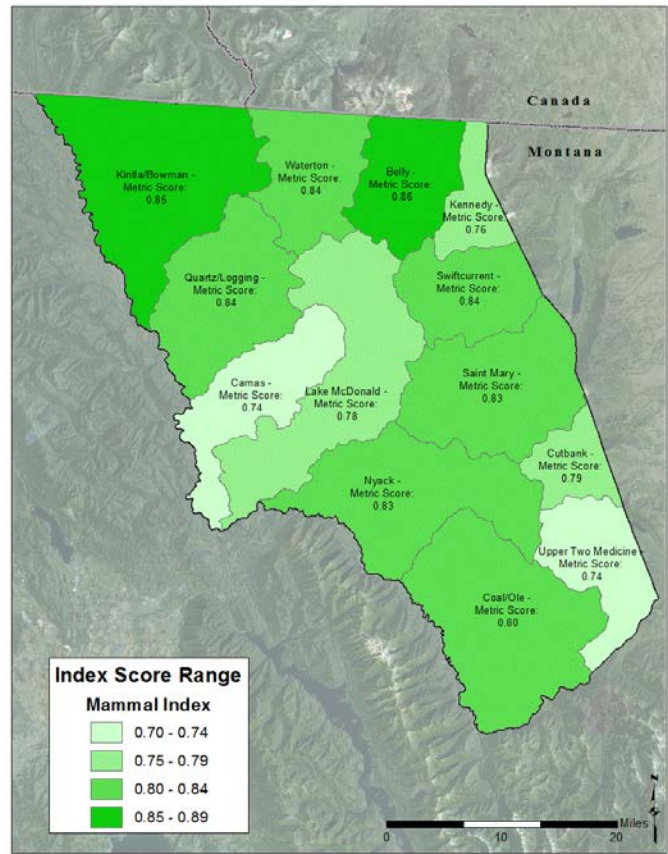


Table E.7. The mammal condition metric and index scores.

Watershed	Sheep Escape Terrain	Goat Escape Terrain	Talus	Spruce-Fir Forest	Prey	Snow-Denning	Harvest Poaching	Human Disturbance	Mammal Condition Index
Belly	1.00	1.00	1.00	0.33	0.47	0.89	0.74	0.97	0.86
Camas	0.33	0.33	0.81	0.66	0.73	0.81	0.71	0.82	0.74
Coal/Ole	0.66	1.00	0.90	0.66	0.55	0.86	0.7	0.86	0.80
Cut Bank	0.66	0.66	0.87	0.33	0.42	0.83	0.63	0.98	0.79
Kennedy	0.66	1.00	0.91	0.33	0.42	0.81	0.61	0.89	0.76
Kintla/Bowman	1.00	1.00	0.96	1.00	0.63	0.96	0.66	0.91	0.85
Lake McDonald	0.66	0.66	0.87	1.00	0.65	0.89	0.76	0.78	0.78
Nyack	0.66	0.66	0.87	0.66	0.61	0.90	0.77	0.91	0.83
Quartz/Logging	0.66	0.66	0.86	0.66	0.66	0.86	0.78	0.93	0.84
Saint Mary	1.00	1.00	0.99	0.66	0.47	1.00	0.76	0.85	0.83
Swiftcurrent	1.00	1.00	0.96	0.33	0.47	0.87	0.77	0.92	0.84
Upper Two Medicine	0.66	0.66	0.89	0.33	0.48	0.83	0.66	0.85	0.74
Waterton	0.66	0.66	0.89	0.66	0.48	0.89	0.73	0.99	0.84

Vegetation Condition

Vegetation condition is an important attribute for many of the metrics used throughout all of the park's ecological condition assessment indices presented above. The condition index presented here only captures divergence from ideal conditions as measured by three stressor metrics that assess non-native species, grazing, and potential disturbance from human concentration. As a result, Kintla/Bowman, Camas, Lake McDonald and other watersheds that scored in the lower range have higher concentration of human interaction than other watersheds (Table E.8).

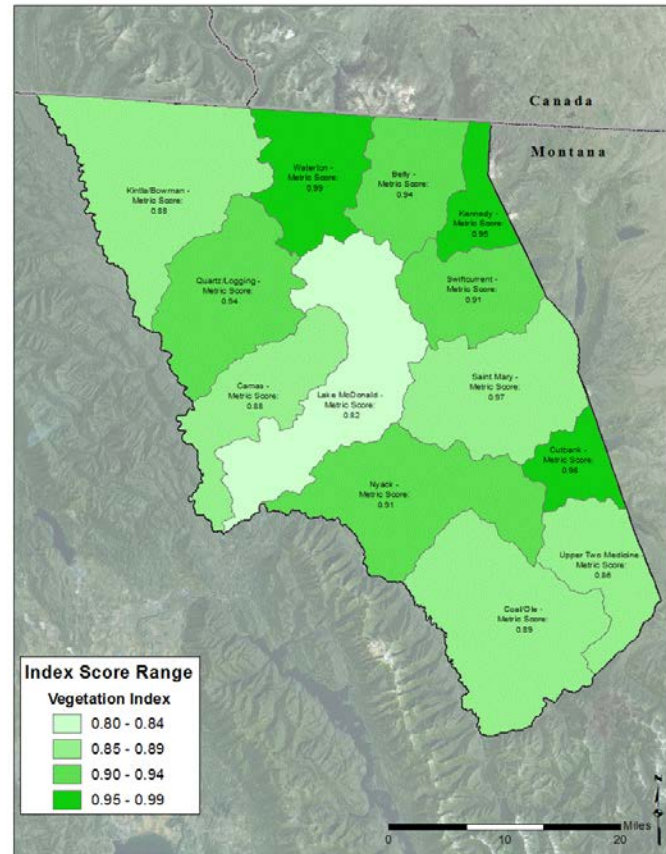


Table E.8. The vegetation condition metric and index scores.

Watershed	Exotic Species	Human Disturbance	Grazing Trespass	Index Score
Belly	0.96	0.97	0.95	0.94
Camas	0.92	0.82	1.00	0.88
Coal/Ole	0.91	0.86	1.00	0.89
Cut Bank	0.99	0.98	0.99	0.98
Kennedy	1.00	0.89	1.00	0.95
Kintla/Bowman	0.83	0.91	1.00	0.88
Lake McDonald	0.83	0.78	1.00	0.82
Nyack	0.91	0.91	1.00	0.91
Quartz/Logging	0.95	0.93	1.00	0.94
Saint Mary	0.88	0.85	1.00	0.87
Swiftcurrent	0.90	0.92	1.00	0.91
Upper Two Medicine	0.93	0.85	0.92	0.86
Waterton	0.99	0.99	1.00	0.99

1. Introduction

In response to increasing threats to the biological integrity of national parks, the U.S. Congress passed legislation in 2003 that instructed the National Park Service to assess environmental conditions in watersheds where park units are located. As a result of this legislation, the Water Resources Division of the National Park Service initiated a multi-year program to fund natural resource condition assessments for each of the 270 park units with significant natural resources. These natural resource condition assessments are intended to synthesize existing research and inventory and monitoring data into a knowledge base for use in park resource planning, decision making, monitoring prioritizations, accountability reporting, and partnership and education efforts. The assessments should provide a spatially explicit multi-disciplinary synthesis of existing scientific data and knowledge, from multiple sources, that helps answer the question: What are the current conditions for important park natural resources? It is the intention of this document to provide an assessment of the current and potential future natural resource conditions to ultimately assist in prioritization of natural resources management actions and associated monitoring to address these conditions. Therefore it is a goal of this document, and associated GIS tools, to blend smoothly with existing management frameworks.

The park published a General Management Plan (GMP) in 1999 with the intention of influencing decisions for the following 20 years or more (NPS 1999). In that document, the park articulates their overall management approach:

The overall guiding philosophy is to manage most of the park for its wild character and for the integrity of Glacier's unique natural heritage, while traditional visitor services and facilities remain. Visitors would be able to enjoy the park from many vantage points. Visitor use would be managed to preserve resources, but a broad range of opportunities would be provided for people to experience, understand, study and enjoy the park. Cooperation with park neighbors would be emphasized in managing use and resources (NPS 1999).

Specifically, natural resources are managed in accordance with NPS policy "to understand natural processes and human-induced effects; mitigate potential and realized effects; monitor ongoing and future trends; protect existing natural organisms, species populations, communities, systems, and processes; and interpret these organisms, systems, and processes to the park visitor" (NPS 1999). The multi-metric condition assessment models in the following chapter were developed to assist with this NPS management guidance by keeping three primary audiences in mind: decision makers such as park superintendents, resource managers at the park, and scientists and technicians engaged to assist parks (e.g., Inventory and Monitoring Network ecologists and data managers). The assessment findings are designed to assist and inform these audiences for, among other things:

- Near-term strategic planning, to allocate limited staff and budget resources toward high priority (relatively more significant or vulnerable) park-managed watersheds and habitats;

- General Management Plan and Resource Stewardship Strategy development, which represent the planning process that formalizes park management zones, Desired Condition management objectives, and associated measurement indicators and targets;
- Park reporting to the Department of Interior’s “land health goals” and to an Office of Management and Budget “resource condition scorecard”;
- Park efforts to communicate and partner with other stakeholders, in order to address watershed- or landscape-scale resource management issues.

1.1 Document Goals

The specific objectives of this project were:

1. To provide park superintendents and managers with initial, science-based judgments about the resource condition status relative to other watersheds within the park, and to provide data, information, and recommendations that will be useful to park managers in their work to define the park’s management zones and desired conditions.
2. To provide assessment statistics and summaries to allow park superintendents and managers to develop reports that meet Government Performance and Results Act and Office of Management and Budget reporting requirements.
3. To develop an assessment framework and process that can be repeated in the future and can serve as a template for resource assessments at other park units.

A main sign of success of this report will be the extent to which it provides park resource managers data and information that help them to see “the big picture” and relationships among critical issues, and to help place emerging issues within a local, regional, national, or global context.

1.2 Document Overview

The document is organized as follows:

- Chapter 2 – Park Overview: This chapter is a general history and description of the park and surrounding areas helpful for those not familiar with the park and its regional context.
- Chapter 3 – This chapter provides a summary of threats to the ecological condition across the entire park which not only extends beyond watershed scale of project, but also beyond the boundaries of the park itself.
- Chapter 4 – This chapter describes the philosophical foundations of watershed-scale multi-metric assessment approaches and this unique application in an area with very limited human disturbance. The chapter also introduces general methods used to develop

multi-metric indices that form the bases of this project and caveats that bound the application of these models.

- Chapter 5 – This chapter details the seven watershed-scale multi-metric indices use to assess condition of the park’s ecological focal areas of concern. This chapter includes specific methods and results for each metric and assessment index.
- Chapter 6 – This chapter provides these results in the context of the park’s pre-existing management boundaries to blend the results for management prioritization.
- Appendices – Appendix A provides a detailed summary of the park’s meteorological attributes and potential climate change scenarios. Appendix B provides overview of the GIS models used in the analysis and Appendix C provides the background maps used to inform the metrics used in the multiple indices.

Because the assessment is broad and integrative, a strong emphasis was placed on conducting spatially-explicit analyses using geographic information systems (GIS) techniques. As a consequence, we developed numerous maps and visualizations of indicators and findings in this report, including a technical appendix, as well as a full suite of GIS datasets.

1.3 What This Document Does Provide

This document provides a baseline ecological assessment of Glacier National Park’s HUC 10 watersheds from the perspective of seven major focal areas selected in collaboration with the GLAC resource management team:

- Streams: The condition of alpine, mid-elevation and lowland streams within the park’s watersheds.
- Large Rivers: The condition of the North and Middle Forks of the Flathead River that form the western boundary to the park.
- Lakes: Potential risks to the condition of the park’s lakes.
- Fish: The condition of native and non-native salmonid species within the park’s watersheds.
- Avian: The condition of biotic and abiotic ecosystem attributes that support a diverse avian population within the park’s watersheds.
- Mammal: The condition of biotic and abiotic ecosystem attributes that support a diverse mammalian population within the park’s watersheds.
- Vegetation: Impacts to the vegetation condition in terms of non-native plants, illegal grazing, and human disturbance within the assessment watersheds.

This document provides GLAC’s resource management team with a watershed-scale assessment tool to define ecological condition within the park. The ecological condition of a watershed within the

park is determined by a combination of metrics that measure the natural range of ecological significance as they interact with metrics that measure the human threats or risk of threats. Specifically, this study evaluates a subset of the biotic and abiotic structural components that describe a natural ecological range of variation in areas of limited disturbance. These are referred to as ‘significance metrics’. This study also assesses the range of impacts to these structural components in areas of the park with increased human interaction. These are referred to as ‘stressor metrics’. Additionally, a small subset of metrics for the lake assessment measure abiotic components that could potentially threaten lake condition. These are referred to as ‘risk metrics’ (See Chapter 4 for more details).

These assessment models provide metrics that assess the ecological significance, anthropogenic disturbance, and risk of future degradation of a park’s watershed only relative to other watersheds within the park. Because the park itself is in outstanding condition relative to other watersheds and mountain ranges within the Rocky Mountains, this model was designed to provide a scaled index of ecological condition within GLAC only (or immediately adjacent to the park in the case of the North and Middle Forks of the Flathead River).

1.4 What This Document Does Not Provide

This document uses existing data provided by the park. These data were extensively analyzed, but no additional data were collected. Where there were gaps in data and knowledge, we have used expert opinion to develop the models and in some cases to score or evaluate sub-index scores for indicators. This combination of both a quantitative and qualitative approach to metric development is common in multi-metric indices for management tools intended to provide scientists, managers and decisions makers with a prioritization approach for their various disciplines. *These indices and metrics are intended to indicate a range in the quality or “condition” of the system and its attributes not as a true measure of ecosystem complexity or cause-and-effect pathways.*

As an index that provides a single score that relates to the quality of the ecosystem, the multi-metric approach used herein is a simplification of ecosystem complexities as they integrate across multiple attributes and across wide topographic, aspect and distribution ranges. Thus, these index scores are intended as ‘pointers’ to areas of concern. The metrics within these indices provide finer detail of the potential drivers of ecosystem structure and function reflected in the index scores. *As a result, metrics and indices that make up this management tool do not provide information on actual quantitative thresholds beyond which ecological resilience is compromised.*

Additionally, there are disturbance vectors such as climate change and air pollution that impact the entire park in a variety of ways. These large scale impacts are addressed in Chapter 3 and Appendix A, but due to the complexity of these impacts across the varied topography of the park and the limit of existing data they have not been integrated into all of the assessment indices. Rather, they are restricted to models that assess alpine areas and lakes. The human impacts metrics within the majority of the assessment models measure the extent of direct human land use impacts such as roads, trails, and facilities.

Finally, the following chapters offer a watershed-scale, multi-metric assessment that focuses on the condition of biotic and abiotic ecosystem attributes within the park. The assessment addresses ranges in condition of natural attributes such as the amount of alpine community per watershed and the ranges of disturbance attributes such as the amount of trails and roads per watershed. However, there are disturbances in and around the park that occur at a scale larger than is appropriate for a multi-metric assessment approach, but do have an influence on the park conditions. Users of this document and the multi-metric indices herein will need to take into account this broad array of externalities to assess potential effects to various sub-indices and thereby impacts to the park.

2. Park Overview

Far away in northwestern Montana, hidden from view by clustering mountain peaks, lies an unmapped corner – the Crown of the Continent – slow-moving ice rivers still plow their deliberate ways, relics of mightier glaciers, the stiffened streams which in a past age fashioned the majestic scenery of today. ~ George Bird Grinnell, Century Magazine, September 1901

Glacier National Park in northwestern Montana, created by act of Congress in 1910, holds the geographic headwaters of a significant portion of the North American Continent. Within Glacier National Park (GLAC) resides the single spire, Triple Divide Peak, where three river systems of the continent converge at the intersection of the Continental and Hudson Divides. Water flowing to the west enters the Columbia River Basin (Pacific Ocean), waters flowing to the northeast flow into the Saskatchewan River Basin (Hudson Bay, Arctic Ocean), and water flowing southeast enters the Missouri River Basin (Gulf of Mexico, Atlantic Ocean). Thus, the montane landscape and its headwaters quite literally form the water tower of the continent. The region containing Glacier National Park has been referred to as the Northern Continental Divide Ecosystem (Salwasser et al. 1987), the Northern Rocky Mountain Province (Bailey 1995), and the Crown of the Continent Ecosystem (Hayden 1989). Although the first two names are most commonly used in scientific literature, they disregard the substantial portion of the contiguous montane system. Glacier National Park and its sister park in Canada, Waterton Lakes National Park, form the heart of the Crown of the Continent, which is more inclusive and representative of the importance of the region and is by far the earliest title given recognizing the regional hydrologic and geographic uniqueness of GLAC and appeared in an article written by George Bird Grinnell (1901) describing his travels in the region. Glacier National Park is characterized by high heterogeneity of watersheds and hydrology. To the east is the steppe of the Great Plains and the Rocky Mountain Front. Interior to GLAC are the belt series mountain ranges dominated by sedimentary geologic formations of mountains and valleys with change in elevation exceeding 6000 feet ¹between the valley floors and along the mountain peaks.

In 1932, Glacier National Park and Waterton Lakes National Park in Canada were designated as Waterton-Glacier International Peace Park; the world's first of now many international peace parks distributed worldwide along international boundaries. Waterton-Glacier International Peace Park holds a United Nations designation as an International Biosphere Reserve and World Heritage Site. Central to this designation is the role of biodiversity and the quality and quantity of water as it interacts with the mountain-valley landscape. Indeed, the distribution and abundance of biota and the way people use the landscape are closely interconnected to the region's headwaters. Some of the best evidence for climatic change globally is found here. The glaciers of GLAC have been shrinking rapidly since the founding of the park in 1910. A recent analysis estimated an $\approx 40\%$ reduction in glacier volume since 1950 and simulation modeling has projected that the glaciers of GLAC will be gone by 2050 (Hall and Fagre 2003). This and future changes will have a significant effect on

¹ English units are preferred by the management team at GLAC and are used throughout this document.

headwater hydrologic regimes and the organisms that are dependent on continuity of flow in alpine running water habitats (Hauer et al. 1997).

The region around Glacier National Park is experiencing rapid growth in human population, particularly in the Flathead River Basin. Natural wildness, recreation and scenic attributes, epitomized by Glacier National Park, are the long-term primary drivers of economic growth for the region. Water quality, the support of aquatic organisms, and the integrity of aquatic and riparian habitats are essential to maintaining the renewable goods and services that characterize the quality-of-life enjoyed by residents and visitors from around the world. Glacier National Park is critically important to global biodiversity. Indeed, GLAC holds one of the highest accumulations of diversity of plants and animals in North America (Hauer et al 2007), including the full array of native carnivores and ungulates. For example, valley bottoms and the river floodplains of GLAC are critical habitat for most of the large animals of the ecoregion, including several species listed as sensitive, threatened or endangered, including bull trout, westslope cutthroat trout, grizzly bear, lynx, and wolverine.

2.1 Park Resource Setting/Stewardship Context

The following summary of the park and its management has been accumulated from information provided in several internal GLAC management documents (e.g. NPS 1999 and 2004).

2.1.1 Background

Glacier National Park is located on the Canadian border in the northwestern section of Montana. The park is in the northern Rockies, and contains the rugged mountains of the Continental Divide. Together with Canada's Waterton Lakes National Park, it forms the Waterton-Glacier International Peace Park, a World Heritage Site (Figure 2.1). Glacier National Park's primary mission is the preservation of natural and cultural resources, ensuring that current and future generations have the opportunity to experience, enjoy, and understand the legacy of Waterton-Glacier International Peace Park. The purpose of Glacier National Park is distilled to three points:

- Preserve and protect natural and cultural resources unimpaired for future generations (1916 Organic Act);
- Provide opportunities to experience, understand, appreciate, and enjoy Glacier National Park consistent with the preservation of resources in a state of nature (1910 legislation establishing Glacier National Park); and
- Celebrate the on-going peace, friendship, and goodwill among nations, recognizing the need for cooperation in a world of shared resources (1932 International Peace Park legislation).

The park's distinctive qualities make it a significant resource regionally, nationally, and internationally (following bullets from NPS 2004).

- Glacier's scenery dramatically illustrates an exceptionally long geological history and the many geological processes associated with mountain building and glaciation;
- Glacier has the finest assemblage of alpine glacial features in the contiguous 48 states, and it has relatively accessible, small-scale active glaciers.

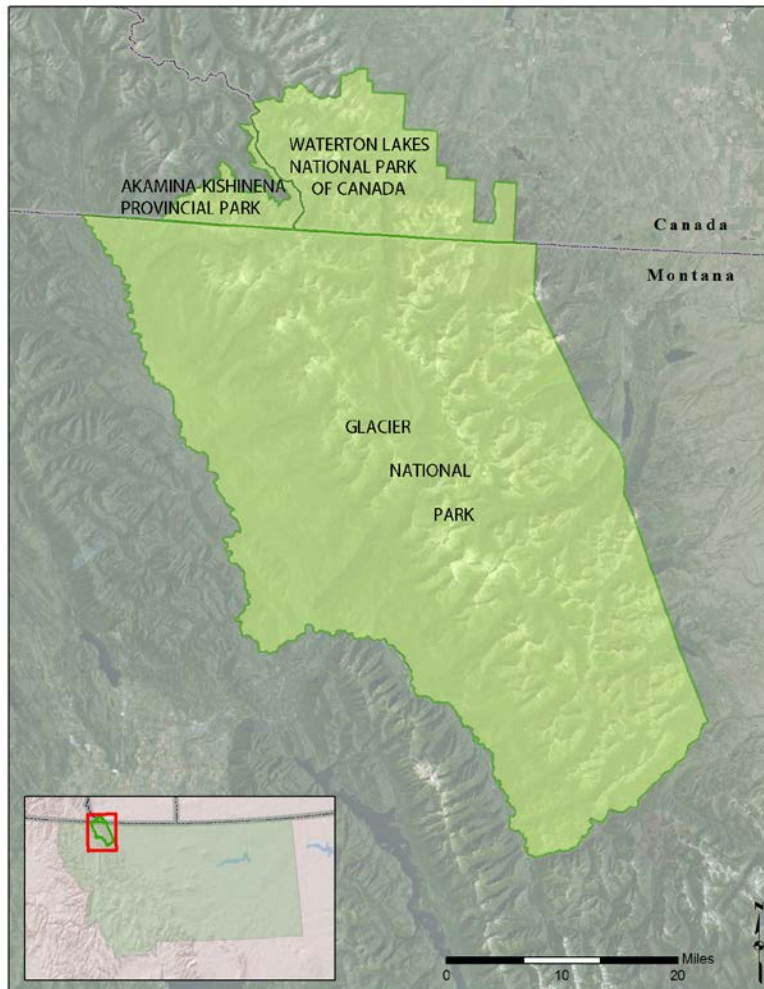


Figure 2.1. Location of Glacier National Park.

- Glacier provides an opportunity to see evidence of one of the largest and most visible overthrust faults in North America, exposing well-preserved Precambrian sedimentary rock formations.
- Glacier is at an apex of the continent and one of the few places in the world that has a triple divide. Water flows to Hudson Bay, and the Atlantic and Pacific Oceans.
- Glacier offers relatively accessible spectacular scenery and increasingly rare primitive wilderness experience;

- The Going-to-the-Sun Road, one of the most scenic roads in North America, is a National Historic Landmark.
- Glacier offers a challenging primitive wilderness experience and opportunities to listen to natural sounds.
- Glacier is at the core of the “Crown of the Continent” ecosystem, one of the most ecologically intact areas remaining in the temperate regions of the world;
 - Due to wide variations in elevation, climate, and soil, four Floristic Provinces connect in Glacier and have produced diverse habitats that sustain plant and animal populations, including threatened and endangered, rare, and sensitive species.
 - Glacier is one of the few places in the contiguous 48 states that continue to support natural populations of all indigenous carnivores and most of their prey species.
 - Glacier provides an outstanding opportunity for ecological management and research in one of the largest areas where natural processes predominate. As a result, Waterton-Glacier International Peace Park has been designated as a world heritage site, and both parks have been designated as biosphere reserves.
- Glacier’s cultural resources chronicle the history of human activities (prehistoric people, American Indians, early explorers, railroad development, and modern use and visitation) show that people have long placed high value on the area’s natural features.
 - American Indians had a strong spiritual connection with the area long before its designation as a national park. From prehistoric times to the present American Indians have identified places in the area as important to their heritage.
 - The park’s roads, chalets, and hotels symbolize early 20th century western park experiences. These historic structures are still in use today.
 - The majestic landscape has a spiritual value for all human beings - a place to nurture, replenish, and restore oneself.
- Waterton-Glacier is the world’s first international peace park.
 - People of the world can be inspired by the cooperative management of natural and cultural resources that are shared by Canada and the United States.
 - Glacier National Park and Waterton Lakes National Park offer an opportunity for both countries to cooperate peacefully to resolve controversial natural resource issues that transcend international boundaries.

Glacier National Park is a cherished natural legacy to the American people and to other people throughout the world. The park provides unique experiences in the natural world and contains superb

examples of pristine natural resources. However, Glacier National Park was rated the most threatened national park and natural area in the 1980 State of the Parks Report to Congress (NPS 2004). Surrounding land use, invasion of non-native species, air quality, changes in climate, international land management inconsistencies, inventory data gaps, funding, and visitor usage are cited as some of the main threats to Glacier National Park when it was placed on the National Park Conservation Association's Ten Most Endangered Parks list (NPCA 2012).

2.1.2 Description and Characterization of Park Natural Resources

The ecological communities of Glacier National Park are distinctly influenced by its location along the main range of the Rocky Mountains, and its geological history. Both of these factors drive climatic environments that dictate the establishment of vegetation types, producing patterns across the landscape that are remarkably predictable given variables such as elevation, aspect, slope and substrate.

Glacier is primarily a mountain park, with two north-south mountain formations, the Livingston and Lewis Ranges, making up most of the terrain (Figure 2.2). Uplifted geologic formations of the Belt Series (primarily) are the foundation of these ranges, mostly composed of sedimentary rock. Subsequent glacial action has carved and molded the deposits into sheer cliffs, broad cirques, hanging valleys and moraines.

The park lies midway along the north-south gradient of the Rocky Mountains, and species from four major floristic provinces converge here: the Cordilleran Floristic Province including the predominant Rocky Mountain subprovinces, as well as the Cascade Mountains subprovince with flora typical of the Pacific Northwest; the Great Plains Floristic Province represented on the eastern margins of the park; and the Boreal Floristic Province with southern limits in the park; and the Arctic-alpine Floristic Province found above tree line (Lesica 2002). Also, the park is affected by two major climatic systems. The weather is alternately dominated by moist Pacific maritime and dry continental air masses, a mix that yields a broad range of temperatures, precipitation, and wind conditions. Add to that the extraordinary amount of topographic relief created by Pleistocene glaciers and ice sheets—a terrain so rugged that any given elevation offers an unusually broad range of exposures, soil conditions, moisture levels, and snow depths—in short, a multitude of microhabitats. Finally, the presence of both calcareous (calcium-rich, derived from limestone) and non-calcareous soils adds to the array of living spaces (Lesica 1985, Edwards 1957, McClelland 1970). The park has been termed a "continental biodiversity node," in other words, a natural mixing zone for biota of continental significance (Stanford 2000). The Continental Divide winds its way roughly through the center of the park, from the north boundary toward the southeast. On either side of the Divide alpine cushion plants are able to establish on sheltered sites with adequate moisture. Moving lower, where the climate becomes less physically harsh, alpine meadows develop and form a mosaic with shrubby krummholz vegetation. Lower still, subalpine woodlands develop on mountain slopes, becoming denser toward the bottom of deeply carved mountain valleys. Forests are replaced by shrubland and grassland vegetation along part of the park's western boundary, where soil is fertile and well-developed. On the park's eastern edge, coniferous forest is replaced by a mixture of aspen woodlands and grasslands (Figure 2.3).

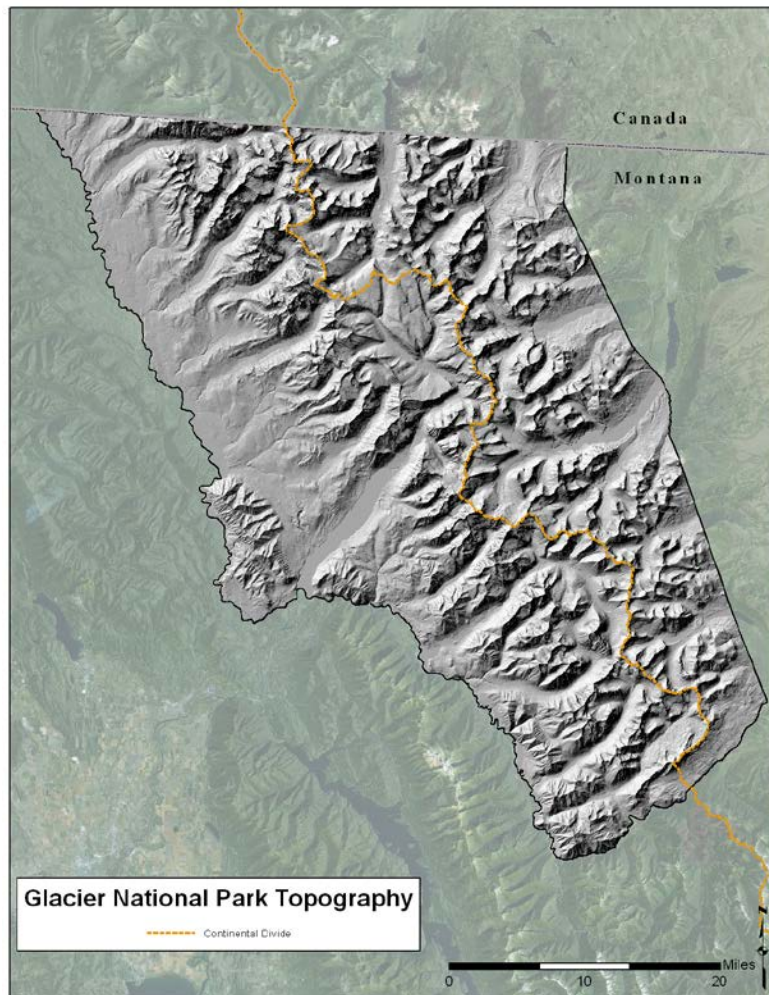


Figure 2.2. Topography of Glacier National Park.

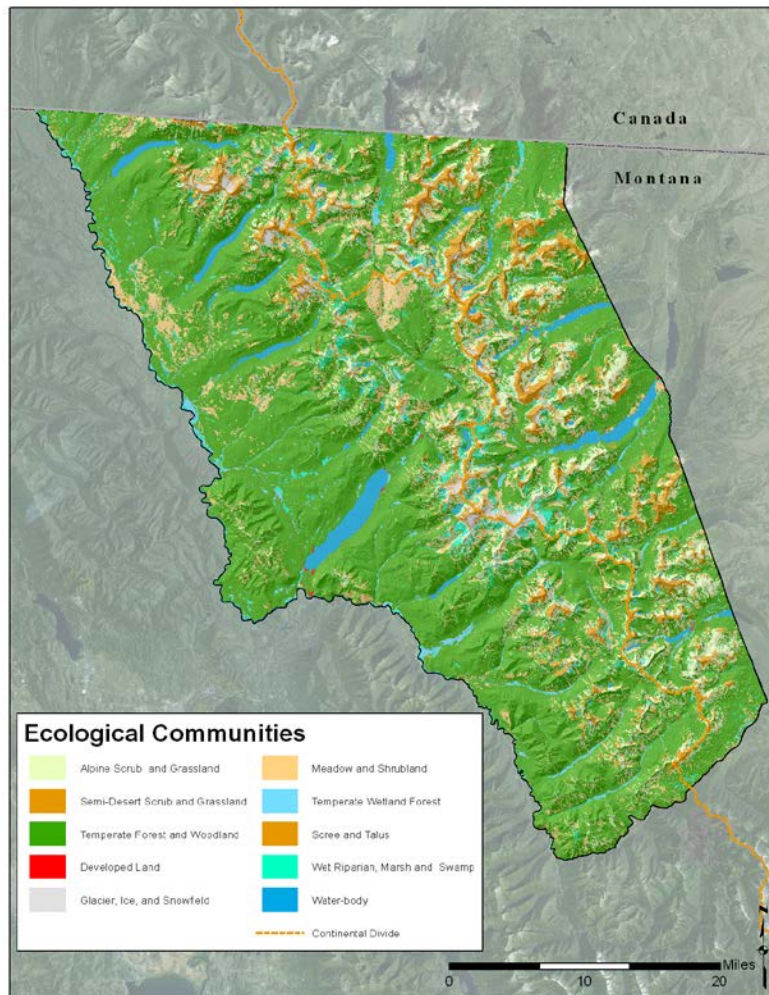


Figure 2.3. Ecological communities of Glacier National Park.

3. Park Wide Threats

There are three major threats that are pervasive to the region and influence the overall park condition; climate change, air quality degradation, and land use surrounding the Park). Because the scale of these impacts can be park-wide, they are addressed separately in this chapter. To a limited extent, these major threats are included in the models in the following chapters. For example climate change is included as a relative change in alpine area over time with the 2007 vegetation mapping used for this effort set as time zero (see Section 5.1.4.5), buffering from potential air pollution deposition is included for lake systems (see section 5.3.1), finally land use adjacent to the park is included in a rasterized attenuated spatial proximity score (see Section 5.1.4.4).

3.1 Climate

The following is a brief summary of an extended assessment of current and future climatic condition related to the park provided in Appendix A. Due to the predicted changes in climate from continued greenhouse gas emissions (Intergovernmental Panel on Climate Change; IPCC 2007); climate change has become a long term concern for Glacier National Park. The continuing disappearance of GLAC's glaciers is one of the most notable and widely cited changes within the national park system. Climate models suggest that some of the largest glaciers will likely be gone by 2030 and of the estimated 150 glaciers existing within the park in 1850, only 25 glaciers larger than 25 acres remain today (U.S. Department of the Interior Geological Survey; USGS 2010). Although the shrinking and disappearance of GLAC's glaciers is the most noticeable direct effect of increasing temperatures, other critical climate change impacts include possible transformations in the park's snowpack and water resources, increased disturbance frequency and severity both in terms of fire and insect outbreaks, and changes in growing seasons and vegetation dynamics.

The current climate of GLAC is distinguished by its location on the Continental Divide where it sits on the boundary between maritime and continental dominated climates (Finklin 1986, Carrara 1989) (See Figure 3.1). The seasonal cycle is defined by long winters and short summers (Finklin 1986). Pacific maritime air masses often dominate the western side of the park bringing significant snowfall in the winter (Carrara 1989). In contrast, the park's east side is more dominated by dry continental air masses resulting in cold winters and dry, sunny summers (Rockwell 2007). Both sides of the park usually experience minimum precipitation during July and August (Finklin 1986). The wettest times of year are in the winter, especially for the western side, and in late spring from April to June (Carrara 1989). Given the rugged topography of the landscape, many microclimates exist and temperature/precipitation regimes can change drastically over just a short distance.

Climate warming trends have become increasingly evident in the general western Montana region within which GLAC resides. Using observations from 9 U.S. Historic Climatology Network (USHCN) weather stations within the region, Pederson et al. (2010) recently found that the annual average temperature in western Montana increased 2.39°F (1.33°C) over the 20th century. More importantly, Pederson et al. (2010) analyzed trends in ecologically critical temperature thresholds from 1900-2006. They found that the average annual number of days with daily minimum temperatures (T_{min}) below freezing decreased around 16 days while the annual number of extremely

hot days with a daily maximum temperature (T_{max}) $\geq 90^{\circ}\text{F}$ (32.2°C) increased threefold. The annual number of extremely cold days where T_{min} was $\leq 0^{\circ}\text{F}$ (-17.8°C) also decreased from an average of 20 days from 1895-1980 to an average of 14 days from 1981-2006. Lastly, the Pederson et al. study, along with another analysis of two weather stations in the region (Caprio et al. 2008), revealed an annual asymmetry in the warming trends with the greatest warming seen in the late winter to early spring and the least in the fall.

The western Montana temperature trends documented by Pederson et al. (2010) are similar to those found throughout the American West over the past century (e.g.- Groisman et al. 2004, Mote et al. 2005, Knowles et al. 2006, Bonfils et al. 2008). Consequently, multiple independent analyses have documented possible climate warming impacts in the American West including changes in: snowpack (Mote et al. 2005), the proportion of precipitation falling as rain instead of snow (Knowles et al. 2006), the timing of stream flow runoff (Stewart et al. 2005), wildfire activity (Westerling 2006), insect outbreaks (Raffa et al. 2008), and tree mortality rates (van Mantgem et al. 2009). Given these current changes and predictions of continued and intensified warming (IPCC 2007), understanding the effects of climate change within GLAC has become critical. Stakeholders will need to develop a capacity to properly manage the changing GLAC landscape under this new climatic regime; however, the interactions between climate warming and ecosystem processes at the scale of the park are not yet well understood. Therefore, the objective of a portion of this study is to initiate an approach to provide a clearer picture of possible future climate change impacts across the GLAC landscape with a focus on analyzing projected changes in temperature and precipitation and subsequent impacts on the park's growing season and vegetation productivity and changes in available habitat for animals important to the park's monitoring and management objectives.

3.1.1 Summary of Future Climate Condition

This climate change impact study examined possible long term impacts to vegetation productivity within GLAC from the 1980s to the 2020s, 2040s, and 2080s. Composite mean projections of Pacific Northwest temperature and precipitation from an ensemble of global climate models (GCMs) were downscaled to GLAC at 30-arcsec (around 800m) resolution for the low (B1) and high (A1B) greenhouse gas emission scenarios. The downscaled projections were used to drive an ecosystem model called Biome-BGC that analyzes possible specific impacts to seasonal temperature thresholds, growing seasons, vegetation water stress and productivity, and overall carbon sink/source trends. Different impacts and trends were compared along elevation gradients of vegetation land cover.

Average winter T_{max} temperatures within GLAC appeared to be most susceptible to moving above freezing in the future, thus signifying possible impacts to biological processes and freeze/thaw cycles (Pederson et al. 2010). Areas above 5,750 feet were least likely to move above key freezing thresholds given the specific projected changes in temperature. Nevertheless, the projected increases in temperature resulted in an upward movement of the general elevation at which the crossing of freezing thresholds occurred.

The model shows that earlier snowmelt timing appear to have a substantial impact on conifer forest productivity and summer water stress, largely offsetting increases in growing season length,

especially at the lower and mid-elevations within the park. Colder, higher elevation forested areas exhibit greater relative increases in productivity due to the releasing of temperature constraints and longer growing seasons. These productivity patterns are largely consistent with other modeling and observational studies. In the northern Rockies, a comparable but less extensive simulation analysis (Boisvenue and Running 2010) found productivity increases resulting from longer growing seasons to be largely offset by increased water stress with some sites additionally displaying a decline in total carbon stocks. Long term observational analysis of ecosystem CO₂ exchanges at a site in the Colorado Rocky Mountains also found years with longer growing seasons to be correlated with overall lower rates of forest CO₂ uptake and rates of annual carbon sequestration to be highly dependent on snowmelt timing and availability (Monson et al. 2002, Sacks et al. 2006). Similarly, in a modeling study of a snow-dominated watershed in Yosemite National Park (Tague et al. 2009), the effects of temperature increases on productivity at a site were highly dependent on the shift in timing of snowmelt relative to the growing season. Lastly, Douglas-fir tree ring and growth studies along elevation gradients in the Pacific Northwest have also shown annual growth at mid and low elevations to be more dependent on water availability than temperature and negatively correlated with warmer growing season temperatures (Case and Peterson 2005, Littell et al. 2008).

3.1.2 Limitations and Assumptions

As with all simulation studies involving climate projections and the modeling of ecosystem impacts, there are necessary uncertainties and limitations (Littell et al. 2010). For instance, the downscaling of GCM projections to GLAC made several simplifying assumptions. Despite capturing general spatial climate patterns, the downscaling method used did not maintain the exact projection trends produced by the GCMs nor did it account for possible changes in climate variability (Mote and Salathé 2009). Furthermore, it was assumed that every area in GLAC would experience the same change in temperature and precipitation. In complex topography, there will likely be great variation in the degree of change. For instance, mountain ridges more coupled to the free-atmosphere may experience greater temperature changes than convergent basins and depressions (Dobrowski 2010). Additionally, while the downscaled climate grid was at a much finer scale than GCM outputs, many important microclimate and fine-scale biophysical factors were likely still not captured and there wasn't an obvious climate gradient between the western and eastern sides of the park. However, downscaling climate projections to even finer scales is likely inappropriate given the uncertainties involved (Wiens and Bachelet 2010).

In the context of these limitations and others detailed in the Appendix A, the results of this modeling exercise should not be used as predictions of impacts to specific sites within the park. The results should be considered as a best guess hypothesis of how ecosystems will respond along elevation gradients within GLAC based on possible future temperature and precipitation scenarios. For instance, the results are not fine scale enough to capture biophysical gradients between Lake McDonald and Saint Mary Lake and the differences in ecosystem response between the two sites. On the other hand, the results do indicate how a high elevation forest in GLAC could respond differently than a mid-elevation forest.

3.2 Air Pollution

GLAC is a Class I air quality area and, as such, receives the highest protection granted by the Clean Air Act (CAA). The NPS, as the Federal Land Manager (FLM), has “an affirmative responsibility” to protect the air quality related values (AQRVs) in Class I areas” (42 U.S.C. §7470(2)). AQRVs are resources sensitive to air quality, including lakes, streams, vegetation, soils, wildlife, and visibility. The CAA (Section 169A and 169B) set a specific goal for visibility in Class I areas: “the prevention of any future, and the remedying of any existing, impairment of visibility in mandatory Class I Federal areas which impairment results from man-made air pollution” (42 U.S.C. §7491 et seq. (1977)). Congress further stated that “the FLM should assume an aggressive role in protecting the air quality values [and in] cases of doubt the land manager should err on the side of protecting the air quality-related values for future generations” (Senate Report No. 95-127, 95th Congress, 1st Session, 1977). To fulfill this responsibility, the NPS monitors air quality and AQRVs in GLAC, and periodically evaluates their conditions and trends. Air quality parameters monitored include:

- Atmospheric deposition of nitrogen and sulfur compounds (wet - rain and snow), 1980 - present,
- Atmospheric deposition of nitrogen and sulfur compounds (dry - particles and gases), 1995 - present,
- Atmospheric deposition of mercury (wet - rain and snow), 2003 - present
- Ozone concentrations, 1992 - present,
- Visibility (fine particle sampler), 2000 - present (previous visibility sampler, 1988 - 2000), and
- Visibility (light scattering), 2007 - present.

The following sections describe air quality parameters monitored in the park and summarize conditions and trends in data.

3.2.1 Atmospheric Deposition of Nitrogen and Sulfur Compounds

Sources and Effects

Sulfur and nitrogen compounds are emitted as pollutants into the atmosphere and, after transport and transformation, may be deposited by either wet deposition (rain or snow) or dry deposition (particles, aerosols, or gases) into lakes, streams, and soils. Sulfate deposition forms from sulfur dioxide emissions released when coal is burned for power production. Nitrogen deposition results from emissions of both oxidized and reduced forms of nitrogen. Oxidized nitrogen compounds (e.g., nitrogen oxides) are formed naturally by fuel combustion in fires or human induced by fuel combustion in vehicles, power-plants, and industry. These compounds are deposited as nitrates and nitric acid. Reduced nitrogen compounds (e.g., ammonia) are released by agricultural activities, fires,

and other sources and deposited as ammonia or ammonium. Once deposited into ecosystems, sulfur and nitrogen both contribute to acidification of lakes, streams and soils, with subsequent loss of sensitive species of fish and wildlife. Nitrogen compounds, because nitrogen is an essential plant nutrient, may also cause unwanted fertilization or eutrophication, with subsequent changes in soil nutrient cycling and plant community structure and composition. Human activity has greatly increased the amount of reactive (bioavailable) nitrogen in ecosystems. While this has allowed food production for an ever-expanding human population, it has also caused great environmental disruption. Excess nitrogen degrades water quality and changes natural plant communities. Nitrogen favors certain plant species, such as invasive grasses, allowing them to out-compete native species leading to a loss of biodiversity (Brooks, 2003). Increased grass cover can increase fire risk in arid ecosystems (Rao et al. 2010). Species shifts can lead to an altered hydrological regime (Allen et al., 1998). In a survey of results from over 900 species in a variety of ecosystems across the U.S., Suding and colleagues (2005) found that nitrogen fertilization in natural ecosystems caused plant species loss that ranged from more than 60% for rare species to 10% for common species, with significant effects to biodiversity.

High elevation ecosystems in the Rocky Mountains, Cascades, Sierra Nevada, southern California, and the upland areas of the eastern U.S. are very sensitive to atmospheric deposition of nitrogen and sulfur compounds due to a limited ability to neutralize acid deposition and to absorb excess nitrogen. Monitoring has found that several lakes in GLAC are sensitive to acidification, having acid-neutralizing capacities (ANC) of < 100 microequivalents per liter ($\mu\text{eq}\cdot\text{L}^{-1}$); three of the lakes are considered very sensitive, with $\text{ANC} < 50 \mu\text{eq}\cdot\text{L}^{-1}$. However, a modeling analysis of lake chemistry and basin characteristics in GLAC predicted that many lakes in the park are relatively insensitive to acidic deposition because they are situated on high-buffering-capacity bedrock types such as carbonates and calcium silicates (Nanus et al. 2009).

Lakes in high elevation areas of the Rockies, as well as the eastern Sierras, have been found to respond to very low levels of nitrogen deposition. In lakes at Rocky Mountain NP (Colorado), Shoshone National Forest (Wyoming), Beartooth Mountains (Wyoming), and the Inyo National Forest (California), nitrogen loadings of approximately 1.5 kg/ha/yr of nitrogen deposition (wet only) caused diatom communities to shift from being dominated by species adapted to low nitrogen conditions to communities more typical of disturbed, mesotrophic conditions.

Two lakes in GLAC, Old Man and Snyder, were studied to evaluate their sensitivity to enrichment effects from nitrogen deposition. These lakes were found to be phosphorus limited and therefore unlikely to respond to the enrichment effects of nitrogen (Saros et al. 2010a). However, there may be high-elevation lakes in the park that are nitrogen-limited and responsive to added nitrogen (Nanus et al. 2009). Climate change is a complicating factor. Melting glaciers are releasing large amounts of stored nitrate into high elevation lakes in GLAC and other areas of the Rockies (Saros et al. 2010b).

Alpine vegetation communities may also be at risk from nitrogen deposition. In Rocky Mountain National Park, changes in alpine plant individual species abundance occurred at nitrogen loadings (wet + dry) of 4 kg/ha/yr (Bowman et al. 2006). A recent analysis concluded that GLAC ecosystems were at high risk from nitrogen deposition, particularly because of extensive areas of alpine

vegetation, wetlands, and meadows, and a number of high elevation lakes, all known to be sensitive to nitrogen enrichment (Sullivan et al. 2010).

Monitoring

A wet deposition sampler is located at the NPS Air Quality Monitoring Station near West Glacier. The sampler is part of the National Atmospheric Deposition Program and provides data on the chemistry of rain and snow. Figure 3.1 shows a trend plot of wet nitrogen deposition from 1980-2010. Although there is no clear trend, annual deposition values have approached or exceeded the 1.5 kg/ha/yr level known to cause changes in nitrogen-limited lakes. An analysis of 2000-2009 data for concentrations of nitrate and ammonium in wet deposition found no significant ($p \leq 0.05$) trend in either parameter (NPS 2010a).

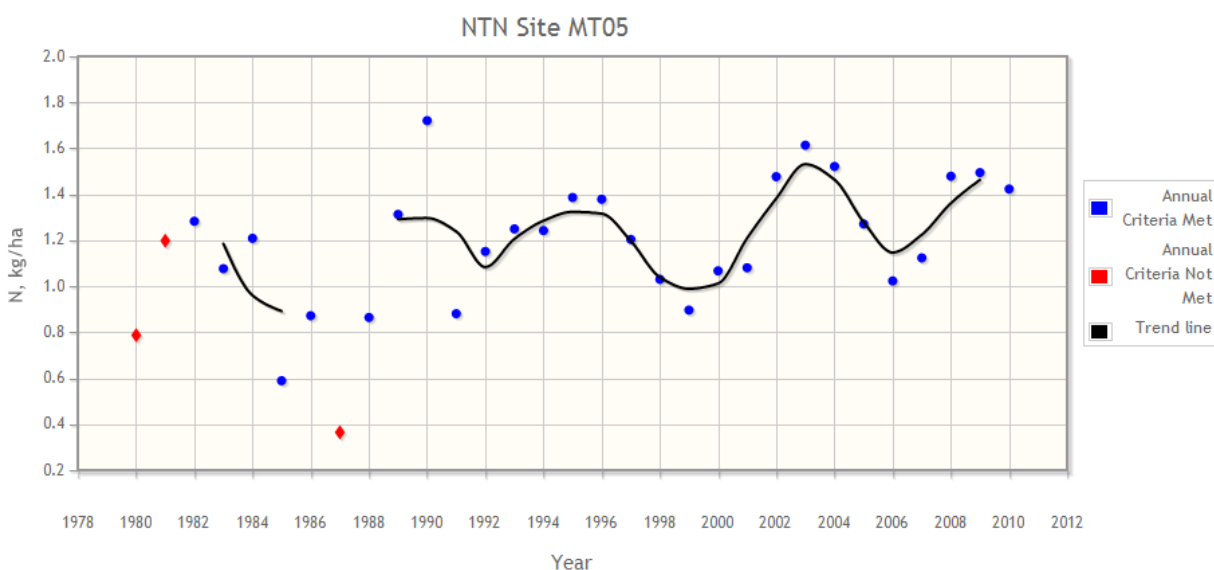


Figure 3.1. Inorganic nitrogen (N - nitrate+ammonium) deposition in kilograms per hectare (kg/ha), Glacier NP, 1980-2010 (NADP 2012).

Figure 3.2 shows a trend plot of wet sulfate deposition from 1980-2010. Sulfate deposition has decreased significantly over that time, likely due to emissions reductions on coal-burning power plants required by the Acid Rain Program of the Clean Air Act. More recently, sulfur concentrations in wet deposition were relatively unchanged from 2000-2009. Sulfur (S) deposition is one-third of sulfate (SO_4) deposition, so wet sulfur deposition is now about 0.6 kg/ha/yr.

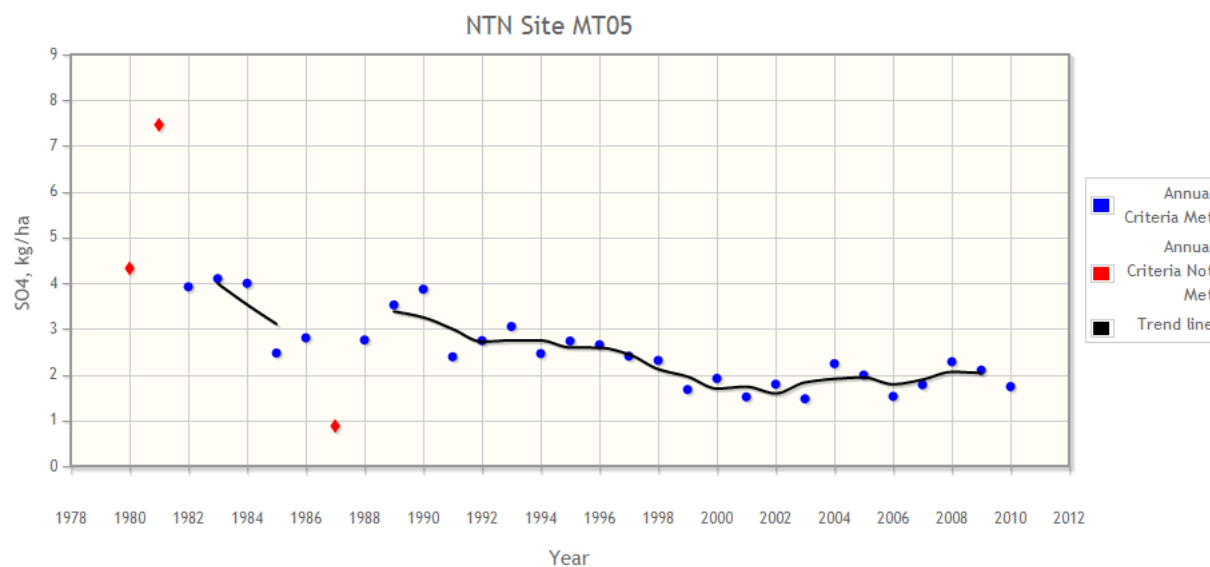


Figure 3.2. Sulfate deposition in kilograms per hectare (kg/ha), Glacier NP, 1980-2010 (NADP 2012).

A dry deposition sampler is located at the NPS Air Quality Monitoring Station near West Glacier and is part of the Clean Air Status and Trends Network (CASTNet). The sampler collects dry particles and gases from the air on filters, which are then analyzed. A model is then used to estimate the deposition rates of sulfate, nitrate, ammonium, and other constituents, factoring in vegetation type and meteorology.

Figure 3.3 shows total combined inorganic nitrogen deposition from CASTNet and NADP. Wet deposition is over 80 percent of total deposition. Nitrate and ammonium contribute about equally to wet deposition. No trend over time is obvious, and amounts of total deposition are below amounts known to cause changes in alpine plant communities in other areas of the Rocky Mountains (Bowman et al. 2006).

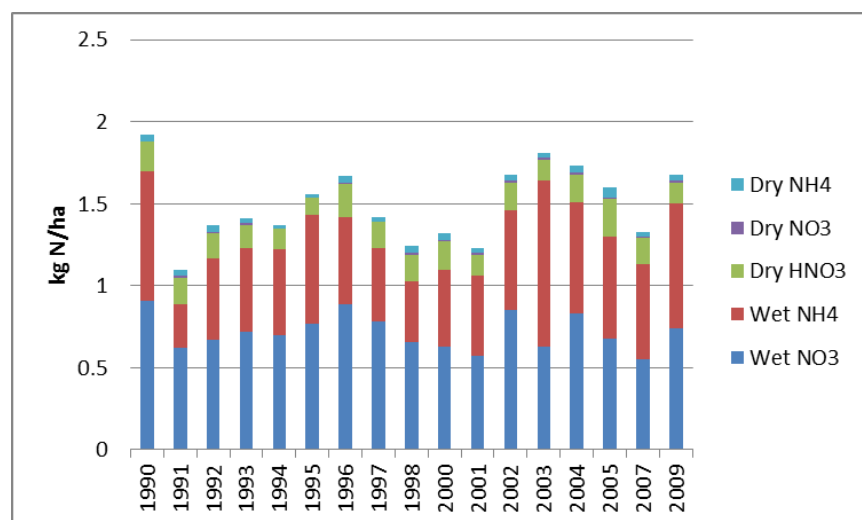


Figure 3.3. Total nitrogen deposition, 1990-2007, Glacier NP from CASTNet measurements of dry deposition and NADP measurements of wet deposition.

Figure 3.4 shows total combined sulfur deposition from CASTNet and NADP. Wet deposition is about 80 percent of total deposition. As noted above, sulfur deposition has decreased over time likely due to emissions reductions from coal-burning power plants.

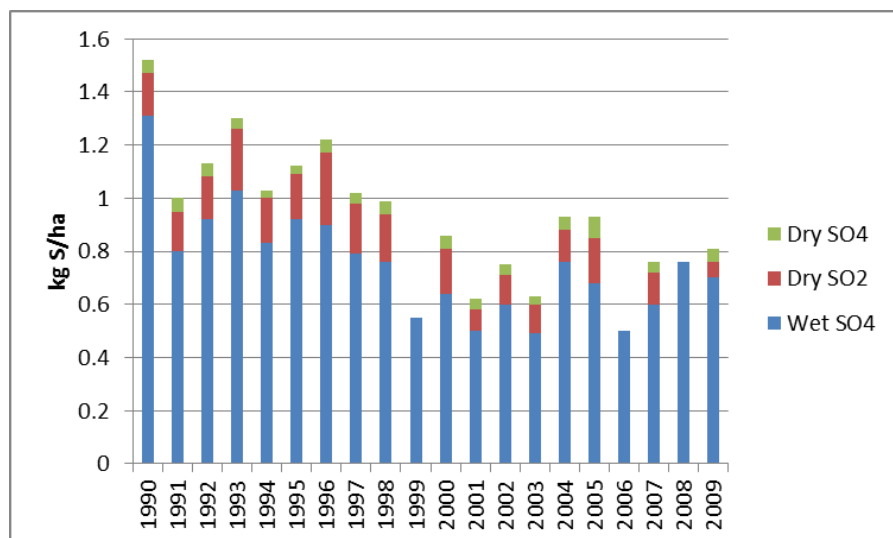


Figure 3.4. Total sulfur deposition, 1990-2007, Glacier NP from CASTNet measurements of dry deposition and NADP measurements of wet deposition.

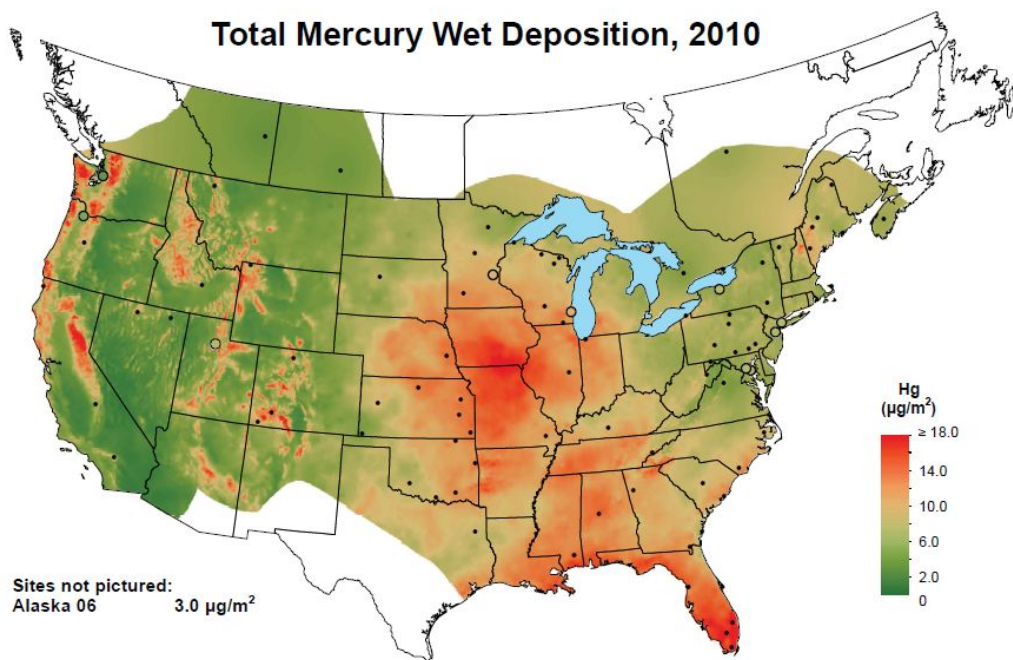
3.2.2 Atmospheric Deposition of Mercury

Sources and Effects

The chief source of mercury to the atmosphere is the combustion of coal for power production. In addition, incinerators, mining processes, and other industries emit mercury. Sources can be local, regional, or global. Once deposited, mercury can be transformed by ecosystem processes into a very toxic form, methylmercury, that accumulates through the foodchain, sometimes reaching toxic levels in fish and wildlife. Certain ecosystems facilitate methylation, including the wetlands and lakes found in GLAC. The Western Airborne Contaminants Program (WACAP) found levels of mercury in fish in Oldman and Snyder Lakes that exceeded wildlife (kingfishers) health thresholds. Physiological symptoms of contaminant stress in fish (kidney and/or spleen macrophage aggregates) were significantly related to mercury and age of fish in both lakes (Landers et al. 2008).

Mercury Deposition Monitoring

Mercury is monitored in rain and snow as part of the Mercury Deposition Network (MDN) and is monitored at the NPS Air Quality Monitoring Station near West Glacier. An isopleths map of mercury deposition (Figure 3.5 and 3.6) indicates that deposition is relatively low in GLAC. However, mercury deposition is not directly related to ecosystem impacts. Rather, the ability of ecosystems to transform inorganic mercury to organic methylmercury will influence the uptake and accumulation of mercury in fish and wildlife.



National Atmospheric Deposition Program/Mercury Deposition Network
<http://nadp.isws.illinois.edu>

Figure 3.5. Total mercury wet deposition, 2010.

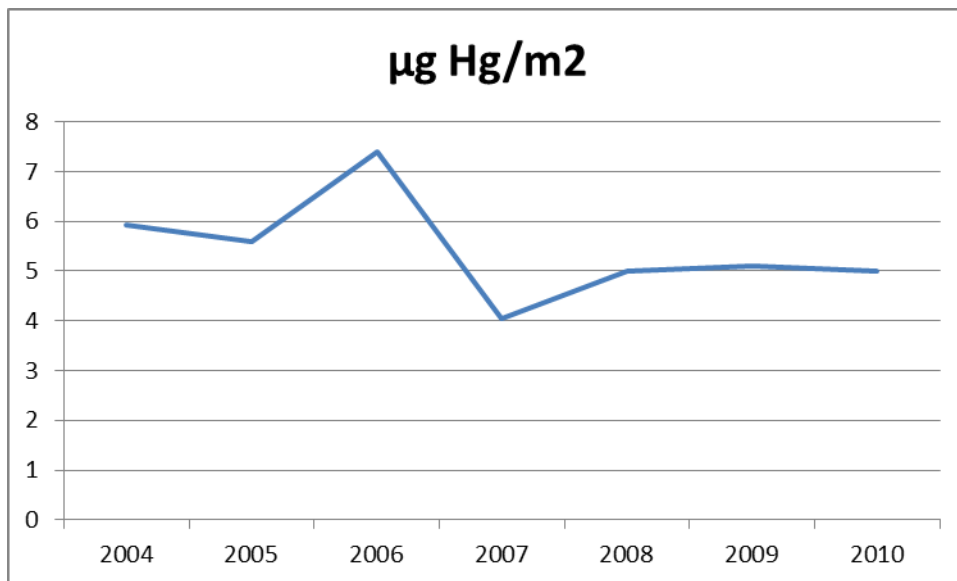


Figure 3.6. Wet deposition of mercury in micrograms per square meter ($\mu\text{g}/\text{m}^2$) in Glacier NP, 2004-2010.

3.2.3 Other Atmospheric Contaminants

WACAP analyzed lake sediments, fish, water, air, and vegetation in Glacier NP and other national parks for a number of other airborne contaminants besides mercury, including industrial by-products

and pesticides. Concentrations and deposition of polycyclic aromatic hydrocarbons (PAHs) were found to be significantly elevated (3.6 to 60,000 times greater) in Snyder Lake than in Oldman Lake and lakes from seven other western national parks. PAHs, produced by the incomplete combustion of fossil fuels and biomass burning, pose risks to human and ecosystem health because of their toxicity. A local aluminum smelter was identified as a major source of PAHs to the Snyder Lake catchment (Usenko et al. 2010). Dieldrin, DDT, and chlordane, toxic pesticides banned for use in the U.S., were found at elevated levels in fish from Oldman Lake. A few fish from Oldman Lake displayed intersex symptoms (male and female reproductive structures in the same fish) that may be indicative of hormonal disruption caused by these contaminants, although the sample size was small (Landers et al. 2008).

3.2.4 Visibility

Visibility is monitored in GLAC with a fine particle sampler at the NPS Air Quality Monitoring Station near West Glacier and a nephelometer (to measure light scattering) at the West Glacier Horse Stables. Both are part of the Interagency Monitoring of Protected Visual Environments (IMPROVE) Network. Fine particles absorb or scatter light, causing haze and reducing visibility. Congress set a national goal of restoring natural visibility conditions in Class I areas, including GLAC, by 2064. States are generally required to develop plans to meet that goal, which specifies that progress must be demonstrated in improving visibility on the haziest days and preventing visibility degradation on the clearest days. However, Montana deferred their plan development to EPA and, in April 2012, EPA proposed a Federal Implementation Plan for visibility improvement in the state (<https://federalregister.gov/a/2012-8367>). Improvement over approximately 60 years will be evaluated every 10 years, starting around 2008. Data from the IMPROVE Network are used to demonstrate progress towards the goal. The fine particle sample uses filters to collect particles; the filters are then analyzed for sulfate, nitrate, carbon, soot, and other constituents. Visibility estimates are “reconstructed” from the fine particle data, and expressed as deciviews (dv). The dv scale is near zero for a pristine atmosphere and increases as visibility degrades. A change of one dv is perceptible to the human eye. Visibility of 9 dv is equivalent to a visual range of about 100 miles (160 km). Figure 3.7 shows the relationship between deciview, visual range, and light extinction.

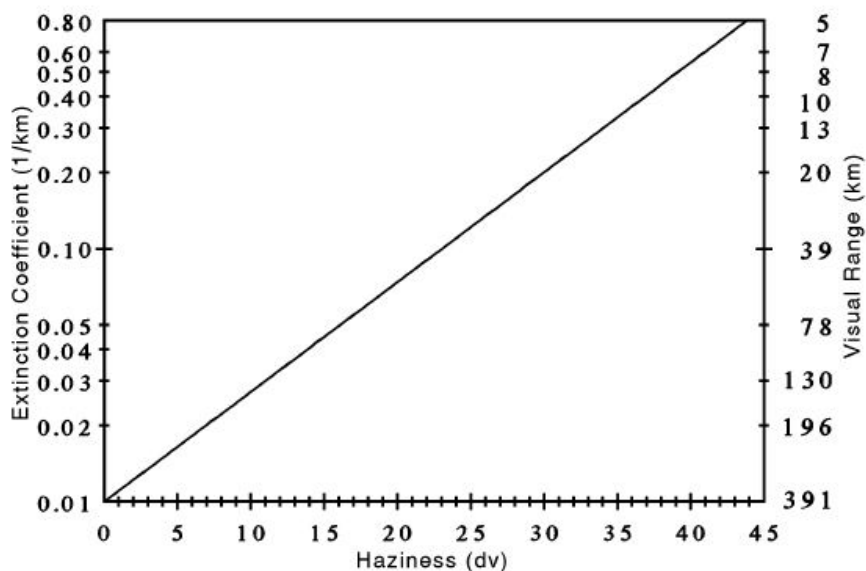


Figure 3.7. Visual range (km) and light extinction as a function of haziness expressed as deciview (dv).

From 2000-2009, visibility on the haziest or clearest days did not significantly ($p \leq 0.05$) improve or degrade in Glacier NP. Visibility is considered to be in moderate condition (NPS 2010a). Figure 3.8 shows visibility, expressed in deciviews (dv), from 1989-2008, on the best and worst visibility days, with the goals set by EPA for the best and worst days. By 2064, visibility on the best days should be 2.42 dv; visibility on the worst days should be 9.18 dv.

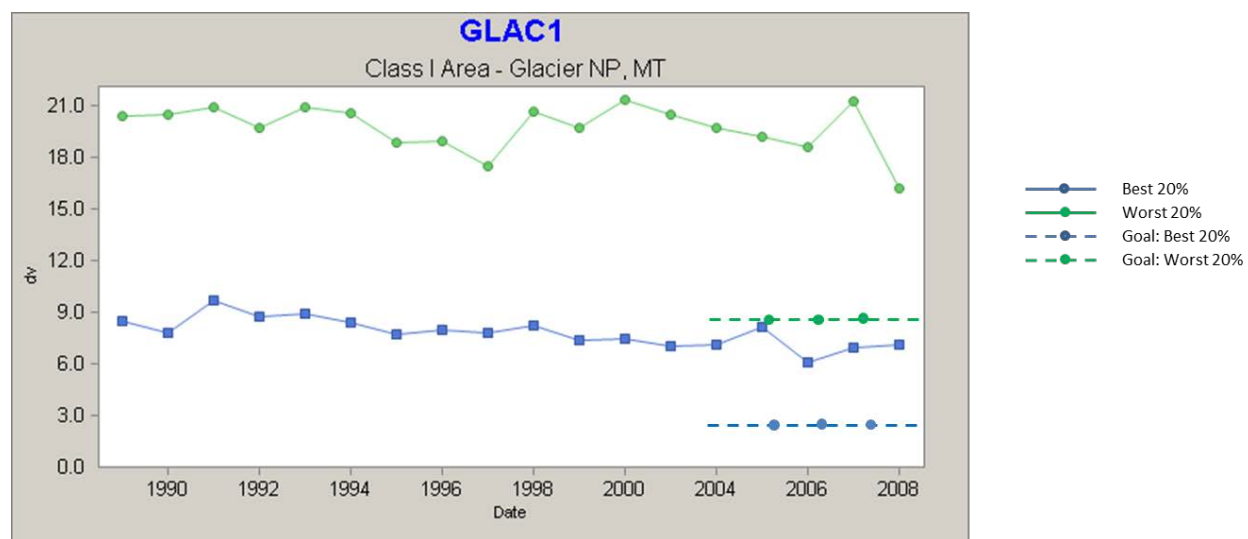


Figure 3.8. Trends in visibility (deciview – dv) for the 20 percent of days with best and worst visibility, Glacier NP, 1989-2008, with goals for visibility improvement on best and worst days (VIEWS 2012).

Sources and Effects

One of the most widespread air pollutants is ground-level ozone, which harms vegetation as well as human health. Ozone is not emitted directly from smokestacks or vehicles. It is formed when other

pollutants, primarily nitrogen oxides (from vehicles, power plants, industry, and fires), and volatile organic compounds (from vehicles, solvents, industry, and vegetation), react in the atmosphere in the presence of sunlight, usually during the warm summer months. Ozone is a respiratory irritant and can trigger a variety of health problems including chest pain, coughing, throat irritation, and congestion. It can worsen bronchitis, emphysema, and asthma. Ground-level ozone also can reduce lung function and inflame the linings of the lungs. Repeated exposure may permanently scar lung tissue. The Environmental Protection Agency (EPA) has established a “primary” ozone standard to protect human health. This standard was revised in 2008 in order to be more protective of human health. To attain this standard, the 3-year average of the fourth-highest daily maximum 8-hour average ozone concentrations measured at each monitor within an area over each year must not exceed 75 parts per billion (ppb).²

Ozone also affects vegetation, causing significant harm to sensitive plant species in both managed and natural systems. Ozone enters plants through leaf openings called stomata and oxidizes plant tissue, causing visible injury (e.g., stipple and chlorosis) and growth effects (e.g., premature leaf loss, reduced photosynthesis, and reduced leaf, root, and total dry weights). Ozone-sensitive plant species that occur in the park are listed in Table 3.1. EPA has established a “secondary” ozone standard to protect vegetation. The secondary standard is currently identical to the primary, but EPA has proposed setting a separate secondary standard in the range of 7-15 ppm-hours, based on the W126 metric. The W126 is a plant-exposure index that preferentially weights the higher ozone concentrations most likely to affect plants and sums all weighted concentrations during daylight hours over three months during the growing season.

Table 3.1. Ozone-sensitive plant species in Glacier National Park (NPSpecies 2012).

Species that are Ozone Sensitive in Glacier National Park (GLAC)	
Scientific Name	Common Name
<i>Symphoricarpos albus</i>	common snowberry
<i>Vaccinium membranaceum</i>	tall huckleberry
<i>Apocynum androsaemifolium</i>	bitterroot
<i>Apocynum cannabinum</i>	common dogbane
<i>Amelanchier alnifolia</i>	serviceberry
<i>Physocarpus malvaceus</i>	ninebark
<i>Rubus parviflorus</i>	thimbleberry
<i>Populus tremuloides</i>	quaking aspen
<i>Salix scouleriana</i>	Scouler's willow

Monitoring

The ozone monitor in GLAC is located at the NPS Air Quality Monitoring Station near West Glacier. It is the only ozone monitor in Montana, providing a valuable record of conditions in the region. Figure 3.9 and 3.10 show long-term trends in ozone concentrations and cumulative exposures in

² In January 2010, EPA proposed revisions to the primary ozone standard of 75 ppb. In late 2010 or early 2011, EPA is expected to promulgate a new standard more stringent than the present standard.

GLAC. Levels are consistently below the human health standard and exposures expected to harm vegetation. An analysis of data from 1989-2008 show that concentrations are stable and ozone condition is considered good (NPS 2010a).

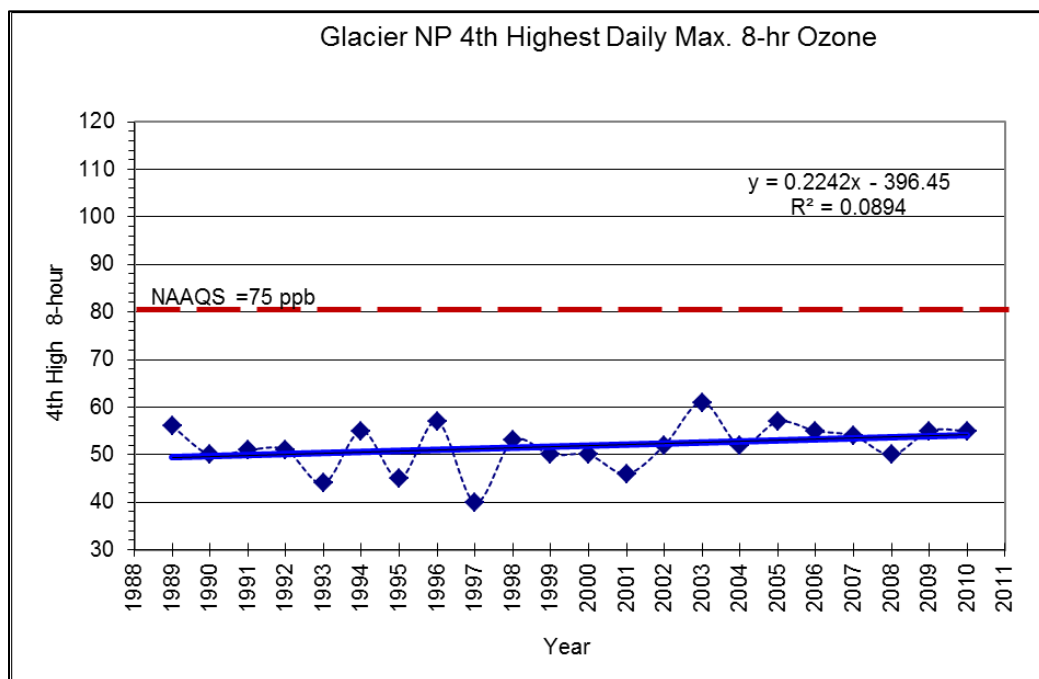


Figure 3.9. Trends in ozone concentrations, 1989-2010, Glacier National Park. Primary ozone National Ambient Air Quality Standard (NAAQS) of 75 parts per billion (ppb) is based on 3-year average of annual 4th-highest 8-hour concentration.

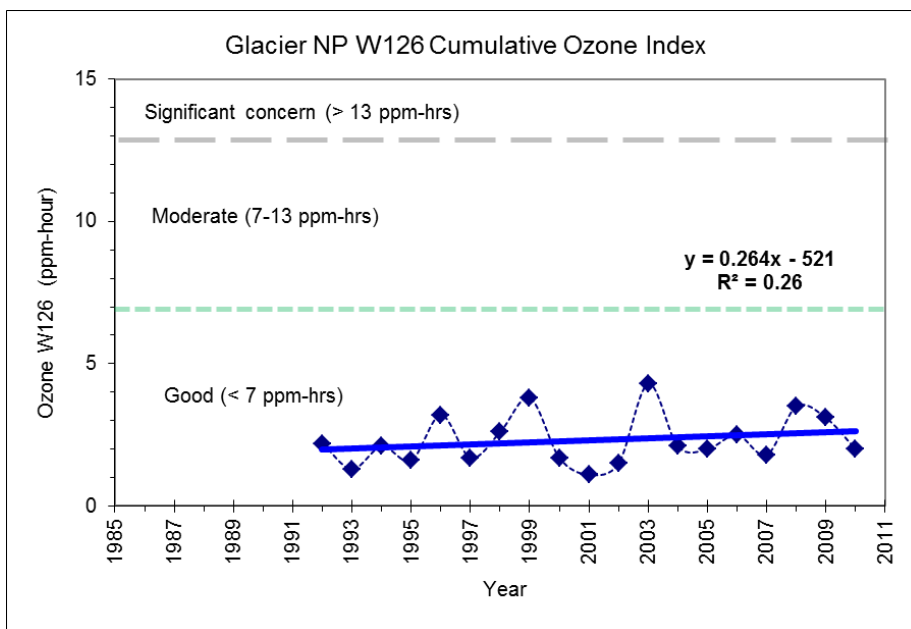


Figure 3.10. Trends in ozone W126 in parts per million-hours (ppm-hrs), 1992-2010, Glacier National Park. The air quality condition for the cumulative ozone W126 index is rated “good” at Glacier NP (NPS-ARD; www.nature.nps.gov/air/who/npsPerfMeasures.cfm) at exposures of less than 7 Human Threats.

Human activities within and around the park thrive mainly on tourism, agriculture and regional trade. Glacier National Park is among the most prominent tourist destinations in Montana for both nonresidents and Montanans. NPS, 2004 summarize a 2001 Montana State survey of nonresident summer travelers to Montana and report that 43% of vacationers in Montana visited Glacier National Park, second highest to Yellowstone National Park. Local agricultural goods include hay, wheat, barley and some hardy fruits and livestock but these agricultural activities have steadily dropped in the region because of Federal crop reduction programs and increased exurban development of agricultural land (NPS 2004). Finally, Kalispell is approximately 33 miles from the park's entrance at West Glacier and is the main trade center for northwest Montana. The region also provides a wide range of recreational opportunities and tourism-related businesses, variety of manufacturers, professional services, timber production, electric power generation, medical care and housing development. Collectively, these human activities have placed a stress on the ecological communities within and around the park.

3.2.5 Within the Park

Glacier National Park's commercial services plan (NPS 2004) summarized visitation data and report an annual visitation to the park that ranged between 1.7-1.8 million and of those about 750,000 are from out of state. The park provides necessary infrastructure to support the large number of annual visitors and facilitate access to the natural amenities. These include roads, maintained trails, campgrounds, lodges, visitor support facilities, as well as personnel housing and management facilities (Table 3.2 and Figure 3.11). The construction of trails and roads to the heart of the park's backcountry have allowed the introduction of non-native species, disturbance to sensitive native plant communities, and interaction with wildlife throughout the park.

Table 3.2. GLAC infrastructure

Watershed	Roads (miles)	Trails (miles)	Lookout Count	Number Campsites	Number Campgrounds	Number Back- Country Campgrounds	Number of Buildings
Belly	0.70	48.07	1	0	0	10	11
Camas	21.90	42.34	2	0	0	0	3
Coal/Ole	11.50	81.31	3	0	0	4	16
Cut Bank	1.20	18.73	0	15	1	1	5
Kennedy	2.80	15.96	0	0	0	3	3
Kintla/Bowman	28.70	78.73	2	60	2	3	63
Lake McDonald	71.50	127.25	2	495	4	0	377
Nyack	8.70	77.54	1	0	0	5	154
Quartz/Logging	8.80	26.22	0	14	2	0	17
Saint Mary	24.90	70.62	3	235	2	5	118
Swiftcurrent	12.20	54.88	1	114	1	1	128
Upper Two							
Medicine	6.60	56.60	0	101	1	4	33
Waterton	0.00	40.79	2	0	0	3	16

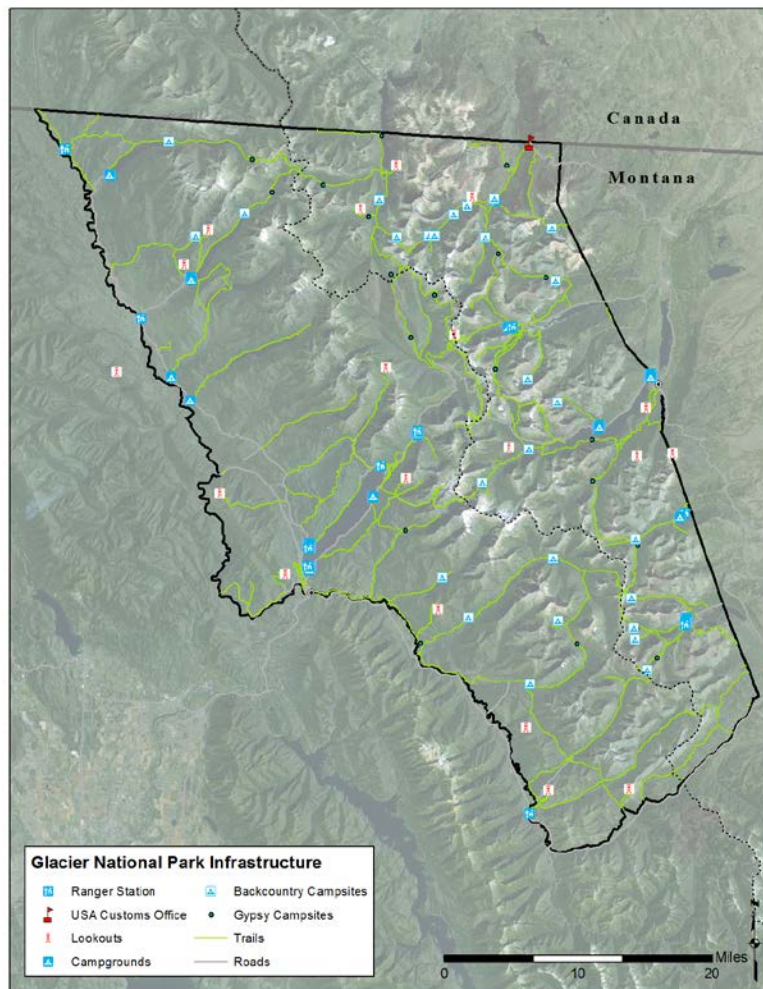


Figure 3.11. Park Infrastructure.

3.2.6 Surrounding the Park

The NPS landscape monitoring project (NPScape) has identified and is currently evaluating and reporting on a suite of landscape-scale measures for all 270+ park units serviced by the NPS Inventory and Monitoring Program (NPS 2010b). NPScape is evaluating measurements at multiple ecologically relevant scales: a 1.86 mile (3 km) ‘boundary layer’, a local area within 18.64 miles (30 km) of park boundaries, and a broad-scale analysis zone that reflects park context, watersheds, and biome boundaries. NPScape provide data to assist with the assessment of potential threats from nutrient enrichment, eutrophication, sedimentation, invasive species, water and air pollution, development on adjoining private lands and other elements that are management concerns. Below are a few of these elements within 18.64 miles (30 km) of the park boundary. These analyses and related figures are products of the NPScape effort.

Population

The U.S Census (2000) indicates that there are approximately 114,261 people (about 13% of the state's total population) in the three counties closest to the park (Flathead, Glacier, and Lake Counties) (Figure 3.12, NPS 2004). Flathead County contains the town of Kalispell, whose population in 2000 was 14,223 and is the largest municipality in the region. Glacier County, to the east of the park, contains the Blackfeet Indian Reservation and 76% of Glacier County's population is made up of members of the Blackfeet Tribe. The Flathead Indian Reservation, home of the Confederated Salish and Kootenai Tribes, is in Lake County to the south of the park. Over 26% of Lake County's population is American Indian.

Over the last several years, there has been sizable population growth on the west side of the Continental Divide in Flathead and Lake Counties, but growth in Glacier County, on the east side of the mountains, has remained slow. A gradually slower rate of future population growth is expected for the entire three-county area, projected to increase from 114,225 in 2000 to 134,190 in 2010 and 154,260 in 2020 (NPS 2004).

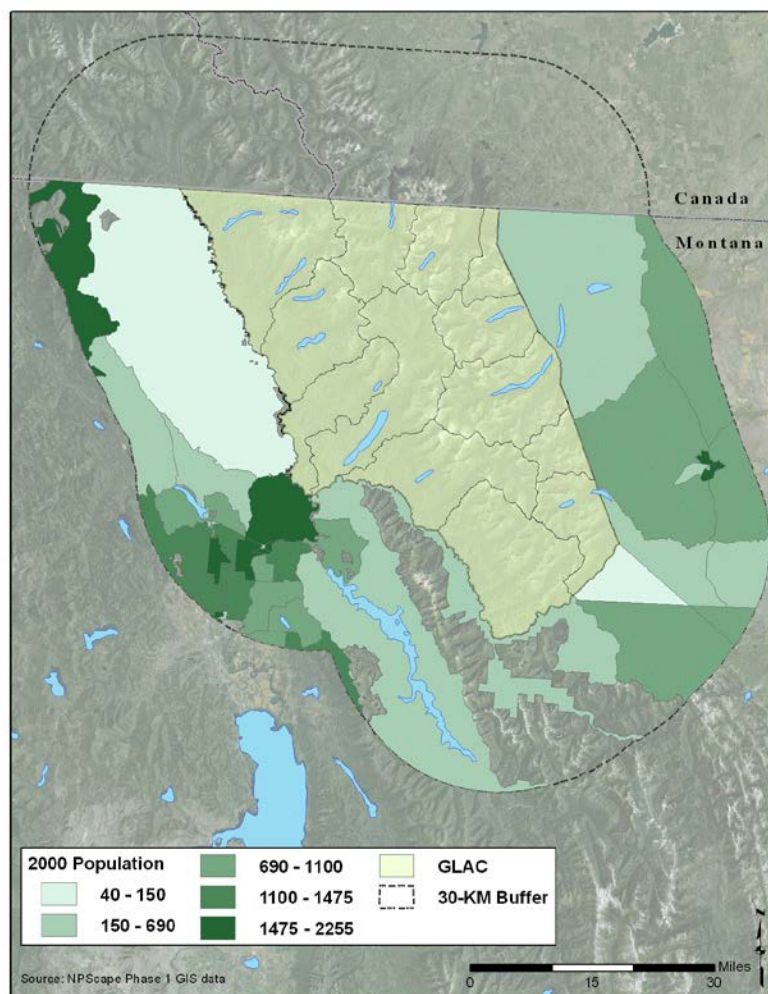


Figure 3.12. Population of census blocks (U.S Census 2000) within 30 kilometers of the park boundary.

Land Ownership

Glacier National Park is surrounded mostly by publicly owned and Indian reservation land (Figure 3.13). Most of the land west and south of the park, west of the Continental Divide, is Flathead National Forest, and to the south and east of the divide is Lewis and Clark National Forest (known as the Badger-Two Medicine area). The 1.5 million-acre Blackfeet Indian Reservation is on the park's eastern boundary. Canada's Waterton Lakes National Park, in the province of Alberta, is directly north of GLAC and east of the Continental Divide. The province of British Columbia manages land north of GLAC and west of the Continental Divide. The Akamina-Kishinena Provincial Park, British Columbia, is located in the most southeastern corner of British Columbia. These varied land ownerships have led to a variety of land uses within the region. Figure 5.14 provides a general overview of areas that have been developed into urban or agriculture activities and others that remain relatively intact with some forest practices and grazing activities.

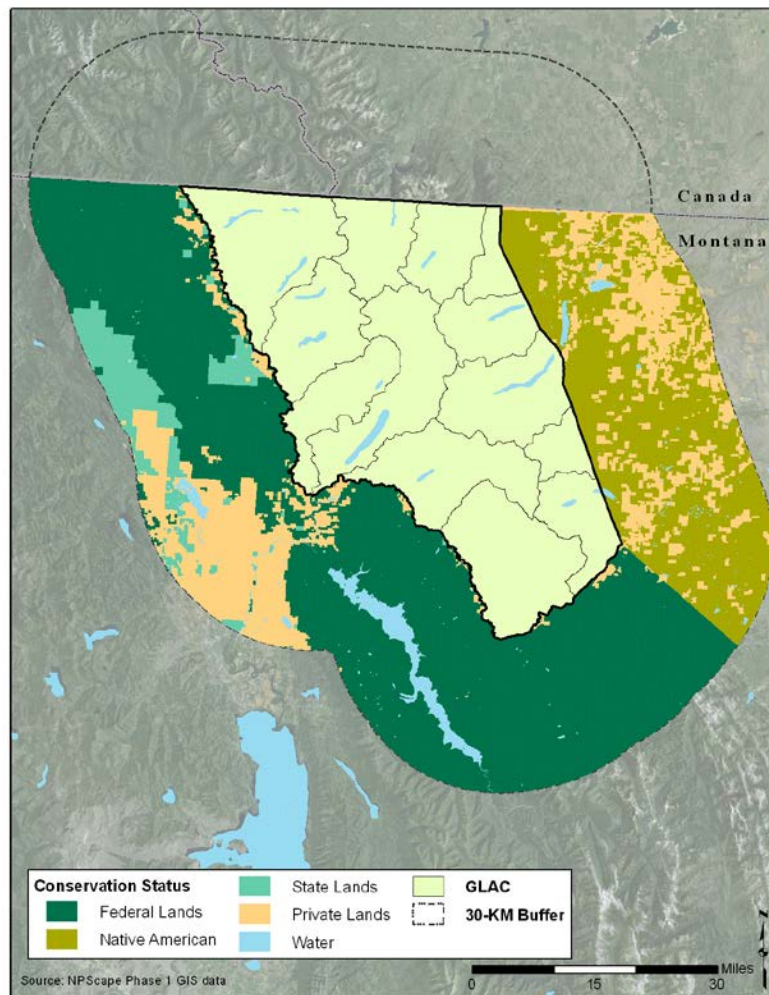


Figure 3.13. Land ownership within 30 kilometers of the park.

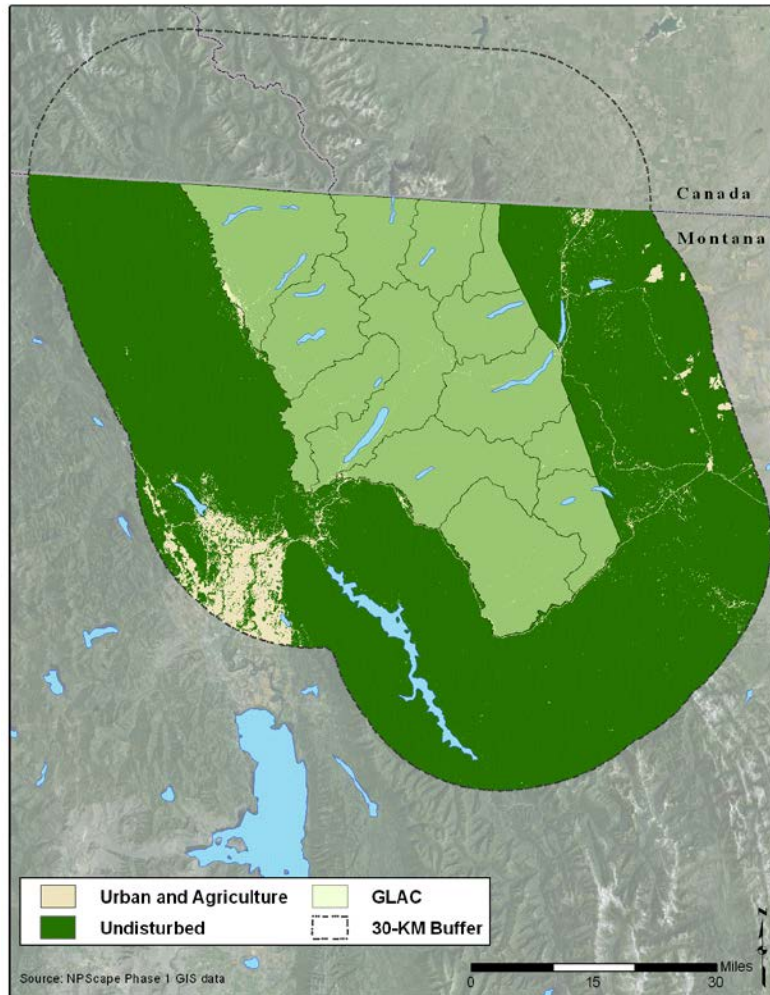


Figure 3.14. Land use within 30 kilometers of the Park Boundary.

Roads

Overall, the greatest human threats for GLAC mammal populations lie just outside the borders of the park and are not directly related to the park itself. For instance, grizzly bears that remain within the park are much safer than those who leave its boundaries (Kendall et al. 2008). From 1976 to 2000, about 91% of the 401 known grizzly bear mortalities that occurred within about 25 miles of GLAC happened outside the park (Kendall et al. 2008). Road/animal interaction is the major cause of mortality in the region. U.S. Highway 2, located along the southern boundary of GLAC, has moderate traffic volumes ranging between 1,500 and 5,000 vehicles per day (MDT 2009). In recent years, the U.S. Highway 2 corridor has been a significant source of mortality for mammals near GLAC due to vehicle collisions, train collisions, and management removals associated with human residences. The U.S. Highway 2 corridor acts as a partial barrier by decreasing successful animal movements from GLAC to the Bob Marshall/Great Bear Wilderness complex to the south, especially bears (Waller and Servheen 2005). Waller and Servheen (2005) found that bear movement across U.S. Highway 2 is inversely related to traffic volume. The BNSF railroad line runs parallel to U.S.

Highway 2 and thus compounds the barrier effects of the Highway and is also a significant source of mortality (Waller and Servheen 2005). Figure 3.15 provides a visual representation of road concentrations surrounding the Park.

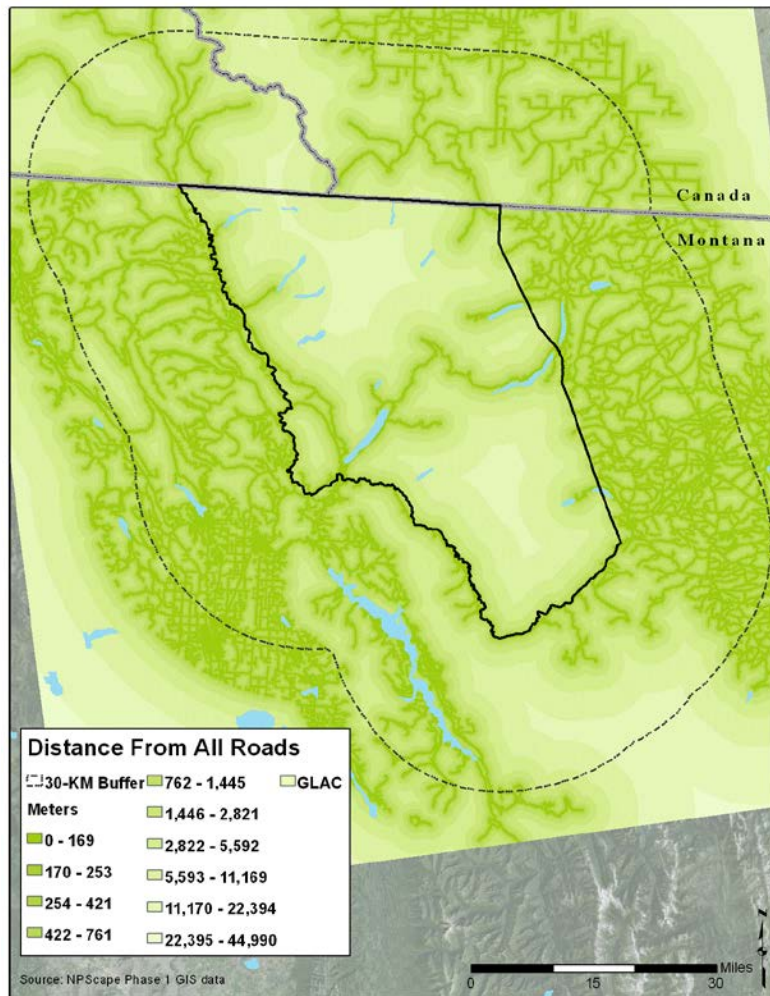


Figure 3.15. Distance from all roads (in meters) within 30 kilometers of the Park Boundary.

4. Multi-Metric Assessment Approach and Background

4.1 Glacier National Park Management Framework

It is a goal of this document, and associated GIS tools, to blend smoothly with existing management frameworks. The park's General Management Plan (GMP) presents a strategy to guide future decisions based on six geographic management areas. Each of these areas is made up of management zones. These areas and the zones within have different management priorities based on the land and visitor uses that are appropriate to the development and activities are described for those zones. The six geographic areas include; 1) Many Glacier, 2) Goat Haunt-Belly River, 3) Going-to-the-Sun Road Corridor, 4) Two Medicine, 5) Middle Fork, and 6) North Fork (Table 4.1 and Figure 4.1). The geographic areas vary in the amount of infrastructure and visitor access and as a result vary in the intensity of park management. Additionally, each area is made up of four types of management zones that guide specific management approaches (Figure 4.2). These zones are the: 1) Visitor Service Zone, 2) the Day Use Zone, 3) Rustic Zone, and 4) Backcountry Zone. The Visitor Service and Rustic Zones are currently used in park planning, while the Day Use and Backcountry zones are in working draft. The Visitor Service Zone includes developed areas, paved roads, and campgrounds with potable water and sanitation facilities. The Rustic Zone will include primitive facilities and campgrounds representative of early western national park development and traditional visitor experiences in them. The Day Use Zone, currently in working draft, includes selected areas generally with specific destinations that visitors can reach easily within a day from visitor use zones. Finally the Backcountry Zone, also currently in working draft, is an area where natural resource management is focused on protection and (when necessary) restoration of resources and natural processes.

Table 4.1. Areas of General Management Zones within the Management Areas

General Management Areas	Area (Acres)	Visitor Services (acres)	Rustic Zone (acres)	Backcountry (acres)*	Day Use (acres)*
Goat Haunt	165,472	1,202	0	163,467	1,216
Going-to-the-Sun Road	183,855	15,017	26	165,386	5,205
Many Glacier	65,935	1,908	0	60,651	4,455
Middle Fork	225,769	195	0	225,577	0
North Fork	286,111	18	571	285,259	0
Two Medicine	80,830	533	17	78,459	2,442
Total	1,007,972	18,873	614	978,799	13,318

*These management zones are preliminary and areas are estimated.

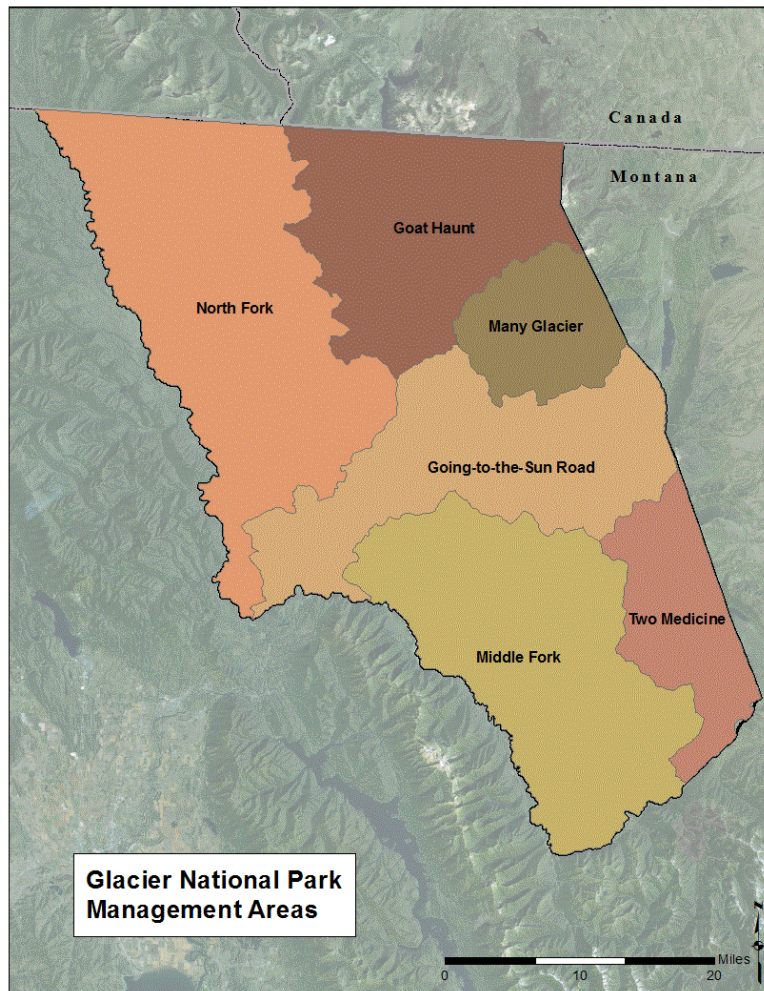


Figure 4.1. General management areas within Glacier National Park.

Because most natural processes are predominately bound by watersheds, this document will present the analyses and summaries in a watershed context rather than the existing management zone context. For this approach we summarize each indicator at a common scale - the Hydrologic Unit Code, level 10 (HUC 10) - for consistency and comparability. The HUC-10 watershed scale was selected over the finer scale HUC-12 during initial meetings with GLAC resource staff. The finer scale HUC-12 watershed assignments would create approximately 60 assessment watersheds. The spatial analysis tools in the following chapter have been created and delivered to the park's GIS team for this project and can be applied to these 60 finer scale HUC-12 watersheds with minor modifications. For example, elevation specific metrics should not be applied in sub-basins that do not include that elevation range. However, the park's resource team expressed an interest in reporting only on the condition of the HUC-10 assessment watersheds for this effort. Therefore, the HUC 10 watersheds used for the remainder of the document, with slight modifications resulting in 13 different assessment area providing a finer resolution than the existing the management zones and can be used in unison as the management needs arise (Table 4.2 and Figure 4.3).

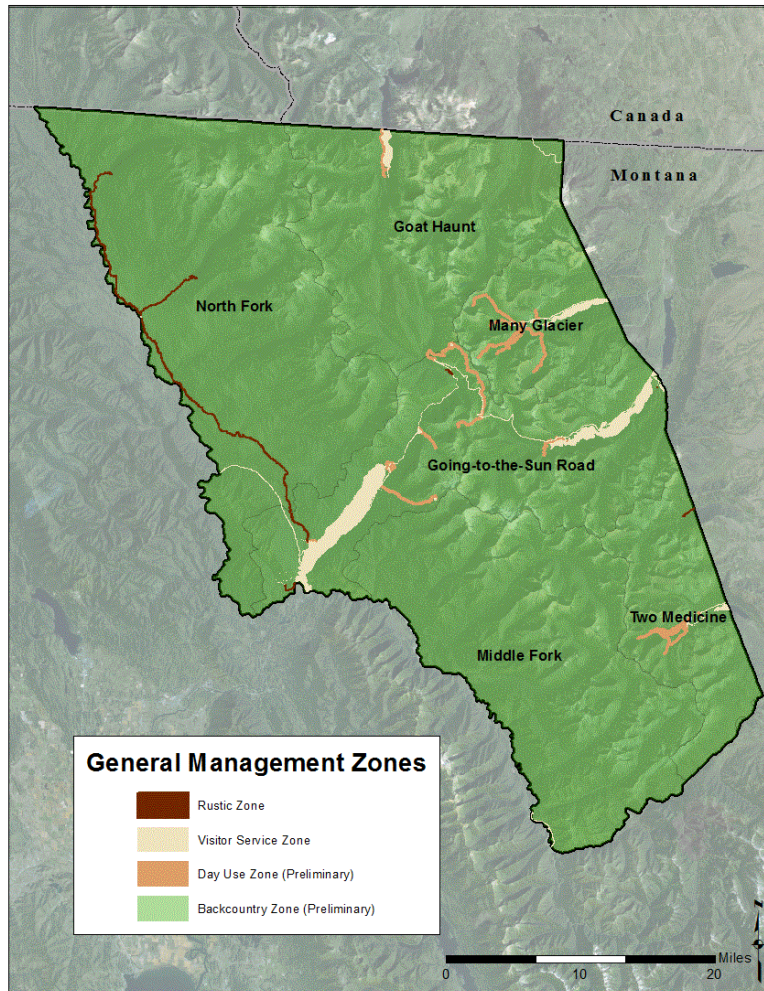


Figure 4.2. General management zones within the management areas of Glacier National Park.

Table 4.2. HUC-10 Watershed Assessments Areas.

Hydrologic Unit Code - Level 10 Watershed Name	Watershed Area (Acres)
Belly	57,109
Camas	66,103
Coal/Ole	123,833
Cut Bank	27,283
Kennedy	26,608
Kintla/Bowman	132,186
Lake McDonald	119,523
Nyack	105,842
Quartz/Logging	87,828
Saint Mary	93,953
Swiftcurrent	53,780
Upper Two Medicine	53,776
Waterton	60,434
GNP Total	1,008,256

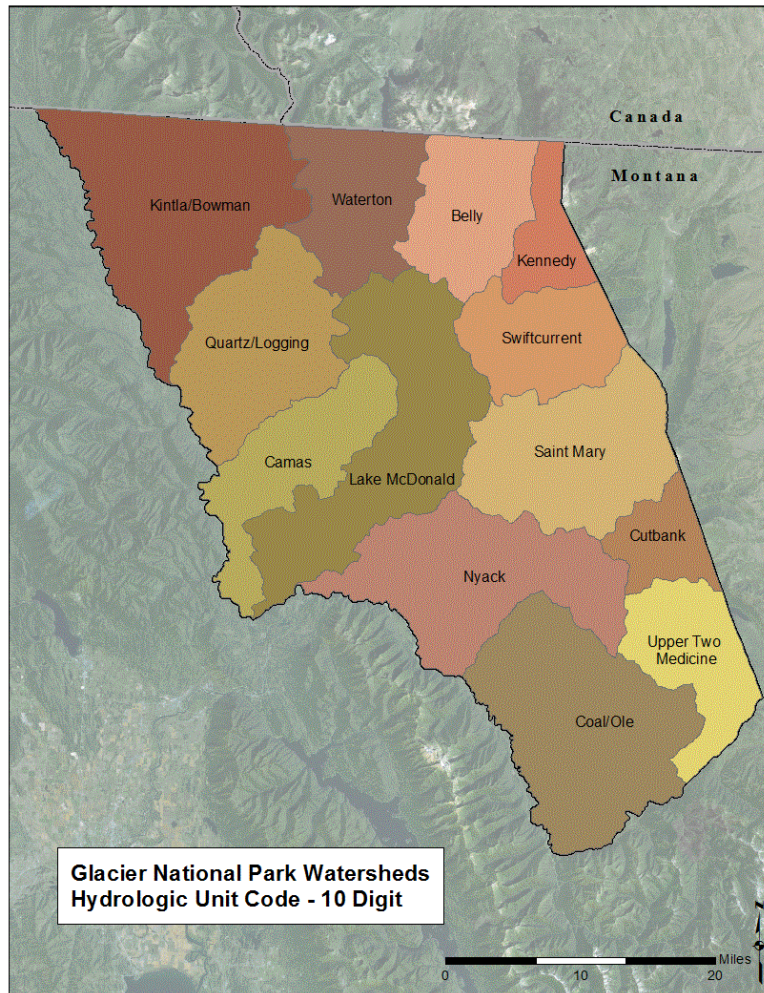


Figure 4.3. Watershed assessment areas used for this study.

4.2 Analysis of Condition

This document provides a baseline assessment of the ecosystem condition of Glacier National Park’s watersheds, specifically, the condition of a subset of biotic and abiotic structures necessary to maintain the health of specific ecological focal areas. This watershed assessment focuses on seven major focal ecological focal areas that were selected during initial meetings with GLAC resource staff as important ecological components to the GLAC monitoring and assessment program. The seven focal areas include: 1) stream systems, 2) North and Middle Fork of the Flathead River, 3) lake systems, 4) fish populations, 5) avian populations, 6) mammal populations, and 7) vegetation. These focal Elements, summarized in Table 4.3, are further described in Chapter 5. The condition of each focal element and the average ecological condition across all focal elements are provided in Chapter 6.

Table 4.3. Description of the Assessment Focal Elements.

Focal Assessment Elements	Overview of Assessments
1. Steams	The condition of alpine, mid-elevation and lowland streams, and rivers, within the park's watersheds
2. Flathead River	The condition of the North and Middle Forks of the Flathead River adjacent to the park
3. Lakes	The condition of the lakes with the park's watersheds.
4. Fish	The condition of native and non-native salmonid species within the park's watersheds and the North and Middle Forks of the Flathead River.
5. Avian	The condition of biotic and abiotic ecosystem attributes that support a diverse avian population within the park's watersheds.
6. Mammal	The condition of biotic and abiotic ecosystem attributes that support a diverse mammalian population within the park's watersheds.
7. Vegetation	The condition of the vegetative land cover, and to a lesser degree the non-vegetative land cover (e.g. talus, snow fields, glaciers), within the assessment watersheds

GLAC is at the core of the “Crown of the Continent” ecosystem, one of the most ecologically intact areas remaining in the temperate regions of the world making GLAC a regionally ecological significant resource. However, to provide GLAC resource personnel with a prioritization tool for future monitoring and management, an approach was necessary to distinguish areas of higher and lower ecological significance in a landscape with very limited human impacts. Most ecosystem function assessments (e.g. HGM: Smith et al. 1995), integrity assessments (e.g. IBI: Karr and Chu 1997), or condition assessments (CRAM: Collins et al. 2007) commonly adopt a Reference Condition Approach (RCA: Bailey et al. 2007) where a site-of-interest is compared to a gradient of similar ecosystems that range from relatively unexposed to severely altered by stressors. If such a gradient were applied to GLAC, nearly all sites would exist at the non-impacted range of an RCA. An assessment that provides a result in which all sites are in near-perfect condition would be uninformative to GLAC’s resource managers. As detailed in the section below, a new approach to assess a range of ecological conditions in an ecologically intact system was developed for this project to assist resource staff in monitoring and management prioritization.

This document uses the term ‘ecological condition’ as a means to capture three aspects of the park’s relatively unimpacted ecological systems: ecological significance, threats to that significance, and risks to that significance. Ecological significance as measured by the contemporary natural range of biotic and abiotic ecosystem attributes that occur in the majority of the park where there are very few to no human impacts. The idea behind measuring significance is that there are areas in the park with more diverse habitat than other areas. This increased diversity provides increased resilience to potential ecosystem changes due to global impacts such as climate variability, regional impacts due to air quality, or local impacts due to increased human interaction (Chapin et al. 2000, Elmqvist et al. 2003). To provide GLAC with a watershed-scale prioritization tool to assist with finer scale monitoring or management decisions, we applied a suite of metrics to capture this contemporary natural variation. Second, this assessment captures the range of human land use impacts on the natural ecosystem. Human impacts within the park are limited, but there are areas of higher and lower concentrations providing a human disturbance gradient similar to those commonly used in

other RCA-based assessments approaches. Third, this assessment captures potential threats (risks) to the parks ecological significance. These risks assess potential future impacts from stressors such as air pollution or climate change. However, these risks are ameliorated by the system's ability to buffer against those potential impacts. Ecological condition, as measured here, is a combination of metrics that measure the natural range of ecological significance as they interact with metrics that measure human threats or risk within the park.

Preliminary Model Caveats

There are caveats throughout this document specific to individual models, but there are elements that the end-user should be aware of during the application of all models. Due to the existing range of ecological attributes within the park, the scale of this assessment, and the multiple temporal and spatial scales human induced impacts, there are several important caveats should be noted.

This document reports on a pilot approach to an ecological assessment of natural resource conditions in and immediately adjacent to GLAC. The broad project objective was to evaluate the conditions for a subset of important park natural resources - that is, a set of ecological attributes and resource condition indicators most relevant to GLAC. The report relied on evaluation and synthesis of existing scientific data and information from multiple sources, combined with best professional judgment from an interdisciplinary team of specialists. *To the extent possible, we have made use of quantitative data and analyses, but, especially where there are gaps in data and knowledge, the report also recognizes the practical need to use expert opinion for many of the indicators.*

This assessment approach uses ecosystem attributes that can be derived from existing data to measure, only within or immediately adjacent to the park's boundaries, the range of the park's ecological significance as well the range of human land use impacts that threaten that significance and potential threats (risk) to that significance. These are referred to as 'risk metrics' (e.g. presence of boat ramps and *potential* invasion of non-native or drastic expansion of individual native aquatic species). *Clearly the distinction between known and potential stress is not definitive, it is the responsibility of the end-user to make this distinction in the management decision.* To the extent possible, we have made use of quantitative data and analyses, but, especially where there are gaps in data and knowledge, relied on expert opinion for many of the metrics. These attributes are simplified to metrics (explained below) that range from 0 to 1 which, through expert opinion, indicate the quality of that attribute. These metrics are further simplified as they are combined into a multi-metric index. *These indices are intended to indicate a range in the quality of the system and its attributes not a true measure of ecosystem complexity or cause-and-effect pathways.* It is a simply management tool to provide scientist, managers and decisions makers with a prioritization approach for their various disciplines.

As stated above, HUC-10 watershed assignments create 13 assessment watersheds within the park. As the assessment indices are applied to these watersheds there is yet another simplification of ecosystem complexities as these indices integrate across wide topographic, aspect and distribution ranges. Again these index scores are intended as 'pointers' to areas of concern. The metrics within these indices provide finer detail of the potential drivers of the index score and the raw data used in

the metric scoring provide further detail. As stated the text below, an area may receive a low index score due to simplified patch complexity (e.g. reduced habitat structure in the confined reaches of the Flathead River) or due to proximity of human infrastructure or both. *It is incumbent upon the end-user to examine the details within this document and supporting data to support their ultimate management or monitoring decisions.*

Finally, there are disturbance vectors such as climate change and air pollution that impact the entire park in variety of ways. These large scale impacts are addressed in Chapter 3 and Appendix A, but due to the complexity of these impacts across the varied topography of the park and the limit of existing data they have not been integrated in all of the assessment indices. Rather, they are limited to models that assess alpine areas and lakes. The human impacts metrics within the majority of the assessment models measure the extent of direct human land use impacts such as roads, trails and facilities.

4.3 Assessment Models and Condition Indices

Assessing ecological condition of relatively unimpacted areas is not commonly performed and there is no clear guidance to conduct such an assessment. Therefore a new approach was developed to address the park's unique ecological aspects. During initial meetings with NPS staff, it was agreed that the assessment of condition would follow methods commonly used by the HGM-Approach to assessing ecosystem function (Smith et al. 1995). For this effort, the approach was modified to address multiple aspects of the park's ecosystem across large spatial scales with a limited range of direct human disturbance. The modified approach was influenced by existing efforts to assess ecological condition in large landscapes (Schweiger et al. 2002, Tiner 2004, White and Maurice 2004, Whigham et al. 2007, and Jacobs et al. 2010) and ecological risk of large landscapes (Landis and Wiegiers 1997, Cormier and Suter 2008, and Schleier et al. 2008).

This modification of the HGM-Approach resulted in a multi-metric index for each of the seven focal areas. Index-based models have been developed throughout the world to provide politicians and decision makers with the ecological information on which they base their resource management decisions and communicate those decisions to the public (Turnhout et al, 2007; Dramstad 2009). Index-based models used to assess the ecosystem condition in the United States generally provide a quantitative measure describing where a system lies on a disturbance continuum ranging from least impacted condition to highly impaired (Fennessy et al. 2004). In reviews of contemporary aquatic assessment models, an index was the predominant approach (Bartoldus 1999; Diaz et al. 2004; Fennessy et al. 2004; Böehrer and Jochem 2007).

There are a total of thirty-two metrics used in development of the assessment models in this effort. Table 4.4 provides the focal area and key ecological attribute where the metrics are applied, the metric name and symbol, which of the three metric types it is, and a definition of the metric.

Table 4.4. Relationship of Metrics to Focal Areas for Glacier National Park. Metric Type: S = significance metric. P = stressor (perturbation) metric. R = risk metric.

Focal Area	Key Ecological Attribute	Metric Name	Metric Symbol	Metric Type	Metric Definition
Streams	Stream Type Diversity	Alpine Stream	V ¹ _{APLINESTR}	S	Stream type diversity composed of multiple streams subsections associated source, adjacent vegetation or landscape (e.g. wet meadows, forest, or confined valley)
		Subalpine Stream	V _{SUBALPINESTR}	S	
		Valley Bottom Stream	V _{VLYBTMSTR}	S	
	Stream Stressors	Alpine Stream Buffer	V _{ALPSTRBUF}	P	Proximity of stream buffer to human disturbance from park infrastructure.
		Subalpine Stream Buffer	V _{SUBSTRBUF}	P	
		Valley Bottom Stream Buffer	V _{VLYVALBUF}	P	
Flathead River	Riparian and Buffer Condition	Floodplain Connectivity	V _{FPCONNECT}	S	Cover of native vegetation patches in the river's floodplain and buffer
	Riparian and Buffer Stressor	Buffer Condition	V _{BUFFCDN}	P	Extent and type of anthropogenic land cover in in the river's floodplain and buffer.
		Floodplain Condition	V _{FPCDN}	P	
		Buffer Road Density	V _{BUFFROAD}	P	Extent of road density in in the river's floodplain and buffer.
		Floodplain Road Density	V _{FPROAD}	P	
Lake	Potential Lake Risk	Potential Acid Sensitivity	V _{ACID-SEN}	R	The ability of a lake's sub-watershed to buffer acidic atmospheric inputs.
		Potential Aquatic Nuisance	V _{EXOTIC}	R	Potential exposure to nuisance aquatic species from boat access.
		Potential Nutrient Sensitivity	V _{ALGAE}	R	Potential sensitivity of a lake to increased nutrient input.
Fish	Salmonid Distribution	Flathead Salmonid Distribution	V _{FLTHDFISH}	S	Metrics derived from ratios of native salmonid and non-native salmonids in GLAC lakes and streams as well as the Flathead system.
		Lake Salmonid Distribution	V _{LAKEFISH}	S	
		Stream Salmonid Distribution	V _{STRFISH}	S	
Avian	Bird Habitat Condition	Alpine Habitat	V _{ALPINEHAB}	S	Diversity of avian habitat.
		Fire Habitat	V _{FIREHAB}	S	
		Bird Diversity	V _{BIRDDIV}	S	Bird diversity as measured by a sum of typical number of birds found in vegetation patches found in the park.
	Bird Stress	Human Disturbance	V _{HUMANDIST}	P	Proximity of avian habitat to human infrastructure.

¹. The symbol consists of a 'V' for variable and a descriptive title.

Table 4.4. Continued. Relationship of Metrics to Focal Areas for Glacier National Park. Metric Type: S = significance metric. P = stressor (perturbation) metric. R = risk metric.

Focal Area	Key Ecological Attribute	Metric Name	Metric Symbol	Metric Type	Metric Definition
Mammals	Mammal Habitat Condition	Goat Escape Habitat	V _{ESCAPEGOAT}	S	Proximity of escape terrain to forage.
		Sheep Escape Habitat	V _{ESCAPESH}	S	
		Prey Elevation	V _{PREY}	S	Surrogate measure of ungulate habitat to support carnivorous prey.
		Snow Field Habitat	V _{SNOW}	S	Diversity of mammal habitat.
		Spruce and Fir Forest Habitat	V _{SPRUCEFIR}	S	
		Talus Habitat	V _{TALUS}	S	
	Mammal Stress	Illegal Hunting	V _{BNDRYEDGE}	P	Proximity of mammal habitat to the park boundary as a surrogate measure of potential poaching.
		Human Disturbance	V _{HUMANDIST}	P	Proximity of mammal habitat to human infrastructure.
Vegetation	Vegetation Stress	Illegal Grazing	V _{GRAZE}	P	Known extent of illegal grazing.
		Invasive Plants	V _{WEED}	P	Known extent of non-native and invasive plant species.
		Human Disturbance	V _{HUMANDIST}	P	Proximity of vegetation habitat to human infrastructure.

Typical of multi-metric indices, each of these metrics represents a variable in the models and consists of four components (Schneider 1994). These include: (a) metric name and symbol; (b) methods to measure the metric via a procedural statement for quantifying or qualifying the measure directly or calculating it from other measurements; (c) range of values (i.e., numbers, categories, or numerical estimates; Leibowitz and Hyman 1997) that are generated by applying the procedural statement, and (d) a scheme to provide a sub-index score for each metric. Table 4.5 provides examples of these components.

Table 4.5. Components of a metric.

Metric Name and Symbol	Measures Descriptions	Range of Values	Scoring Scheme
River Buffer Condition (V _{BUFFCDN})	Characteristic plant communities. No grazing, or development beyond walking trails, horse paths, and bike trails. LULC Codes 41, 42, 43, 52, 71, 90, and 95	Descriptive	Categorical (e.g. 0, 0.5, 1.0)
Human Disturbance (V _{HUMANDIST})	Percent of watershed human disturbance measured by proximity of raster cells to roads, facilities, campground, and trails.	0 to 100%	Continuous (e.g. 0-1)

Attributes chosen for this assessment may be presented as ratios, percentages, or description. The next step in model development is to normalize these various results by applying a sub-index to each metric which standardizes the variables by transforming them to dimensionless scores that use the same scale. Table 4.6 provides an example of a scored metric. The scores range from 0 to 1 and

provide a means of qualifying the conditions related to the metric; 0 being poor and 1 being excellent. Some of these metrics may be further weighted based on expert opinion. These assigned weighting multipliers are qualifiers used to disperse the results and assist in the index development only and are not intended to actually quantify the true contributions of each metric to the ecosystem support.

Table 4.6. Post-fire habitat metric scoring.

Metric Criteria:	Metric Score
Watershed contains greater than 15,000 acres of post fire habitat	1.00
Watershed contains between 300 – 15,000 acres of post fire habitat	0.50
Watershed contains less than 300 acres of post fire habitat	0.10

Finally, the metrics are combined into a series of multi-metric assessment indices that integrate information across a suite of ecological attributes. The assessment models for this document are expressed as a simple formula that combines metrics in certain ways to yield an estimate of the watershed condition relative to the focal area of interest. The condition index is best expressed as a percentage of total possible points. The design of the indices allows additional attributes and threats to be added in the future as more monitoring data becomes available.

Below is a scale for interpreting a condition index. This scale provides a coarse “snapshot” of the ecological condition of each focal area and allows comparison to previous or future assessments. As stated above, these indices are intended to indicate a range in the quality of the system and its attributes not a true measure of ecosystem complexity, cause-and-effect pathways or actual thresholds where a system may lose resilience. These measurements are beyond the scope of this effort. It is a simply management tool to provide scientist, managers and decisions makers with a prioritization approach for their various disciplines and the qualifiers of condition help point the specialists toward the problems within their interest. It is important, however, that these specialists examine the individual metric scores in order to identify specific ecosystem attributes that may be imperiled. The indices are designed to provide a score between 0 and 1; for example, a score of 0.66 has a condition of 66% of its potential and is considered “fair” (Table 4.7).

Table 4.7. Relationship of Index Score and Condition.

Index Score	Percent of Optimum	Interpreted Condition
<0.50	Less than 50%	Critically Compromised
0.50 – 0.59	50% to 59%	Poor
0.60 – 0.69	61% to 69%	Fair
0.70 – 0.79	71% to 79%	Good
0.81 – 0.89	81% to 89%	Very Good
≥0.90	90% and Greater	Excellent

In this document, the authors and GLAC resource management have identified seven ecosystem focal elements (see Table 3.1) relevant to Glacier National Park. Thirty three metrics were assessed. In Chapter 5, the metrics are described in detail.

4.4 Spatial Data Overview

All spatial analysis was completed using ESRI ArcGIS (GIS) Version 10.0 with all data projected in the NAD-1983, UTM Zone 12N. Numerous GIS data layers were applied to the spatial analysis necessary to develop the metrics and the associated maps. Several of the layers were provided by the GLAC GIS team or the State of Montana’s geographic information clearinghouse (<http://nris.mt.gov/gis/>). Other layers were created specifically for this project and are available through the GLAC-GIS office. The most critical GIS data layers are listed below (Table 4.8). Because of the numerous GIS layers used for this project, the layer name is included parenthetically only at the first mention of its use in the metric specific methods in later chapters. For example: “the digital elevation model (DEM10.grd) was used to establish shaded relief in the background of each GLAC image. The digital elevation model was also used to establish elevation specific habitat zones.”

Table 4.8. Listing of datasets, attributes, and scale of data used to access metrics.

Content	Layer Acquired	Source
Park Boundary	Boundary2003	Glacier National Park GIS Department
Background Aerial Image	World_Imagery.lyr	ESRI ArcGIS Online
2001 Land Use and Cover Class	NLCD, National Land Cover Database – 2001	USGS Seamless Data
Assessment Watersheds	GNP_HUC10-2011	USGS NHD Hydrological Database
Streams/Waterbodies	Major Lakes and Streams - 1:100,000 scale	NRIS Montana State GIS Data
	Streams	Glacier National Park GIS
Roads	Transportation network – Date unknown	ESRI Geodatabase
Topography	National Elevation Dataset	Glacier National Park GIS
Wetland Coverage	National Wetland Inventory – 2005	US Fish and Wildlife Service
GLAC Land Cover	GLAC_VegMap	Glacier National Park GIS

The GLAC land cover data layer, as documented by the USGS-NPS Vegetation Mapping Program (VMP) (Hop et al. 2007), plays a particularly import role in this analysis. The goals of the park’s VMP were to (1) adequately describe and map plant communities and other land cover of the park and (2) provide useable baseline vegetation information to scientists and NPS resource managers. The project, initiated in 1998 and completed in 2009, resulted in the production of a list of plant communities (a plant community classification), their ecological description and a map showing their distribution produced in UTM coordinates (NAD 83) with a 1:24,000 scale and a minimum mapping unit of 0.5 hectares. The project reported an overall accuracy of 87.9% above the acceptable minimum total accuracy for land cover classification of 85% (Anderson et al. 1976).

The VMP project is useful in summarizing current conditions of Glacier’s vegetation because it allows quantitative analysis of the relative abundance of developed and markedly disturbed areas. The map and associated metadata provide a broad overview of current vegetation, broken into units

that indicate and define land cover at relatively coarse resolution (1.25 acres). The detail and extent of the VMP for the Park provided the basis for many of the vegetation based metrics used throughout this condition assessment. Metrics like the alpine habitat for the bird assessment, and spruce-fir habitat for the mammal assessment were derived from these data.

More complete information about these and other GIS data layers can be found in the methods section of each focal area description, Appendix B (GIS Models) and the metadata associated with the GIS geodatabase.

5. Watershed Scale Condition Assessment

In this section we provide condition assessment models for each of the seven focal areas: 1) stream systems, 2) North and Middle Fork of the Flathead River, 3) lake systems, 4) fish populations, 5) avian populations, 6) mammal populations, and 7) vegetation.

5.1 Focal Area – Stream Systems

In response to degraded water quality, loss of potable water supplies, loss of fishable waters and conversion of wetlands, the US federal government developed and passed the 1972 Federal Water Pollution Control Act (33 U.S.C. 1344). The purpose of this act, which later became known as the Clean Water Act (CWA), was to “...restore and maintain the chemical, physical, and biological integrity of the waters of the United States.” Since 1972, the United States has invested millions of dollars in the development of approaches to conducting environmental assessment of the nation’s waters (see Barbour et al. 1996, and Stevenson and Hauer 2002 for reviews). Recent attempts to develop guidelines for stream and lake assessment have the advantage of building upon experiences from a long history of aquatic ecosystem assessment as well as recent innovations. This assessment addressed streams and tributaries within the interior of the park, and are divided into 3 overarching types, Alpine Streams, Subalpine Streams, and Valley Bottom Streams.

5.1.1 Alpine Streams

Alpine streams throughout the world have varied hydrologic and biogeochemical characteristics, as well as variation in biota. Despite the worldwide distribution of alpine stream systems, studies of their biota and biogeochemistry are limited (Ward 1994). There are three main types of alpine streams developed from descriptions in the European literature of the Alps; kryal, krenal and rhithral, each with distinct biotic and abiotic characteristics (Illies and Botosaneanu 1963). Kryal streams are fed by year-round melt water directly from snowfields, icefields and glaciers and are characterized by high heterogeneity within and between streams of this type. Krenal streams arise as springbrooks hydrologically maintained by groundwater. Krenal streams generally have relatively stable chemical, hydrological and thermal conditions. Rhithral streams are characterized by seasonal snowmelt, and have wide temperature fluctuations, as well as diverse biota. Krenal streams transition into rhithral streams as distance from the groundwater sources increase and waters coalesce from the spring source. Alpine streams often have high gradients with waters flowing over bedrock and cobble-boulder substrate, high dissolved oxygen levels, high variation in temperature regimes due to open canopies and summer solar radiation, and low nutrient concentrations.

Alpine streams of GLAC occur abundantly along the continental divide. Waters of these alpine springbrooks generally are supplied by permanent snowfields or small icefields isolated behind mounds of colluvium. Stream temperatures remain at 32-33°F (0-0.5°C) at the springhead and vary less than 36°F (2°C) within 0-32 feet (0-10 m) of the source. However, solar radiation in mid-summer can quickly elevate the temperature of these streams. Mid-afternoon temperatures as high as 70-73 F (21-23°C) in alpine streams can occur within only a few hundred meters of their source. Although these streams can become quite warm during the day, night temperatures are often 32-37°F (0-3°C).

Thus, diel temperature flux in the alpine, at distances of a few hundred meters from the source, can vary $>64^{\circ}\text{F}$ (18°C).

Fauna of the alpine streams of GLAC is dominated by aquatic insects. Generally within 330 feet (100 m) of their source, krenal streams are dominated by several species of Simuliidae (black flies) and Heptageniidae (mayflies) (Hauer et al. 2000). The endemic stonefly, *Lednia tumana*, inhabits a narrow stream-type and spatial distribution, restricted to short sections (about 1,650 feet or 500 m) of cold, krenal alpine streams directly below glaciers, permanent snowfields, and springs (Muhlfeld et al. 2011). Simulation models suggest that climate change threatens the potential future distribution of these sensitive habitats and the persistence of *L. tumana* through the loss of glaciers and snowfields. The caddisfly, *Allomyia bifosa*, is found exclusively near the springhead of permanently flowing krenal alpine springs fed by snow or ice fields and associated with wet meadows (Hauer et al. 2007). Alpine aquatic invertebrates are ideal early warning indicators of climate warming in mountain ecosystems as the habitat that supports their life histories become increasingly reduced in distribution and abundance (Muhlfeld et al. 2011).

5.1.2 Subalpine Streams

The subalpine streams of Glacier National Park are highly variable, but tend to have similar unifying characteristics. Hydrologically, these streams receive most of their flow from rain and snow deposited at high elevation of the alpine and within the subalpine zone of the mountain slopes. Abundant groundwater enters these streams following discharge into small springs along the toe of side slopes. Stream discharges in GLAC subalpine streams closely follow that of a snowmelt regime (Poff and Ward 1989). Hauer et al. (2000 and 2003a) in a study of McDonald Creek in Glacier National Park observed inter-annual variation in the magnitude and timing of maximum discharge, but this occurred each year of an 8-year study between mid-May and mid-June. Discharge typically increased >10 times the autumn base flow. Over 90% of the total nitrogen flux from the McDonald Creek basin occurred as NO_3 with maximum concentrations approaching $450\mu\text{g/L}$, but minimum concentrations less than $100\mu\text{g/L}$. These low concentrations predominate throughout the fall and winter base flow period and increase very rapidly at the onset of spring runoff. The rate of increase in NO_3 concentrations is significantly greater than the rate of increase in spring discharge. This suggests that nitrate is accumulated and concentrated in the groundwater over the winter near the valley floor where the first snow melt that initiates the flood period occurs in the spring and discharges high NO_3 water from side slope aquifers into the stream. Nitrogen concentration decreases after the initial pulse in the early spring; and although discharge increases, primarily driven by high elevation snowmelt as the spring warming progresses, nitrogen concentration decreases. This is most likely the result of dilution of the groundwater by melting snows from high elevation. Although we have no direct evidence, we strongly suspect that the high concentration of Alder (*Alnus spp.*) in avalanche chutes and high slope wetlands may play a significant role in the loading of NO_3 to subalpine shallow aquifers. Many studies have shown that soils directly surrounding stands of Alder are rich in nitrogen allowing for increased production by neighboring species. Postgate (1978) showed how Alder communities can increase soil nitrogen as much as $100\text{kg N/hectare/year}$ through the mineralization

of leaf litter alone. On a floodplain in the Alaskan interior, Alder communities are believed to have increased total soil nitrogen accumulation by a factor of four over a twenty year span (Walker, 1989).

In the pristine forest streams of Glacier National Park, Hauer et al. (2000) observed very predictable temperature regimes closely correlated with elevation. This has a direct effect on the distribution of stream organisms including benthic macroinvertebrates and fish. Hauer et al. collected over 100 species of the three dominant orders of aquatic insects occurring commonly in GLAC subalpine streams (i.e., Ephemeroptera, mayflies; Plecoptera, stoneflies; and Trichoptera, caddisflies). Taxa within the same order and possessing similar trophic relations had abundance patterns and predictable distributions along the elevation and temperature gradient.

5.1.3 Valley Bottom Streams and Rivers

Valleys of Glacier National Park were modified by Pleistocene alpine glaciers that carved through the landscape. Valley bottom, alluvial streams and rivers are characterized by broad and active alluvial floodplains, with highly complex physical and biological interactions between stream channels, surficial backwaters, springbrooks, and buried paleo-channel networks (Stanford and Ward 1993, Hauer et al. 2003b, Stanford et al. 2005). These complex interactions within and between habitats are driven by strong lateral and vertical flux of water and materials including flood-caused cut and fill alluviation, routing of river water and nutrients above and below ground, channel avulsion, and dynamics of large wood. The strong forces are driven by the river hydrologic regime and sediment dynamics to form and maintain a complex, dynamic distribution of resource patches and associated biota: the shifting habitat mosaic (SHM; Stanford et al. 2005). These characteristics are critically important in maintaining water quality, bioproduction, and biodiversity of the stream and river systems of the valley floors.

Floodplains composed of coarse sediments engaged in the processes embodied by the SHM are penetrated by river waters creating complex three-dimensional mosaics of surface and subsurface habitats (Brunke and Gonser 1997, Poole 2002). Ground water – surface water interactions are critical characteristics of these streams and their floodplain corridors. Alluvial aquifer water returning to the surface is generally higher in NO_3 and PO_4 than surrounding surface flows, resulting in patches of high algal productivity (Bansak 1998, Wyatt et al. 2008). In these valley bottom tributary streams with broad floodplain reaches, hyporheic return flow also results in increased macroinvertebrates growth and productivity (Pepin and Hauer 2002) and growth rates of riparian vegetation (Harner and Stanford 2003). Native species of fish, particularly the salmonids (bull trout, westslope cutthroat trout, mountain whitefish) focus on the complexity of floodplains and spawn in habitats dominated by extensive groundwater – surface water interaction (Baxter and Hauer 2000).

The riparian floodplains of montane alluvial rivers are extremely ecologically diverse. The valley floodplains of GLAC have high biodiversity, from riparian plant species and aquatic food webs (Stanford et al. 2005) to large carnivores (Demarchi et al. 2003). The continuity of these highly diverse components of the GLAC landscape is very dependent on hydrologic linkages and the high water quality associated with the geology as well as the park's pristine character (Stanford and Ellis 2002).

5.1.4 Methods: Aquatic Resources as Indicators of Streams and Rivers

The following is a summary of each variable used in the stream and rivers assessment models. Each variable provides the variable code, name, definition, the rationale for selecting and scaling the variable, and the scaled variable in table form or a description of the formulas and methods used to scale the variable. As with all models in the assessment it provides a score for a watershed derived from the diversity of the habitat and proximity to human activity that is relative to other watersheds in the park only.

The streams and rivers condition index is made up of three metrics; alpine streams ($V_{ALPINESTR}$), subalpine streams ($V_{SUBALPINESTR}$), and valley bottom streams ($V_{VLYBTMSTR}$). These three stream types were derived for each watershed from the park's available elevation and topological data from the digital elevation model (DEM; dem10.grd). The Flathead River index is addressed separately.

Alpine Stream ($V_{ALPINESTR}$)

Alpine streams were defined as any GLAC streams (streams_clip.shp) located above 6,500 feet on the DEM and within alpine vegetation cover types on the GLAC vegetation classification data (glac_vegmap.shp). An alpine layer was created (Alpine_trueveg_wtrshd.shp) which was intersected with GLAC study watersheds (GNP_HUC10_2011.shp) to create the final alpine streams GIS layer (alpine_streams.shp).

Streams located within this alpine area were divided into six classes based on their hydrogeomorphic position. Five of these classes were based on the stream outlets proximal to: 1) wet meadows, 2) snowfields, 3) shrub wetlands, 4) glaciers, and 5) lakes as determined by the polygons within the GLAC vegetation classification dataset. Total stream length for each class was determined within a consistent buffer distant of 300 feet (INFISH 1995) down slope of each of the five polygon classes. The remaining class includes all streams within the alpine areas that are outside of the outlet buffers. A weighted multiplier was established for each outlet class based on sources of carbon and outlet stream temperature likely to occur at the outfalls of each class type. These assigned weighting multipliers are derived from expert opinion and are qualifiers used to disperse the results and assist in the index development only and are not intended to actually quantify the true contributions of biotic support per class. Multipliers, buffers, and data sources listed in Table 5.1.

Table 5.1. Data source, buffer distance, and weighted multiplier for each alpine class.

Land Cover	Data Source	Buffer distance (ft)	Weighted Multiplier
Wet Meadow	glac_vegmap.shp	300	6
Shrub Wetlands	glac_vegmap.shp	300	5
Snowfields	glac_vegmap.shp	300	4
Glaciers	1998_glaciers.shp	300	3
Lakes	lakes_clip.shp	300	2
Other	glac_vegmap.shp	N/A	1

The following describes the steps necessary derive the final Alpine Stream Metric score from these 6 stream classes:

1. Proportion of alpine stream associated with an outlet class was determined within a watershed (stream outlet class length divided by total alpine stream length; e.g. sum of all wet meadow outlet stream lengths divided by the total alpine stream length).
2. A weighting multiplier was then applied to each class relative to their general quality in term of their contribution to stream biotic support (see Table 5.1). For example, shrub meadows generally provide more fine particulate organic matter to support downstream biota than the outlets of lakes. As above, these assigned weighting multipliers are qualifiers used to disperse the results and assist in the index development only and are not intended to actually quantify the true contributions of biotic support per class. The formula for the weighted habitat diversity is:

$$\text{Weighted habitat diversity} = ((6 * \text{wetmeadow} + 5 * \text{shrubwetland} + 4 * \text{snowfield} + 3 * \text{glacier} + 2 * \text{lake} + \text{otherstreams}) / 21)$$

3. The watershed's weighted habitat diversity scores are then divided by the maximum score across all watersheds to acquire relative habitat diversity score relative to maximum habitat diversity in the park.
4. Adjusting the score for unimpacted conditions: These stream metrics measures the diversity of naturally occurring ecosystem attributes within the park and will later be joined with a metric that measures the extent of human disturbance in the park. A choice was made to lift the diversity scores to be between 0.8 and 1.0 to balance the effects of natural system diversity and human perturbation on the overall condition index. This allows the stream ecological significance score to be further scaled toward the unimpacted range of the spectrum. The logic is that streams in the park's alpine habitat will show a range of conditions, with diverse alpine systems scoring higher than less diverse systems. However if an alpine system exists in the park in the 2011 assessment and is not impacted by human interaction, it will not score lower than 0.80. The formula for the final metric score is:

$$V_{\text{ALPINESTR}} = (\text{Weighted habitat diversity} + 4) / 5.$$

For future assessments, this final score is multiplied by the total current alpine area divided by the 2011 total alpine area. For this 2011 assessment, the multiplier is equal to 1.0, but for future assessments this may be less than 1 due to alpine habitat loss resulting from such impacts as climate change which will result in a lower overall condition score compared to the 2011 results. Additionally, the overall metric score may change if there are future changes in the land cover that makes up the six different alpine stream classes.

Subalpine Streams ($V_{\text{SUBALPINESTR}}$)

Subalpine streams were defined as any GLAC streams located below the alpine habitat and above the valley bottom systems as defined below. These streams were intersected with the GLAC study watersheds creating a new subalpine streams GIS layer (subalpine_streams.shp).

Subalpine streams were divided into 4 classes based on their hydrogeomorphic position or vegetation cover within each watershed's subalpine area. These classes were defined by; 1) proximity to a lake outlet, 2) location within avalanche chutes, 3) location within forest cover, or 4) all other streams in the subalpine area as determined by the polygons within the GLAC vegetation classification dataset. Stream length was determined for lake land cover class using the buffer distances and data sources listed in Table 5.2. The stream buffers were chosen based on the relative area of channel lengths in the elevation zone. The following describes the steps necessary derive the final Subalpine Stream Metric score from these 4 stream classes:

1. Stream outlet class length relative to the maximum outlet density in the park: The relative length was determined for each stream outlet class by dividing the stream class length by the total subalpine stream length within a watershed. This gave a score between 0 and 1 that provided a comparison of subalpine stream habitat diversity within the park.
2. Weighted subalpine habitat diversity: As above, these assigned weighting multipliers are qualifiers used to disperse the results and assist in the index development only and are not intended to actually quantify the true contributions of biotic support per class. The formula for the weighted diversity is:

$$\text{Weighted Habitat Diversity} = ((2 * \text{Avalanche Chute} + 2 * \text{Lake outlet} + \text{Forested Streams} + \text{Non-Forested Streams}) / 7)$$

3. Habitat diversity relative to maximum outlet habitat diversity in the park: The watershed's weighted diversity score is then divided by the maximum across all watersheds to acquire a relative diversity score.
4. Adjusting the score for unimpacted conditions: These stream metrics measures the diversity of naturally occurring ecosystem attributes within the park and will later be joined with a metric that measures the extent of human disturbance in the park. A choice was made to lift the diversity scores to be between 0.8 and 1.0 to balance the effects of natural system diversity and human perturbation on the overall condition index. This allows the stream ecological significance score to be further scaled toward the unimpacted range of the spectrum. The logic is that streams in the park's subalpine habitat will show a range of conditions, with diverse subalpine systems scoring higher then less diverse systems. However, if a subalpine system exists in the park in the 2011 assessment and is not impacted by human interaction, it will not score lower than 0.80. The formula for the final metric score is:

$$V_{\text{SUBALPINESTR}} = (\text{Weighted habitat diversity} + 4) / 5.$$

Table 5.2. Data source, buffer distance, and weighted multiplier for each subalpine class.

Land Cover	Data Source	Buffer distance (ft)	Weighted Multiplier
Avalanche Chutes	Glac_vegmap.shp	N/A	2
Lakes Outlet	lakes_clip.shp	600	2
Forested Streams	Glac_vegmap.shp	N/A	1
Other	Glac_vegmap.shp	N/A	1

Valley Bottom Streams ($V_{VLYBTMSTR}$)

To define the park's valley bottom streams, the floodplain of streams within the park were digitized using the GLAC stream layer, the digital elevation map, and visual assistance from oblique views within Google Earth's 3-D models (<http://www.google.com/earth/index.html>). The digitized floodplain areas were saved as a new GIS layer (valley_unconfined.shp). The furthest upstream floodplain area in each stream defined the upstream extent of the valley bottom system. All stream sections below that upstream extent and were not in a floodplain, were defined as confined reaches and were saved separate GIS layer (valley_confined_streams.shp).

Valley bottom streams were divided into 3 classes based on their hydrogeomorphic position within each watershed. These classes were based on; 1) proximal to a lake outlet, 2) stream reaches within an unconfined floodplain, and 3) stream reaches within a confined valley bottom (lacking defined floodplain). Stream length was determined for each class using the buffer distances and data sources listed in Table 5.3. The stream buffers were chosen based on the relative area of channel lengths in the elevation zone. The following describes the steps necessary derive the final Valley Bottom Stream Metric score from these stream classes:

1. Stream outlet class length relative to the maximum outlet density in the park: The relative length was determined for each stream outlet class by dividing the stream class length by the total valley bottom stream length within a watershed. This gave a score between 0 and 1 that provided a comparison of valley bottom stream habitat diversity within the park.
2. Weighted subalpine habitat diversity: As above, a weighting multiplier was then applied to each class relative to their general contribution to stream biotic support. The formula for the weighted diversity is:

$$\text{Weighted diversity} = ((5 * \text{Lake Outlet} + 2 * \text{Unconfined Valley Bottom} + \text{Confined Valley Bottom}) / 8)$$

3. Habitat diversity relative to maximum habitat diversity in the park: The watershed's weighted diversity score is then divided by the maximum across all watersheds to acquire a relative diversity score.
4. Adjusting the score for unimpacted conditions: These stream metrics measures the diversity of naturally occurring ecosystem attributes within the park and will later be joined with a metric that measures the extent of human disturbance in the park. A choice was made to lift the diversity scores to be between 0.8 and 1.0 to balance the effects of natural system diversity and human perturbation on the overall condition index. This allows the stream ecological significance score to be further scaled toward the unimpacted range of the spectrum by applying this formula: $(\text{relative diversity score} + 4) / 5$. The logic is that streams in the park's alpine habitat will show a range of conditions, with diverse alpine systems scoring higher than less diverse systems. However valley bottom system not impacted by human interaction will not score lower than 0.80. The formula for the final metric score is:

$$V_{VLYBTMSTR} = (\text{Weighted habitat diversity} + 4) / 5.$$

Table 5.3. Data source, buffer distance, and weighted multiplier for each valley bottom class.

Land Cover	Data Source	Buffer distance (ft)	Weighted Multiplier
Lakes Outlet	valley_lake1500outlets.shp	1500	5
Unconfined valley bottom	valley_unconfined.shp	N/A	2
Confined valley bottom	valley_confined_streams.shp	N/A	1

Stream Buffer Disturbance ($V_{ALPSTRBUF}$, $V_{SUBSTRBUF}$, $V_{VALSTRBUF}$)

Potential impacts of the park's streams and stream buffers are likely to occur through interactions with the park's roads, trails, and camping and facilities infrastructure. Riparian areas in the park are variable and generally there are insufficient scientific data to support the use of specific buffer width the will attenuate all human disturbance (Palik et al. 2000; Todd 2000). Recommend buffers to protect fish and aquatic habitat are wide ranging. For example recent literature review conducted by Montana Department of Environmental Quality show recommendation ranging from 40 to 300 feet (Ellis 2008). For the purposes of this condition assessment, a buffer of 300 feet was selected following the recommendations from INFISH (1995).

A raster based assessment was developed using five raster datasets (or shape files converted to raster) available from the park: park's roads geo-database, railways from the BNSF geo-database, trails (Trails_20050501.shp), buildings (building2006.shp), and campsites (campsites.shp). For consistency, all rasters developed for this assessment consisted of a 30-meter grid (about 100-feet). A potential impact buffer was established for each dataset based on 100-foot increments. These increments were assigned graduated scores on potential impacts to buffer condition (Table 5.4) based on expert opinion only. If the cell was less than or equal to the Euclidean buffer distance and greater than the previous buffer distance the cells received the assigned cell score. If greater than the max distance then the cell score was 1.0. The layers were then superimposed and the lowest of each layer's cell score was assigned to the final cell layer and all cells outside these buffers have a score of 1.0. Finally, the park-wide raster was clipped to the approximate 300-foot (90-meter) stream buffers and the cell score were averaged determine the park's buffer condition for the alpine, sub-alpine and valley bottom streams. The cell scores were then averaged for each watershed.

The potential impact buffers applied to the infrastructure made a few assumptions (Table 5.4). All roads in the park are not the same, but for this assessment they are treated as large highways assuming that a culvert is placed under the paved areas, shoulders and trapezoidal fill that would be 100 feet from the center line and where a stream buffer would score a '0'. The next 100 feet would be cleared of vegetation and the stream buffer would score a '0.1'. The next 100 feet would be disturbed forest and the stream buffer would score '0.5' and beyond that the stream buffer would be unimpacted and score a '1.0'. The same logic was applied to railroads. We assumed for building and campsites that the adjacent areas would be thinned to a distance of 100 feet where a stream buffer would score '0.5'. Human interaction would gradually diminish to a distance of 300 feet where the stream buffer would score increase to '0.9'. Trails would have an impact to stream buffers to a distance of 200 feet from potential human interaction. These assumptions are an oversimplification

of the parks interactions with stream buffers, but because the interaction with stream buffers in the park are limited, the approach allows for an increased signal in the metric scoring.

Table 5.4. Human disturbance ($V_{\text{HUMANDIST}}$) metric scoring assigned to the appropriate raster cells.

Raster	Approximate Buffer size (ft)	Total Buffer size (m)	Raster Cell Score Assigned to Buffer Distances									
			0	0.1	0.2	0.3	0.4	0.5	0.6	0.7	0.8	0.9
Road 1	300	90	100	200	-	-	-	300	-	-	-	-
Railroad	300	90	100	200	-	-	-	300	-	-	-	-
Building and Campsites	300	90	-	-	-	-	-	100	-	200	-	300
Trail	200	60	-	-	-	-	-	100	-	-	-	200

GLAC Stream Condition Index

To acquire an overall condition score for each watershed, we applied following index. For each elevation zone, a significance metric that captures the relative stream type diversity is multiplied by a stressor metric that measures the degree that stream buffers interact with human infrastructure. In areas where there is little interaction within the buffer, this multiplication and square root element of the model has a similar effect on the condition score as averaging. However where the buffer impacts are greater in this contemporary assessment or if human infrastructure increases in the future of the park this multiplicative and square root element of the model will drive the scores much lower. An additional constant was added to this model to account for change in alpine area due to future loss of alpine area from climate change or potential disturbances.

$$\text{Stream Condition Index} = (\text{Square Root } ((V_{\text{ALPINESTR}} * \text{AlpChnge}) * V_{\text{ALPSTRBUF}}) + \text{Square Root } (V_{\text{SUBALPINESTR}} * V_{\text{SUBSTRBUF}}) + \text{Square Root } (V_{\text{VLYBTMSTR}} * V_{\text{VALSTRBUF}}))/3$$

AlpChnge = current alpine area/2007 alpine area (derived Hop et al 2007). For this 2012 assessment, Alpchnge = 1.

5.1.5 Stream Condition Results

Subalpine Streams ($V_{\text{ALPINESTR}}$)

Table 5.5 provides the proportions (see methods above) of alpine stream classes within each of the park's watersheds. For example, no wet meadows are mapped in the alpine area of Coal/Ole and Kintla/Bowman watersheds and therefore those streams have a 0.0 for that outlet class.

Table 5.5. Relative density of watershed alpine stream classes and the resulting metric score.

Watershed	Relative Habitat Density						Adjusted Metric Score
	Wet Meadow Outlet	Shrub Alpine Outlets	Snowfield Outlet	Glacier Outlet	Lake Outlet	Other Alpine Streams	
Belly	0.00	0.06	0.27	0.05	0.02	0.61	1.00
Camas	0.02	0.00	0.00	0.00	0.00	0.98	0.90
Coal/Ole	0.00	0.00	0.27	0.00	0.01	0.72	0.97

Watershed	Relative Habitat Density						Adjusted Metric Score
	Wet Meadow Outlet	Shrub Alpine Outlets	Snowfield Outlet	Glacier Outlet	Lake Outlet	Other Alpine Streams	
Cut Bank	0.01	0.02	0.12	0.00	0.02	0.82	0.94
Kennedy	0.00	0.04	0.09	0.00	0.03	0.84	0.94
Kintla/Bowman	0.00	0.00	0.32	0.01	0.02	0.65	0.99
Lake McDonald	0.00	0.01	0.28	0.00	0.02	0.68	0.98
Nyack	0.02	0.00	0.31	0.06	0.02	0.60	1.00
Quartz/Logging	0.01	0.02	0.28	0.02	0.02	0.66	0.99
Saint Mary	0.02	0.03	0.27	0.02	0.01	0.64	0.99
Swiftcurrent	0.02	0.00	0.20	0.01	0.02	0.74	0.96
Upper Two Medicine	0.00	0.04	0.14	0.00	0.00	0.82	0.95
Waterton	0.01	0.01	0.30	0.02	0.05	0.61	1.00

Four other watersheds show 2% wet meadow outlet class and are the highest found in the park. These outlet proportions were applied to the weighted sub-index provided in the methods above to derive the alpine stream condition metric score. All streams scored very high with this assessment, with Belly and Nyack scoring the highest and the less diverse Cut Bank and Kennedy scoring the lowest (Figure 5.1).

Subalpine Streams ($V_{\text{SUBALPINESTR}}$)

Table 5.6 provides the proportions (see methods above) of subalpine stream classes within each of the park's watersheds. For example, Swiftcurrent and Cut Bank have the highest proportion of stream length associated with lake outlet class and Kennedy has the highest proportion of stream length in forested area and watersheds with the highest diversity of stream classes, relative to the weighted categories, scored the highest for this condition metric (Figure 5.2).

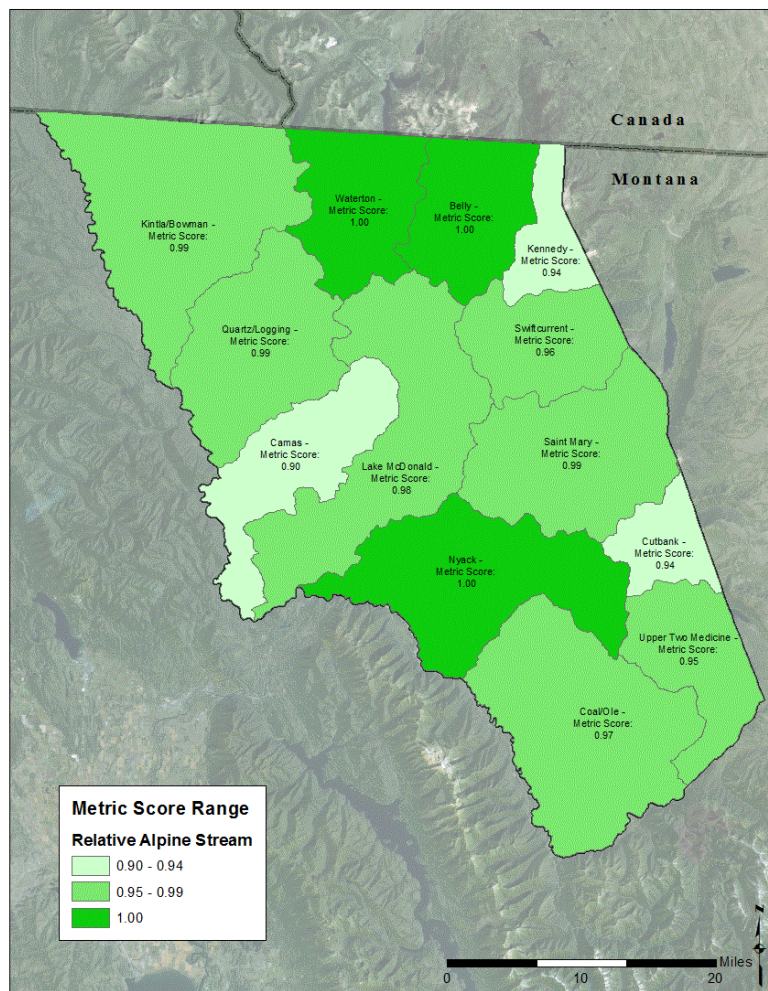


Figure 5.1. Metric measuring alpine stream condition in GLAC.

Table 5.6. Relative length of watershed subalpine streams classes and the resulting metric score.

Watershed	Adjusted Relative Stream Length				Metric Score
	Lakes Outlet	Streams in Avalanche Chutes	Forested Streams	Non-forested Streams	
Belly	0.02	0.17	0.63	0.19	0.98
Camas	0.00	0.14	0.79	0.07	0.98
Coal/Ole	0.01	0.21	0.68	0.09	0.99
Cut Bank	0.03	0.08	0.71	0.18	0.97
Kennedy	0.02	0.04	0.83	0.11	0.96
Kintla/Bowman	0.01	0.10	0.81	0.09	0.97
Lake McDonald	0.01	0.19	0.63	0.17	0.98
Nyack	0.01	0.27	0.61	0.11	1.00
Quartz/Logging	0.01	0.10	0.77	0.12	0.97
Saint Mary	0.02	0.13	0.64	0.21	0.98
Swiftcurrent	0.05	0.16	0.54	0.25	0.99
Upper Two Medicine	0.02	0.10	0.68	0.20	0.97
Waterton	0.02	0.28	0.57	0.13	1.00

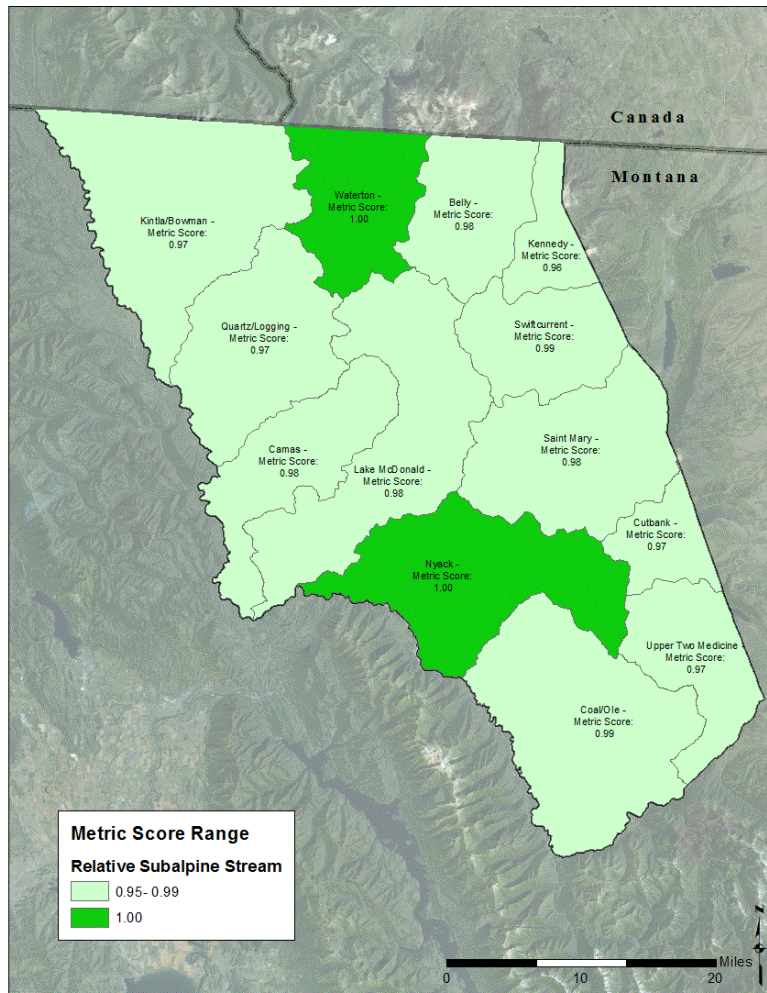


Figure 5.2. Metric measuring subalpine stream conditions in GLAC.

Valley Bottom Streams ($V_{VLYBTMSTR}$)

Table 5.7 provides the proportional length (see methods above) of valley bottom stream classes within each of the park's watersheds. For example, because Upper Two Medicine has most (22) lakes associated with valley bottom streams and therefore 18% of the streams length associated with lake outlets however, although Lake McDonald has a very large lake, it only has (3) valley bottom lakes and only 3% of the streams length associated with lake outlets. Watersheds with the highest diversity of these stream classes, relative to the weighted categories, scored the highest for this condition metric (Figure 5.3).

Table 5.7. Relative length of watershed valley bottom streams classes and the resulting metric score.

Watershed	Adjusted Relative Stream Length			Metric Score
	Lake Outlet	Unconfined Valley	Confined Valley	
Belly	0.15	0.58	0.26	0.99
Camas	0.06	0.68	0.25	0.97
Coal/Ole	0.02	0.69	0.29	0.96
Cut Bank	0.05	0.60	0.35	0.96
Kennedy	0.10	0.71	0.19	0.98
Kintla/Bowman	0.04	0.36	0.60	0.93
Lake McDonald	0.03	0.52	0.45	0.94
Nyack	0.02	0.63	0.35	0.95
Quartz/Logging	0.06	0.42	0.52	0.95
Saint Mary	0.07	0.54	0.39	0.96
Swiftcurrent	0.09	0.83	0.08	0.99
Upper Two Medicine	0.18	0.56	0.25	1.00
Waterton	0.09	0.52	0.40	0.96

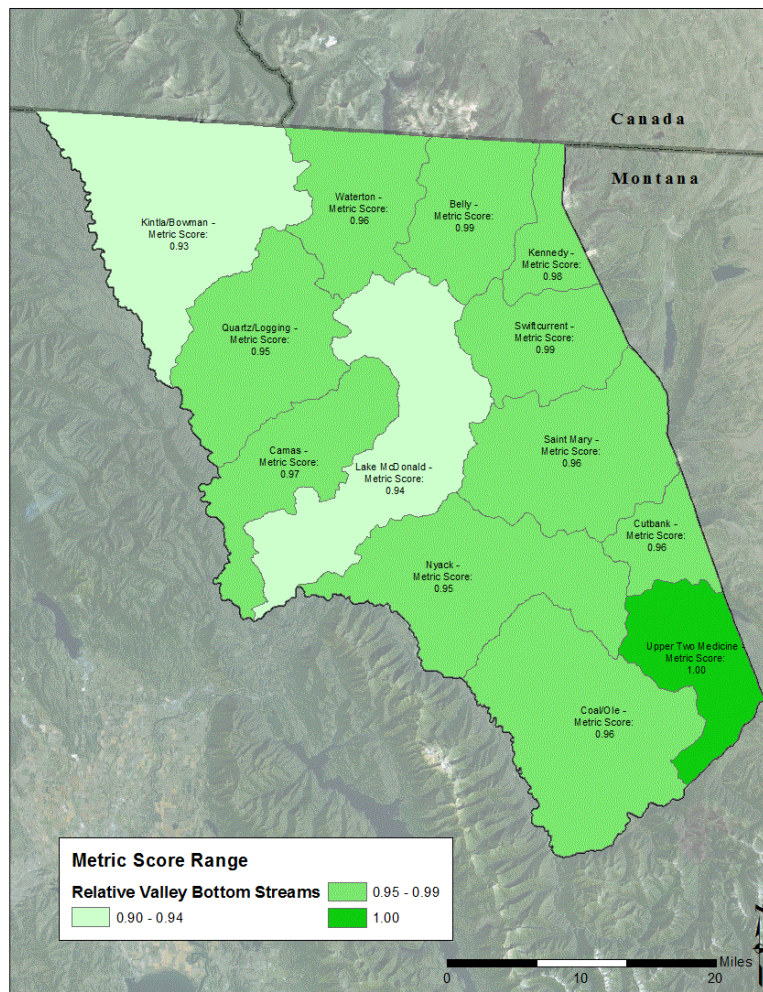


Figure 5.3. Metric measuring valley bottom stream conditions in GLAC.

Stream Buffer Integrity (V_{ALPBUF} , V_{SUBBUF} , V_{VALBUF})

As stated above, potential impacts of the park's streams and their buffers are likely to occur through interactions with the park's roads, trails, and camping and facilities infrastructure. It is clear that degree of interaction between infrastructure and streams will vary from site-to-site. These buffer integrity metrics are an oversimplified measurement of these interactions intended to provide park managers to with information of where these impacts are likely to be greatest. Table 5.8 shows the degree of interactions of park infrastructure and stream buffers in alpine, subalpine and valley bottom streams. In the alpine and subalpine areas, all watersheds scored very high. The lowest score was in Lake McDonald watershed do the Going-to-the-Sun Road and its nearby trails. In the valley bottom areas, Lake McDonald watershed again scored the lowest due to the road networks and facilities (Figure 5.4).

Table 5.8. Stream buffer condition as measured by its proximity to park infrastructure.

Watershed	Metric Scores		
	Alpine Buffer	Subalpine Buffer	Valley Bottom Buffer
Belly	1.00	0.98	0.93
Camas	1.00	0.97	0.93
Coal/Ole	1.00	0.97	0.95
Cut Bank	0.98	0.98	0.91
Kennedy	1.00	0.98	0.91
Kintla/Bowman	0.99	0.98	0.94
Lake McDonald	0.94	0.94	0.74
Nyack	0.99	0.98	0.93
Quartz/Logging	1.00	0.99	0.96
Saint Mary	0.99	0.96	0.91
Swiftcurrent	0.99	0.96	0.91
Upper Two Medicine	1.00	0.96	0.91
Waterton	0.99	0.98	0.94

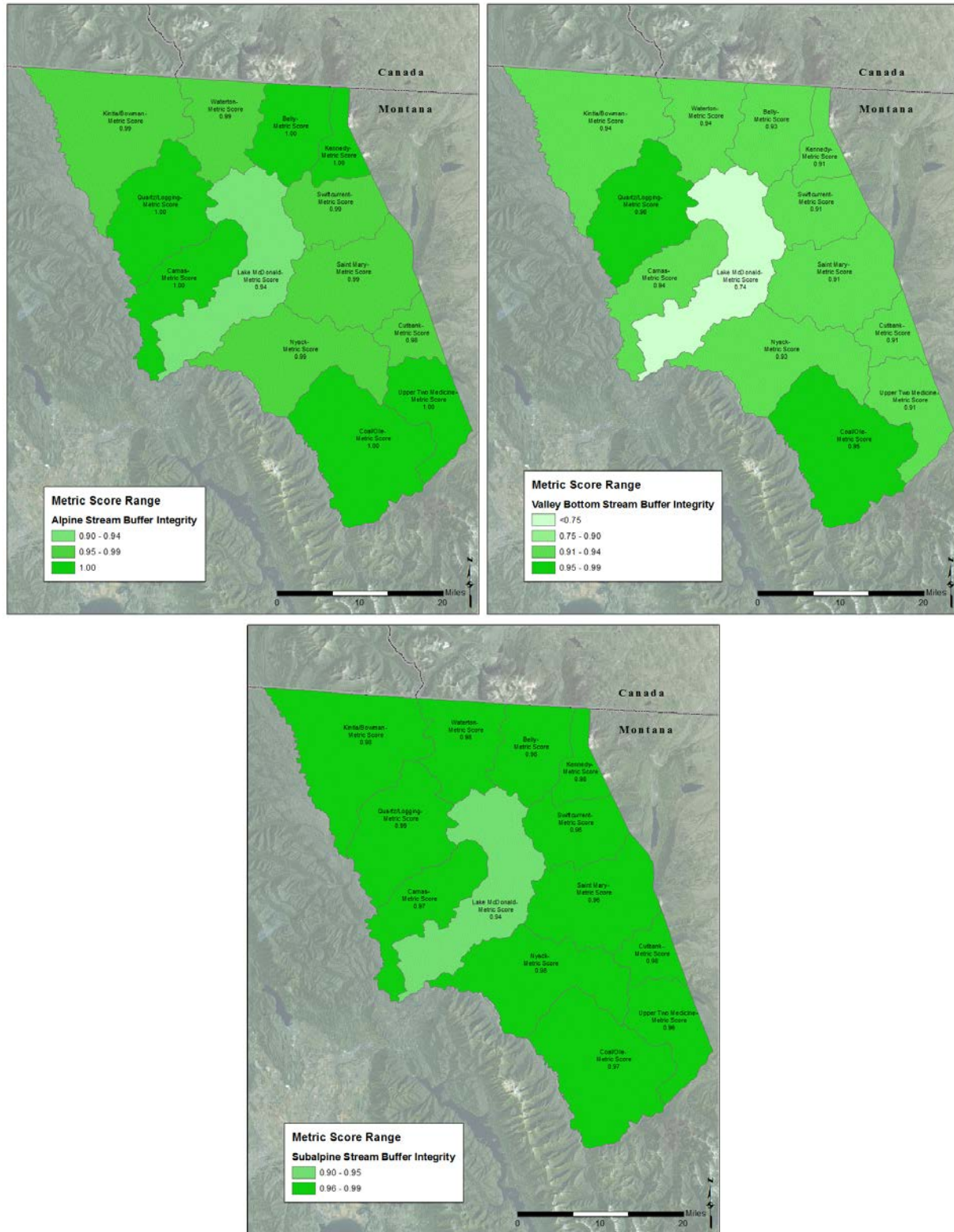


Figure 5.4. Metric measuring Alpine stream condition in GLAC.

GLAC Stream Condition Index

Six metrics: alpine, subalpine and valley bottom stream significance, and three buffer stressor metrics for each zone were combined to provide an assessment index of stream condition in the park's watersheds (Table 5.9). The ecological-significance metrics measure the relative extent stream systems and the weighted outlet classes within the watershed. Additionally, the stressor metrics measure likely impacts to stream buffer due to proximity to park infrastructure. Here, Lake McDonald watershed scored the lowest (index score of 0.92) due predominately to buffer impacts in each zone (Figure 5.5).

Table 5.9. Stream condition score for all watersheds with GLAC.

Watershed	Metric Scores						Index Score
	Alpine Stream	Alpine Buffer	Subalpine Stream	Subalpine Buffer	Valley Bottom Stream	Valley Bottom Buffer	
Belly	1.00	1.00	0.98	0.98	0.99	0.93	0.98
Camas	0.90	1.00	0.98	0.97	0.97	0.93	0.96
Coal/Ole	0.97	1.00	0.99	0.97	0.96	0.95	0.97
Cut Bank	0.94	0.98	0.97	0.98	0.96	0.91	0.96
Kennedy	0.94	1.00	0.96	0.98	0.98	0.91	0.96
Kintla/Bowman	0.99	0.99	0.97	0.98	0.93	0.94	0.97
Lake McDonald	0.98	0.94	0.98	0.94	0.94	0.74	0.92
Nyack	1.00	0.99	1.00	0.98	0.95	0.93	0.97
Quartz/Logging	0.99	1.00	0.97	0.99	0.95	0.96	0.98
Saint Mary	0.99	0.99	0.98	0.96	0.96	0.91	0.96
Swiftcurrent	0.96	0.99	0.99	0.96	0.99	0.91	0.97
Upper Two Medicine	0.95	1.00	0.97	0.96	1.00	0.91	0.96
Waterton	1.00	0.99	1.00	0.98	0.96	0.94	0.98

5.1.6 Assessment of availability and gaps in monitoring data

Alpine shrub and emergent marsh wetlands are an important component in the alpine stream condition wetland assessment (Mitch and Gosselink, 2000). Hop et al. (2007) reported producer accuracy (omission) of 87% for wet meadows in their land cover map. This is above the acceptable minimum total accuracy for land cover classification of greater than 85% (Anderson et al. 1976). However, it is the opinion of the authors that there is an error of omission in the classification of the alpine wetlands (e.g. wet meadows) greater than what is accounted for in the GLAC vegetation classification accuracy assessment. This opinion is based on extensive field experience within the park. Higher detail in the mapping of wetlands within the park would not only increase the robustness of the alpine stream condition metric, but would allow an assessment of the park's wetland aquatic resources as well.

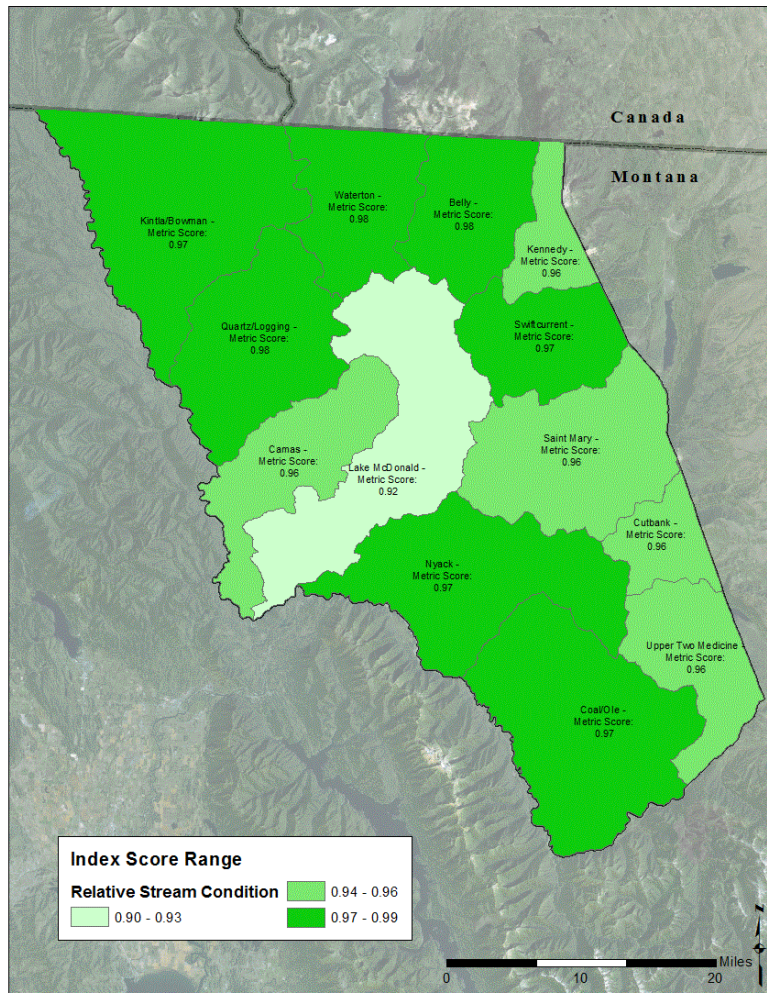


Figure 5.5. Index measuring overall stream conditions in GLAC.

5.2 Focal Area - North Fork and Middle Fork of the Flathead River

River drainage networks throughout the Northern Rocky Mountains are an integral part of the landscape mosaic that forms regional patterns of topography, geochemistry, vegetation, and the biophysical processes that provide the template for ordering biological systems; including the distribution and forms of wetlands on floodplain surfaces. Physical, chemical and biological patterns and processes in river networks are structurally and functionally linked and operate across a hierarchy of spatio-temporal scales. At the landscape scale the river network is intimately linked to longitudinal gradients, riparian vegetation and processes in and around wetlands, and surface-subsurface water exchange (Stanford and Ward 1993, Jones and Mulholland 1999). The later has a profound effect on floodplain water flux.

The North Fork and Middle Fork of the Flathead River make up the western and southwestern boundary of GLAC. These large fifth-order rivers are among a very small suite of large rivers in the conterminous 48 US states that are completely unregulated by dams or diversions. The National Wild and Scenic Rivers System was created by Congress in 1968 (Public Law 90-542; 16 U.S.C. 1271 et

seq.) to preserve certain rivers with outstanding natural, cultural, and recreational values in a free-flowing condition for the enjoyment of present and future generations. Both the North Fork and Middle Fork of the Flathead River were added to this designation in 1976 and are part of the National Wild and Scenic Rivers System. The Middle Fork has its headwaters in the Bob Marshall Wilderness Area. As it flows north-by-northwest to its confluence with the North Fork, the Middle Fork emerges from the wilderness complex and encounters the US Highway 2 and Burlington Northern Santa Fe Railroad transportation corridor at Bear Creek at the southwestern tip of GLAC. Along the Middle Fork's length where it forms the southwestern border of the GLAC to its confluence with the North Fork, it passes through a series of confined and unconfined reaches within a narrow valley. There are only two major floodplain reaches along this section of the Middle Fork; between the town of West Glacier and the confluence of the North Fork and the other at what is known as the Nyack Floodplain.

The North Fork has its headwaters in southeastern British Columbia (BC), Canada. As it flows south-by-southeast to its confluence with the Middle Fork near West Glacier, the North Fork flows through a broad U-shaped valley with expansive alluvial floodplains. The North Fork valley is a major contributor to the biodiversity of GLAC and is regarded as one of the wildest rivers in America. However, unlike the Middle Fork with headwaters in wilderness designated area, the North Fork in British Columbia has a 30-40 year history of proposed industrial development in the form of coal mining and coal bed methane (CBM) extraction, oil and gas leases, gold mine prospecting, and phosphate mine prospecting. Recently, these have been part of a Transboundary negotiation and subsequent memorandum of understanding between BC and Montana to ban all mining, CBM or other gas and oil development in the North Fork; BC and Canada have passed protection, however, the negotiations and bills by Montana and the USA are still in process as this report is being developed. Nonetheless, until the headwaters of the North Fork are placed in a permanent protected status with international recognition, the threat to the ecological integrity of the North Fork will remain at significant risk. We refer you to Hauer and Sexton (2010), and Hauer and Muhlfield (2010) for greater detail into the potential effects of coal mining in Canada on the ecological integrity of the Transboundary North Fork.

The nature and scope of the river-riparian corridors often changes dramatically from high gradient headwaters to braided middle reaches to meandering lowland sections (Lorang and Hauer 2006). At the landscape spatial scale, the natural state of the North Fork and Middle Fork alluvial river systems are characterized by alternating confined and unconfined valley segments occurring in series along the longitudinal gradient. Confined valley segments are generally characterized by narrow valley walls, near-surface bedrock, absence of a floodplain, and relatively high stream gradient. In unconfined alluvial segments, these rivers flow across deposits of gravel and cobble associated with alluvial floodplains. These reaches commonly have a vertical dimension of groundwater-surface water interaction extending tens of meters into the alluvium and a lateral dimension under the floodplain for hundreds of meters (Stanford et al. 2005).

A fundamental driver of physical, chemical and biological patterns and processes of the river network of these two rivers is the spatial and temporal dimension of flooding and the role of riparian

and floodplain wetlands in the ecological functions along their riverine-corridor ecosystem. The interaction of climate, geomorphology, hydrologic conditions, vegetation, wetlands, river channel complexity and floodplain connectivity affect the intensity, predictability, and duration of floods. In the North and Middle Forks of the Flathead River, the annual hydrograph is dominated by the spring snowmelt period that extends from late March or early April through June.

Ecologically, streams and rivers reflect the legacy of their catchments, their geomorphology, hydrologic and climatic drivers, biogeochemistry, and the complexity of their habitat development. Inorganic and organic materials are transported downstream from erosional zones characterized by confined stream reaches and high gradients to depositional zones characterized by unconfined reaches and relatively low gradients. Thus, the materials are deposited on expansive geomorphic landforms (i.e., floodplains) that have filled the valley with alluvium. As stated by Stanford (1998), “The process of cut (erode) and fill (deposit) alluviation creates the physical features and characteristics of the river corridor.” This process, which results in the transport and deposition of bed-sediments, is also critical to maintaining the zones of preferential flow between surface waters and hyporheic groundwaters. The floodplain landforms of the North Fork and Middle Fork river-corridors are viewed correctly when placed in the context of a dynamic mosaic of habitats that transition between saturated and unsaturated conditions in both time and space and act as interconnected patches on the floodplain surface and below ground. Many of these features can be easily recognized on the surface of the floodplain using aerial photographs.

5.2.1 Flathead River Methods

The assessment here is for use in floodplain-wetland complexes where the river is unconfined and has a broad floodplain. These floodplain-wetland complexes are ecologically diverse. Overbank flows scour and deposit sediments and create a shifting mosaic of complex hydrologic habitats such as bars exposed at low flows, secondary channels, sloughs, and backwater ponds. These areas are referred to as the parafluvial. Other areas are inundated less frequently, become stable, and come to be dominated by advanced-stage plant communities. These areas are referred to as the orthofluvial, and are divided into the active orthofluvial, i.e., the area that is annually inundated by overbank flows, and the passive orthofluvial, i.e., the area that is rarely inundated by overbank flows (Hauer and Lamberti 2006). These areas provide a complex environment, resulting in floodplains that consist of integrated wetland/upland complexes with many surface habitats that are ecologically linked to the functioning riparian/floodplain wetlands.

To prepare for the analysis of the North and Middle Forks of the Flathead River adjacent to the park, the floodplain was digitized using the GLAC stream layer, the digital elevation map (slope threshold greater than 5%), background USDA National Agriculture Imagery Program (NAIP: seamless.usgs.gov), and visual assistance from oblique views within Google Earth’s 3-D models. Each assessment area was selected based on continuous floodplain reaches separated by geomorphic constrictions on the valley resulting in thirteen assessment areas (*northfork.shp* and *middlfork.shp*). A 0.62-mile (1-km) buffer was arbitrarily applied each assessment area (Figure 5.6) to assess anthropogenic influences adjacent to the floodplain (e.g. roads, ex-urban development, agriculture

etc.). This buffer was established solely on best profession judgment. Buffers on both sides of the floodplain assessment site were joined and treated as one assessment area resulting in thirteen buffer assessment sites.

The following is a summary of each variable used in the Flathead River assessment model. Each variable provides the variable code, name, definition, the rationale for selecting and scaling the variable, and the scaled variable in table form.

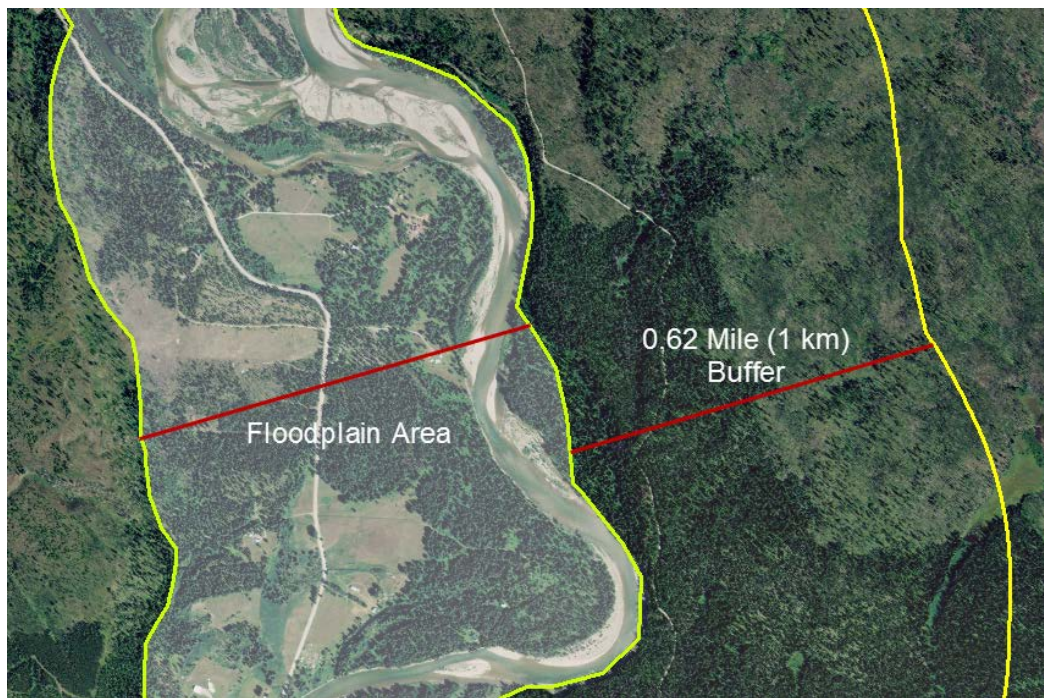


Figure 5.6. Example of selected floodplain area and 0.62 mile buffer on the Flathead River (North Fork).

Several of the metrics for the Flathead River assessment relied on the U.S. Geological Survey's land cover and land use (LULC) remote sensing interpretation (Fry et al. 2009) to provide spatially appropriate data on LULC. For this project we used the 2001 National Land Cover Database (NLCD) from USGS Seamless Data (seamless.usgs.gov), in a 30-m cell size ARCGRID. The raster was converted to polygon for the metric calculations. NLCD was chosen to for ease of comparison to later efforts of Multi-Resolution Land Characteristics Consortium (mrlc.gov) to classify national Landsat coverage. Table 5.10 lists the LULC codes are found within the study area and used in the following assessment variables.

Table 5.10. List of USGS' 2001cover types prevalent among the floodplain-wetland complexes of alluvial gravel-bed rivers of the Southern Rocky Mountains.

USGS LULC Type	Description
11	Open water
21	Developed open space area with <20 percent
22	Developed area with >20-49 percent
23 or 24	Developed areas. >50% impervious areas.
31	Exposed cobble riverbed and secondary channels during base flow and inundated during

USGS LULC Type	Description
	most annual high flows. (Caution LULC Code 31 also includes gravel pits)
41	Deciduous forest >5 meters tall greater than 20% cover
42	Evergreen forest >5 meters tall greater than 20% cover
43	Mixed deciduous forest and evergreen forest >5 meters tall greater than 20% cover
52	Shrub dominated over 20% shrub cover.
71	Dry herbaceous dominated (shrub cover less than 20%).
81 and 82	Agricultural field, may be a meadow or plowed, often planted and hayed, may have origin as a forested surface, but now logged, or may have been a natural meadow.
90	Woody wetlands shrub or forest greater than 20% cover
95	Moist herbaceous dominated in linear depressions (paleochannels) (shrub cover less than 20%).

Buffer (V_{BUFFROAD}) and Floodplain (V_{FPROAD}) Roads Density

To evaluate road density, data from Montana transportation data (NRIS 2011) were assessed within the thirteen buffer and floodplain assessment areas. A road density (Total Site Road and Railroad Length (ft)) / (Site Area (acre)) was determined for each buffer assessment area and sub-index scores were derived based on a site's density relative to the highest road density in all the river and buffer assessment areas. The highest road density is 0.0026 feet of road for every acre of assessment area (Site Middle Fork Buffer 1). To create a sub-index score between 0 and 1, the following formula was used:

$$V_{\text{BUFFROAD}} \text{ Sub-Index Score} = (\text{Maximum Road Density (linear mile/sq. mile)} - \text{Assessment Site Road Density (linear mile/sq. mile)}) / \text{Maximum Road Density (linear mile/sq. mile)}$$

Buffer and Floodplain Condition (V_{BUFFCDN} and V_{FPCDN})

The extent of human-altered land cover polygons within an assessment area serves as an indicator of the site's overall anthropogenic stressors. Table 5.9 presents a series of approximate ranges of losses of habitat in the buffer and the floodplain. To calculate the metric score, the relative areas of each polygon within the assessment areas were calculated and multiplied by the weighted sub-score in Table 5.11. As with all metrics in these models, these categorical breaks are not based on actual ecological thresholds. Rather they are best professional judgment of the relative anthropogenic stress from each of the LULC types. The scores were then totaled for each assessment area to obtain the assessment site metric score that ranged between 0 and 1.

Table 5.11. Description of land cover and the weighted sub-score assigned to Land Use and Land Cover (LULC) polygons.

Buffer and Riparian Land Use Criteria	Weighted Sub-score
Characteristic plant communities. No grazing, or development beyond walking trails, horse paths, and bike trails. LULC Codes 41, 42, 43, 52, 71, 90, and 95 (11- Open water in Buffer, excluded in Riparian)	1.0
Characteristic plant communities. May have very light grazing by domesticated animals (e.g., cattle, horses). Minor departure from the characteristic plant community, undisturbed condition across more than 90% of the area of the buffer. Minor departures include LULC codes 31	0.8

Buffer and Riparian Land Use Criteria	Weighted Sub-score
Moderate departure from characteristic plant coverage. May have moderate levels of grazing by domesticated animals (e.g., cattle, horses). Undisturbed condition across more than 50% of the area of the buffer. Moderate departures include LULC codes 81 and 82.	0.4
Significant departure from characteristic plant coverage over 75% of the buffer area. May have heavy grazing by domesticated animals (e.g., cattle, horses). May include low density domiciles. Significant departures include LULC codes 21 and 22.	0.3
Highly significant departure from characteristic plant coverage over >75% (most) of the buffer area. LULC codes 23.	0.2
Highly significant departure from characteristic plant coverage over >75% (most) of the buffer area. May include paved parking lots or other major disturbances and concentrations of anthropogenic activities. LULC codes 24.	0.0

Floodplain Habitat Connectivity ($V_{FPCONNECT}$)

Connectivity of riparian habitat decreases with human disturbance, (e.g., grazing/land clearing, agriculture, and urbanization), and this influences the ability of wide-ranging wildlife to locate, access, utilize, and disperse from a variety of habitat types. In the disturbed conditions, mixed conifer, cottonwood forest, and shrub community cover is significantly reduced and replaced by pasture or domestic or commercial development. V_{FPCON} assesses the amount of woody cover, wetlands and exposed cobble in the riparian area and was scaled using best professional judgment. The total areas for the appropriate LULC codes within the assessment areas were derived and the scaled scores were applied. The total areas for the 31, 41, 42, 43, 52, 90 and 95 LULC codes (see Table 5.11) within the assessment areas were derived and this total area was divided by the total area of the assessment area which providing a continuous score:

$$V_{FPCON} \text{ Sub-Index Score} = \text{Total area of polygons with LULC code of 31, 41, 42, 43, 52, 71, 90, and 95 (acre) / Total Area of Assessment Site (acre)}$$

Flathead River Condition Index

To acquire an overall condition score for each study area on the Flathead River, the following index was applied the condition metrics. The significance metric that measures the condition of the buffer 1 kilometer outside of the floodplain is considered twice as important as the stressor metric that measures road density in the buffer based on professional opinion. Collectively these metrics provide an assessment of the buffer considered as important as the two remaining significance metrics that measure floodplain connectivity and land cover and the remaining stressor metrics that measure the floodplain road density. As with all models in the assessment it provides a score for a watershed derived from the diversity of the habitat and proximity to human activity that is relative to other watersheds in the park only.

$$\text{Index} = (((((V_{BUFFCDN} * 2) + V_{BUFFROAD}) / 3) + V_{FPROAD} + V_{FPCDN} + V_{FPCONNECT}) / 4)$$

5.2.2 Flathead River Results

A total of 13 reaches were assessed along the approximately 100 river miles of the North and Middle Forks of the Flathead River adjacent to the park. The reaches were selected based on changes in physiographic conditions, predominantly at points where the riparian areas are confined by the adjacent upland slopes. The linear distance of these reaches ranged from about 4.0 to 15.0 miles in length and averaged about 7.5 miles in length (Table 5.12 and Figure 5.7).

Table 5.12. North and Middle Fork Flathead River assessment reaches and acreages.

Reach Name	Riparian Site Acreage	Buffer Site Acreage	Site Length (Miles)
Middle Fork 1	826	4565	13
Middle Fork 2	178	3536	10
Middle Fork 3	3892	8009	21
Middle Fork 4	161	2802	8
Middle Fork 5	460	5276	17
Middle Fork 6	330	3540	11
Middle Fork 7	188	3399	10
North Fork 1	1401	5403	9
North Fork 2	538	11129	13
North Fork 3	1077	10975	13
North Fork 4	5225	4674	30
North Fork 5	4618	4264	31
North Fork 6	2331	3368	16

Reach Road Density (V_{BUFFROAD} and V_{FPROAD})

All assessment areas contain a combination of major paved roads, secondary paved and unpaved roads, and/or railroad. These predominantly occur in the areas outside the park. Road density is an indirect measure of the degree of human interaction within the assessment reach (Trombulak and Frissell 2000, Theobald 2003, Nielsen et al. 2004). The lowest score in the buffer assessment area that contains the town of West Glacier (Middle Fork Reach 1) and the lowest score in the floodplain area is the reach upstream from West Glacier (Middle Fork Reach 2). This assessment area contains a confined reach where the Burlington Northern and Santa Fe railroad is directly adjacent to the river (Table 5.13, Figure 5.8, and 5.9).

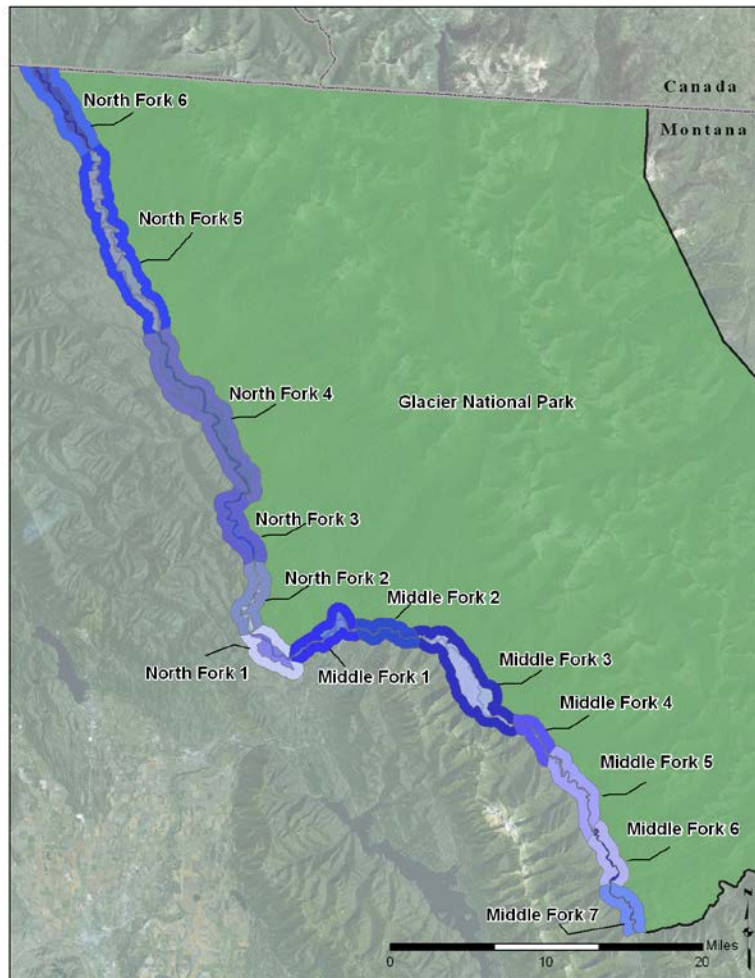


Figure 5.7. Locations of Flathead River reaches and local features.

Table 5.13. Measurements of road density and related metric scores for V_{BUFFROAD} and V_{FPROAD} .

Buffer Name	Buffer Road Density (linear mile/sq. mile)	Buffer Road Density Metric Score	Floodplain Road Density (linear mile/sq. mile)	Floodplain Road Density Metric Score
Middle Fork 1	2.6	0.00	1.5	0.43
Middle Fork 2	1.5	0.43	1.6	0.39
Middle Fork 3	0.6	0.77	0.9	0.65
Middle Fork 4	1.6	0.38	0.0	0.99
Middle Fork 5	1.6	0.37	0.0	1.00
Middle Fork 6	1.6	0.38	0.8	0.70
Middle Fork 7	1.3	0.52	0.5	0.82
North Fork 1	1.2	0.54	0.5	0.83
North Fork 2	1.4	0.45	0.3	0.88
North Fork 3	1.6	0.40	1.2	0.55
North Fork 4	1.2	0.55	0.6	0.78
North Fork 5	1.2	0.55	1.5	0.42
North Fork 6	1.8	0.33	0.4	0.83

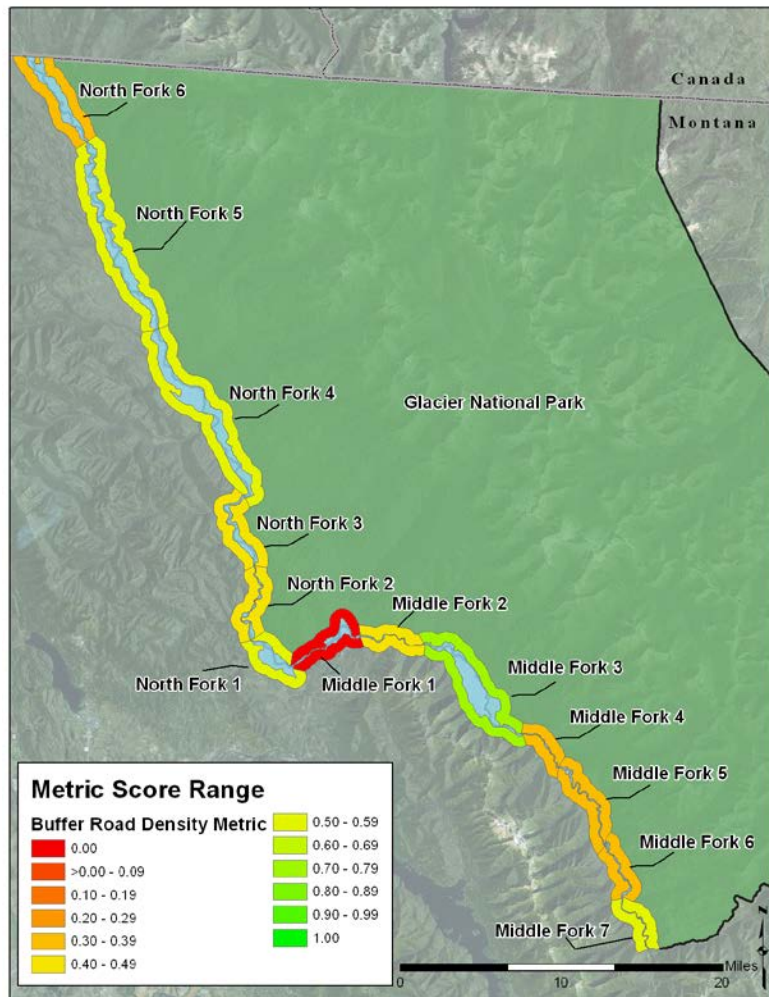


Figure 5.8. Flathead River buffer Road Density metric range.

Buffer Land Use Condition (V_{BUFFCDN})

The overall land use in the assessment area is rural and forested with some agriculture use. The buffer area assesses both sides of the North and Middle Forks. Although one half of the buffer area in each assessment reach is within the park, the buffer was assessed as a whole for each reach. In general, the buffer in the study area is fairly intact. However, there are varied land uses in the assessment areas, such as agriculture, housing, and golf courses, which diverge from the native conditions. The lowest score is in the assessment areas that contains the town of West Glacier (Middle Fork Reach 1) (Table 5.14 and Figure 5.10).

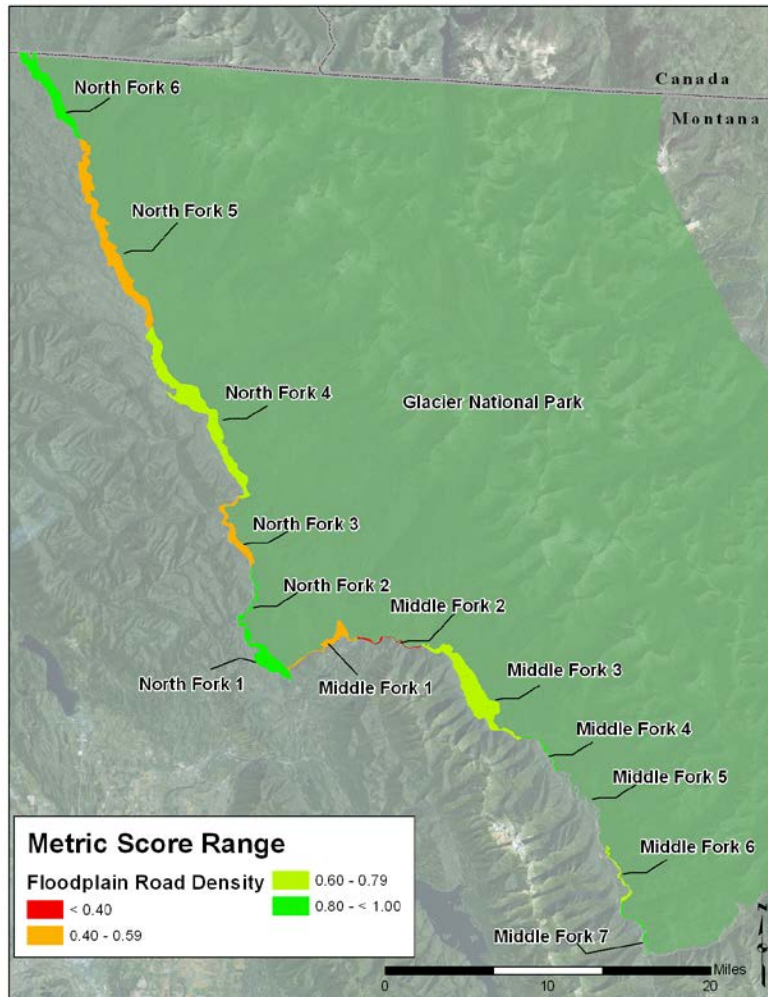


Figure 5.9. Flathead River floodplain road density metric score range.

Table 5.14. Flathead River buffer land use metric scores with in the study area.

Riverine Reach Name	Buffer Land Use Metric Score
Middle Fork 1	0.94
Middle Fork 2	0.95
Middle Fork 3	0.98
Middle Fork 4	0.96
Middle Fork 5	0.97
Middle Fork 6	0.97
Middle Fork 7	0.97
North Fork 1	0.97
North Fork 2	1.00
North Fork 3	1.00
North Fork 4	0.99
North Fork 5	0.95
North Fork 6	1.00



Figure 5.10. Flathead River buffer land Use metric score range.

Floodplain Land Use Condition (V_{FPCDN})

As with the buffer land use assessment above, the floodplain land use of the Flathead River is relatively intact. There are minor departures from the forested, shrub, and herbaceous communities typically found in healthy riparian areas. These departures include agricultural fields, roads and urbanized areas. As with the buffer land use, the lowest floodplain land use score is in the assessment area that contains the town of West Glacier (Middle Fork Reach 1) (Table 5.15 and Figure 5.11).

Table 5.15. Flathead River floodplain land use metric scores with in the study area.

Riverine Name	Floodplain Land Use Metric Score
Middle Fork 1	0.77
Middle Fork 2	0.90
Middle Fork 3	0.86
Middle Fork 4	1.00
Middle Fork 5	0.97
Middle Fork 6	0.98
Middle Fork 7	0.96
North Fork 1	0.93
North Fork 2	1.00
North Fork 3	0.96
North Fork 4	0.94
North Fork 5	0.81
North Fork 6	1.00

Floodplain Connectivity ($V_{FPCONNECT}$)

The contiguity of habitat patches serves as an indicator of the reach's capacity to function as habitat for wide-ranging wildlife. Unlike the land use condition metric, this metric assesses the composition of remaining native land cover. Within the assessment areas there are departures from a continuous land cover made up of mixed conifer, cottonwood forests, and shrub communities along with forested wetlands and open cobble bar. There are several assessment reaches where these cover class have been replaced with pasture or domestic or commercial development. As with other metrics in this assessment, the lowest floodplain connectivity score is in the assessment area that contains the town of West Glacier (Middle Fork Reach 1) (Table 5.16 and Figure 5.12).

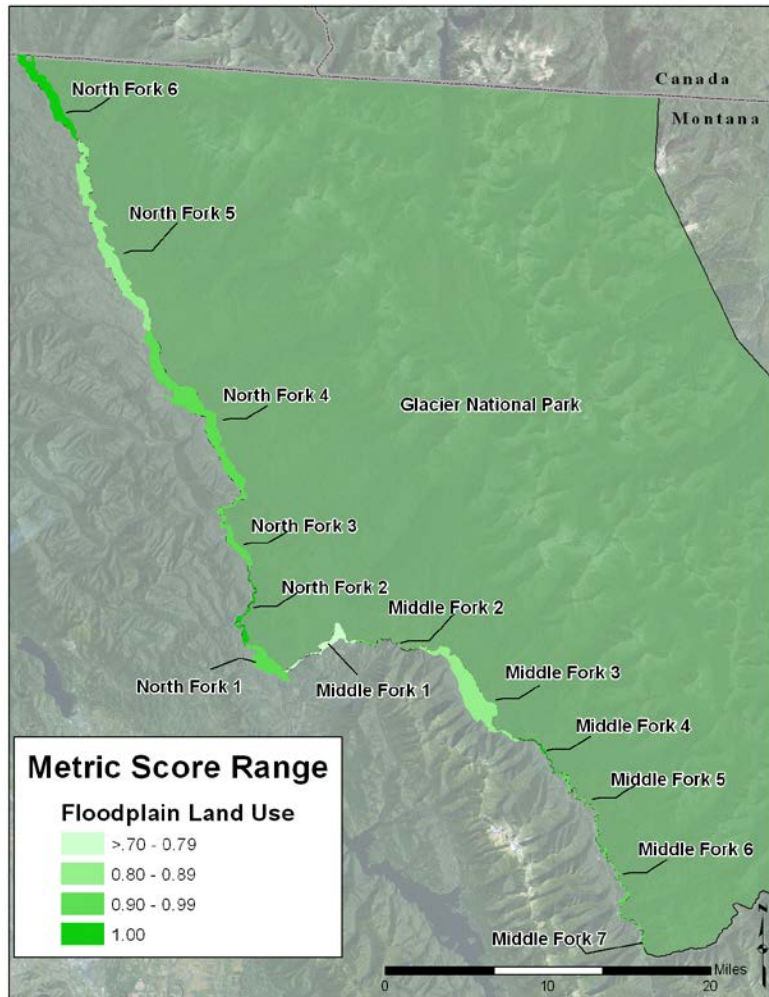


Figure 5.11. Flathead River floodplain land use metric score range.

Table 5.16. Measurement or Condition for $V_{FPCONNECT}$.

Riverine Name	Percent Cover of 2001 LULC Codes 31-71 and 90	Floodplain Connectivity Metric Score
Middle Fork 1	50%	0.50
Middle Fork 2	77%	0.77
Middle Fork 3	72%	0.72
Middle Fork 4	81%	0.81
Middle Fork 5	81%	0.81
Middle Fork 6	87%	0.87
Middle Fork 7	89%	0.89
North Fork 1	78%	0.78
North Fork 2	80%	0.80
North Fork 3	75%	0.75
North Fork 4	82%	0.82
North Fork 5	59%	0.59
North Fork 6	95%	0.95



Figure 5.12. Flathead River floodplain connectivity metric score range.

Flathead River Condition Score

The Flathead River condition scores represent a combination of significance metrics that measure the range of natural vegetation patch connectivity and four stressor metrics that measure human alterations within the riparian area and buffers of the Middle and North Forks of the Flathead River. For instance, Middle Fork Reach 2 is a confined channel with a limited floodplain and thereby limited habitat diversity. Middle Fork Reach 1 has a broad floodplain but it has been impacted by the urban activities of the town of West Glacier. Both of the scores of these two reaches represent the departure from floodplain conditions that provide a diverse native habitat. In the North Fork, Reaches 2 and 3 scored the lowest due high road densities in the buffer and floodplain and low wetland density in both reaches. All scores represent a departure from an unaltered floodplain condition resulting from concentrated human use (Table 5.17 and Figure 5.13).

Table 5.17. The metric and index scores for each floodplain assessment area in Glacier National Park.

Riparian Reach Name	Buffer		Floodplain			Index
	land Use	Road Density	Land Use	Connectivity	Road Density	
Middle Fork 1	0.94	0.00	0.77	0.50	0.43	0.58
Middle Fork 2	0.95	0.43	0.90	0.77	0.39	0.71
Middle Fork 3	0.98	0.77	0.86	0.72	0.65	0.79
Middle Fork 4	0.96	0.38	1.00	0.81	0.99	0.89
Middle Fork 5	0.97	0.37	0.97	0.81	1.00	0.89
Middle Fork 6	0.97	0.38	0.98	0.87	0.70	0.83
Middle Fork 7	0.97	0.52	0.96	0.89	0.82	0.87
North Fork 1	0.97	0.54	0.93	0.78	0.83	0.84
North Fork 2	1.00	0.45	1.00	0.80	0.88	0.87
North Fork 3	1.00	0.40	0.96	0.75	0.55	0.77
North Fork 4	0.99	0.55	0.94	0.82	0.78	0.85
North Fork 5	0.95	0.55	0.81	0.59	0.42	0.66
North Fork 6	1.00	0.33	1.00	0.95	0.83	0.89

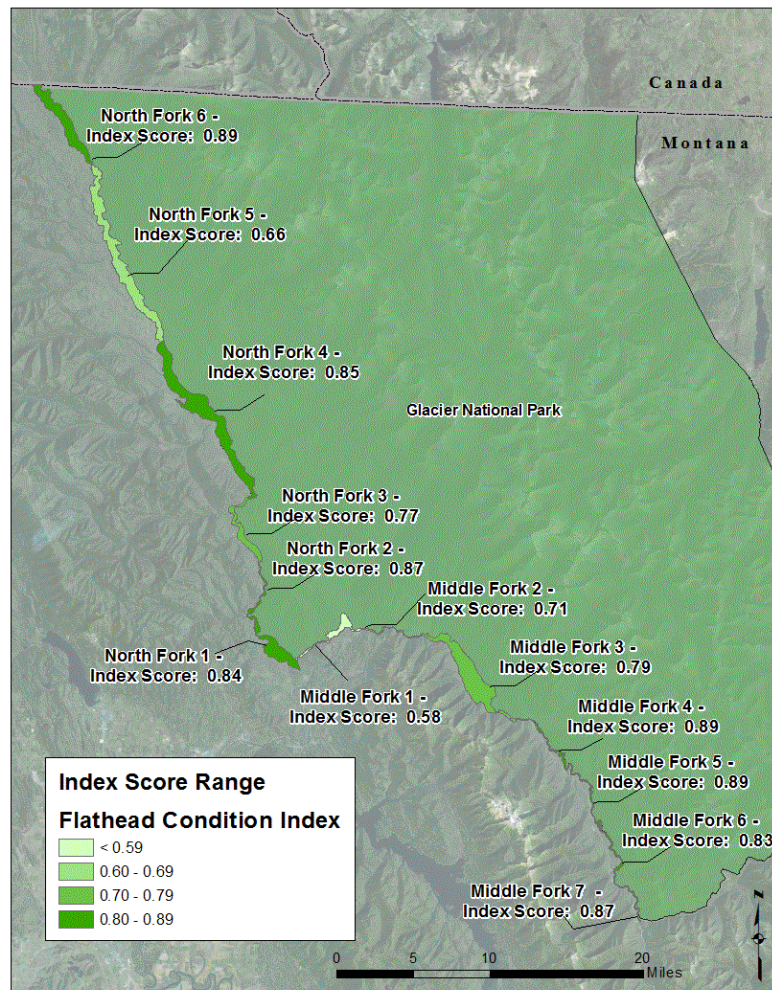


Figure 5.13 Flathead River condition index score range.

5.2.3 Assessment of availability and gaps in monitoring data

Landsat based thematic land cover products and other data spatially appropriate for assessments at this scale generally follow standardized reporting guidelines that articulate known uncertainties inherent in their efforts (e.g. USBB 1947, Anderson et al. 1976). The NLCD map accuracy is well documented (Wickham et al. 2010) for the Rocky Mountain Region at 79% for 2001 for Anderson Level II classification. Uncertainty is a known degree of unreliability of knowledge ranging from certainty (determinism) to total ignorance or a lack of awareness that knowledge is wrong or imperfect. The position along this range translates into a state-of-confidence (Walker et al. 2003). Further research is needed to determine the impact on multi-metric index scores from error propagation resulting from known uncertainties such as the accuracy of the 2001 NLCD.

Wetlands were not addressed in the section because of the limited data. National Wetland Inventory (NWI) data was used as an important metric in the Flathead River assessment; however, like other nationwide surveys of natural resources it is important to be cautious of the continuity and extent of this coverage. It is generally recognized that NWI has varying accuracy (Stolt and Baker 1995, Morrissey and Sweeney 2006). Evaluations of NWI have reported various error rates in studies performed around the country, for example very low, less than 5%, omission and commission error rates were reported in Massachusetts (Swarthout et al., 1981) and Michigan (Kudray and Gale, 2000). However, in other studies omission error rates were found to be much higher; about 50% omission was found in a Nebraskan study (Kuzila et al. 1991), 68% in Vermont (Morrissey and Sweeney 2006) and greater than 85% in Virginia (Stolt and Baker, 1995). In general, omission tends to be a common bias with NWI data (Tiner, 1997).

5.3 Focal Area – Glacier's Lakes

The lakes of the park were formed through glacial activity. At its maximum, 10,000–20,000 years BP, the last Wisconsin glaciation covered about $\frac{1}{4}$ of the world's land area. Glacial lobes from the Cordilleran Ice Sheet extended down the Rocky Mountain Trench (a tectonic fault block basin) covering the western region of GLAC with subsequent alpine glaciers reaching into the eastern region of the park. Advancing glaciers scraped the land, pushing rock and earth, scouring deep basins and depositing terminal moraines that eventually became glacial lakes. As the Cordilleran Ice Sheet retreated, further reworking of the landscape occurred leaving behind layers of stones and fine particles of variable thickness on top of the underlying rock (glacial till). Soils today developed from the physical and biological/chemical weathering of the drift layer and the subsequent incorporation of organic matter. In regions underlain by extremely hard rock and little overlying glacial drift, the glaciers scraped the bedrock, creating shallow basins now occupied by lakes, ponds and wetlands. Through these glacial and tectonic processes a variety of lake types (*sensu* Hutchinson 1957) were formed.

High-elevation lakes are ice covered in winter (some are ice free for only a few months) and are hydrologically dominated by snow melt and some by both glacial and snow melt. Located in drainage basins with low average air temperatures, minimal vegetation and poorly developed soils, most high-elevation lakes (particularly alpine lakes) tend to be nutrient poor. However, the alpine

and subalpine lakes of GLAC vary in their chemistry, productivity and biotic communities. Differences in the extent of vegetation and soil development, bedrock chemistry, climate, ratio of drainage area to lake volume and biotic history all play a role in present day lake chemistry and productivity.

Most of the valley bottom lakes are a result of glacial erosion and subsequent deposition of lateral and terminal moraines in deepened and widened tectonic fault-block valleys. In general, valley bottom lakes are more productive than higher elevation lakes due to the larger ratio of drainage area to lake volume, greater soil and vegetation development, higher supply rates of all major and minor nutrients (longer contact time between water and soils), higher temperatures and longer growing season.

In order to establish a water quality baseline for select lakes in GLAC, the National Park Service (NPS) and the Flathead Lake Biological Station (FLBS) documented the annual variability in water chemistry, physical characteristics and plankton communities of a subset of the park's lakes from 1984 to 1990 (Ellis et al. 1992, 2002). Five valley bottom lakes and eight alpine and subalpine lakes were monitored. The majority of lakes sampled in this study were strongly phosphorus (P) limited. That is, there is a paucity of P relative to nitrogen (N) and production of phytoplankton must be limited by the input of P (Wetzel 2001). An increase in the atmospheric deposition of P could cause an immediate stimulus of autotrophic productivity (Ellis and Stanford 1988a, 1988b) and secondarily alter the food web of these lakes through the process of eutrophication.

Bergstrom (2010) showed that the dissolved inorganic nitrogen (DIN) to total P ratio was a better indicator than the ratio of total N (TN) to total P (TP) for determining N and P limitation of phytoplankton. Ratios of DIN:TP for several of the high elevation lakes and one low elevation lake studied by Ellis et al. (1992, 2002) were borderline between P limitation and N limitation. It is possible that these lakes may be co-limited by both N and P. Studies have reported co-limitation of phytoplankton growth by P and N in nearby Flathead Lake (Spencer and Ellis 1990). The increase in atmospheric deposition of ammonium and nitrate in the northwest U.S. (Lehmann et al. 2005) has the potential to increase algal production in some of the high-elevation lakes limited or co-limited by N. Several of the high-elevation lakes and one valley bottom lake were very soft-water systems (low conductivity) reflecting the lack of bicarbonate-rich limestone formations within the Belt Series geology of GLAC. While they are not the most dilute lakes in the world (cf. Eilers et al. 1990), they clearly have very little buffering capacity and would be more sensitive to acidic precipitation than lakes influenced by more carbonate-rich facies of the Belt Series. All of the lakes were oligotrophic or ultra-oligotrophic.

Since the early limnological studies of GLAC lakes, an analysis of the concentrations and biological effects of airborne contaminants in air, snow, water, sediments, lichens, conifer needles and fish in two watersheds in GLAC has been conducted (Landers et al. 2008; seven other national parks in the western U.S. were included in this study). Semi-volatile organic compounds (SOCs) and heavy metals (e.g., Hg) were the primary focus of the study. The sediment of both lakes contained SOCs, polycyclic aromatic hydrocarbons, Pb, Cd and Hg. Sediment profiles indicated SOCs have not decreased since use ceased, but most of the other contaminants decreased about the time reductions

in emissions were required by the Clean Air Act. Numerous pesticides and Hg were detected in fish from the lakes. These contaminants are of major concern for the health of the lakes, particularly the biota.

The geologic and elevation gradients probably had the greatest natural influence on biotic assemblages and the introduction of fish in alpine lakes has likely produced the most measurable effects in relation to other potential pollutants (Ellis et al. 2002). Detrended correspondence analysis showed that the environmental gradient in geology among the lake watersheds exhibited the greatest strength in accounting for the variation in the phytoplankton community. However, upon examination of taxonomic groups of both phytoplankton and zooplankton, significant differences were observed in lakes with fish versus lakes without fish. The biomass of phytoplankton, grouped by class, was significantly different in lakes with fish. The biomass of Cryptophyceae, Xanthophyceae and Bacillariophyceae were all significantly lower in fishless lakes than in lakes with fish. These differences may reflect variable grazing of the phytoplankton community due to differences in zooplankton species present in lakes with fish versus fishless lakes. Lakes containing fish did not have many large zooplankton (i.e. copepods and cladocera) and the community was usually dominated by the smaller rotifers. Large zooplankton, particularly the red-bodied *Hesperodiaptomus shoshone*, were always present in the fishless lakes. Clearly, grazing by fish has an effect on the pelagic food web.

From the time of the parks establishment through the early 1970's, large numbers of non-native fish were planted across the park, and in some cases established self-sustaining reproducing populations. Introductions or invasions of nonnative organisms can result in major changes in the trophic structure of aquatic ecosystems, often altering the abundance, biomass or productivity of a population, community or trophic level across more than one link in the food web (Carpenter et al. 1985, 2010). The purposeful introduction of 20 vertebrate and invertebrate species to nearby Flathead Lake (a large downstream lake in the Flathead watershed) over the last century resulted in a trophic cascade affecting the phytoplankton and zooplankton communities, planktivorous fishes, piscivorous fishes and even terrestrial bald eagles (Ellis et al. 2011). This resulting alteration of the entire food web of Flathead Lake extended into GLAC resulting in the loss of nonnative kokanee salmon from their primary spawning grounds (McDonald Creek), the dispersal of the large fall congregation of bald eagles that fed on the kokanee, and more importantly, the dramatic increase in an additional nonnative top predator (i.e., lake trout) which is invading numerous lakes and streams within GLAC.

5.3.1 Methods: Glacier Lakes

Acid Sensitivity ($V_{\text{ACID-SEN}}$)

The most sensitive measure of water's ability to buffer acidic atmospheric inputs is acid neutralizing capacity (ANC). Nanus et al. (2009) conducted an assessment of the sensitivity of lakes to acidic aerosol deposition in five Rocky Mountain national parks, including GLAC. Utilizing lake basin characteristics and ANC measurements, they calibrated statistical models to predict which lakes had a high probability for sensitivity to acidic deposition. Thirty-three lakes were sampled in GLAC and three had ANC concentrations < 50 ueq L, three within a range of 100–200 ueq L and the remaining

lakes were > 200 ueq L (see Fig. 2, Nanus et al. 2009). Utilizing data from all five national park lakes Nanus et al. (2009) found that lakes most likely to be sensitive to acidic deposition are located in basins with elevations >3000 m, with >80% of the catchment bedrock having low buffering capacity and with <30% of the catchment having a northeast aspect.

Alkalinity also approximates the ability of surface waters to neutralize acidity. The mean alkalinity for five valley bottom lakes and eight alpine and subalpine lakes in GLAC from annual collections for the period 1984–1990 (Ellis et al. 1992, 2002) in relation to the percent of a lake's contributing watershed containing argillite plus quartzite is shown in Figure 5.14. This figure suggests that as the percent of argillite plus quartzite in a lake's contributing watershed increases, the alkalinity of the lake decreases and thereby the lake's ability to buffer acidic aerosol deposition also decreases.

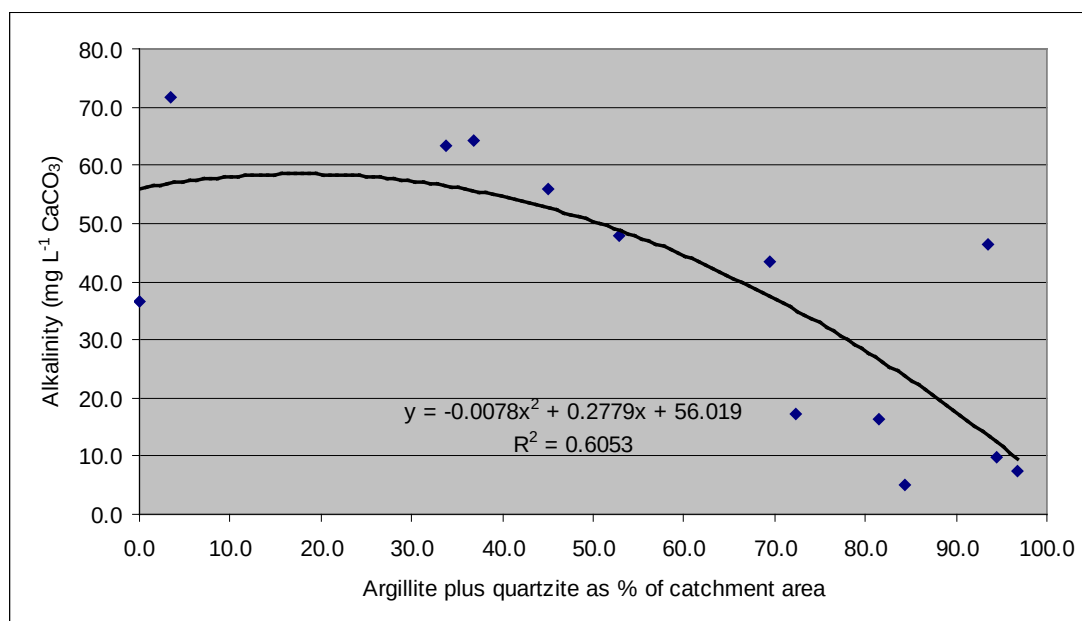


Figure 5.14. Approximate relation between the percent of contributing watershed comprised of argillite plus quartzite and its relative acid buffering capacity.

The percent of argillite plus quartzite in a lake's contributing watershed can be calculated with the park's existing data. The lake basin areas were calculated by joining all catchments above all lakes from the National Hydrological Database (NHD) catchment shape files (catchments.shp). This layer was then intersected with the soils layer (soils.shp) to express the percent coverage of quartzite plus argillite bedrock within each lake basin. A union of these basins with the lakes spatial layer determined the percent argillite plus quartzite for each lake's contributing watershed.

This percentage was used as a metric for the sensitivity to potential acid risks in the park's lakes. Lakes with ANC < 100 ueq L are considered to be very sensitive to acidic deposition (Williams and Tonnessen 2000). Lakes with ANC values less than 100 ueq/L or alkalinity values less than 5 mg/L CaCO₃ (about 85% argillite plus quartzite in the contributing basin) tend to be more susceptible to acidification. The metric was scored according to this percentage of the contributing watershed that contained argillite and quartzite associated with levels of alkalinity (Figure 5.14 and Table 5.18).

Table 5.18. Acid Sensitivity ($V_{\text{ACID-SEN}}$) metric scoring.

Acid Sensitivity Metric Criteria:	Metric Score
Percent of contributing watershed comprising argillite plus quartzite < 85 %	1.00
Percent argillite plus quartzite 85% - < 100 %	0.50

Enhanced Algal Production (V_{ALGAE})

As stated above, the dissolved inorganic nitrogen (DIN) to total phosphorus (TP) ratio is a good indicator for determining whether N or P (or both N and P) would stimulate algal growth, thus trending toward more productive conditions. These data are only available for a few of the park's lakes and are non-representative of the entire park, but because this is spatially explicit data that can be augmented through increased monitoring, it was used as a metric. The scaling (Table 5.19) was based on Bergstrom (2010), which states that lakes with a DIN:TP ratio greater 3.4 have a high probability of P limitation, while a ratio below 1.5 indicates N limitation. The paper also states that phytoplankton shift from N to P limitation when DIN:TP ratios increase from 1.5 to 3.4. It is feasible that some lakes within that shifting range may be co-limited by both N and P, that is, both nutrients would stimulate algal growth.

Although lakes at both ends of the DIN:TP spectrum are at risk of increased algal production, the metric scores (Table 5.19) were based upon the potential for increased algal growth from additional N inputs due to the well documented increase in atmospheric deposition of ammonium and nitrate in the northwest U.S. (Lehmann et al. 2005). However, the metric could also be designed for increasing P inputs (i.e., DIN:TP ratios >3.4 at high risk), should such a trend eventuate. Clearly, most of the GLAC lakes would be degraded by additional inputs of P (see Table 5.21). The metric scores in Table 5.21 were assigned to each lake watershed. If no data were available for the DIN:TP ratio, the lake received a score of 1.0 for the time-being until more data is available. Each lake area was then multiplied by its assigned sub-metric score and this figure was totaled for each watershed and divided by the total area of all lakes in the watershed resulting in a final metric score between 0 and 1.

Table 5.19. Enhanced Algal Production (V_{ALGAE}) metric scoring.

Metric Criteria:	Sub-Metric Score
Dissolved inorganic nitrogen to total phosphorus ratio ≥ 3.4	1.00
Dissolved inorganic nitrogen to total phosphorus ratio 2.5 - <3.4	0.80
Dissolved inorganic nitrogen to total phosphorus ratio 1.5 - <2.5	0.50
Dissolved inorganic nitrogen to total phosphorus ratio <1.5	0.01

Risk of Invasive Diatoms, Mollusks and Aquatic Macrophytes (V_{EXOTIC})

Boats are a primary potential source of invasive aquatic species to the lakes of the northern Rocky Mountains. These invasive species include plants; Eurasian water milfoil (*Myriophyllum spicatum*) and purple loosestrife (*Lythrum salicaria*), invasive invertebrates; zebra mussel (*Dreissena polymorpha*), Quagga mussel (*Dreissena bugensis*), New Zealand mud snail (*Potamopyrgus antipodarum*); and the invasive diatom didymo (*Didymosphenia geminata*). This metric addresses the

potential risk of exposure of the park's lakes to nuisance aquatic species, the extent of non-native salmonid fish species that are already in the park's lakes are addressed separately in the fish section below. Proximity of the park's lakes to boat ramps, paved roads and unpaved roads was used as a measure of the potential risk and is scaled in qualitative categories in Table 5.20. This score represents potential risk of invasion and expansion of these species, not actual measurements of such. As with the metric above, the metric scores in Table 5.20 were assigned to each lake watershed. Each lake area was then multiplied by its assigned sub-metric score and this figure was totaled for each watershed and divided by the total area of all lakes in the watershed resulting in a final metric score between 0 and 1.

Table 5.20. Invasive mollusks and aquatic macrophytes metric scoring.

Metric Criteria:	Metric Score
No road within 300 feet of lake.	1.00
Unpaved Road adjacent to lake with no formal boat ramp	0.90
Paved Road adjacent to lake with no formal boat ramp	0.80
Unpaved Road adjacent to lake with formal boat ramp	0.70
Paved Road adjacent to lake with formal boat ramp	0.60
Nuisance aquatic species are present	0.01

Calculation of Total Lake Condition Score

To acquire an overall lake condition score for each watershed, the following index was applied the condition metrics. This model assesses the risk to GLAC lakes that could potentially degrade their ecological condition. The model is constructed to measure the risk to water chemistry equally and these collectively have an influence on lakes, but the multiplicative aspect of the model indicates that exposure to nuisance aquatic species will severally degrade a lake's conditions. Because the lakes in GLAC are not currently acidified, have excessive algae growth or invasive species, this index measures only the risk of these degradations occurring.

$$\text{Lake Condition Score} = ((V_{\text{ACID}} + V_{\text{ALGAE}})/2) * V_{\text{EXOTIC}})$$

5.3.2 Lake Condition Results

Enhanced Algal Production (V_{ALGAE})

Data on the dissolved inorganic nitrogen to total phosphorus ratio is only available for 13 lakes in the park. Four of these 13 lakes have a ratio that put these lakes at risk of enhanced algal production with increasing nitrogen deposition (Table 5.21). As a result the watersheds containing these lakes scored lower than others in the park (Table 5.22 and Figure 5.15). If data was not available it is assumed that the lake has a DIN:TP ratio >3.4 until further data is available.

Table 5.21. DIN:TP ratios for GLAC lakes where data was available (Ellis et al. 1992).

Lake	Watershed	DIN:TP Ratio
Upper Dutch	Camas	2.0
Cobalt	Upper Two Medicine	2.2
Beaver Woman	Coal/Ole	2.4
Stoney Indian	Waterton	2.5
Two Medicine	Upper Two Medicine	2.6
Medicine Grizzly	Cut Bank	2.9
Gyr Falcon	Quartz/Logging	5.80
Gunsight	Saint Mary	5.80
Snyder Lakes 2	Lake McDonald	6.50
Swiftcurrent	Swiftcurrent	8.80
St. Mary	St. Mary	23.80
Waterton	Waterton	36.90
McDonald	Lake McDonald	47.30

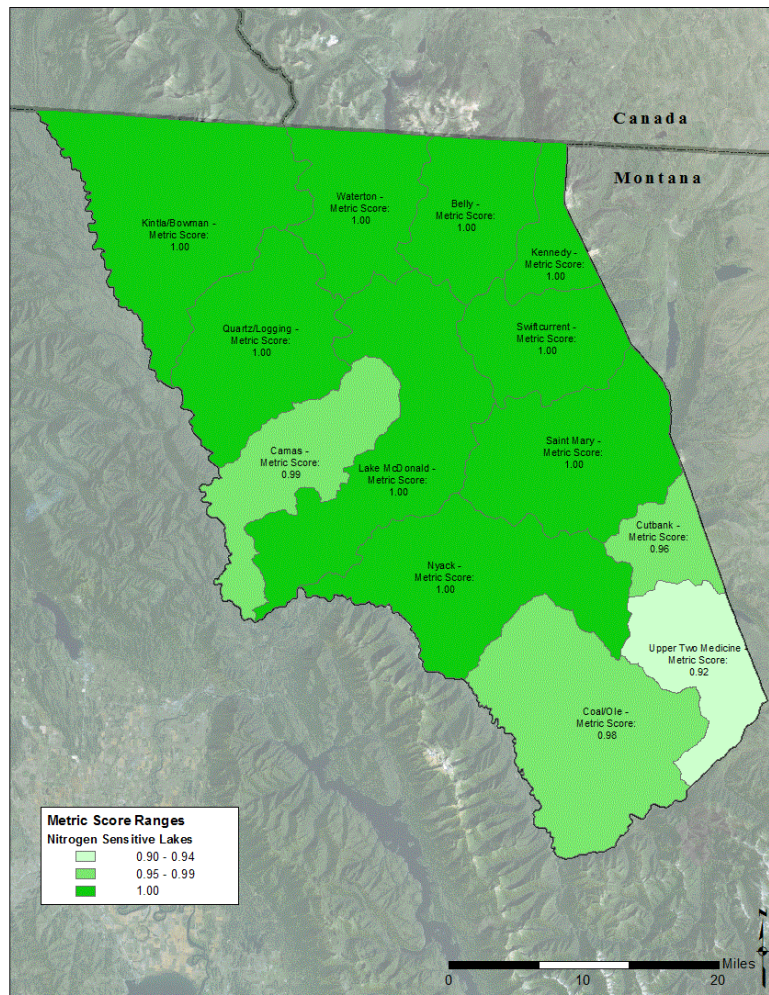


Figure 5.15. Metric for lakes in GLAC that are potentially at risk of enhanced algal production.

Table 5.22. Watersheds within GLAC that contain lakes sensitive to increasing nitrogen which would result in enhanced algal production.

The 4 categories of DIN:TP ratios ¹ found in sample lake contributing basins and the percent of lakes in those categories.					Metric Score Range
Watershed	<1.5	1.5 - <2.0	2.0 - <3.5	>3.4	
Belly	0%	0%	0%	100%	1.00
Camas	0%	0%	100%	0%	0.99
Coal/Ole	0%	0%	100%	0%	0.98
Cut Bank	0%	0%	100%	0%	0.96
Kennedy	0%	0%	0%	100%	1.00
Kintla/Bowman	0%	0%	0%	100%	1.00
Lake McDonald	0%	0%	0%	100%	1.00
Nyack	0%	0%	0%	100%	1.00
Quartz/Logging	0%	0%	0%	100%	1.00
Saint Mary	0%	0%	0%	100%	1.00
Swiftcurrent	0%	0%	0%	100%	1.00
Upper Two Medicine	0%	0%	100%	0%	0.92
Waterton	0%	0%	50%	50%	1.00

Note: If the DIN:TP data were not available for a lake, it is assumed that the ratio was >3.4 until detailed data can be provided.

Acid Sensitivity ($V_{ACID-SEN}$)

The percent of argillite plus quartzite in each lake's contributing watershed was determined a sub-index score was assigned to each lake above and below 85% (see Table 5.18). The area of each lake was multiplied by the sub-index score, totaled for the watershed and divided by the total lake area in that watershed. The subsequent weighted average provided the watershed scale metric score. From these lake assessments, it was found that lake systems in the Cut Bank and Camus watersheds have a higher sensitivity to acid deposition then other watersheds in the park (Table 5.23 and Figure 5.16).

Table 5.23. Percent watershed that is comprised of argillite and quartzite.

Watershed	Greater Than or Equal		Metric Score Range
	To 85%	Less Than 85 %	
Belly	0%	100%	0.98
Camas	7%	93%	0.74
Coal/Ole	13%	87%	0.89
Cut Bank	58%	42%	0.74
Kennedy	29%	71%	0.84
Kintla/Bowman	1%	99%	0.99
Lake McDonald	0%	100%	0.99
Nyack	6%	94%	0.84
Quartz/Logging	0%	100%	1.00
Saint Mary	2%	98%	0.99
Swiftcurrent	2%	98%	0.98
Upper Two Medicine	8%	92%	0.89
Waterton	1%	99%	0.99

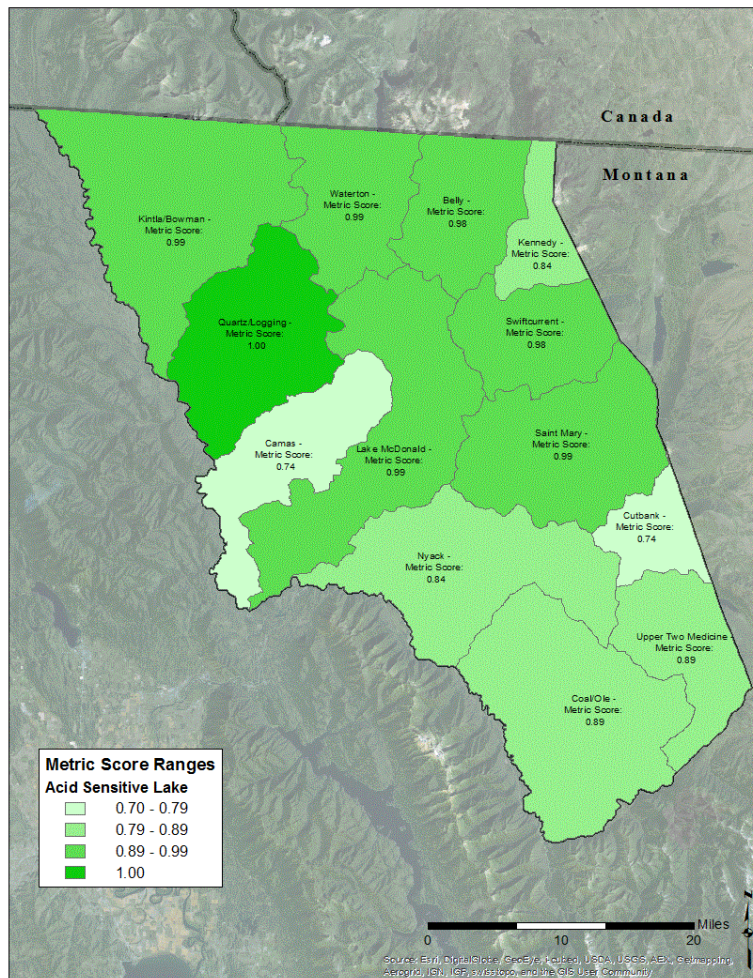


Figure 5.16. Metric for lakes in GLAC that are potentially threatened by acidification.

Risk of Invasive Diatoms, Mollusks and Aquatic Macrophytes (V_{EXOTIC})

Several of the larger lakes within the park either have a boat ramp on the lake or are adjacent to a paved road. As a result Saint Mary and Lake McDonald watersheds have the highest risk of invasion by nuisance aquatic species. (Table 5.24 and Figure 5.17).

5.3.3 GLAC Lake Condition Score

The GLAC lake condition (risk) scores represent a combination of risk metrics that measure the range of natural variability of attributes that buffer lakes from potential acidification or increased eutrophication and potential human degradation resulting from the introduction of aquatic nuisance species. Lake McDonald, Saint Mary and Upper Two Medicine watersheds scored the lowest (i.e., at highest risk) primarily because of potential exposure to non-native aquatic species (Table 5.25 and Figure 5.18).

Table 5.24. Percent of lake area with various types of boat access.

Watershed	Paved Road w/ Ramps	Unpaved Road w/ Ramps	Paved Road w/no Ramps	Unpaved Road w/no Ramps	No Road	Metric Score
Belly	0%	0%	0%	0%	100%	1.00
Camas	0%	0%	0%	0%	100%	1.00
Coal/Ole	0%	0%	0%	0%	100%	1.00
Cut Bank	0%	0%	0%	0%	100%	1.00
Kennedy	0%	0%	0%	0%	100%	1.00
Kintla/Bowman	0%	80%	0%	1%	19%	0.76
Lake McDonald	94%	0%	0%	0%	6%	0.63
Nyack	0%	0%	0%	0%	100%	1.00
Quartz/Logging	0%	0%	0%	0%	100%	1.00
Saint Mary	87%	0%	0%	0%	13%	0.65
Swiftcurrent	0%	5%	65%	0%	31%	0.86
Upper Two Medicine	60%	0%	1%	0%	40%	0.76
Waterton	56%	0%	0%	0%	44%	0.78

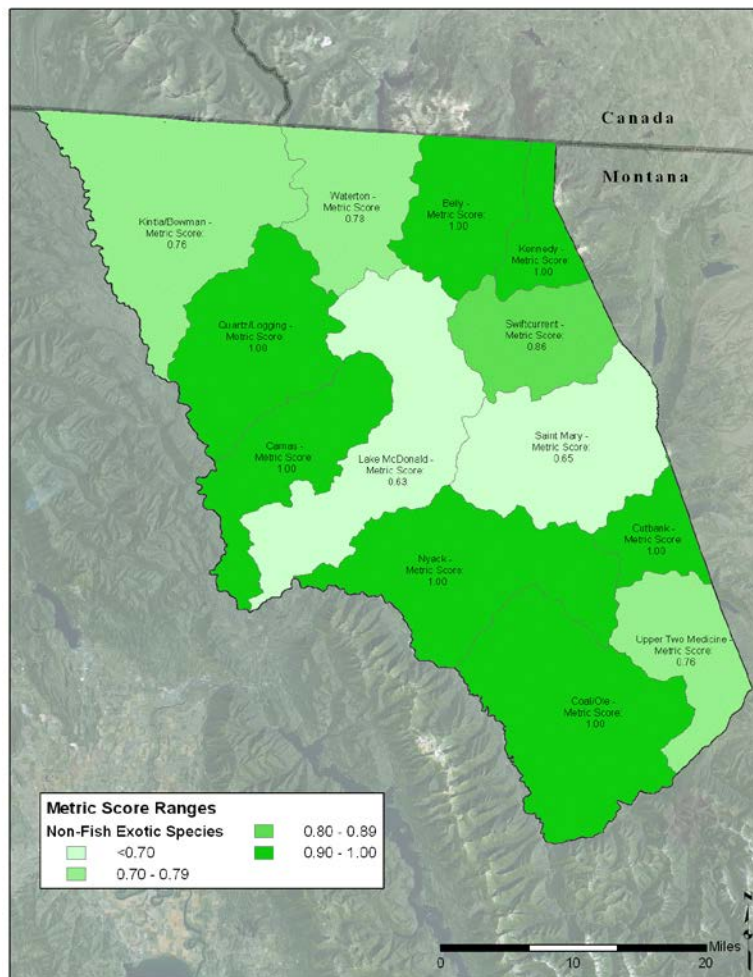


Figure 5.17. Metric for lakes in GLAC that are potentially threatened by exotic species.

Table 5.25. The lake metric and index scores in each watershed in Glacier National Park.

Watershed	Acid Sensitive Lakes	Nitrogen Sensitive Lake	Exotic Species (Non-Fish) Risk	Lake Condition Index
Belly	0.98	1.00	1.00	0.99
Camas	0.74	0.99	1.00	0.87
Coal/Ole	0.89	0.98	1.00	0.94
Cut Bank	0.74	0.96	1.00	0.85
Kennedy	0.84	1.00	1.00	0.92
Kintla/Bowman	0.99	1.00	0.76	0.76
Lake McDonald	0.99	1.00	0.63	0.63
Nyack	0.84	1.00	1.00	0.92
Quartz/Logging	1.00	1.00	1.00	1.00
Saint Mary	0.99	1.00	0.65	0.65
Swiftcurrent	0.98	1.00	0.86	0.85
Upper Two Medicine	0.89	0.92	0.76	0.69
Waterton	0.99	1.00	0.78	0.78

5.3.4 Assessment of availability and gaps in monitoring data

Data is limited on the DIN:TP ratio and the alkalinity (or preferably acid neutralizing capacity) and other basic water chemistry of GLAC lakes. Increased monitoring of the DIN: TP ratio would provide the data necessary to refine the enhanced algal production metric. Determination of acid neutralizing capacity of high and low elevation GLAC lakes within each watershed would provide a more precise measurement of the sensitivity of lakes to acidic precipitation. The additional data from Nanus et al. (2009) should be incorporated into the acid sensitivity metric; however at the time of this document production, those data were not available. Analysis of the lake condition parameters $V_{\text{ACID-SEN}}$ and V_{ALGAE} could be improved by assessing risk within subwatersheds as the larger lake watersheds transect varying parent material, soils, forest cover and other inherent characteristics that influence those parameters. Additionally, a finer resolution of lake catchment information would refine the acid sensitivity metric.

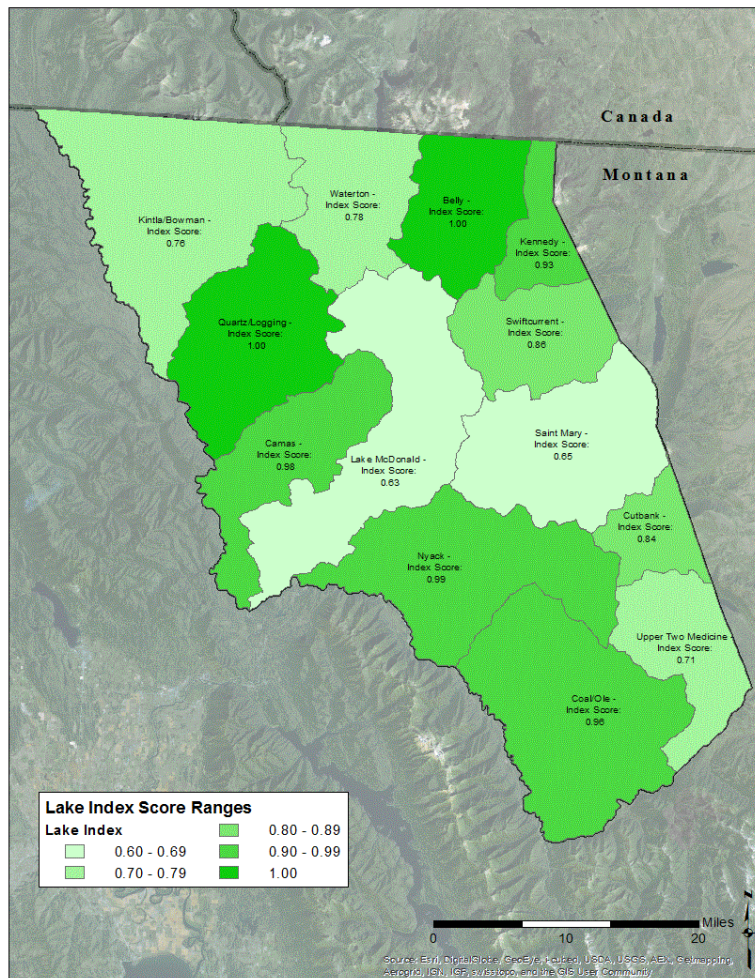


Figure 5.18. Index for lake condition in GLAC.

5.4 Focal Area – Native and Invasive Fish Populations

Glacier National Park supports 713 lakes ranging in size from fractions of acres up to Lake McDonald covering about 6,900 acres, and greater than 250 miles of stream habitat for aquatic species (GLAC GIS data). A diversity of native and introduced fish species occur in park waters (Table 5.26). However, there is limited historic (Read et al. 1982, Weaver et al. 1983) data to base precise native fish distributions or abundance estimates. Most of the effort in GLAC has been focused in the North and Middle Forks of the Flathead River and their tributaries in the park. More recently, significant effort has been focused on describing the distribution of bull trout in the St. Mary River drainage on the east side of the park. In the Flathead River Basin (Columbia Drainage) Flathead Lake and the Flathead River upstream of the lake, including the connected and accessible headwater streams and lakes (i.e., in the park and the Bob Marshall and Great Bear Wilderness), historically functioned as an interconnected watershed for migratory fish. Early in the 20th century, much of the interest in fishery resources related to “improving” the existing fishery by introducing native and non-native fish to historically fishless lakes (e.g., Yellowstone cutthroat trout to Hidden Lake) and introducing non-native species to lakes well populated with fish, but considered to have

too few species in the community (e.g., lake trout, lake whitefish, kokanee, yellow perch, etc. introductions into Flathead Lake). Herein we focus the assessment analysis on two genera, *Salvelinus* (char) and *Oncorhynchus* (trout) and the compromised ecological integrity of GLAC native populations due to either competitive exclusion or hybridization of the native species by introduced non-natives. See Appendix B for distribution maps of all salmonid species.

Table 5.26. Native (Nat) and introduced (Intro) salmonids in the three Drainages of Glacier National Park (modified from Downs et al 2011).

Species	Columbia Drainage	Missouri Drainage	Hudson Bay Drainage
Arctic grayling (<i>Thymallus arcticus</i>)	Introduced	--	Introduced
Brook trout (<i>Salvelinus fontinalis</i>)	Introduced	Introduced	Introduced
Bull trout (<i>Salvelinus confluentus</i>)	Native	--	Native
Lake trout (<i>Salvelinus namaycush</i>)	Introduced	--	Native
Lake whitefish (<i>Coregonus clupeaformis</i>)	Introduced	--	Native
Mountain whitefish (<i>Prosopium williamsoni</i>)	Native	Native	Native
Pygmy whitefish (<i>Prosopium coulteri</i>)	Native	--	Native
Kokanee (<i>Oncorhynchus nerka</i>)	Introduced	--	Introduced
Rainbow trout (<i>Oncorhynchus mykiss</i>)	Introduced	Introduced	Introduced
Westslope cutthroat trout (<i>Oncorhynchus clarkii lewisi</i>)	Native	Native	Native
Yellowstone cutthroat trout (<i>Oncorhynchus clarkii bouvieri</i>)	Introduced	Introduced	Introduced

5.4.1 *Salvelinus* (char)

Bull trout (*Salvelinus confluentus*) are native in GLAC watersheds located west of the Continental Divide and east of the Continental Divide north of the Hudson Bay Divide. In addition, GLAC supports both native (Hudson Bay drainage) and introduced (Columbia River drainage) populations of lake trout (*Salvelinus namaycush*), which are found principally occupying lake habitats. When lake trout are either introduced or are an invasive species into areas that have been historically occupied by bull trout, lake trout tend to out-compete the native bull trout in lake habitats leading to significantly reduced bull trout abundances in locations that were previously known to be strong populations (Fredenberg 2002). Although lakes in GLAC have experienced introductions and invasions of nonnative fishes, extirpations of native species as a direct result of the establishment of nonnative species has not been observed. It is believed that most recent invasions of lakes has occurred as a result of out-migration from an expanding lake trout population in Flathead Lake as a result of food web changes with cascading impact to both Flathead Lake and the upper Flathead River Basin (Ellis et al. 2011). Meeuwig et al. (2008) used a landscape ecological approach to examine the influence of landscape characteristics and heterogeneity on native fish species richness among lakes in Glacier National Park in the North and Middle Fork of the Flathead drainages. They found that nonnative species, particularly lake trout (*Salvelinus namaycush*), have become widespread throughout many of the tributaries of the North and Middle Forks of the Flathead River in GLAC, but they also showed that the upstream extent of lake trout distribution was limited by the presence of barriers to fish dispersal.

Lake trout invasion of lakes in the North and Middle Forks of the Flathead River from Flathead Lake has been the focus of recent research culminating in an action plan to conserve bull trout (Fredeberg et al. 2007). They grouped 17 lakes assessed for lake trout invasion into three threat categories: 1) secure lakes; Upper Kintla, Trout, Arrow, Isabel, and Upper Isabel, 2) vulnerable lakes; Akokala and Cerulean, and 3) compromised lakes; Lower Kintla, Bowman, Upper Quartz, Middle Quartz, Lower Quartz, Logging, Rogers, Harrison, McDonald, and Lincoln. Secure lakes were small backcountry lakes with fish passage barriers in the drainage downstream of the lake. As a result, they considered these lakes to have the most secure populations of bull trout. Vulnerable lakes were grouped together because they believed there is a high likelihood that they could become compromised by lake trout because of the absence of physical structures that would preclude fish passage in the drainages downstream thus giving access to invasive fishes moving upstream. Compromised lakes were defined as containing lake trout or brook trout (*Salvalinus fontinalis*). The status of lake trout invasion and corresponding status of bull trout populations in each lake was determined to be variable. These invasions illustrate there are no physical barriers downstream of these lakes to preclude ongoing lake trout movement or future invasions of other species from other waters in the interconnected Flathead Basin. See Appendix C for distribution maps of all char species.

5.4.2 *Oncorhynchus* (trout)

Westslope cutthroat trout (*Oncorhynchus clarkii lewisi*) are native in GLAC waters throughout the park in each of the watersheds of this assessment. Westslope cutthroat trout is a “Species of Concern” in Montana (Natural Heritage Program and American Fisheries Society) and as such is managed as a species of concern by the NPS. This unique subspecies of inland native trout has been petitioned for listing under the Endangered Species Act (ESA). However, in 2000, the US Fish and Wildlife Service determined that listing was not warranted. GLAC is considered a range-wide stronghold for westslope cutthroat trout; the long term persistence of non-hybridized populations is threatened by recent spread of nonnative rainbow trout introgression (Hitt et al. 2003, Boyer et al. 2008).

Recent work in the North Fork and Middle Fork Flathead Rivers has shown a rapid increase in hybridization spreading in an upstream direction, threatening potentially pure westslope cutthroat trout populations in GLAC. For example, using molecular DNA techniques, Hitt et al. (2003) found new hybridization in 8 of 11 (73%) reaches that were determined to be non-hybridized in 1988. Boyer et al. (2008) and Muhlfeld et al. (2009a) found that hybridization is spreading among reaches in an upstream direction from source streams in the lower river, and may not be constrained by environmental factors (Muhlfeld et al. 2009b). These data suggest that hybridization is spreading upstream, threatening non-hybridized (i.e., genetically pure) westslope cutthroat trout stocks in GLAC.

Westslope cutthroat trout have long been considered an integral component of biodiversity, culture and economy in GLAC. They are part of a historic fishery that is a fundamental part of the biodiversity of the park. As such, protecting native fish resources is a high priority for conservation and management programs in GLAC. Invading nonnative species, rainbow and lake trout, could

overwhelm and replace native westslope cutthroat trout due to hybridization, competition, and predation. Westslope cutthroat trout are particularly susceptible to hybridization with nonnative rainbow trout in situations in which anthropogenic habitat disturbances increase water temperature and degrade stream habitats. Habitat degradation and fragmentation have been identified as leading factors in the decline and extirpation of westslope cutthroat trout populations throughout their range (Liknes and Graham 1988). Muhlfeld et al. (2009b) showed that hybridization is likely to spread further up the North Fork and Middle Fork of the Flathead River and basin tributaries, causing additional westslope cutthroat trout populations to be lost, unless populations with high amounts of rainbow trout admixture are suppressed or eliminated. They also showed that protection of hybridized populations facilitates the expansion of hybridization. To preserve non-hybridized westslope cutthroat trout populations, managers should consider eradicating hybridized populations with high levels of rainbow trout admixture and restoring streams characterized by warm temperatures and high levels of disturbance. See Appendix C for distribution maps of all trout species.

5.4.3 Methods GLAC Fish

Stream Native/Non-Native Fish ($V_{\text{STREAMFISH}}$) and Flathead Fish ($V_{\text{FLTHDFISH}}$)

The spatial distributions of native and non-native salmonid species (see Table 5.26) within the park were provided by Montana Fish, Wildlife, and Parks (fwp.mt.gov/fishing/mFish/). These distributions are generated from a combination of actual sampled distribution and best professional judgment. The distribution layer was applied to all permanent streams within each watershed. If a species was present, the mapped portion of the stream within the species distribution received a numerical assignment of 1.0 representing 100% occupancy for that species. If the species is absent, the stream portion received a score of 0.0 representing 0% occupancy. All See Appendix C for distribution maps of all salmonid species.

A similar approach was used for the distribution of cutthroat-x-rainbow trout hybrid. However, information from Boyer et al. (2008) and Muhlfeld et al. (2009a) suggests that there is a concentration of hybrids at the confluence of the Middle Fork and North Fork that dissipates up the North Fork to the town of Polebridge, Montana. Above that point the cutthroat-x-rainbow trout hybrid have limited to no occurrence. To capture this decreasing distribution the North Fork was divided into 20 even segments from the confluence to Polebridge. These segments were scored as 1.0 (100% occupancy) at the confluence section to 0.0 (0% occupancy) at Polebridge with decreases of 5% at each segment to capture the decreasing concentrations of the cutthroat-x-rainbow trout hybrid. For the purpose of this assessment, it was assumed that the cutthroat-x-rainbow trout hybrid decreasing concentrations occur in a radius from the North Fork/Middle Fork confluence. Therefore, this segmented scoring was also applied to the Middle Fork upstream from the confluence with the same stream segment length and occupancy assignments. This approach was also applied to tributaries from the park that intersects with the North and Middle Fork of the Flathead River within this radius. For example, a park stream has its confluence on a North Fork segment with 60% occupancy; the joining stream would be assigned 55% occupancy and would decrease in occupancy

in same segments lengths used in the North Fork/Middle Fork and continue upstream until it reaches 0% occupancy.

The following describes the steps necessary to derive the final Stream Native-Non-native Metric score:

1. The sum of total permanent stream length presumed to be occupied by each salmonid species, including cutthroat-x-rainbow hybrids, was derived for each watershed. These lengths were divided by the total length of the permanent streams as mapped by GIS stream shape files provided by GLAC (stream.shp) within each watershed to obtain a percent occupancy for each species.
2. The sum of the percent occupancy of all native species and all non-native species for each watershed was determined. Because this is a cumulative percent occupancy for each watershed, the sum occupancy may be larger than 100%.
3. A ratio of native to non-native salmonid occupancy was acquired with a final score ranging from 0 to 1 using the following formula:

$$V_{\text{STREAMFISH}} \text{ (or } V_{\text{FLTHDFISH}}) = \frac{\text{Native stream occupancy}}{\text{sum of native and non-native stream occupancy}}$$

Lake Native/Non-native Fish (V_{LAKEFISH})

The spatial distribution of native and non-native salmonid species in the park's lakes (See Table 5.26) were also provided by Montana Fish, Wildlife, and Parks and the distribution layer was applied to all lakes within each watershed. As with the streams, the distributions were generated from a combination of actual sampled distribution and best professional judgment. If the distribution maps indicated that a species was present in a lake, the lake received a numerical assignment of 1.0 representing 100% occupancy for that species. If the species is absent, the lake received a score of 0.0 representing 0% occupancy. All See Appendix C for distribution maps of all salmonid species.

The distributions of the cutthroat-x-rainbow trout hybrid for lakes were mapped as an extension of the hybrid mapping for streams. If a lake as associated with a stream containing hybrids, then the lake received an occupancy assignment relative to the stream segment occupancy, however, the lake was treated as one segment of the hybrid distribution and received one occupancy assignment despite its size. For example, a stream at the outlet of a lake has hybrid occupancy of 70% then the lake received an occupancy score of 60% and stream segments entering the lake received an occupancy assignment of 50%.

The following describes the steps necessary derive the final Lake Native-Non-native Metric score:

1. The sum of total lake area occupied by each salmonid species, including cutthroat-x-rainbow hybrids, was derived for each watershed. The area of lakes occupied by a species was divided by the total lake area from GIS lake shape files provided by GLAC (lake.shp) within each watershed to obtain a percent occupancy for each species.

2. The sum of the percent occupancy of all native species and all non-native species for each watershed was determined. Because this is a cumulative percent occupancy for each watershed, the sum occupancy may be larger than 100%.
3. A ratio of native to non-native salmonid occupancy was acquired with a final score ranging from 0 to 1 using the following formula:

$$V_{\text{LAKEFISH}} = \text{native lake occupancy} / \text{sum of native and non-native lake occupancy}$$

Calculation of GLAC Fish Condition Score

To acquire an overall fish condition score for the park, the following index was applied the fish distribution metrics. The model is simply an average of the native / non-native ratios of GLAC's streams and lakes. The fish condition of the Flathead River's North and Middle Forks were provided as a separate index below.

$$\text{Fish Condition Index Score} = ((V_{\text{STREAMFISH}} + V_{\text{LAKEFISH}})/2)$$

5.4.4 Spatial Analysis Results

Please note that the fish distribution provided by Fish Wildlife and Parks were generated from a combination of actual sampled distribution and best professional judgment, therefore the following data are the best available estimate of distributions. Additional sampling would be required. These results use the best available data to provide a prioritization of future monitoring efforts. Appendix C provides maps of specific fish distributions in the park's lakes and streams.

Stream Native/Non-native fish ($V_{STRFISH}$)

The range of native and non-native occupancy in GLAC stream are provided in Tables 5.27a and 5.27b and the condition scores are provided in Table 5.27c. Cut Bank has no native salmonids mapped in its streams but a high occupancy of non-native salmonids. As a result this watershed scored the lowest in the park for stream fish condition. Alternatively Kintla/Bowman has no mapped non-native salmonids and therefore scored the highest for this metric (Figure 5.19).

Table 5.27a. The percent occupancy of native salmonids in GLAC streams.

Watershed	Percent Presence of Native Stream Fish				
	Bull Trout	Lake Whitefish	Mountain Whitefish	Cutthroat Trout	Lake Trout
Belly	22	0	28	13	9
Camas	14	0	32	39	0
Coal/Ole	29	0	33	43	0
Cut Bank	0	0	0	0	0
Kennedy	32	0	21	25	0
Kintla/Bowman	45	0	27	55	0
Lake McDonald	2	0	18	44	0
Nyack	21	0	22	25	0
Quartz/Logging	11	0	23	39	0
Saint Mary	15	0	18	24	0
Swiftcurrent	20	0	6	29	0
Upper Two Medicine	0	0	12	1	0
Waterton	0	19	0	10	19

Table 5.27b. The percent occupancy of non-native salmonids in GLAC streams.

Watershed	Percent Presence of Non-Native Stream Fish				
	Brook Trout	Rainbow Trout	Yellowstone Cutthroat Trout	Cutthroat-x-rainbow Hybrid	Arctic Grayling
Belly	31	33	0	0	16
Camas	1	1	0	11	0
Coal/Ole	16	0	0	1	0
Cut Bank	50	37	29	0	0
Kennedy	6	0	0	20	0
Kintla/Bowman	0	0	0	0	0
Lake McDonald	22	14	3	17	0
Nyack	25	0	0	9	0
Quartz/Logging	0	0	0	11	0
Saint Mary	2	24	0	5	0
Swiftcurrent	30	0	0	7	0
Upper Two Medicine	25	7	8	0	0
Waterton	51	27	0	0	0

Table 5.27c. The stream native/non-native salmonids occupancy and metric score in GLAC streams.

Watershed	Stream Native Sum	Stream Non-Native Sum	Stream Fish Metric Score
Belly	72	80	0.47
Camas	85	13	0.87
Coal/Ole	105	17	0.86
Cut Bank	0	116	0.00
Kennedy	78	26	0.75
Kintla/Bowman	127	0	1.00
Lake McDonald	64	56	0.53
Nyack	68	34	0.67
Quartz/Logging	73	11	0.87
Saint Mary	57	31	0.65
Swiftcurrent	55	37	0.60
Upper Two Medicine	13	40	0.25
Waterton	48	78	0.38

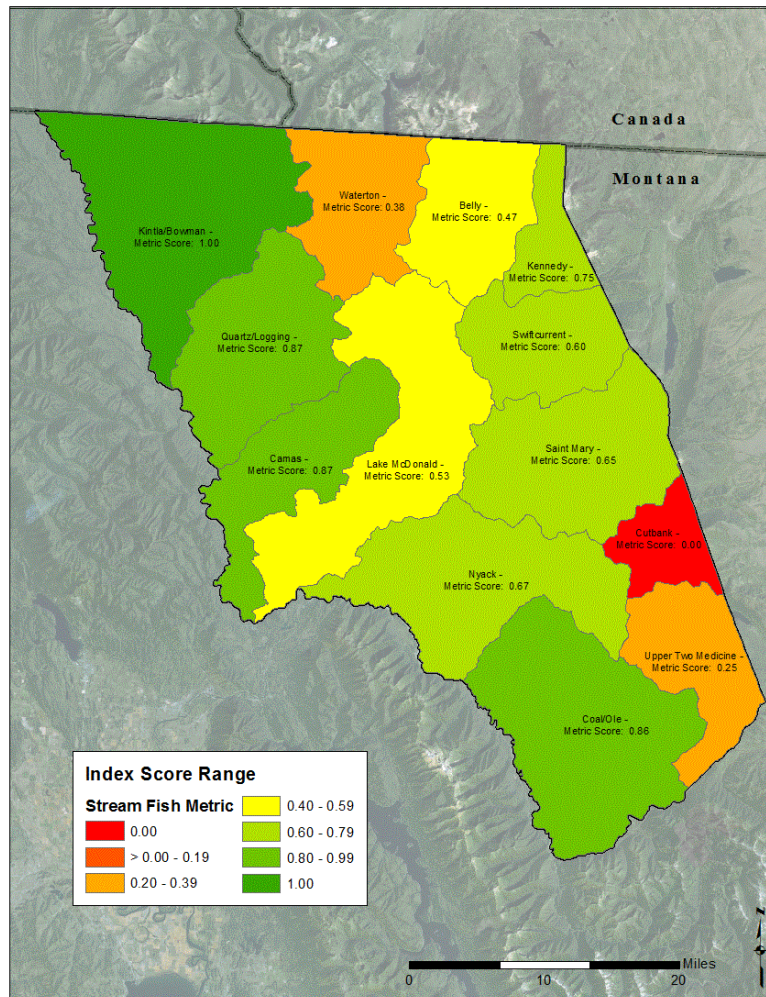


Figure 5.19. Metric for fish condition in GLAC streams.

Lake Native/Non-native fish (V_{LAKEFISH})

The range of native and non-native occupancy in GLAC lakes are provided in tables 5.28a and 5.28b and the condition scores are provided in tables 5.28c. Cut Bank and Upper Two Medicine have no native salmonids mapped in its lakes but a high occupancy of non-native salmonids. As a result these watersheds scored the lowest in the park for lake fish condition. Lake McDonald has the highest occupancy of native fish relative to the non-native fish occupancy and therefore scored the highest for this metric (Figure 5.20).

Table 5.28a. The percent occupancy of native salmonids in GLAC lakes.

Watershed	Percent Presence of Native Fish					
	Bull Trout	Lake Whitefish	Mountain Whitefish	Pygmy Whitefish	Cutthroat Trout	Lake Trout
Belly	0	0	39	0	6	39
Camas	65	0	26	0	65	0
Coal/Ole	14	0	0	0	15	0
Cut Bank	0	0	0	0	0	0
Kennedy	30	0	0	0	0	0
Kintla/Bowman	92	0	81	0	81	0
Lake McDonald	94	94	94	94	94	0
Nyack	59	0	59	0	59	0
Quartz/Logging	90	0	90	0	90	0
Saint Mary	0	87	3	0	87	0
Swiftcurrent	2	0	65	0	0	0
Upper Two Medicine	0	0	0	0	0	0
Waterton	0	56	0	0	2	56

Table 5.28b. The percent occupancy of non-native salmonids in GLAC lakes.

Watershed	Percent Presence of Non-Native Fish						
	Brook Trout	Lake Trout	Kokanee	Rainbow Trout	Yellowstone Cutthroat Trout	Cutthroat-x-rainbow Hybrid	Arctic Grayling
Belly	3	0	0	55	0	6	16
Camas	0	15	0	15	27	65	0
Coal/Ole	0	0	0	0	0	15	0
Cut Bank	0	0	0	18	9	0	0
Kennedy	0	0	0	0	21	0	0
Kintla/Bowman	0	80	80	0	0	81	0
Lake McDonald	0	94	94	94	4	24	0
Nyack	87	59	54	54	0	36	0
Quartz/Logging	0	86	0	0	3	90	0
Saint Mary	93	87	0	92	6	87	0
Swiftcurrent	82	0	76	65	0	0	0
Upper Two Medicine	75	0	0	55	4	0	0
Waterton	57	0	0	65	0	2	0

Table 5.28c. The native/non-native salmonids cumulative percent occupancy and metric score in GLAC Lakes.

Watershed	Native Sum Cumulative Percent	Non-Native Sum Cumulative Percent	Lake Fish Metric Score
Belly	84	79	0.52
Camas	156	123	0.56
Coal/Ole	30	15	0.66
Cut Bank	0	27	0.00
Kennedy	30	21	0.59
Kintla/Bowman	254	242	0.51
Lake McDonald	468	308	0.60
Nyack	177	290	0.38
Quartz/Logging	270	180	0.60
Saint Mary	177	365	0.33
Swiftcurrent	67	223	0.23
Upper Two Medicine	0	135	0.00
Waterton	113	124	0.48

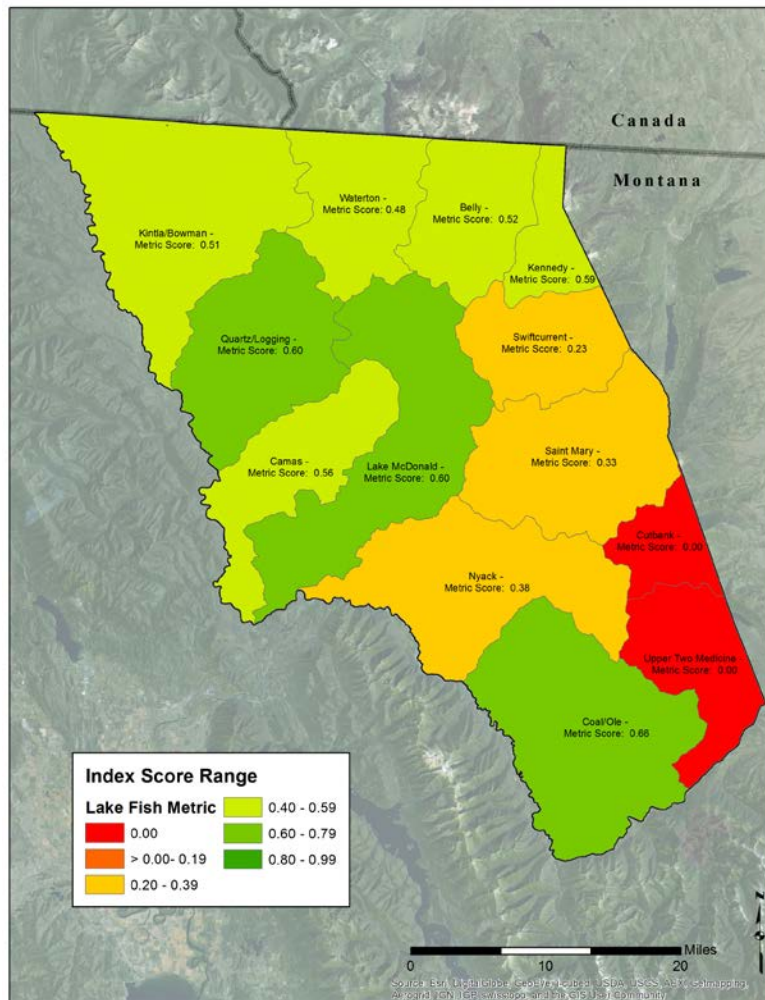


Figure 5.20. Metric for fish condition in GLAC lakes.

Fish Condition Index

The distributions of salmonid populations are used to calculate a ratio of native to non-native salmonids in GLAC lakes and streams. Metrics derived from these ratios are averaged to provide an overall index of salmonid condition for each watershed (Table 5.29). Cut Bank has no native salmonids in either its lakes or streams and therefore scored a 0.00 for condition. Upper Two Medicine has no native salmonids mapped in its lakes and therefore scored low. Lake McDonald and the Belly watersheds have the highest ratio of native fish relative to the non-native fish occupancy in its lakes and Kintla/Bowman in its streams and therefore scored the highest for this index. However all watersheds have been impacted by non-native fish species. (Figure 5.21).

Table 5.29. The fish metric and index scores in each watershed in Glacier National Park.

Watershed	Stream Fish Metric	Lake Fish Metric	GLAC Fish index
Belly	0.47	0.52	0.49
Camas	0.87	0.56	0.72
Coal/Ole	0.86	0.66	0.76
Cut Bank	0.00	0.00	0.00
Kennedy	0.75	0.59	0.67
Kintla/Bowman	1.00	0.51	0.76
Lake McDonald	0.53	0.60	0.57
Nyack	0.67	0.38	0.52
Quartz/Logging	0.87	0.60	0.74
Saint Mary	0.65	0.33	0.49
Swiftcurrent	0.60	0.23	0.41
Upper Two Medicine	0.25	0.00	0.13
Waterton	0.38	0.48	0.43

Table 5.30a. The percent occupancy of native salmonids in the North and Middle Forks of the Flathead River.

Flathead River Assessment Area	Percent Presence of Native Fish		
	Bull Trout	Mountain Whitefish	Cutthroat Trout
Middle Fork 1	100	100	100
Middle Fork 2	100	100	100
Middle Fork 3	100	100	100
Middle Fork 4	100	100	100
Middle Fork 5	100	100	100
Middle Fork 6	100	100	100
Middle Fork 7	100	100	100
North Fork 1	100	100	100
North Fork 2	100	100	100
North Fork 3	100	100	100
North Fork 4	100	100	100
North Fork 5	100	100	100
North Fork 6	100	100	100

Table 5.30b. The percent occupancy of non-native salmonids in the North and Middle Forks of the Flathead River.

Flathead River Assessment Area	Percent Presence of Non-Native Fish			
	Arctic Grayling	Rainbow Trout	Lake Trout	Cutthroat-x-Rainbow Hybrid
Middle Fork 1	0	100	100	88
Middle Fork 2	0	100	100	70
Middle Fork 3	0	100	100	48
Middle Fork 4	0	100	100	27
Middle Fork 5	0	100	100	9
Middle Fork 6	0	100	100	0
Middle Fork 7	0	100	100	0
North Fork 1	0	100	100	92
North Fork 2	0	100	100	77
North Fork 3	0	100	100	56
North Fork 4	93	6	100	21
North Fork 5	100	0	100	0
North Fork 6	100	0	100	0

Table 5.30c. The percent occupancy of non-native salmonids in the North and Middle Forks of the Flathead River.

Flathead River Assessment Area	Native Sum	Non-Native Sum	Flathead Fish Index Score
Middle Fork 1	300	288	0.51
Middle Fork 2	300	270	0.53
Middle Fork 3	300	248	0.55
Middle Fork 4	300	227	0.57
Middle Fork 5	300	209	0.59
Middle Fork 6	300	200	0.60
Middle Fork 7	300	200	0.60
North Fork 1	300	292	0.51
North Fork 2	300	277	0.52

Flathead River Assessment Area	Native Sum	Non-Native Sum	Flathead Fish Index Score
North Fork 3	300	256	0.54
North Fork 4	300	220	0.58
North Fork 5	300	200	0.60
North Fork 6	300	200	0.60

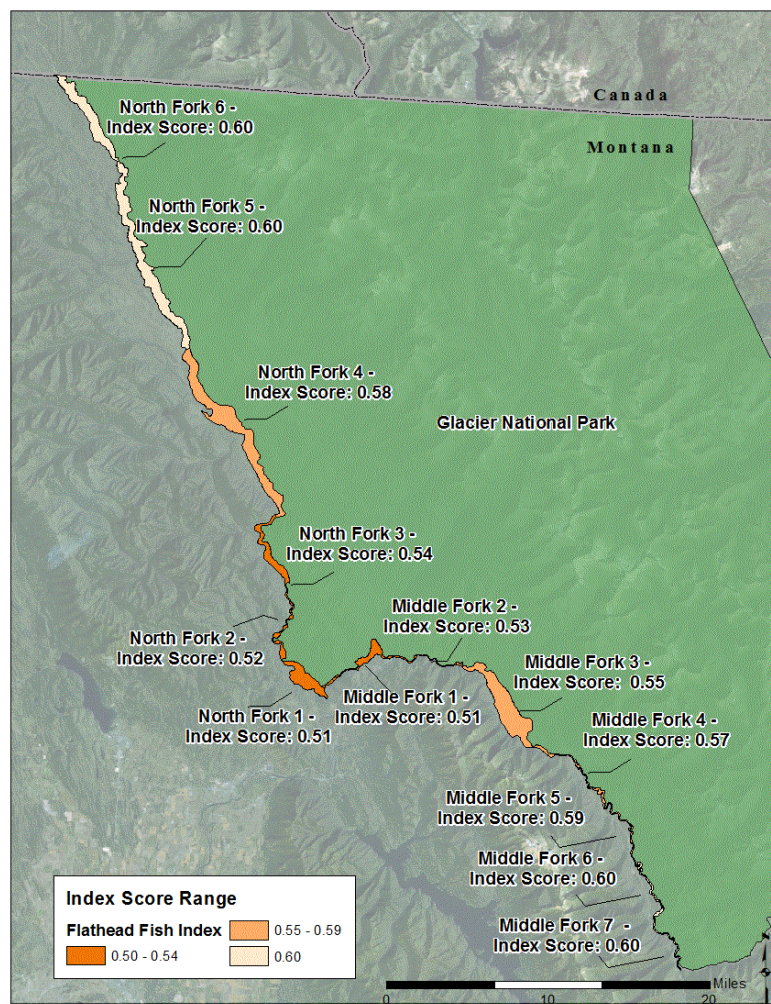


Figure 5.22. Flathead River fish condition index score range.

5.5 Focal Area - Avian Community

5.5.1 Overview: Using landbirds as an indicator species group

Using a small number of indicator species of birds to monitor ecosystem integrity is challenging (Hutto 1998). It is both cost- and time-prohibitive to monitor all bird species (Thibodeau 1983), therefore indicator species are selected. However, because of niche specialization, the maintenance of specific indicator species cannot guarantee the maintenance of all other species (Tracy and Brussard 1994). Additionally, it is common to select indicator species from the selection of Threatened, Endangered, and sensitive species; however, these populations can be rare and/or difficult to monitor.

The use of landbirds, as a collectively large group of indicator species, has provided the potential to improve upon the existing approach of monitoring a small number of indicator species because the number of indicator species will now be large enough and ecologically broad enough to require the maintenance of a variety of environmental conditions across landscape scales. In this assessment, we will use landbirds as an indicator survey group to evaluate the “health” of bird communities among different watersheds in Glacier National Park.

Summary of current conditions for birds

GLAC, with its diversity of habitat types and relatively intact ecosystems, supports an outstanding diversity of bird species. Over 260 bird species (Shea 2004) have been reported in the park. In 2004, the University of Montana’s Avian Science Center (ASC: avianscience.dbs.umt.edu) established a set of 260 points distributed along 26 landbird monitoring transects within the park. Thirty seven habitat types, as defined by the ASC’s landbird monitoring program vegetation classification scheme were surveyed in 2004 and 2005 (Young et al. 2004). The ASC detected 102 bird species using a single survey protocol (point counts). A comparison of ASC survey data from inside the park with data collected on National Forest lands in northwest Montana reveals that overall bird diversity and rates of occupancy by selected bird species within specific vegetation types are higher inside than outside the park. The presence of Glacier National Park is, therefore, not only critical to the maintenance of grizzly bear, wolf, and wolverine populations, but numerous bird species as well.

Bird communities in burned forests are unique compared to those in green, unburned forests (Hutto 1995, Caton 1996, Kotliar et al. 2002, Smucker et al. 2005). The ASC has investigated the local and landscape level factors that influence the distribution of birds in burned forests on US Forest Service lands and within Glacier National Park. In 2005, 2006, and 2007 ASC surveyed an additional 360 points within the park; survey points fell in a range of fire severities, from unburned forest adjacent to burned forest to severely burned forest with 100% tree mortality and standing dead snags. ASC detected 96 species, including post-fire specialists such as the Black-backed Woodpecker. For the 29 most commonly detected species, ASC compared density estimates from US Forest Service lands to those inside the park (Bate 2009). Thirteen species were significantly more abundant inside the park, whereas only six species were more abundant outside the park. Most importantly, a number of the more sensitive species to land disturbance, including Black-backed Woodpecker, Olive-sided Flycatcher, and Brown Creeper were among those more abundant inside the park. This suggests that the park provides high quality post-fire habitat.

Glacier National Park supports large tracts of forest undisturbed by human development and use, and this may be the single most important strategy for maintaining high-quality breeding bird habitat (Robinson et al. 1995). Forest fragmentation from anthropogenically driven vectors such as high road density, land development, and or land clearing that is followed by increased non-native or invasive plant species is thought to increase rates of nest predation and nest parasitism by Brown-headed Cowbirds to the point that many heavily fragmented landscapes function as population sinks, where low reproductive rates are outpaced by adult mortality. Road density within the park is very low and

so it is unlikely that fragmentation is affecting bird populations. Many other factors contribute to high habitat quality, including lack of human land use activities and exclusion of non-native species.

However, natural disturbances such as wildfire, floods, avalanches, and wind storms that fragment the landscape into diverse habitat mosaics are elemental to avian community health. Large and small disturbance events maintain a mosaic of habitat types at different successional stages (Sousa 1984; Turner 1997), which results in a diversity of habitat types. Because no two species occupy the same niche, it is important to maintain a diversity of habitat types and structural features across broader landscapes. Glacier National Park supports a wide range of habitats, including a variety of forest, riparian, shrub, and alpine habitats. These habitats support high bird species diversity, which is another important element for healthy bird communities. In addition, many of these habitat types are uncommon elsewhere in the region, including unlogged post-fire forest and alpine habitat. These and other key habitat types are important because many species are relatively restricted to a single habitat. Thus, the park has an important role to play in maintaining biodiversity across the region because it maintains habitat types in their natural condition.

In this assessment, the examination of many of the beneficial factors that contribute to bird community health in Glacier National Park is not possible due to the limited available data. However, excellent data on plant community composition, (i.e. habitat), has been developed for the park by the USGS-NPS Vegetation Mapping Program and it is feasible to examine bird community composition and diversity among watersheds based on the amount of different habitat types including the amounts of key habitat types important to sensitive species.

The single biggest contemporary threat to bird populations nationwide is the alteration or loss of habitat (Rappole 1996; Fiona and Monkkonen 2002), but this threat is minimal in GLAC since 92% of its lands are managed as wilderness. This wilderness designation has resulted in the protection of native vegetation from most of the factors that threaten bird community health. On the other hand, most federal, state, and private lands outside the park are heavily managed and influenced by many factors, including roads, timber harvest, grazing, hunting, and development. The main threat to the park from these activities is therefore confined to edges along the border of the Park. Contemporary threats in the region but beyond the park's boundary include energy development outside the park such as increased oil and gas development and wind farms. Finally, because of the migratory nature of many of the bird species found within the park, they spend much of their life cycle outside of the park where habitat loss poses a very real threat these species. This threat lies beyond the park's management influence.

Some kinds of recreation within the park may pose a threat to avian community health. Specifically, boating, fishing, and other activities on lakes within the park may disturb nesting waterfowl and Bald Eagles. Other forms of human disturbance, including hiking and camping, have the potential to disturb wildlife movement, foraging activities, nest success, and even survival. Camping areas and heavily used day use areas have the potential to increase populations of nest predators such as corvids, squirrels, and chipmunks if surplus food is available. Existing park policies of limiting user access and requiring that food is stored in bear proof containers and that wildlife not be fed are likely to mitigate these threats.

Climate change is also a serious threat to avian communities in the park, particularly those high elevation species that have a restricted range. Climate change is likely to influence plant community distribution and phenology and this will affect food resources that birds depend on such as insects, fruits and seeds, and flowers for hummingbirds.

5.5.2 Methods: Avian Condition

Bird diversity (V_{BIRDDIV})

Bird diversity is closely correlated with habitat diversity (especially structural diversity) because each species depends on specific habitat features. Examples of these features include tree species composition, features of the shrub understory layer, standing dead trees (snags), riparian vegetation, and dense canopy cover. Often, these features are found only in a few habitat types, and thus many species are restricted to a handful of habitats. An extreme example is the Common Yellowthroat, which is virtually restricted to wetland habitat (Hutto and Young 1999). Because of these specialist species, overall bird diversity tends to be tied to high habitat diversity, rather than large tracts of a smaller number of habitats.

GLAC supports a wide range of ecological system plant classifications, from Rocky Mountain Cedar Hemlock Rainforest to Rocky Mountain Alpine Meadows. These habitats have been mapped by the USGS-NPS Vegetation Mapping Program (VMP). This project provides a list of 28 plant communities, their ecological description, and a GIS layer showing their distribution (Hop et al. 2007). This list of plant communities, or habitat types, can be used to examine bird diversity within the park based on ASC's understanding of bird-habitat relationships.

The ASC has operated a Landbird Monitoring Program (LBMP) in western Montana since 1994. As part of this program, ASC also collects data on the dominant habitat type at each point surveyed (Young et al. 2004). By tying bird distribution data to the vegetation type we can understand the relationship between bird occurrence and habitat type. The habitat types used in the LBMP classification scheme were cross-referenced to the 28 plant communities provided by the VMP project. This resulted in 20 different habitat types that correspond with habitat types used in the LBMP habitat scheme (Table 5.31). Data collected from 2363 points, including 260 points within GLAC along with ASC's understanding of bird-habitat relationships (Hutto and Young 1999) were then used to generate bird species lists for 13 of 20 habitat types. ASC currently have insufficient data on the bird community composition in the remaining seven habitat types within the park.

Table 5.31. Crosswalk of VMP project ecological descriptions of plant communities and LBMP habitat type classification scheme. For those habitats in italics we had sufficient data to generate bird habitat relationships.

Ecological Description (NVC2_L6X) from Veg. Map Program	Habitat name for report from LBMP
<i>Mountain Perennial Glacier and Snowfield (non-NVC)</i>	<i>None</i>
<i>Rocky Mountain Shoreline Vegetation</i>	<i>None</i>
Developed Area (non-NVC)	Developed Area
Other Cultural Area (non-NVC)	Developed Area
Rocky Mountain Montane Grassland	Intermountain Grassland
Inter-Mountain Basin Montane Sagebrush Steppe	Sagebrush Steppe
Northern Rocky Mountain Lower Montane Deciduous Shrubland	Dry Shrubfield
Northern Rocky Mountain Avalanche Chute Shrubland	Subalpine Mesic Shrubfield
Rocky Mountain Montane Limber Pine - Juniper Woodland	Limber Pine-Juniper Woodland
Rocky Mountain Mesic Montane Conifer Forest	Mixed Coniferous Forest
Rocky Mountain Subboreal and Montane Conifer Forest	Lodgepole Pine Forest
Rocky Mountain Subalpine Mesic Conifer Forest and Woodland	Subalpine Spruce-Fir Forest
Rocky Mountain Subalpine Whitebark Pine and Subalpine Larch Woodland	Subalpine Spruce-Fir Forest
Northern Rocky Mountain Conifer Swamp and Riparian Forest	Cedar-Hemlock Forest
Rocky Mountain Cedar - Hemlock Rainforest	Cedar-Hemlock Forest
Rocky Mountain Conifer Swamp and Riparian Forest	Cedar-Hemlock Forest
Northern Rocky Mountain Ponderosa Pine Woodland	Dry Ponderosa Pine-Douglas Fir Forest
Rocky Mountain Subalpine (Cool) Deciduous Broadleaf and Mixed Forest	Mixed Deciduous-Coniferous Forest
Open Water Stream/River and Lake/Pond (non-NVC)	Lakes and Ponds
Western North America Emergent Marsh	Marsh
Rocky Mountain Wet Meadow and Snowbed	Sedgeland-Wet Meadow
Northern Rocky Mountain Montane Riparian Forest	Montane Riparian Habitat
Rocky Mountain Subalpine and Montane Riparian Shrubland	Montane Riparian Habitat
Rocky Mountain Alpine Dry Scrub and Fell-field	Alpine Scrub and Meadow
Rocky Mountain Alpine Meadow	Alpine Scrub and Meadow
Rocky Mountain Alpine Cliff, Scree, and Other Rock Vegetation	Alpine Cliff, Talus and Scree
Rocky Mountain Early Successional Forest, Shrubland, and Forb Meadow	Early Successional Forest
Rocky Mountain Shoreline Vegetation	Montane Riparian Habitat
Rocky Mountain Subalpine Whitebark Pine and Subalpine Larch Woodland	Mixed Coniferous Forest
Rocky Mountain Subalpine and Montane Riparian Shrubland	Montane Riparian Habitat

Commonness Defined: Since bird diversity is closely tied to the habitats within a watershed, we calculated a score for bird diversity that is based on habitat diversity. However, a grand list of species associated with each habitat within a watershed could be misleading because some common habitat types provide habitat for a large number of generalist species. These common habitats with large species lists obscure the value of rare plant communities which provide habitat for a small and unique assemblage of species. For example, Watershed-A might include four common habitats and 72 bird species, while Watershed-B might include four different habitat types as well, but with three of these habitats supporting only a handful of bird species that are relatively restricted to a particular habitat. Consequently the grand list for Watershed-B might include only 47 bird species. So, which

watershed is more valuable for birds? One could argue that Watershed-B is more valuable because of the presence of these rare bird species in specialized habitats. To deal with this issue of habitat specialization, the habitat breadth or “commonness” of each species was assessed by applying correction factors. A correction factor of 1 was applied to species that are encountered in many habitat types (greater than five), 2 was applied to species encountered in two to four habitat types, and correction factor of 3 was applied to encountered only in one habitat type. Each bird species was multiplied by these correction factors, and summed for each habitat type to produce an overall diversity score that incorporates both the number of species and their degree of habitat specialization. Then the amount of each habitat in a watershed was multiplied by the diversity score for each habitat. These measures of bird diversity, adjusted for habitat area, were then summed to produce a total score for each watershed.

The intent of this assessment is to address the extent to which each watershed provides habitat for a diversity of bird species, with an emphasis on species that are habitat specialists. Thus, scores are based on a combination of the diversity of habitat types, total number of species, and the habitat breadth of those species (Table 5.32):

Table 5.32. Bird Diversity (V_{BIRDDIV}) metric scoring.

Metric Criteria:	Metric Score
Mean commonness score is above 25	1.00
Mean commonness score is between 15 and 25	0.75
Mean commonness score is between 5 and 15	0.50
Mean commonness score is below 5.	0.25

Post-fire habitat (V_{FIREHAB})

Periodic wildfires are the primary recurring disturbance that has shaped vegetation and faunal communities in western North America (Habeck and Mutch 1973; Agee 1993; Arno and Allison-Bunnell 2002). Wildfires create a mosaic of post-fire conditions when severity and frequency vary over space and time and this contributes to landscape heterogeneity. Post-fire habitats are valuable in their own right because they support a number of habitat features and biological legacies (e.g. snags and burned out root holes) that are important for many plant and animal species (Whelan 1995; Smith 2000; Franklin et al. 2000).

Bird communities in burned forests are unique compared to those in green, unburned forests (Hutto 1995, Caton 1996, Kotliar et al. 2002, Smucker et al. 2005). Data collected from burned forest habitat in Glacier National Park and northwest Montana indicate that at least ten species are more frequently detected in burned forest than any other habitat type. In fact several species, including the Black-backed and Three-toed Woodpeckers are nearly 10 times more abundant in burned forest conditions than in any other major vegetation type or condition (Hutto 1995). Thus, to the extent that these species depend on post-fire habitat, the amount of this habitat type within the park contributes to the overall health of bird communities. Post-fire habitat within the park is even more valuable to wildlife because the majority of wildfires outside of national parks and wilderness areas are still aggressively suppressed. Even more importantly, fires outside the park burn through heavily

managed lands, which do not support fire-dependent bird species nearly as well as the less heavily, managed lands inside the park (Hutto 2008).

The overall health of bird communities depends on the presence and condition of key habitats for habitat specialists. We could examine numerous key habitats, including riparian habitats and white-bark pine communities. Here we focus in on two habitat types that are either rare or of lower habitat quality outside the park. Thus watersheds in the park with high proportions of these habitat types are particularly valuable for maintaining healthy populations of the species that depend on these habitats.

Many wildfires that originate in Glacier National Park are allowed to burn because the park's Fire Management Plan permits naturally ignited wildfires to burn, unless developed areas are at risk or other factors indicate that suppression is required. We used the Monitoring Trends in Burn Severity (MTBS) dataset to calculate the total number of acres of recently burned forest (1984 - 2008) within each watershed (MTBS Data Access 2010). Since burned forest provides valuable habitat for a unique bird assemblage, the amount of post-fire habitat in a watershed can be used to calculate a score for post-fire bird community occurrence (Table 5.33): It should be noted that most fire dependent species will move long distances within the region to take advantage of other recent burns and that this watershed scale assessment provides only an assessment of available habitat relative to other areas in the park.

Table 5.33. Post-fire habitat (V_{FIREHAB}) metric scoring.

Metric Criteria:	Metric Score
Watershed contains greater than 15,000 acres of post fire habitat	1.00
Watershed contains between 300 – 15,000 acres of post fire habitat	0.50
Watershed contains less than 300 acres of post fire habitat	0.10

Alpine habitat ($V_{\text{ALPINEHAB}}$)

High-elevation vegetation communities represent a small proportion of the total land area, both in Glacier National Park, and throughout western North America. These alpine habitat types are thought to be particularly vulnerable to global climate change due to habitat fragmentation and shifts in species ranges (Theurillat and Guisan 2001; Beniston 2003; Dirnböck et al. 2003). Latitudinal and elevational shifts in species ranges have been documented for a number of species (Parmesan 2006; Wilson et al. 2007). For these reasons this habitat type should be closely monitored to determine whether local extinctions are occurring.

The Landbird Monitoring Program has surveyed only a handful of points in the park's herbaceous and shrub tundra habitat types. These data, combined with information from the Birds of North America individual species accounts (Poole 2005), reveal that bird communities in this subalpine habitat are unique, supporting a number of the park's species that are not found in other habitat types, including American Pipit, Gray-crowned Rosy-Finch, and White-tailed Ptarmigan.

Alpine habitats in Glacier National Park warrant close monitoring due to their vulnerability to climate change. Alpine habitat areas are above 6,500 feet on the DEM and within alpine vegetation

cover types on the GLAC vegetation classification data (glac_vegmap.shp): Rocky Mountain alpine cliff, scree, and other rock vegetation, Rocky Mountain alpine dry scrub and fell-field, Rocky Mountain alpine meadow, and Rocky Mountain wet meadow and snowbed. An alpine layer was created (Alpine_trueveg_wtrshd.shp) which was intersected with GLAC study watersheds (GNP_HUC10_2011.shp) to create the final alpine GIS layer. The amount of alpine habitat in a watershed can be used to calculate a score for alpine bird community occurrence (Table 5.34).

Table 5.34. Alpine habitat ($V_{\text{ALPINEHAB}}$) metric scoring.

Metric Criteria:	Metric Score
Watershed contains greater than 20,000 acres of alpine habitat	1.00
Watershed contains between 10,000 – 20,000 acres of alpine habitat	0.66
Watershed contains less than 10,000 acres of alpine habitat	0.33

Human Disturbance ($V_{\text{HUMANDIST}}$)

In GLAC a number of different types of recreation have the potential to affect birds negatively. Hiking, boating, and camping certainly affect bird movement and foraging activities for the period of time that humans occupy an individual's territory. However, the question of whether these disturbances translate into significant population consequences is uncertain. Human disturbance of wildlife is really only relevant when it causes a population decline due to lowered reproductive success or survival (Gill 2001).

There are many benefits to concentrating visitor activity into designated camping areas (e.g. decreased habitat fragmentation, facilitation of safe food storage and garbage removal, etc.) but there may also be consequences for avian communities. There is good evidence that many native species such as corvids, Brown-headed Cowbirds, squirrels, and mice can tolerate increased human disturbance (Marzluff et al. 1994; Marzluff and Ewing 2001) and may benefit from increased food resources associated with camping areas. These species are also efficient nest predators (or parasites in the case of the Brown-headed Cowbird), and so increases in their populations near camping areas has the potential to lower nest success and juvenile survival for landbird species in those areas.

Concentrating human activity has the potential to support artificially high populations of corvids (e.g. Common Raven, American Crow, Gray Jay, Stellar's Jay) which may in turn cause higher predation pressure on landbirds. While we do not currently have data to examine corvid populations near and far from zones of human activity we can estimate how the potential risk varies among watersheds.

Unfortunately, there are currently no data from Glacier National Park to investigate whether camping areas and high day use areas (e.g. picnic areas and popular hiking trails) are a threat to landbird communities. However, we can estimate the *risk* to bird communities by using a surrogate measure of impact from the area proximal to human use based on the proximity to roads, railroads, buildings and campsites, and trails. A raster based assessment was developed using five raster datasets (or shape files converted to raster) available from the park: park's roads geo-database, railways from the BNSF geo-database, Trails_20050501.shp, buildings building2006.shp, and campsites.shp. For consistency, the same buffers area applied to roads, railroads, campsites, structures, and trails are

applied for the analysis of avian, mammals, and vegetation ecological condition assessment. The buffers was applied to the various types of roads found in or near the park: Roads-1 are paved major highways (2-mile buffer), Roads-2 are primary paved roads within the park (1-mile buffer), Roads-3 are secondary paved roads within the park (0.5 miles buffer), and Roads-4 are the park's gravel or two-track roads (0.25-mile buffer). Buffers were also applied to the railroad (2 miles), building and campsites (0.25 miles), and tails (300 feet). Although the park has requested that all analysis effort was to be completed in English units, raster analysis was completed in metric units to correspond to potential future Landsat data format. Therefore, each raster layer was established with a 30-meter grid and the human infrastructure was buffered and corresponding buffer grid was scored following the criteria in Table 5.35. If the cell was less than or equal to the Euclidean buffer distance and greater than the previous buffer distance the cells received the assigned cell score. If greater than the max distance then the cell score was 1.0. The layers were then superimposed and the lowest of each layer's cell score was assigned to the final cell layer. The cell scores were then averaged for each watershed.

Table 5.35. Human disturbance ($V_{\text{HUMANDIST}}$) metric scoring assigned to the appropriate raster cells.

Raster	Total Buffer size (mile)	Total Buffer size (m)	Raster Cell Score Assigned to Buffer Distances (m)									
			0	0.1	0.2	0.3	0.4	0.5	0.6	0.7	0.8	0.9
Road 1	2.00	3218	50	402	754	1106	1458	1810	2162	2515	2867	3219
Road 2	1.00	1609	50	223	397	570	743	916	1090	1263	1436	1609
Road 3	0.50	805	50	134	218	302	385	469	553	637	721	805
Road 4	0.25	402	50	89	128	167	207	246	285	324	363	402
Railroad	2.00	3218	50	402	754	1106	1458	1810	2162	2515	2867	3219
Building	0.25	402	50	89	128	167	207	246	285	324	363	402
Trail	300 (ft)	~90	-	-	-	-	-	-	-	30	60	90

Calculation of condition index

The primary objective of evaluating the ecological condition of bird communities in Glacier National Park is to establish a baseline index that can be used to measure how conditions change in the future, especially with threats such as global climate change in mind. It is important to realize that low scores for the three ecological attributes, bird diversity and amount of key habitats for unique bird assemblages, does not indicate that the watershed is in poor condition. Rather a low score should be interpreted to mean that the watershed has a lower potential to support high bird diversity and/or unique bird assemblages requiring the two habitats (post-fire and alpine) evaluated in this assessment. However, one of the attributes, the amount of post-fire habitat, is dynamic and watershed scores could shift in future years as new wildfires occur. For all attributes the species lists associated with different habitat types are likely to shift with global climate change, and so these metrics can be re-calculated in future years to determine how conditions for birds have changed among watersheds.

The threats evaluated in this ecological assessment are a baseline estimation of bird community's exposure to human disturbance. It is important to note that this assessment does not actually measure whether these threats negatively affect bird communities. Thus watersheds with a low score should not be interpreted as negatively affected by human disturbance; rather a low score suggests that these watersheds have a potential for these negative effects. The ecological assessment scores can thus be used to develop diverse monitoring approaches that could address human impacts and potential mitigation efforts.

The final index is intended to capture a combination of each of the above metrics to represent the general condition of each watershed to support a healthy bird population. By necessity, the index is a simplification of the complex elements necessary to maintain avian populations. However the collection of these metrics into an index provides insight on the relative condition of the selected habitat types, human impacts and general bird diversity of each of the Park's watersheds. As with all models in the assessment it provides a score for a watershed derived from the diversity of the habitat and proximity to human activity that is relative to other watersheds in the park only. The bird index is as follows:

$$\text{Bird Condition Score} = \text{square root of } (V_{\text{HUMANDIST}} * (((V_{\text{FIREHAB}} + V_{\text{ALPINEHAB}})/2) + V_{\text{BIRDDIV}})/2))$$

5.5.3 Avian Condition Results

We used five metrics to assess the health of bird communities among different watersheds within the park. Bird diversity and the amount of two key habitats were considered attributes that contribute to the overall health of bird communities, while human disturbance and concentrated human activity were evaluated as potential threats to bird community health. There was variation among watersheds for all five metrics, and we had sufficient data for analysis for each metric in most watersheds. All analyses involved using geographic information systems (GIS) to generate the area of a particular habitat within a watershed, and these areas were used in the final calculation of the metric (ESRI).

Bird diversity (V_{BIRDDIV})

There was little variability in the total number of habitat types among watersheds; most watersheds supported 20 to 25 habitats (Table 5.36). Consequently the total species lists for each watershed were quite similar (range = 101 – 105). This is because most watersheds start in the high alpine region and descend to forested valley bottoms passing through a range of habitats in between. However when we accounted for variability in the number of habitats in which a species was detected and the amount of each habitat in a watershed, the resulting bird diversity scores differed among watersheds. Bird diversity scores ranged from 29.60 to 40.92. Although diversity scores were closely correlated with the number of habitat types in a watershed (Pearson Correlation = .834, $p = 0.001$), the watershed with the most habitat types did not always have the highest diversity score. Commonness score accounts for the total number of species, degree of habitat specialization, and total area of each habitat type within a watershed. For example Kintla/Bowman watershed had 24 habitat types, but the bird commonness score for this watershed was near the middle at about 38. This is most likely due to the dominance of a single habitat type, subalpine spruce-fir forest, at 42% of the total area. The metric scores by watershed represent a healthy baseline that could be re-evaluated in the future (Figure 5.23).

Table 5.36. Number of habitats, commonness score, and assessment score for each watershed.

Watershed	Number of Habitats	Commonness Score	Bird Diversity Metric
Belly	22	29.60	1.00
Camas	24	40.92	1.00
Coal/Ole	22	33.62	1.00
Cut Bank	22	30.09	1.00
Kennedy	22	28.35	1.00
Kintla/Bowman	24	37.67	1.00
Lake McDonald	25	37.81	1.00
Nyack	25	35.35	1.00
Quartz/Logging	23	38.69	1.00
Saint Mary	23	31.62	1.00
Swiftcurrent	23	30.43	1.00
Upper Two Medicine	22	31.19	1.00
Waterton	20	32.82	1.00

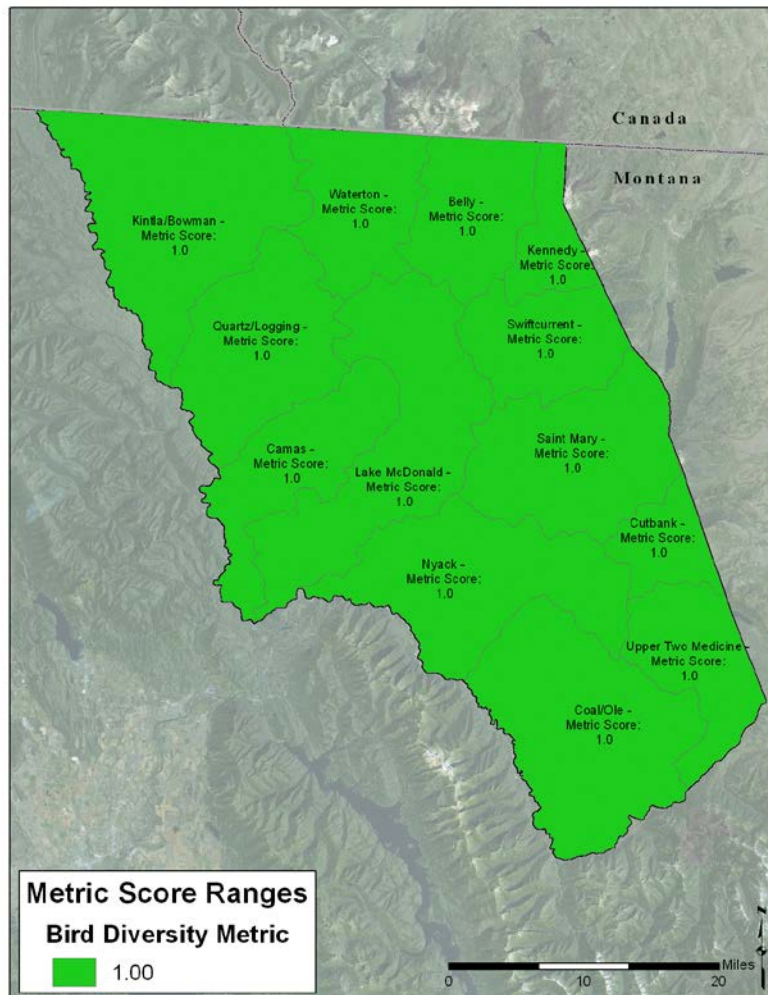


Figure 5.23. Range of bird diversity metric scores

Post-fire habitat (V_{FIREHAB})

For the purposes of this study, a minimum of 300 acres was considered to be a significant amount based on the estimated size of a single Black-backed Woodpecker's home range. Seven of the 13 watersheds in Glacier National Park have had at least 300 acres of burned land since 1984 (Table 5.37) (MTBS Data Access 2010). Only one watershed, Saint Mary River, has had a fire within the last six years, the time period that is ideal for post-fire specialists, perhaps making this watershed the most valuable for fire-dependent species. However burned habitats do continue to provide habitat for post-fire specialists beyond the initial six year period, and many secondary cavity nesters (e.g. House Wren, Mountain Bluebird) move into these older burned forests. Burned forest habitats are important for at least 24 bird species and as many as 87 species have been documented in burned forests (Hutto 1995). It should be noted that most fire dependent species will move long distances to take advantage of recent burn and that this watershed scale assessment provides only an assessment of available habitat relative to other areas in the park. The range of metric scores by watershed is presented in Figure 5.24.

Table 5.37. The years in which fires occurred, total area burned (acres), and assessment score for each watershed in Glacier National Park.

Watershed	Fire years	Total Acres Burned	Fire Habitat Score
Belly	2003	0.40	0.1
Camas	1999, 2001, 2003	40381.70	1.0
Quartz/Logging	1988, 1994, 1999, 2001, 2003	36935.20	1.0
Cut Bank	2003	15.94	0.1
Nyack	1984, 2003	12371.70	0.5
Kennedy Creek	2003	23.50	0.1
Kintla/Bowman Lake	1994, 2000, 2003	51546.10	1.0
Lake McDonald	1998, 2003	47444.50	1.0
Saint Mary River	2006	18,734.00	0.1
Coal/Ole	1984, 2003	24156.20	0.5
Swiftcurrent Creek	1984	54.31	0.1
Upper Two Medicine River	2003	0.20	0.1
Waterton	1998	1,065.30	0.5

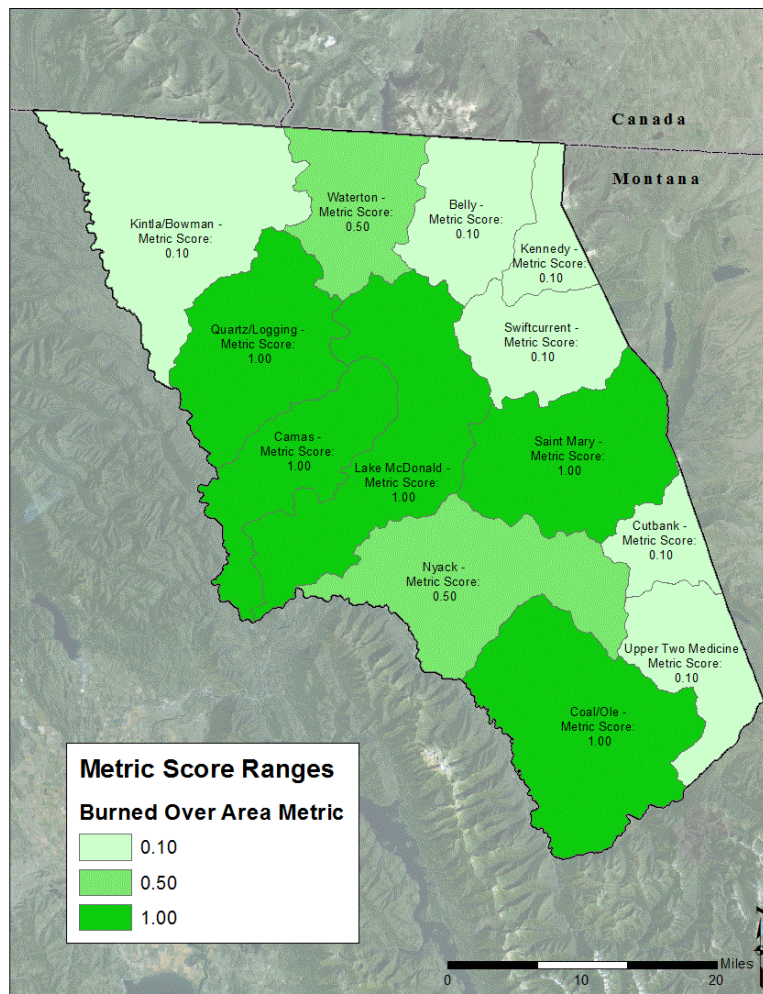


Figure 5.24. Range of specialized bird habitat (burned over area) in GLAC.

Alpine habitat ($V_{\text{ALPINEHAB}}$)

All thirteen watersheds within the park supported the four types of ecological system plant classifications that we lumped as alpine habitat for this analysis: Rocky Mountain alpine cliff, scree, and other rock vegetation; Rocky Mountain alpine dry scrub and fell-field; Rocky Mountain alpine meadow; and Rocky Mountain wet meadow and snowbed (Table 5.38). This speaks to the fact that Glacier National Park is a mountain park, supporting much of the alpine habitat in the state of Montana. Alpine habitats are important for at least 25 bird species, many of which occur in no other habitat (e.g. Gray-crowned Rosy-Finch and White-tailed Ptarmigan); these species are particularly vulnerable to climate change and warrant close monitoring. The range of metric scores by watershed is presented in Figure 5.25.

Table 5.38. The number of alpine habitat acres and assessment score in each watershed in GLAC.

Watershed	Alpine acres	Alpine Score
Belly	24,183.52	1.00
Camas	3,340.60	0.33
Coal/Ole	18,224.99	0.66
Cut Bank	13,780.33	0.66
Kennedy	10,833.71	0.66
Kintla/Bowman	17,920.49	0.66
Lake McDonald	20,939.31	1.00
Nyack	19,914.18	0.66
Quartz/Logging	11,117.45	0.66
Saint Mary	34,742.87	1.00
Swiftcurrent	17,452.61	0.66
Upper Two Medicine	16,892.48	0.66
Waterton	21,890.60	1.00

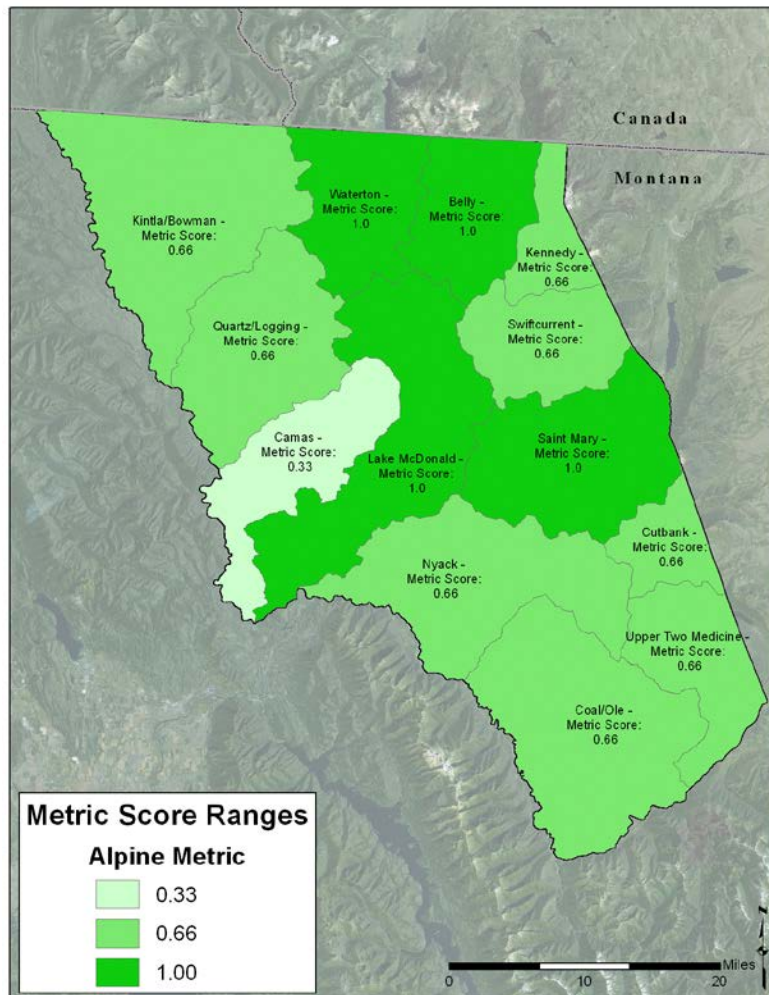


Figure 5.25. Range of specialized bird habitat (alpine area) in GLAC.

Human disturbance ($V_{HUMANDIST}$)

Watersheds with developed infrastructure including roads, buildings, campsites, and trails scored the lowest with this human disturbance metric (Table 5.39). Due to the numerous roads, lodges, facilities and in-holdings, Lake McDonald scored the lowest. Coal/Ole and Upper Two Medicine were affected by their proximity to major highways and population centers. The range of metric scores by watershed is presented in Figure 5.26.

Table 5.39. The human impact metric score in each watershed in Glacier National Park.

Watershed	Human Impact Score
Belly	0.97
Camas	0.82
Coal/Ole	0.86
Cut Bank	0.98
Kennedy	0.89
Kintla/Bowman	0.91
Lake McDonald	0.78
Nyack	0.91
Quartz/Logging	0.93
Saint Mary	0.85
Swiftcurrent	0.92
Upper Two Medicine	0.85
Waterton	0.99

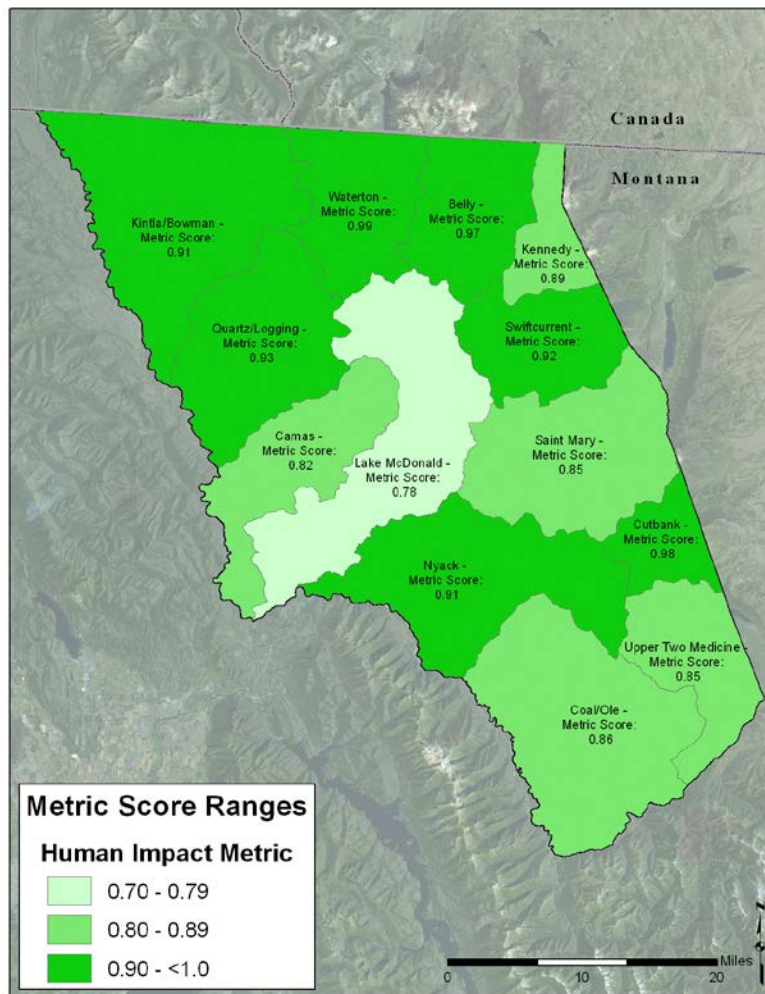


Figure 5.26. Range of potential human impact on bird habitat within GLAC.

Bird Condition Index Score

Avian condition index is comprised of three significance metrics that measure habitat and bird diversity and one stressor metric that measures proximity of bird habitat to human infrastructure. Metrics were combined to provide an assessment index of avian condition in the park's watersheds. Birds are very mobile and, although these metrics measure the range of natural variability of contemporary habitat in the park, for metrics like fire habitat bird species can travel long distances to locate preferable areas. Given that, Kennedy Creek and Upper Two Medicine watersheds scored the lowest predominantly due to a combination of low post fire habitat and high corvid habitat. Waterton and Quartz/Logging scored the highest amongst all watersheds (Table 5.40 and Figure 5.27).

Table 5.40. Each bird condition metric and index scores.

Watershed	Bird Diversity	Fire Habitat	Alpine	Human Impact	Bird Condition Index Score
Belly	1.00	0.10	1.00	0.97	0.87
Camas	1.00	1.00	0.33	0.82	0.83
Coal/Ole	1.00	1.00	0.66	0.86	0.89
Cut Bank	1.00	0.10	0.66	0.98	0.82
Kennedy	1.00	0.10	0.66	0.89	0.78
Kintla/Bowman	1.00	0.10	0.66	0.91	0.79
Lake McDonald	1.00	1.00	1.00	0.78	0.88
Nyack	1.00	0.50	0.66	0.91	0.85
Quartz/Logging	1.00	1.00	0.66	0.93	0.92
Saint Mary	1.00	1.00	1.00	0.85	0.92
Swiftcurrent	1.00	0.10	0.66	0.92	0.80
Upper Two Medicine	1.00	0.10	0.66	0.85	0.77
Waterton	1.00	0.50	1.00	0.99	0.93

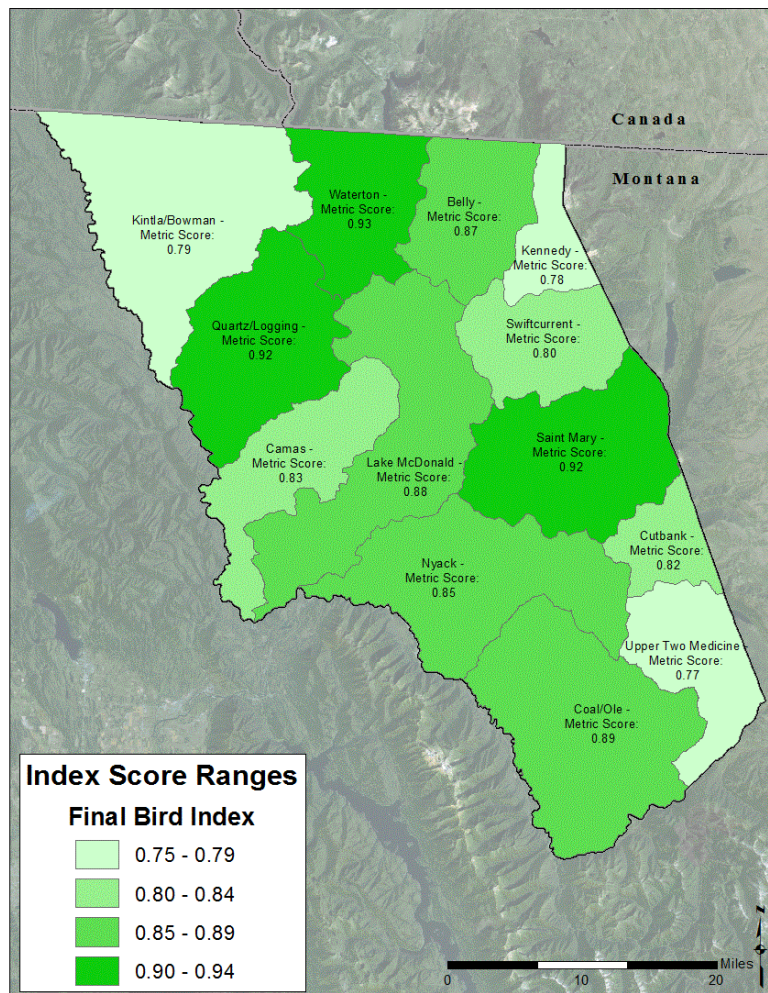


Figure 5.27. Final Bird Condition index score range.

5.5.4 Assessment of availability and gaps in monitoring data

Bird density and population trend monitoring

A number of species specific studies have been conducted in the park (e.g. Harlequin Duck, Common Loon). However, easily accessible database of previous and current survey efforts and the data associated with those surveys is lacking. Such a database would allow for a more comprehensive assessment of the adequacy of different survey designs, data quality, and gaps in monitoring data.

Monitoring changes in bird density is valuable for assessing the health of bird communities and tracking how populations may change over time. Trend monitoring is also necessary for evaluating the effects of global climate change and understanding shifts in bird distribution. Although funding may be limited, it would be ideal for the park to be part of a region-wide long-term bird monitoring program because this would allow the park to evaluate the ecological integrity of bird populations within the park relative to conditions across the region and thereby evaluate park management.

Glacier National Park has a critical role to play within the region because lands within the park represent a largely unmanaged “reference condition” that region-wide trends could be compared against.

In 2010, a regional bird monitoring program was initiated at the scale of Bird Conservation Regions (BCR). Western Montana, including Glacier National Park, falls within BCR 10. In the sampling design land ownership is treated as a stratum, and so the park was designated as one of 26 strata in western Montana. In 2010 and 2011 1x1 km grids (24.7 acres), consisting of 16 point count stations, were surveyed in Glacier National Park. This level of sampling allows the park to contribute to regional population trend estimates. If future funding is available, a larger sampling effort (10 – 15 grids) would be ideal to obtain reliable density estimates for bird populations within the park. The level of sampling necessary to obtain reliable population trend estimates within a stratum could be evaluated as data accumulate over time, however it is unlikely that trend estimates would be possible at a watershed scale. One consideration for increasing the effort in a long-term trend monitoring program is that grids, or clusters of survey points, could fall in very remote areas, which increases the cost of each sample. In addition, the current program of integrated monitoring at the BCR scale is unlikely to have sufficient sampling to evaluate bird-habitat relationships, especially in rare habitat types.

Habitat specific monitoring to track unique bird assemblages

The Avian Science Center established 26 transects (260 survey points) along roads and trails within Glacier National Park. They collected data on the habitat type(s) within 328 feet (100m) of each point and these points could serve as the foundation for monitoring bird communities in specific habitats. Habitat-based bird monitoring differs from population trend monitoring because the focus is to examine how differences in habitat quality influence bird abundance and species composition. Thus, habitat specific monitoring has the potential to yield information on the *cause* of changes in population trends. By focusing on a small number of habitats we can ensure an adequate survey effort in each type, whereas a program designed to monitor long term trends is unlikely to have sufficient sampling across all habitats.

For this assessment, we used bird data collected across all of northwest Montana, thus most data came from managed lands outside the park. While this information was adequate for generating basic bird-habitat relationships, we know that bird abundance and community composition vary between managed lands and the conditions inside the park. In addition we only had bird data in 13 of 20 VMP-LBMP cross-referenced habitat types, and so we were unable to generate bird-habitat relationships for some habitat types. An assessment of bird community health within the park could be improved with increased sampling within the park in key habitat types so that bird assemblages associated with these habitats can be tracked. We suggest focusing on a small number of habitat types that are either at risk (e.g. alpine, white-barked pine) or poorly understood (e.g. intermountain grasslands). An assessment based on actual data collected within the park would be more relevant for evaluating the ecological integrity of the park’s bird communities.

Species specific monitoring

Many species are not adequately monitored via point counts (e.g. non-breeding species, rare species, waterfowl, shorebirds, raptors). These species require other survey techniques and many require species specific monitoring (e.g. playback surveys for a particular owl species, stream surveys for Harlequin Ducks). A number of single species studies have been conducted in the park, but density and population trend data for these species were not available and therefore were not used in this analysis. Thus, current species specific monitoring efforts may be sufficient for some species, but data were not readily available for this assessment.

5.6 Focal Area - Mammals

5.6.1 Overview: Using mammals as an indicator species group

Glacier National Park's native wildlife community is diverse and remains relatively intact. Almost all the species that lived here 400 years ago remain; only bison (*Bison bison*) are missing. Wildlife represent a surprising diversity due in large measure to the floristic diversity of the park (see Figure 3.6), which stems from its geographic location, climate, topography, and soils.

Wildlife communities have remained relatively intact in the park because protection came early (the park was established in 1910) and because the park and surrounding wildlands are large—the park alone encompasses over a million acres. Most of the park is managed as non-huntable wilderness and is surrounded by other large areas of wild country like the Bob Marshall and Great Bear Wilderness Complex (1.5 million acres) to the south and southwest and Waterton Lakes National Park in Canada.. The portion of the North Fork of the Flathead in Canada remains the largest unsettled drainage in southern Canada outside of a park (Long 2000).

One indicator of the park's wildness is the integrity of the carnivore community. According to Weaver (2001), the carnivore assemblage on the west side of the park in the North Fork of the Flathead (also referred to as the Transboundary Flathead) appears unmatched in North America for its variety, completeness, use of valley bottomlands, and density of species which are rare elsewhere. Because of these unique characteristics and the valley's strategic position as a linkage between national parks in both Canada and the U.S., the North Fork of the Flathead "may be the single most important basin for carnivores in the Rocky Mountains" (Weaver 2001).

Carnivores and ungulates require large areas for long term population viability. As large as the park and surrounding wildlands are, in the face of ever increasing and new threats, they may not provide enough security for some species. For example, individual wolf (*Canis lupus*) packs require hundreds of square miles and habitats that include winter ranges of relatively high density of ungulates that only occur along the edges of the park.

The Transboundary Flathead (TBF) has been classified as a threatened "source" (i.e. refugia and core area for population expansion) area for carnivores (Carroll et al. 2004). Modeling indicates that without increased conservation measures in the TBF region, long term persistence of large carnivores

is in doubt here and in regions to the south with which it forms a vital connection (Carroll et al. 2003, 2004). Significant progress was made in that direction with the recent moratorium on energy development proclaimed for the Flathead (Hauer and Muhlfeld 2010). Threatened sources are of the highest priority for immediate conservation action (Carroll et al. 2004). In relatively lesser-developed landscapes like the greater TBF, demographic rescue (i.e. immigration via dispersal that offsets mortality) from intact surrounding buffer habitat helps protect park carnivore populations from extinction by increasing their effective area and decreasing their isolation. Therefore, connectivity planning must focus on ensuring functional connectivity in a broad landscape like the greater TBF. For example, the continued functioning of dispersal linkages between and among southern Alberta, British Columbia, Montana, and Idaho is essential for long term persistence of wolverines (*Gulo gulo*) (Cegelski et al. 2003, Krebs et al. 2004) and lynx (*Lynx rufus*) (Schwartz et al. 2002) in the southern portion of their range.

Human activities in a linear distribution across the landscape cause fragmentation of habitats and populations. Mountain valleys in the Rocky Mountains are a focal area for this type of fragmentation because these valleys concentrate human use areas like highways, railroads, housing developments, agriculture, and energy transmission lines (Gude et al. 2007). The Interprovincial Highway 3 corridor in British Columbia and Alberta is just such a mountain valley where human activities are concentrated. The Highway 3 valley is particularly important to the conservation of wildlife in general and medium and large carnivores in particular because the connection between the Transboundary Flathead and the GLAC ecosystem to the south of the valley and contiguous populations of carnivores in the central Canadian Rockies to the north of the valley. The Highway 3 corridor is fragmenting these carnivore populations and habitats as traffic volume on the highway and adjacent railroad line increases and human population density and development continue to increase in the entire area (Apps et al. 2007). Along the Middle Fork of the Flathead, the Nyack/Essex portion of US Highway 2 on the south side of GLAC and the Stillwater/Swift Creek portion of US Highway 93 between GLAC and the Salish Mountains west of the park are two important and threatened linkage zones.

Mounting evidence supports the value of carnivores as a surrogate guild of species (e.g., umbrellas, flagships, sentinels, and keystones) for assessing, monitoring, and maintaining ecosystem integrity (Kunkel 2003, Soule et al. 2003, Rooney et al. 2006, Dalerum et al. 2008). The value of carnivores as surrogates is even more imperative when they are species-at-risk as six of these species are in the TBF (wolverines [species of special concern western Canada and a candidate species in the US], grizzly (*Ursus arctos*) [threatened US], wolf [endangered US], lynx [threatened US], badgers (*Taxidea taxus*) [endangered Canada], and fisher (*Martes pennant*) [blue list BC]) and also the suite of species that define the critical importance of the ecosystem (Weaver 2001). Including the prey of carnivores makes these assessments more valuable and comprehensive especially when the prey themselves are flagships (e.g., goats, sheep).

Bighorn sheep

Dicus (2002) indicated that bighorn sheep (*Ovis canadensis*) appear to still occupy most of the winter range areas in GLAC that they occupied in the 1930s (Keating 1985), although fire exclusion very likely has degraded lower elevation portions of these winter ranges and hunting pressure outside the park continues to impact sheep on winter ranges along GLAC's boundary. Information on bighorn sheep distribution in GLAC is very limited. As discussed by Keating (1985), a map overlay from 1939 (based on 1934-1939 surveys) depicting park-wide bighorn sheep winter range has survived, although no thorough description of methods and considerations of the 1939 study still exists.

The first concerted efforts to estimate ungulate populations in GLAC through systematic survey counts began in the early 1920s. GLAC staff estimated a 1924 park-wide population of 1,111 bighorn sheep. This estimate very likely included duplicate counts because it used surveys from both summer and winter range areas (Keating 1985). Adjustment of this 1924 estimate, by discarding summer range counts, and of the 1917 Seton estimate, by removing unsuitable habitat from the park-wide extrapolation, resulted in more realistic park-wide estimates of 475 to 600 bighorn sheep (Keating 1985). Fluctuations in survey effort and timing make park-wide comparisons between historic and current bighorn sheep numbers very difficult. After 1940, organized, park-wide survey counts had a reduced geographical coverage, and by the 1960s the park-wide survey effort had collapsed. Based on recent field research on sheep movements, Keating (personal communication, October 1, 2010) guessed the Glacier/Waterton population at between 700 and 800.

It is unknown to what degree sheep populations fluctuate in GLAC or what the primary limiting factors are. The following discussion of sheep in Yellowstone Park may have bearing on GLAC. White et al. (2008) found that winter severity and disease were the biggest factors affecting sheep in Yellowstone National Park. Counts of sheep decreased following the severe winter of 1997, but then increased by 7% annually during 1998-2005. Recruitment followed a similar temporal pattern, decreasing to 7-11 lambs/100 ewes during the severe winter of 1997 and the following winter, but then increasing to 21-34 lambs/100 ewes during 1998-2005. Annual estimates of survival for 14 adult females and four males 1-3 years old were high (0.94) and indicative of an increasing or constant population. The presence of wolves did not prevent the bighorn sheep population from increasing slowly during the decade following reintroduction. However, sheep counts remain low compared to the 487 sheep observed before an outbreak of a disease of the eye (keratoconjunctivitis) caused 60% mortality during 1982, suggesting that other factors limited the recovery of this relatively isolated, high-elevation, native sheep population in Yellowstone National Park.

Dicus (2002) focused research on sheep habitat use on two study areas on the east side of GLAC, Many Glacier and Two Medicine. Based on sheep observation, he developed a habitat model for GLAC with distance to escape terrain, snow cover, solar radiation index, slope, and either land type (from a classified satellite image) or horizontal visibility and two satellite wavelength band reflectance values as main components of the final model. Escape terrain has been described as steep slopes of broken, rocky terrain but no consistent criteria exist for identifying escape terrain (Gross et al. 2002).

In agreement with past bighorn sheep habitat studies (Geist 1971, McCarty and Bailey 1994, Tilton and Willard 1982) and modeling (Dicus 2002, Hughes 1997, Johnson and Swift 2000, Sweanor et al. 1996), DeCesare and Pletscher (2006) found slope and distance to escape terrain were important habitat variables across seasons and sites for sheep in west central Montana. These parameters appear universally important to bighorn sheep habitat in their study areas. Escape terrain has generally been defined as continuous steep slopes of 27-degrees or greater and possessing rocky outcrops and/or cliffs greater than 4 acres in size and at least 49 ft. in height (Geist 1971, Tilton 1977, Smith et al. 1991). Except for some migration movements, bighorn sheep seldom venture more than 984-1,640 feet from escape terrain (Shannon et al. 1975, Gionfriddo and Krausman 1986, Wakelyn 1987).

DeCesare and Pletscher (2006) found areas in or near high-visibility habitats such as grasslands and high-severity burned forests were generally preferred and low-visibility denser forests avoided. They did not detect selection based on horizontal visibility alone (DeCesare and Pletscher 2004). Many recent efforts identifying and modeling suitable bighorn habitat (Hughes 1997, Johnson and Swift 2000, Zeigenfuss et al. 2000) are based on the habitat-evaluation procedure of Smith et al. (1991). The habitat-evaluation procedure of Smith et al. (1991) was a stepwise procedure that identified core habitat based on escape terrain patches and subsequently removed areas from this core habitat that were unsuitable for other reasons (e.g., dense vegetation, close proximity to human development, close proximity to domestic sheep, high elk or cattle concentrations, etc.). Zeigenfuss et al. (2000) identified the 5 key habitat criteria upon which this habitat-evaluation procedure was based: close proximity to large patches of escape terrain, close proximity to water, lack of highway or water barriers, high horizontal visibility, and minimum of 150 m from human development. Most bighorn sheep habitat evaluation procedures are developed to identify suitable bighorn home ranges within larger landscapes, whereas DeCesare and Pletscher (2006) models reflect selection within home ranges.

Dicus (2002) found that primary threats for sheep in GLAC were conifer encroachment, livestock trespass, exotic plants and illegal hunting. Fire suppression has increased conifer cover and sheep prefer open habitats. Livestock spread exotic plants, diseases, and decrease forage for sheep directly.

Mountain Goats

Mountain goats (*Oreamnos americanus*) are distributed in the more rugged terrain throughout GLAC. Chadwick (1983) estimated the park population at around 1,500 based on his population estimate of 300-350 goats in his 120 square mile study area in the center of the park. Similar to sheep, no other estimates of population were available until recently. The degree of population fluctuations is unknown as are limiting factors.

Belt (2010) tested the feasibility of using citizen scientists to monitor goats in GLAC. She found aerial counts in survey viewsheds and 2009 density estimates from uncorrected high counts by volunteers and biologists were similar (1.99 mountain goats/250 acres, 1.91 mountain goats/ 250 acres and 1.87 mountain goats/250 acres respectively). Mean density estimates for all escape terrain at sites, based on corrected high counts by volunteers (0.54 to 0.72 mountain goats/250 acres) and

biologists (0.48 to 0.55 mountain goats/250 acres) were lower than density estimates from the aerial survey counts (0.95 mountain goats/250 acres).

Population dynamics of mountain goats are poorly understood (Festa-Bianchet et al. 1994, Cote and Festa-Bianchet 2003, Hamel et al 2006) and appear to vary widely among herds. Most native populations seem highly sensitive to harvesting including rates as little as 1% (Smith 1988, Festa-Bianchet et al. 1994, Cote et al. 2001). Hunting appears almost totally additive to natural mortality.

Herd-specific factors other than hunting appeared to affect population dynamics of mountain goats (Gonzalez et al. 2003). The wide variation in population trends among herds in the same geographical area suggests that factors other than weather were responsible for changes in population size, because all herds experienced the same yearly changes in weather. Other extrinsic factors that could have affected individual herds include disease, accidents, poaching and predation. Gonzalez et al. (2003) had no evidence of disease, and recorded no mortalities due to falls or other accidents in the intensively studied Caw Ridge herd. The inaccessibility of most herds suggests that poaching was unlikely to be a problem. Their study area, however, had a full complement of large predators. A single predator specializing on mountain goats could have a strong impact on a herd, similar to what has been reported for bighorn sheep (Wehausen 1996, Wehausen 1999, Ross et al. 1997). At Caw Ridge, attacks by wolves and grizzly bears have been witnessed (Côté and Beaudoin 1997) and most kid mortality appears to be due to predation by wolves, grizzly bears and cougars (Festa-Bianchet et al. 1994). Predation by individual specialist predators may be density independent and may not depend on changes in predator populations, possibly explaining the unpredictable, herd-specific changes in numbers that were recorded. Gonzalez et al. (2003) however, had no data on predation for any herd other than Caw Ridge and thus the interpretation is speculative. Females in the Caw Ridge population do not reproduce until four or five years old, and only about 50% of yearling females survive to four years (Festa-Bianchet et al. 1994).

Like sheep, mountain goats are generally associated with escape terrain, described as steep slopes of broken, rocky terrain (Gross et al. 2002). Many authors have noted the importance of distance to escape terrain in mountain goat habitat selection (Fox 1983, Smith 1994, Gross et al. 2002, Poole and Heard 2003, Lele and Keim 2006).

Gross et al. (2002) defined escape terrain for Colorado mountain goats as slopes $\geq 33^\circ$. They developed a model based only on distance to escape terrain that correctly classified 87% of observations and classified 38% of the study area as suitable habitat. Their models provide a way to use readily available data and simple techniques to quickly identify suitable habitat over large geographical areas.

Because a sheer cliff would have a low ruggedness index (signifying no change in slope), mountain goats appear to select areas with high degree of changes in slope and cliff complexity at both the broad and especially fine scales. Due to sensitivity to harvest, potential threats to goats in GLAC include poaching. Additionally, because goats require alpine habitat, encroachment of trees is also a threat. Such an encroachment has been hypothesized as one impact of climate change. However,

Burns et al. (2006) modeled impacts of expected climate change scenarios on mammal species in US national parks and found that no species of the Artiodactyla order are expected to be lost.

Declines in goat numbers at a prominent mineral lick in GLAC (Steve Gniadek, Glacier National Park, unpublished data, cited in Belt 2010), and throughout the neighboring Bob Marshall – Great Bear Wilderness (Koeth 2008), and uncertainty about mountain goat response to climate change (Pettorelli et al. 2007) generated concern about the stability of mountain goat populations in GLAC.

Pika

American pikas (*Ochotona princeps*) are medium-sized (150 g) members of the order Lagomorpha, which also includes rabbits and hares. Pikas are active primarily during day-light hours, live up to seven years, and are found exclusively in association with talus deposits (piles of rocks >1 ft. in diameter) in mountainous areas of North America, from British Columbia to California, and New Mexico to Montana (Moyer-Horner 2011). Pikas are solitary and defend their ~3600 square feet home ranges. In contrast to other small mammals that share the harsh alpine and subalpine habitats, pikas do not hibernate, but rather collect hay-piles during the summer and early fall to supplement their winter caloric needs. Construction of individual hay-piles, characteristic BB-pellet-sized feces, their curious nature, and unmistakable “eep!” vocalizations make pikas quite easy to detect. At their highest latitudes, pikas are found at elevations ranging from 10,000 ft. to sea level. In the more southerly portions of their range, pikas are rarely found below 8000 ft. Pikas have higher metabolic rates and better insulation than other mammals their size, giving them relatively high average (104°F) body temperatures. Prolonged sun exposure at ambient temperatures above 77°F can be fatal (Moyer-Horner 2011).

More than 400 pika-appropriate talus patches were identified in GLAC and over 300 of those patches were surveyed to determine vegetation characteristics, physical environment (e.g. slope aspect), and pika density (Moyer-Horner 2011). He found direct evidence of 1,130 pikas and extrapolated those estimates to indicate there were 1,800 – 3,600 pikas in GLAC. He found pikas more frequently later in the season, at higher elevations, at flatter sites, and in association with forbs (broad-leaved plants such as wildflowers), moss, and taller vegetation. Even at this northern edge of their range in the lower 48 states, pikas prefer the cooler, moister sites. Fewer pikas were found at sites that contained talus with a shallow depth. Measurements revealed below-talus temperatures are 23 – 27°F cooler than above the talus during the day. Talus provides an important refuge from both predators and heat.

The American pika is a sentinel of mammalian response to climate change. In the Great Basin of Nevada and Oregon, an alarming number (7/25 or 28%) of their lowest elevation satellite populations have become locally extinct (extirpated) in the past 60-90 years (Beever et al. 2010). Losses have been connected to chronic summer heat stress and acute winter cold spells perhaps due to low snow cover (Beever et al. 2010). In March of 2010, the U.S. Fish and Wildlife Service rejected a petition to list the American pika as threatened or endangered by rapidly rising temperatures primarily because of insufficient data on how rising temperatures cause extirpations. Burns et al. (2006) did not list pika as a species likely to be lost from GLAC due to climate change. Given large population losses farther south though, we might expect significant population declines. Additionally, given the expected

increase in mammal species that could include pika predators, there may be additional declines (Burns et al. 2006)

Lynx

Lynx (*Lynx rufu*) are snowshoe hare (*Lepus americanus*) specialists and thus tightly linked to hare habitat and abundance. Hares generally cycle at 10 year intervals as do lynx. Cycles on the southern edge of the range (lower 48 states) appear less pronounced (Hodges 1999). Hare abundance is the driver of lynx abundance and other factors are much less important.

Because hare cycles are generally correlated to lynx throughout North America, dispersal of lynx to areas with higher hare abundance is important in population dynamics. Lynx are capable of dispersing over long distances and through many landscapes, even so, maintaining some level of connectivity between Canada and GLAC is important (Schwartz et al. 2002).

Mills et al. (2006) preliminary data suggest that snowshoe hare populations in GLAC are highly concentrated in the southern third of the park and occur in very low densities elsewhere. Areas affected by the 1988 Red Bench fire in the North Fork and more recent fires show limited forest regeneration and did not appear to support snowshoe hare populations.

Lynx home ranges in the southern portion of their range are relatively large with Apps (1999) reporting average ranges from 60,000 – 95,000 acres in the southern Canadian Rockies. Apps (2000) found lynx selecting mid elevations ranging from 5,000 – 6,000 feet and moderate to gentle slopes (<40%) in Kootenay, Banff and Yoho national parks. The only estimate of lynx density in the southern portion of their range is 25,000 acres in the Cascades of Washington (Aubry et al. 1999).

Lynx are also snow adapted and out-compete other predators in soft deep snow. When snow becomes compacted due to human or weather factors, other predators may benefit. A primary competitor are coyotes (*Canis latrans*), but the overall influence of snowmobile trails on coyote movements and foraging success during winter appeared to be minimal in western Montana (Kolbe et al. 2007) and snowmobiles are not allowed in GLAC.

Modeling by McKelvey (unpublished data, USFS) indicate that much of lynx habitat may shift north out of GLAC as a result of climate change. Carroll (2007) found that in the northern Appalachians the combination of climate change, lynx harvest and forest harvest combined to yield significant reductions in lynx.

Gniadek et al. (2001) detected 5 unique lynx in mixed conifer-aspen-meadow and treeline habitats in GLAC; none were detected in the continuous coniferous forest habitats sampled. Squires et al. (2008) studied lynx habitat selection in western Montana and found that lynx generally denned in mature spruce-fir (*Picea-Abies*) forests with high horizontal cover and abundant coarse woody debris. Eighty percent of dens were in mature forest stands and 13% in mid-seral regenerating stands; young regenerating (5%) and thinned (either naturally sparse or mechanically thinned) stands with discontinuous canopies (2%) were seldom used. Female lynx selected den areas with greater spruce-fir tree basal area, higher horizontal cover, and larger-diameter trees compared to random locations

within their home range. Lynx selected den environs in topographically concave or drainage-like areas, and farther from forest edges than random expectation. Squires et al. (2008) indicated that maintaining mature and mid-seral regenerating spruce-fir forests with high horizontal cover and abundant woody debris would be most valuable for denning when located in drainages or in concave, drainage-like basins. Management actions that alter spruce-fir forests to a condition that is sparsely stocked (e.g., mechanically thinned) and with low canopy closure (<50%) would create forest conditions that are poorly suitable for lynx denning.

During winter, lynx preferentially foraged in mature, multilayer forests with Engelmann spruce (*Picea engelmannii*) and subalpine fir (*Abies lasiocarpa*) in the overstory and midstory (Squires et al. 2010). Forests used during winter were composed of larger diameter trees with higher horizontal cover, more abundant snowshoe hares, and deeper snow compared to random availability; multilayer, spruce-fir forests provided high horizontal cover with tree branching that touched the snow surface. During winter, lynx killed prey at sites with higher horizontal cover. Lynx were insensitive to snow depth or penetrability in determining where they killed prey. During summer, lynx broadened their resource use to select younger forests with high horizontal cover, abundant total shrubs, abundant small-diameter trees, and dense saplings, especially spruce-fir saplings. Comparisons of patch-level metrics indicated that lynx selected homogenous spruce-fir patches, and avoided recent clear-cuts or other open patches. Given that lynx in Montana exhibit seasonal differences in resource selection, Squires et al. (2008) encouraged managers to maintain habitat mosaics. Because winter habitat may be most limiting for lynx, these mosaics should include abundant multistory, mature spruce-fir forests with high horizontal cover that are spatially well-distributed.

Wolf

Wolves (*Canis lupus*) are habitat generalists and populations and distributions are driven by ungulate abundance (Fuller 1989). Ungulate abundance cycles with predator abundance and follows habitat conditions including those affected by fire and climate. Severe winters can reduce ungulate density significantly by increasing their vulnerability to predation (Kunkel et al. 2004).

Wolves re-colonized GLAC in the late 1980s. The population increased at a lambda of 1.2 (Pletscher et al. 1997) and peak abundance occurred in the mid-1990s when 3 packs were present and density was 10 wolves/386 square miles. Wolf recolonization resulted in ungulate declines and then wolf populations subsequently declined (Kunkel and Pletscher 1999). Present distribution occurs throughout major valley bottoms in GLAC with wintering ungulates (Kunkel and Pletscher 2001, US Fish and Wildlife Service 2011).

Wolf abundance is also driven by human caused mortality that occurs when wolves come into conflicts with livestock. That issue has been important on the east side of the park where most ungulates winter on the Blackfeet Indian Reservation and come into contact with livestock. As a result wolf presence there has been limited.

Human disturbance near den sites may be a factor influencing success of dens. Otherwise human development and disturbance at levels in GLAC appear to have little impact on wolves. Diseases

including parvo virus, canine distemper and mange can significantly impact populations in the West (Almberg et al. 2010). Management options for these diseases are limited.

Declines in wolf abundance can be short lived as wolves have a high reproductive rate and are excellent dispersers. They disperse long distances and through many types of landscapes. Ensuring connectivity and reducing livestock conflicts are key to management success (Smith et al 2010). Most wolf territories overlap areas outside the park and wolves are subject to legal and control harvest (US Fish and Wildlife Service 2011). Illegal mortality also occurs within GLAC. Warming climate and milder winters may increase ungulate abundance in GLAC and therefore also increase relative wolf abundance.

Fisher

Fishers (*Martes pennanti*) are medium sized mustelids that hunt in woody debris, thick brush, and forests (Powell 1993). They are opportunistic predators that forage on small mammals, birds, snowshoe hares carrion, and porcupines (*Erethizon dorsatum*). In the western United States, fishers are found in low to middle elevation moist coniferous forests with high structural complexity (Heinemeyer and Jones 1994, Jones 1991, Powell and Zielinski 1994, Zielinski et al. 2004). Trapping for fur, in concert with extensive habitat losses, led to widespread extirpation of fishers in the United States by 1930 (Douglas and Strickland 1987, Powell 1993). In Montana, Weckworth and Wright (1968) were unable to find records of fishers trapped or observed between 1930 and 1959. They concluded that fishers were extirpated from the state by 1930. Habitat loss primarily due to logging and climate change will likely have the most impact on current and near future status of the species. Burns et al. (2006) reported that the carnivore most sensitive to climate change was the fisher, and they predicted loss of the fisher from GLAC in their models (Burns et al. 2006).

Little is known about the status of fishers in the Rocky Mountains, as there is little published information on fishers in this region (Heinemeyer and Jones 1994, Powell and Zielinski 1994, Vinkey et al 2006). While there are reports of sightings and tracks in GLAC there is no physical evidence for the presence of fishers in the park (J. Waller, personal communication, November 2010).

Wolverine

Wolverines (*Gulo gulo*) are distributed throughout GLAC (Copeland and Yates 2008). They are largely habitat generalists but restricted to higher mountains in the southern part of the northern US Rockies, the southern part of their range. The wolverine's world-wide range is strongly tied to a specific habitat signature; referred to as tundra or taiga at northern latitudes, boreal at mid-latitudes, and subalpine in the south. In the southern portions of their range, the subalpine life-zone necessary for wolverine presence becomes restricted to an elevational band, resulting in a naturally fragmented distribution. The occurrence of wolverines is constrained by their obligate association with persistent spring snow cover for successful reproductive denning and by an upper limit of thermoneutrality (Copeland et al. 2010). Wolverines are primarily scavengers, and ungulate abundance and carrion is an important population driver. They also rely on smaller mammals and a diversity of prey.

Wolverine home ranges in GLAC averaged 130,000 acres for males and 35,000 acres for females (Copeland and Yates 2008). Based on habitat distribution and spatial use, GLAC appears to support a stable-to-increasing population of between 40 and 45 individuals. Adult wolverine survival in GLAC is about 96% annually. These values, along with a fecundity rate of about 29% (proportion of female kits/female/year) indicates that the GLAC wolverine population is likely increasing by about 5% per year.

Conservation biologists have worked under a rule of genetic variation termed the “50/500 rule”, which states that an N_e (effective population) of > 50 is necessary to ensure short-term survival and minimize the risks of inbreeding, and an $N_e > 500$ to ensure long-term survival through the ability to adapt to environmental change. Effective population sizes in Montana, Idaho, and Wyoming, where most of the wolverines in the contiguous United States exist, were calculated to be 35 (credible limits, 28–52) (Schwartz et al 2009). These numbers underscore the essentialness of viable connective corridors, and emphasize the importance of GLAC as a wolverine refuge and source population to the surrounding region.

With large home ranges like wolves, wolverines are subject to human caused mortality outside and inside the park. Copeland and Yates (2008) reported 2 of the 10 mortalities of wolverines resulted from harvest outside the park. Wolverine are also excellent dispersers but it is unclear how well they can move through landscapes with varying levels of human disturbance and development. Wolverine may be especially sensitive to fragmentation.

Wolverines are a candidate species in the US and a species of special concern western Canada. Further, wolverines are hypothesized to be very sensitive to human developments and activity (Bianci 1994, Rowland et al. 2003) and to climate change (Copeland et al. 2010, Brodie and Post 2010). All 562 reproductive dens from Fennoscandia and North America occurred at sites with persistent spring snow cover. Ninety-five percent of summer and 86% of winter telemetry locations in were concordant with spring snow coverage (Copeland et al. 2010). Reductions in spring snow cover associated with climatic warming will likely reduce the extent of wolverine habitat, with an associated loss of connectivity (Copeland et al. 2010). Data and analysis requested from the University of Washington Climate Impacts Group and the U.S. Forest Service Rocky Mountain Research Station predict a reduction of wolverines’ cold and snowy habitat of 63 percent by 2099. Further, models show that snowpack has strong, nonlinear effects on wolverine population dynamics. Wolverine harvests dropped the fastest in areas where snowpack declined most rapidly and also where snowpack had the greatest effect on population dynamics (Brodie and Post 2010). Moreover, declining snow cover appears to drive trends in wolverine population synchrony, with important implications for overall persistence (Brodie and Post 2010).

Wolverine populations in the United States appear to be receiving migrants from Canada; however, substantial genetic differentiation suggests that gene flow may not be high enough to prevent genetic drift. Recent analyses suggest that at least 400 breeding pairs or 1–2 effective migrants per generation would be needed to ensure genetic viability in the long-term for each of the populations in the United States (Cegelski et al. 2003).

The greater GLAC population of wolverines is likely the largest and most robust in the lower 48 and southern Canada and thus the most critical for long term population persistence in the region (Schwartz et al. 2009). We, however, do not know how abundant or robust it is nor its trend, the area size, configuration and activities required to maintain it.

Grizzly Bear

GLAC has remained one of the few places in the contiguous 48 states of the United States where a natural population of grizzly bears (*Ursus arctos horribilis*) has endured. This is due to the park's size and the early protections provided under its establishment in 1910 (Bailey 1918, Mattson and Merrill 2002). The park is recognized as prime habitat for grizzly bears, including large expanses free of roads and human development as well as abundant bear foods and high-quality habitat areas such as avalanche chutes (USFWS 1993, McLellan and Hovey 2001). Until recently, monitoring of the grizzly bear population within the park relied solely on reported sightings by visitors and employees, with unreliable data prior to 1970 (Gniadek and Kendall 1998). Since the 1920s and 1930s the population has increased from an estimated 60 grizzly bears (Keating 1986) to approximately 241 (Kendall et al. 2008). This report will address the existing population and its monitoring programs as well as current and future threats.

Grizzly bears are thriving in GLAC. Their population has stayed robust throughout the last 40 years and today there are around 241 grizzly bears in GLAC (Kendall et al. 2008). Throughout the Northern Continental Divide Ecosystem (NCDE) Recovery Zone bear densities are highest within GLAC with approximately 30 bears/1,000 km² (Figure 5.28) (Kendall et al. 2008). Density inside GNP was 2.4 times the density outside of the park in the study area. Similar patterns of distribution were found when this area was sampled in 1998 using the same methods (Kendall et al. 2008).

Grizzly bears inhabit the entire park but at higher densities in the center than on the borders (Kendall et al. 2008). Humans are the greatest source of mortality for grizzly bears that reside wholly or partially within GLAC. Most of this mortality occurs along the park's borders or outside of it. Mortality rates are significantly lower in GLAC than the rest of the NCDE (Figure 5.29). As a result of this, GLAC's grizzly bears act as a source population for the NCDE (Dood et al. 2006).

The current GLAC Bear Management Plan (2004) has set three specific goals: 1) Provide for long-term survivability of grizzly bears in GLAC and the NCDE; 2) Fulfill the mandate of Congress, as expressed in the Organic Act of 1916; 3) Minimize the number of incidents involving bear/human confrontations. To accomplish these goals, the GLAC Bear Management Guidelines (2010) identifies specific objectives and guidelines including: education and training for visitors and park employees, strict garbage management practices, aggressive enforcement of these preventative policies, continual research, collaboration with other agencies and interested parties, and biennial re-evaluation of the management plan.

Currently, the population trend (i.e., is the population increasing, decreasing, or stable) for grizzly bears in GLAC is unknown. In 2004, an ecosystem-wide study was initiated by members of the IGBC to calculate trend in the NCDE. For this research, grizzly bears are captured, anesthetized, and

outfitted with VHF or GPS collars to track their movements, habitat use, survival, and reproduction. Mace et al. (2012) reported in a follow up study that the NCDE grizzly bear populations have increased at approximately 3% during the period 2004-2009.

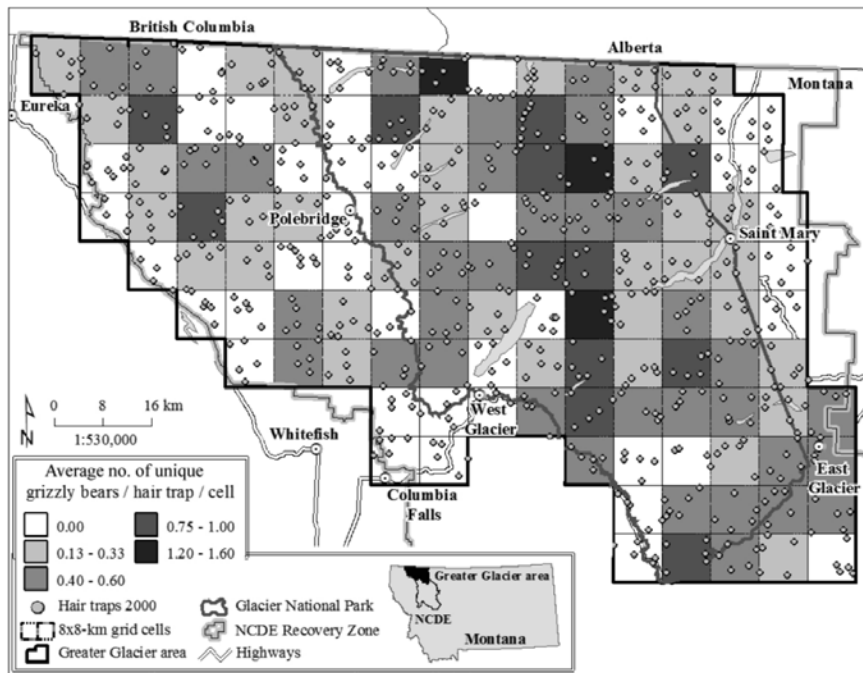


Figure 5.28. Relative density of grizzly bears detected at hair traps systematically distributed in the greater Glacier National Park (GNP) area in northwest Montana, USA, during 15 May–15 August 2000.

Locations - Human-caused Mortalities, NCDE 1999 -2008

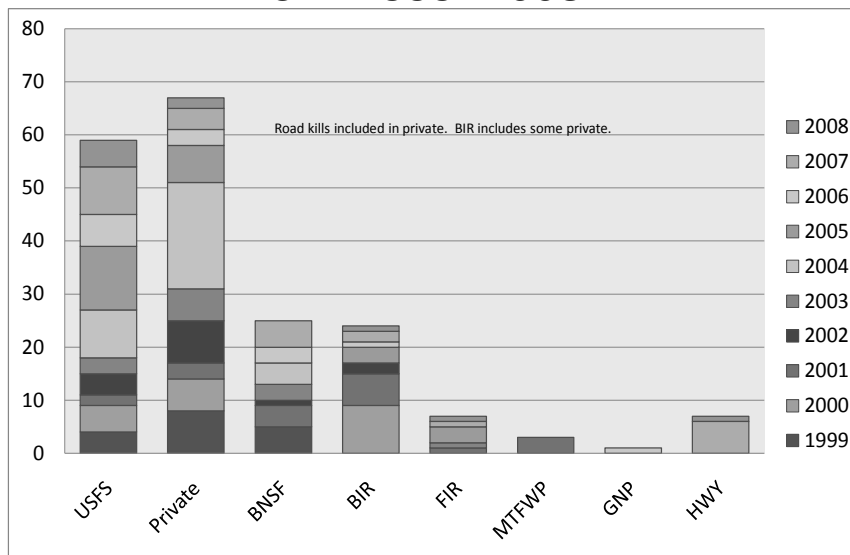


Figure 5.29. Locations of grizzly bear mortalities in the NCDE 1999-2008.

In 2009, an additional long-term trend monitoring program for the NCDE began, headed by the USGS in cooperation with the Flathead National Forest, the U.S. Fish and Wildlife Service, and the U.S. Geological Survey. This program aims to provide fine scale population data such as genetic population structure, local occupancy and density patterns, and localized growth rates using DNA samples collected noninvasively from hair found at natural rub objects (Kendall et al. 2008).

Although GLAC's grizzly bears are awarded superior protections by virtue of living within the park's protected boundaries, they are still vulnerable to several threats. Current threats to GLAC's grizzly bears stem from human interactions and influences. These ongoing stressors include: grizzly bear/human conflicts involving habituation, food-conditioning, and human-caused mortality; a lack of comprehensive land-use planning on private lands; mortalities and/or altered movement patterns induced by the U.S. Highway 2 corridor and the Burlington Northern Santa Fe (BNSF) railway. Every year almost 2.0 million people visit GLAC. The park maintains 151 trails that cover 745.6 miles and 65 backcountry campgrounds that host an average of 26,663 people each year between May and October (NPS 2009a, NPS 2009b). With this many people accessing the heart of grizzly bear territory a potential of human-bear conflicts (Mattson et al. 1996).

Human-grizzly bear encounters are threats to grizzly bears within the park because each encounter increases the likelihood of bears becoming habituated to people. Habituated bears often alter their natural behaviors and spend more time near roads and human settlements where they are more likely to have negative interactions with humans (Albert and Bowyer 1991, Herrero et al. 2005, Mattson et al. 1996). Habituated bears can become food-conditioned bears that begin to perceive human use areas as places to seek food (Herrero et al. 2005). If these bears become aggressive or begin approaching humans without fear, the park must take management actions, such as removal of the bear, to ensure park visitors' safety (GLAC 2006). Additionally, when habituated bears leave the boundaries of the park, they are more vulnerable to human sources of mortality than non-habituated bears (Herrero et al. 2005).

A lack of comprehensive land-use planning on private lands located around the borders of the park amplifies this threat. Montana land-use planning is managed mostly by the local governments at a city or county level (Horwich 2004). Without a uniform planning practice that provides allowances for wildlife, the area around GLAC could become sparsely filled with disjointed and unregulated infrastructure. This will amount to less viable, secure habitat for grizzly bears as well as increased threats of human interactions and attractants associated with housing and permanent human presence.

One of the most effective ways to ensure human-caused mortalities do not threaten the population is to limit the type and amount of human access. Secure habitat is important to the survival and reproductive success of grizzly bears, especially adult female grizzly bears (Mattson et al. 1987, IGBC 1994). Grizzly bear habitat security is primarily achieved by managing motorized access which — (1) minimizes human interaction and reduces potential grizzly bear mortality risk; (2) minimizes displacement from important habitat; (3) minimizes habituation to humans; and (4) provides habitat where energetic requirements can be met with limited disturbance from humans (Mattson et al. 1987, McLellan and Shackleton 1988, McLellan and Shackleton 1989, Mace et al. 1996, Mattson et al. 1996). In 1998, an interagency task force recommended three parameters to

include as components of motorized access management to standardize definitions and methods: 1) open motorized route density (OMRD), 2) total motorized route density (TMRD), and 3) Core area, with no open motorized travel routes or any restricted roads that receive administrative use (IGBC 1998). Glacier National Park follows the standards based on Mace and Waller (1997) of <19% OMRD, <19% TMRD, and >68% Core area as suitable for grizzly bears. These standards are evaluated by subunit within the larger Bear Management Units. Subunits are around 100 mi² based upon the annual home range size of an adult female grizzly bear (Weaver et al. 1986). There are 24 subunits within the park and all of them meet the motorized access density standards and core habitat area requirements within the park except for the Lake McDonald subunit which only has 68% core area.

Grizzly bears increasingly avoid roads in relationship to traffic volume levels (Figure 5.30) (Chruszcz et al. 2003, Waller and Servheen 2005). US Highway 2, located along the southern boundary of GLAC, has moderate traffic volumes ranging between 1,500 and 5,000 vehicles per day (MDT 2009). In recent years, the U.S. Highway 2 corridor has been a significant source of mortality for grizzly bears near GLAC due to vehicle collisions, train collisions, and management removals associated with human residences. The U.S. Highway 2 corridor acts as a partial barrier by decreasing successful bear movements from GLAC to the Bob Marshall Wilderness complex (Waller and Servheen 2005). Waller and Servheen (2005) also show that movement across the U.S. Highway is inversely related to traffic volume (See Figure 5.31).

The BNSF railroad line runs parallel to, and thus compounds the barrier effects of, U.S. Highway 2 and is also a significant source of mortality (Waller and Servheen 2005). From 1980 to 2008 trains have killed 44 grizzly bears (Figure 5.31). The railway has cooperated with the USFWS to reduce its impacts on the grizzly bear population through various mitigation efforts such as prompt grain spill response teams and motion triggered noise makers to keep bears off of trestles. However the train schedule concentrates train traffic during the night time, which is the time of peak bear movements, thus making some collisions unavoidable (Waller and Servheen 2005).

Overall, the greatest human threats for GLAC grizzly bears lie just outside the borders of the park and are not directly related to the park itself. The few threats that exist within the park, such as direct human/bear conflicts at campgrounds or garbage facilities, are heavily regulated and well accommodated under the Bear Management Plan. Grizzly bears that remain within the park are much safer than those who leave its boundaries (Kendall et al. 2008). From 1976 to 2000, <9% of the 401 known grizzly bear mortalities that occurred within 40 km of GLAC happened within the park (Kendall et al. 2008).

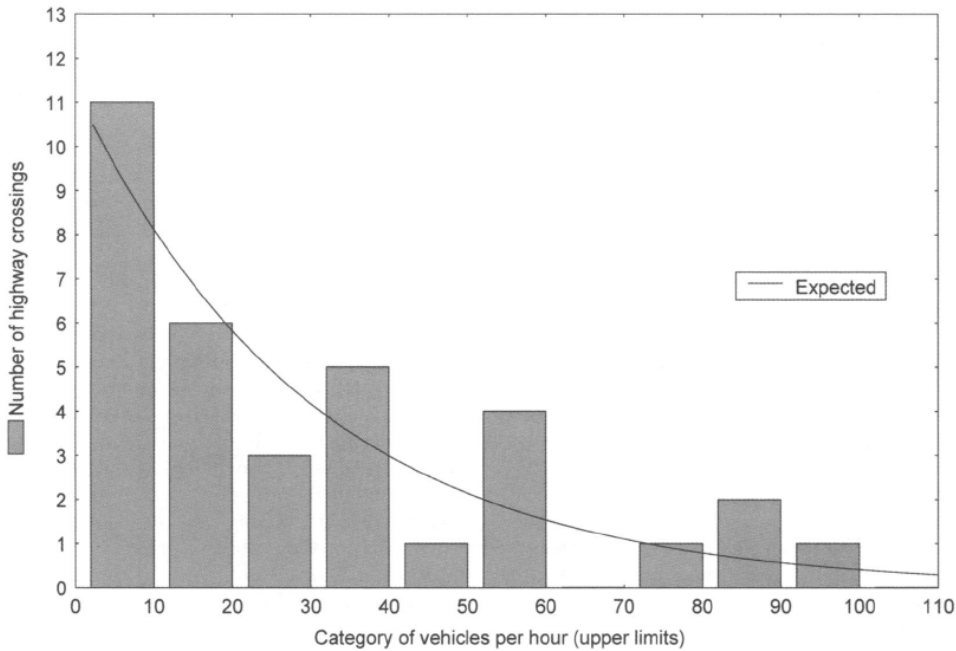
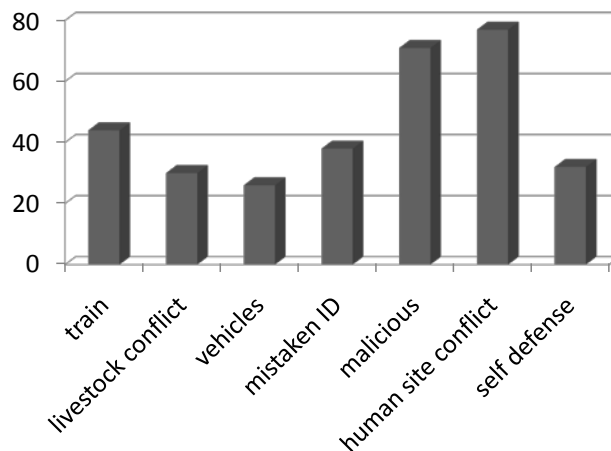


Figure 5.30. Observed grizzly bear crossings of U.S. Highway 2 fitted to an exponential distribution with traffic volume categories, north-west Montana, USA, 1999-2001 (Waller and Servheen 2005).

Some comparative NCDE mortality causes over 28 years, 1980-2008¹



USFWS Grizzly Bear Recovery

¹ Note this graphic does not include all causes of mortality, just those listed. Also, malicious kills are conservative as this does not include uncertain mortalities.

Figure 5.31. Causes of non-natural grizzly bear mortalities within the NCDE

5.6.2 Methods: Mammals

The primary factors that contribute to mammal community health in GLAC include:

1. Relatively low level of disturbance and habitat loss caused by roads and developments,
2. Significant abundance of rugged alpine habitats,
3. Abundant forest cover and habitat diversity including natural disturbance cycles, and
4. No hunting by humans allowing:
 5. a. Natural behavior and density of predators and prey
 6. b. Abundance of food resulting from no human harvest.

The primary factors that threaten mammal communities in GLAC include:

1. Human disturbance, including roads, facilities, hiking and camping, have the potential to disturb wildlife movements and habitat use.
2. The size of GLAC is small relative to home range size of large mammals resulting in limited ability of the park to support viable large mammal populations on its own. Distance to the park boundary is thus a key factor influencing mammal health(Woodroffe and Ginsberg 1998).
3. Climate change will likely make alpine habitats particularly vulnerable due to habitat fragmentation and possible shifts in species ranges (Beniston 2003, Dullinger et al 2004). Latitudinal and elevation shifts in species ranges have been documented for a number of species (Parmesan 2006, Wilson et al. 2005). Alpine habitats may be reduced and more fragmented.

To address the park attributes that are beneficial or detrimental to the general mammal populations we developed metrics that are 1) spatially appropriate, 2) address specific habitat requirements of focal species, and 3) address potential human disturbance.

Sheep (V_{ESCAPESH}P)

Mountain ungulates like bighorn sheep and goats used rugged habitats to evade predators. Sheep and goats will only move a safe distance away from this escape habitat to forage. For sheep, researchers have generally defined this as >27 degree slope possessing rocky outcrops and/or cliffs greater within 1,600 feet of forage. To determine the spatial extent of the escape terrain, we used the GNP vegetation map shapefile (glac_vegmap.shp) and the 10 meter DEM to select areas of 'Rocky Mountain Alpine Cliff, Scree, and Other Rock Vegetation' on areas with greater than 27 degrees slope. We then applied a 1600-foot buffer to all vegetated areas and determined the acres of this buffer within the above escape terrain. To support a viable population of bighorn sheep Dunn (1994; 100 sheep) and Weyhausen (1999; 50 sheep) indicated >5,000 acres of escape terrains was needed.

For the purposes of the assessment, 50 sheep is considered the minimum number to maintain a viable subpopulation in one watershed, therefore a total of 5,000 acres of escape terrain per watershed would be required. Clearly sheep can walk around a mountain and be in another watershed therefore they may use portions of a watershed with less than the minimum escape terrain to maintain the viable subpopulation. These watersheds with less than the optimum area received a lessor metric score (Table 5.41).

Table 5.41. The escape terrain metric scoring scheme for sheep.

Sheep Escape Terrain Metric Criteria:	Metric Score
Greater than 5,000 acres	1.00
Between 2,500 and 5,000 acres	0.66
Less than 2,500 acres	0.33

Goats ($V_{\text{ESCAPEGOAT}}$):

For goats, researchers have generally defined this as >27 degree slope possessing rocky outcrops and/or cliffs greater within 800 feet of forage (Gross et al. 2002). To determine the spatial extent of the escape terrain, we used the GNP vegetation map shapefile (glac_vegmap.shp) and the 10 meter DEM to select areas of ‘Rocky Mountain Alpine Cliff, Scree, and Other Rock Vegetation’ on areas with greater than 27 degrees slope. We then applied an 800-foot buffer all vegetated areas and determined the acres of this buffer within the above escape terrain. About 250 acres of escape terrain supports 1 to 3 goats (Belt 2010). Therefore, supporting a population of 50 goats per watershed would require a minimum of 4,200 acres of escape terrain. Clearly goats can walk around a mountain and be in another watershed therefore they may use portions of a watershed with less than the minimum escape terrain to maintain the viable subpopulation. These watersheds with less than the optimum area received a lessor metric score (Table 5.42).

Table 5.42. The escape terrain metric scoring scheme for goat.

Goat Escape Terrain Metric Criteria:	Metric Score
Greater than 4,200 acres	1.00
Between 2,100 and 4,200 acres	0.66
Less than 2,100 acres	0.33

Talus habitat (V_{TALUS})

For the purposes of this document, a total of 100 pikas were selected as a minimum viable subpopulation. One hundred pikas require greater than 10 acres of talus habitat (Moyer-Horner 2011). To determine the spatial extent of talus polygons we used the GNP vegetation map shapefile (glac_vegmap.shp) to select areas of ‘Cliff, Talus, and Sparse Vegetation’ greater than 10 acres in

size³. Those areas were then summed per watershed (GNP_HUC10_2011.shp). The following describes the steps necessary to derive the final Talus habitat score:

1. The total area of a watershed's 'Cliff, Talus, and Sparse Vegetation' polygons that were 10 acres or larger were divided by the maximum acreage of these polygons across all watersheds to acquire a relative talus habitat score.
2. The relative talus habitat score is then further scaled toward the unimpacted range by applying this formula: (relative pika habitat score + 4)/5. The logic is that the Park's relative talus habitat will show a range of natural conditions. However if talus habitat exists in a watershed, then it will not score lower than 0.80.

Spruce-Fir Forest ($V_{\text{SPRUCEFIR}}$)

As stated above, Squires et al. (2008) found that lynx generally denned in mature spruce-fir (Picea-Abies) forests with high horizontal cover and abundant coarse woody debris. Table 5.43 provides the metric scoring scheme to assess the extent of sufficient denning habitat within the park for lynx. To determine the total acreage of spruce fir forest, we used the GNP vegetation map shapefile (glac_vegmap.shp) to select areas of Subalpine Fir - Engelmann Spruce Forest and Subalpine Fir - Engelmann Spruce Woodland. The total acreage for each watershed was determined and the scoring scheme was applied to each.

Table 5.43. The Spruce – Fir metric scoring scheme.

Talus Metric Criteria:	Metric Score
Greater than 40,000 Acres	1.00
Between 20,000 and 40,000 Acres	0.66
Less than 20,000 Acres	0.33

Prey Abundance (V_{PREY})

Wolf density in GLAC is 10 wolves/250,000 acres in the best habitat. A pack of wolves need about 200 ungulates (deer, elk, and moose) per year to survive, and wolves cause mortality rates in ungulate population of 10% annually and thus 2,000 ungulate would be required to support a single pack. Because total ungulate numbers are not available, elevation is used as a proxy for relative deer and elk density. Because of the low snow depths, low elevations have the best winter range. The park's digital elevation model (DEM) was used to determine the total area of a watershed below 4,000 feet, between 4,000 - 6,000 feet and above 6,000 feet. The percent area in these three categories are multiplied by the scoring scheme in Table 5.44 and summed per watershed.

³ It is likely that this GIS layer may over-estimate talus habitat that is appropriate for pika. Managers interested in pika should apply the best-available mapped talus cover to the methods in this section.

Table 5.44. The prey metric scoring scheme.

Prey Metric Criteria:	Metric Score
Relative watershed area below 4,000 feet	1.00
Relative watershed area between 4,000 and 6,000 feet	0.66
Relative watershed area above 6,000 feet	0.33

Elevation (V_{SNOW})

Den sites by wolverines and bears within GLAC are predominately above 6,000 feet and have a slope less than 45 degrees in basins comprised of deep and persistent snow cover. A DEM was clipped to the Park boundary and reclassified to show elevations above 6,000 feet. This layer was then intersected with a slope raster layer. Mountain Perennial Glacier and Snowfield was selected from the GLAC vegetation layer (glac_vegmap.shp) and the glaciers were erased using the 1998 glacier layer to show snowfield habitat. There were clipped by the area above 6,000 feet with slopes less than 45 degrees. The following describes the steps necessary derive the final snow denning score:

1. The total watershed's snow field acreage is divided by the maximum snow field acreage across all watersheds to acquire a relative snow denning score.
2. The snow denning score is then further scaled toward the unimpacted range by applying this formula: (relative snow denning score + 4)/5. The logic is that the Park's snow denning habitat will show a range of conditions, with diverse alpine systems scoring higher then less diverse systems. However if snow denning habitat exists in the Park in the 2011 assessment, then the watershed not score lower than 0.80.
3. Finally, for future assessments this score will be multiplied by the ratio of the watershed's total contemporary snow field acreage, divided by the 2007 total snow field acreage (Hop et al. 2007). For this 2011 assessment, the multiplier is equal to 1.0, but for future assessments this may be less than 1 due to permanent snow field habitat loss resulting from such impacts as climate change which will result in a lower overall score compared to the 2011 results.

Harvest/poaching outside the park ($V_{\text{BNDRYEDGE}}$)

The closer an animal's home range is to the park boundary the more likely the animal will include area outside the park in its home range where it will be subject to human harvest, legal and illegal. It is also likely that hunters may come inside the boundaries along the edges. This metric scores poaching per watershed based upon distance from the park's boundary. We parsed out distances of less than 0.62 miles (1 km), 0.62 to 5.20 miles (1 – 10 km), and greater than 5.20 miles (10 km) inside the park borders per watershed. We then summed the total area of those ranges and applied a multiplier in Table 5.45 to those areas based on proximity to the park edge. The total scores were then averaged per watershed. Watersheds with lower scores indicate a higher potential for illegal harvest within the park.

Table 5.45. The boundary edge metric scoring scheme.

Prey Metric Criteria:	Metric Score
Relative watershed area greater than 6.21 miles (10 km) from Park boundary	1.00
Relative watershed area between 0.621 miles (1.0 km) and 6.21 miles (10 km) from Park boundary	0.66
Relative watershed area less than 0.621 miles (1.0 km) from Park boundary	0.33

Human Disturbance ($V_{\text{HUMANDIST}}$)

In Glacier National Park a number of different types of recreation have the potential to affect mammals negatively. Hiking, boating, and camping certainly affect mammal movement and foraging activities for the period of time that humans occupy an individual's territory. Unfortunately, there are currently no data from Glacier National Park to investigate whether camping areas and high day use areas (e.g. picnic areas and popular hiking trails) are a threat to mammal communities. However, we can estimate the *risk* to mammal communities by using a surrogate measure of impact from the area proximal to human use based on the proximity to roads, railroads, buildings and campsites, and trails. A raster based assessment was developed using five raster datasets (or shape files converted to raster) available from the park: park's roads geo-database, railways from the BNSF geo-database, Trails_20050501.shp, buildings building2006.shp, and campsites.shp. For consistency, the same buffers area applied to roads, railroads, campsites, structures, and trails are applied for the analysis of avian, mammals, and vegetation ecological condition assessment. The buffers was applied to the various types of roads found in or near the park: Roads-1 are paved major highways (2-mile buffer), Roads-2 are primary paved roads within the park (1-mile buffer), Roads-3 are secondary paved roads within the park (0.5 miles buffer), and Roads-4 are the park's gravel or two-track roads (0.25-mile buffer). Buffers were also applied to the railroad (2 miles), building and campsites (0.25 miles), and tails (300 feet). Although the park has requested that all analysis effort was to be completed in English units, raster analysis was completed in metric units to correspond to potential future Landsat data format. Therefore, each raster layer was established with a 30-meter grid and the human infrastructure was buffered and corresponding buffer grid was scored following the criteria in Table 5.46. If the cell was less than or equal to the Euclidean buffer distance and greater than the previous buffer distance the cells received the assigned cell score. If greater than the max distance then the cell score was 1.0. The layers were then superimposed and the lowest of each layer's cell score was assigned to the final cell layer. The cell scores were then averaged for each watershed.

Table 5.46. Human disturbance ($V_{\text{HUMANDIST}}$) metric scoring assigned to the appropriate raster cells.

Raster	Total Buffer size (mile)	Total Buffer size (m)	Raster Cell Score Assigned to Buffer Distances (m)									
			0	0.1	0.2	0.3	0.4	0.5	0.6	0.7	0.8	0.9
Road 1	2.00	3218	50	402	754	1106	1458	1810	2162	2515	2867	3219
Road 2	1.00	1609	50	223	397	570	743	916	1090	1263	1436	1609
Road 3	0.50	805	50	134	218	302	385	469	553	637	721	805
Road 4	0.25	402	50	89	128	167	207	246	285	324	363	402
Railroad	2.00	3218	50	402	754	1106	1458	1810	2162	2515	2867	3219
Building	0.25	402	50	89	128	167	207	246	285	324	363	402
Trail	300 (ft)	~90	-	-	-	-	-	-	-	30	60	90

Mammal Condition Index

To acquire an overall condition score for each watershed, the following index was applied. Six significance metrics that captures the distribution, density, and extent of mammal habitat provide an averaged of ecological significance for GLAC mammals in each watershed. This significance is degraded by stressor metrics that measure potential exposure to poaching. The model is constructed to emphasize the impact from the proximity to human infrastructure. An additional constant was added to this model to account for change in persistent snow cover due to future loss of alpine area from climate change or potential disturbances. The Mammal Condition Index is as follows:

$$\text{Mammal Condition Score} = \text{square root of } (V_{\text{HUMANDIST}} * ((V_{\text{ESCAPESH}} + V_{\text{ESCAPEGOAT}} + V_{\text{TALUS}} + V_{\text{PREY}} + (V_{\text{SNOW}} * \text{SnwChnge}) + V_{\text{SPRUCEFIR}})/6) + V_{\text{BNDRYEDGE}}/2))$$

SnwChnge = current snow area/2011 snow area. For 2011 assessment SnwChnge = 1

5.6.3 Spatial Analysis Results

We used eight metrics to assess the health of mammal communities among different watersheds within the park. Mammal condition is derived from aspects of habitat necessary for indicator taxa: sheep, goats, pika, wolves, bear, wolverine, and lynx and the human disturbance that has an overall impact. There was variation among watersheds for all eight metrics, and we had sufficient data for analysis for each metric in most watersheds.

Sheep (V_{ESCAPESH})

The above criteria state that about 8,000 acres of sheep escape terrain would be required to maintain a viable population of 100 sheep. Table 5.47 indicates that all watersheds except Camas can support a viable population. Camas is predominately dominated by a low elevation landscape. The range of metric scores by watershed is presented in Figure 5.32.

Table 5.47. The sheep escape terrain acreage and resulting metric score.

Watershed	Escape Terrain (Sum Acres)	Metric Score
Belly	8,003	1.00
Camas	344	0.33
Coal/Ole	4,502	0.66
Cut Bank	2,787	0.66
Kennedy	3,707	0.66
Kintla/Bowman	6,444	1.00
Lake McDonald	2,973	0.66
Nyack	3,165	0.66
Quartz/Logging	2,597	0.66
Saint Mary	7,823	1.00
Swiftcurrent	6,122	1.00
Upper Two Medicine	3,826	0.66
Waterton	4,261	0.66

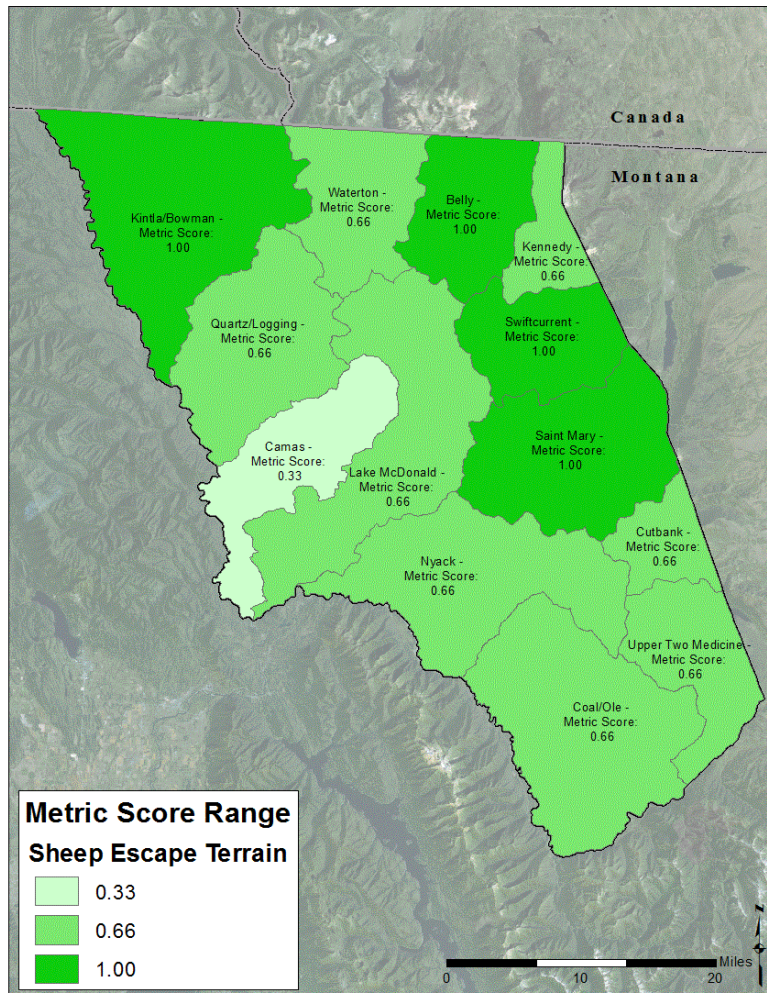


Figure 5.32. Escape terrain metric score range for sheep.

Goats ($V_{\text{ESCAPEGOAT}}$):

The above criteria state that 4,200 acres of escape terrain would be required to maintain a viable population of 50 goats. Five watersheds have goat escape terrain above 4,200 acres (Table 5.48). Camas watershed has the lowest escape terrain available for goats at 344 acres. However, because these areas are near the top of each watershed, it is clear goats can easily walk around a mountain and be in another watershed with sufficient escape terrain to support a viable population. Therefore they may use portions of a watershed with less than the minimum escape terrain to maintain the viable subpopulation for additional forage. The range of metric scores by watershed is presented in Figure 5.33.

Table 5.48. The goat-escape-terrain acreage and resulting metric score.

Watershed	Escape Terrain (Sum Acres)	Metric Score
Belly	6,882	1.00
Camas	344	0.33
Coal/Ole	4,403	1.00
Cut Bank	2,601	0.66
Kennedy	3,192	0.66
Kintla/Bowman	5,706	1.00
Lake McDonald	2,839	0.66
Nyack	2,915	0.66
Quartz/Logging	2,211	0.66
Saint Mary	7,137	1.00
Swiftcurrent	5,169	1.00
Upper Two Medicine	3,705	0.66
Waterton	3,945	0.66

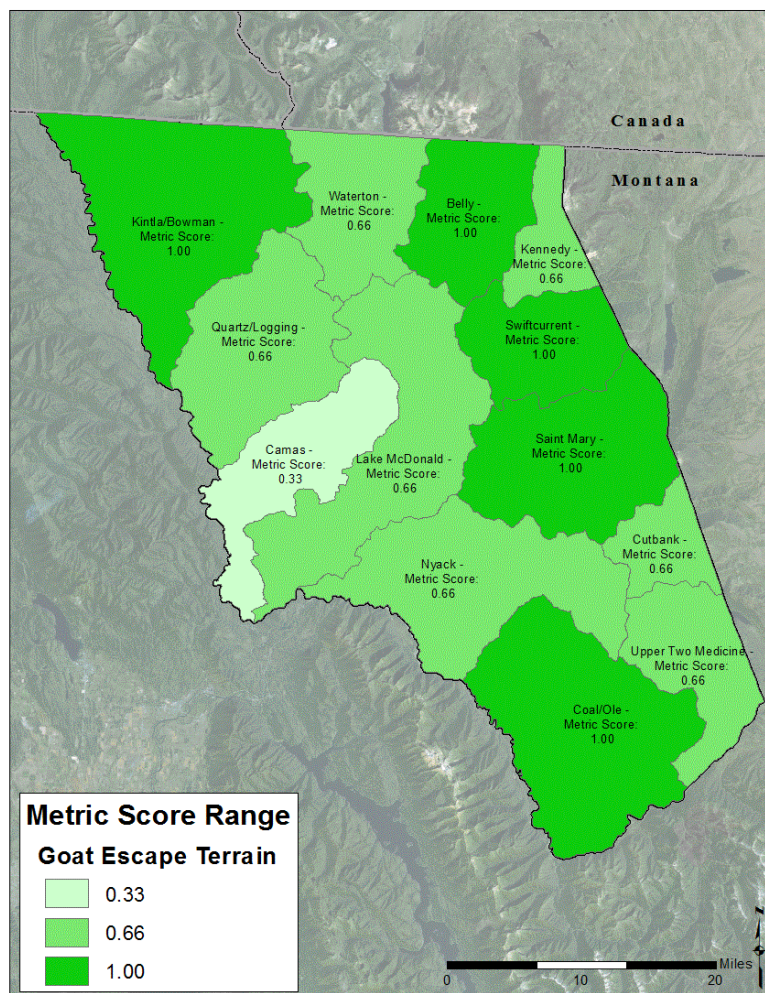


Figure 5.33. Escape terrain metric score range for goat.

Talus habitat (V_{TALUS})

We consider a minimum viable subpopulation of 100 pikas require greater than 10 acres of talus habitat (Moyer-Horner 2011). All watersheds have multiple talus polygons greater than 10 acres in size. Camas has the lowest overall talus presents and about 39% of the talus fields in that watershed are less than 10 acres in size. Saint Mary and Belly watersheds have the largest amount of talus in the park with 91% and 96% of their respective talus fields are greater than 10 acres in size (Table 5.49). The range of metric scores by watershed is presented in Figure 5.34.

Table 5.49. The Talus metric.

Watershed	Total Talus Acres	Greater Than 10 Acres	Metric Score
Belly	9874.26	9461.63	1.00
Camas	451.06	275.26	0.81
Coal/Ole	5802.86	4810.97	0.90
Cut Bank	3813.48	3540.48	0.87
Kennedy	5310.59	5116.95	0.91
Kintla/Bowman	8119.65	7420.36	0.96
Lake McDonald	4082.13	3497.52	0.87
Nyack	3842.58	3182.20	0.87
Quartz/Logging	3484.01	2889.91	0.86
Saint Mary	9902.88	8989.74	0.99
Swiftcurrent	7759.97	7376.89	0.96
Upper Two Medicine	4598.79	4301.11	0.89
Waterton	5027.43	4475.55	0.89

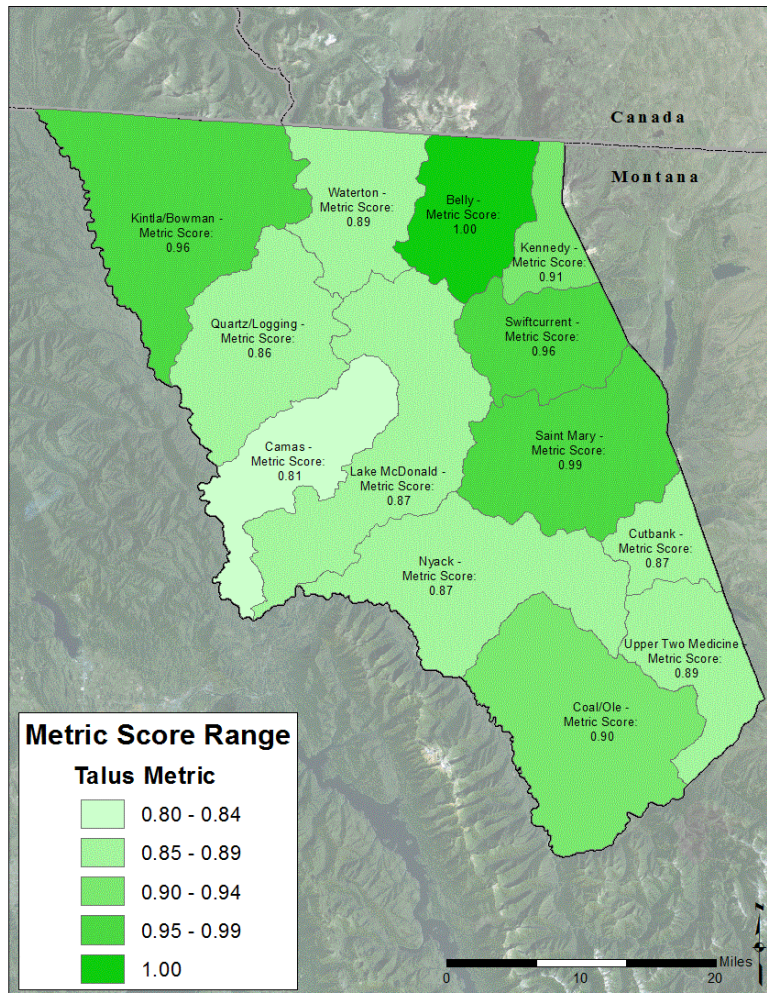


Figure 5.34. Talus polygon metric score range.

Spruce-Fir Forest ($V_{\text{SPRUCEFIR}}$)

We have determined that multistory, mature spruce-fir forests in excess of 40,000 acres are required to support denning for 3-5 lynx. Two of the 13 watersheds in Glacier National Park have had at a spruce-fir forest above 40,000 acres, 6 between 20,000 and 40,000 acres the remainder below 20,000 acres (Table 5.50). Cut Bank and Kennedy have the lowest amount of spruce-forest. The range of metric scores by watershed is presented in Figure 5.35.

Table 5.50. The Spruce-Fir acreage and the resulting metric score.

Watershed	Spruce-Fir Acres	Metric Score
Belly	17,174	0.33
Camas	35,914	0.66
Coal/Ole	37,763	0.66
Cut Bank	7,916	0.33
Kennedy	7,503	0.33
Kintla/Bowman	48,699	1.00
Lake McDonald	42,639	1.00
Nyack	34,534	0.66
Quartz/Logging	33,159	0.66
Saint Mary	30,047	0.66
Swiftcurrent	11,578	0.33
Upper Two Medicine	14,958	0.33
Waterton	24,919	0.66

Prey Abundance (V_{PREY})

We used elevation as a proxy for relative ungulate (deer, elk, and moose) density, because lower elevations have the best winter range. Watersheds on the west side of the park have a lower general elevation than east side watersheds and tended to score higher on the metric (Table 5.51). Camas watershed has 32% of its area below 4,000 feet and scored the highest of all the watersheds. The range of metric scores by watershed is presented in Figure 5.36.

Elevation (V_{SNOW})

The total acreage of snowfields polygons that are 6,000 feet or above in elevation, less than 45 degrees slope and greater than one acre in size area provided in Table 5.52. Watersheds, such as Camas and Coal/Ole, have limited acreage. The range of metric scores by watershed is presented in Figure 5.37.

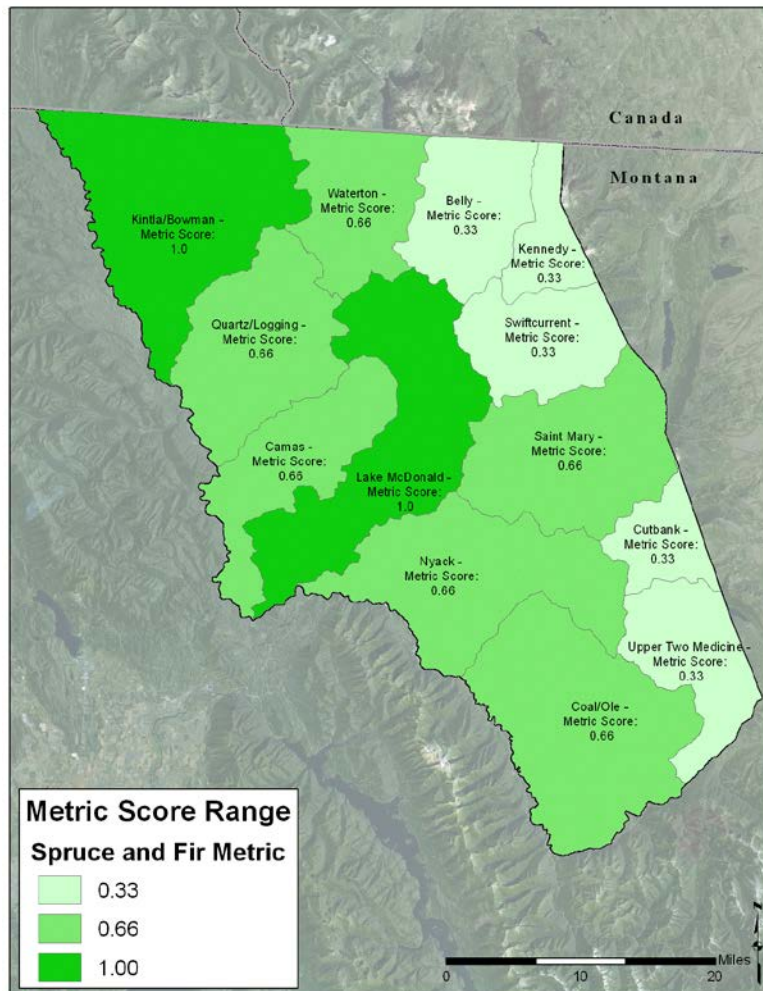


Figure 5.35. Spruce and Fir land cover metric score range.

Table 5.51. The percent of the watersheds that are in the 3 elevation categories and the resulting Prey Metric score.

Watershed	Below 4,000 Feet	4,000 - 6,000 Feet	Above 6,000 Feet	Metric Score
Belly	0%	43%	57%	0.47
Camas	32%	55%	13%	0.73
Coal/Ole	6%	54%	40%	0.55
Cut Bank	0%	27%	73%	0.42
Kennedy	0%	26%	74%	0.42
Kintla/Bowman	15%	59%	25%	0.63
Lake McDonald	27%	43%	30%	0.65
Nyack	16%	53%	31%	0.61
Quartz/Logging	22%	57%	22%	0.66
Saint Mary	0%	44%	56%	0.47
Swiftcurrent	0%	42%	58%	0.47
Upper Two Medicine	0%	45%	55%	0.48
Waterton	0%	45%	55%	0.48

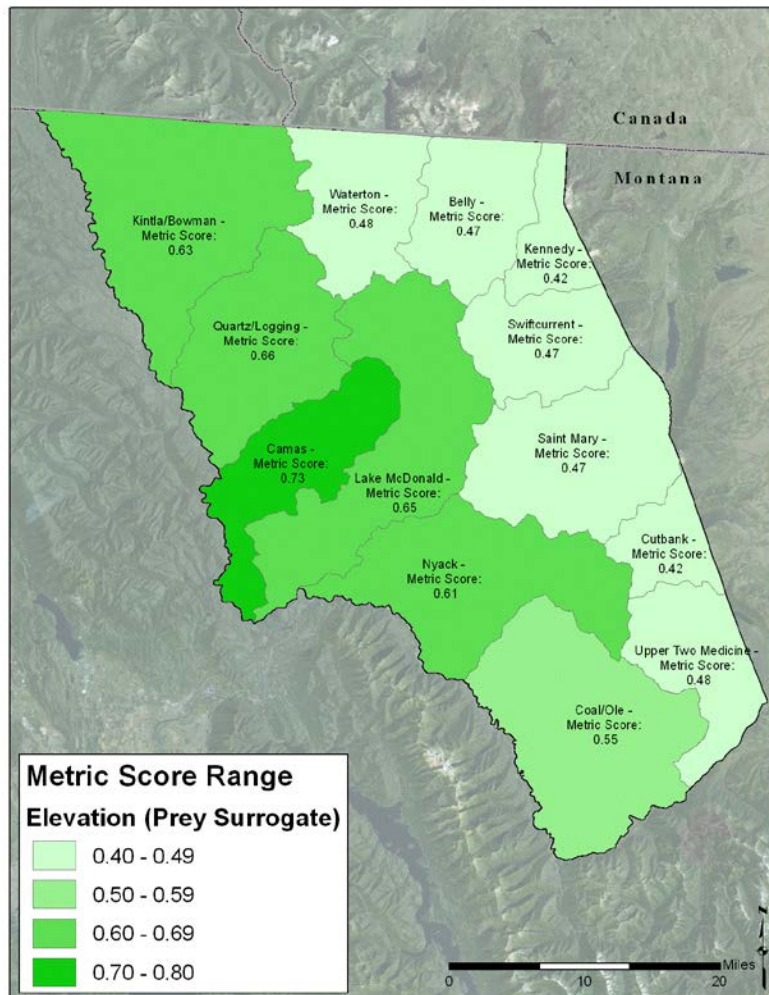


Figure 5.36. Prey surrogate as measured by elevation metric score range.

Table 5.52. Total acres greater than 6,000 Feet with snowfields and have less than a 45 degree slope and the resulting snow-denning metric.

Watershed	Total Acres	Metric Score
Belly	1,044	0.89
Camas	131	0.81
Coal/Ole	659	0.86
Cut Bank	399	0.83
Kennedy	118	0.81
Kintla/Bowman	1,961	0.96
Lake McDonald	1,111	0.89
Nyack	1,208	0.90
Quartz/Logging	690	0.86
Saint Mary	2,382	1.00
Swiftcurrent	774	0.87
Upper Two Medicine	367	0.83
Waterton	1,022	0.89

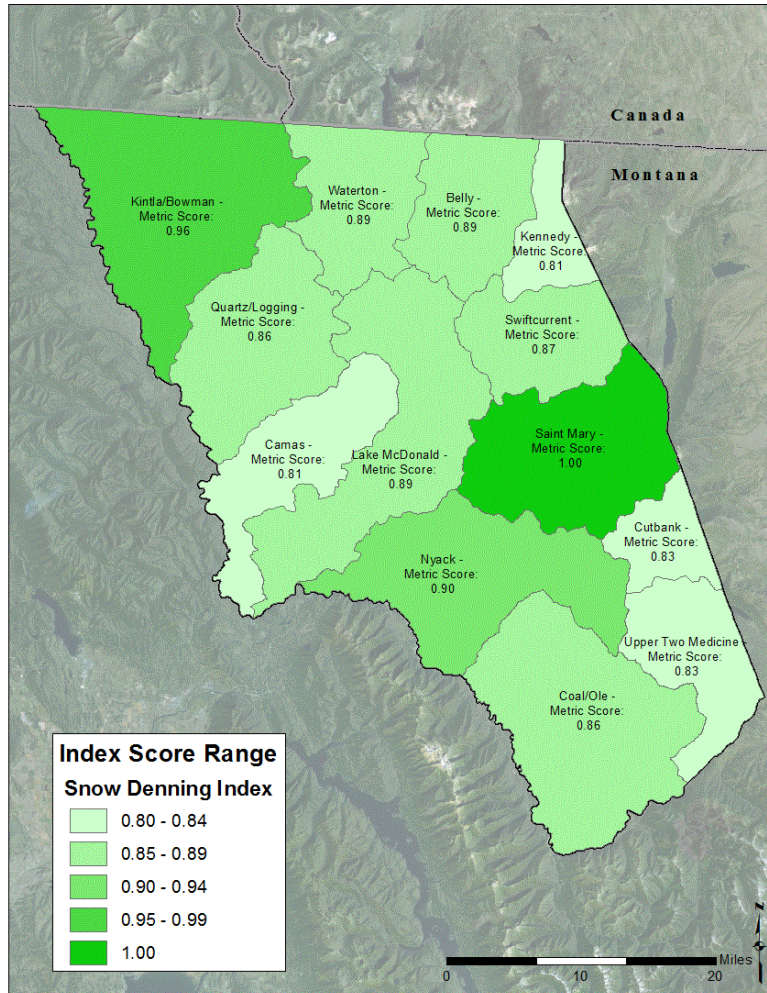


Figure 5.37. Bear and Wolverine denning metric score range.

Harvest/poaching within the Park ($V_{\text{BNDRYEDGE}}$)

To assess the potential threat of harvesting or poaching of animals within or adjacent to the park, we added a series of buffers (less than 0.62 miles (1 km), 0.62 to 5.20 miles (1 – 10 km), and greater than 5.20 miles (10 km)) to the park boundary and scored each watershed according the scheme described in the methods above. As expected, smaller watersheds scored lower than larger watershed (Table 5.53). The range of metric scores by watershed is presented in Figure 5.38.

Table 5.53. The Percent of watershed from Park boundary and the resulting boundary edge metric score.

Watershed	≤ 0.62 Miles	> 0.62 < 6.20 Miles	≥ 6.20 Miles	Metric
Belly	6%	64%	30%	0.74
Camas	13%	59%	28%	0.71
Coal/Ole	10%	69%	21%	0.70
Cut Bank	14%	81%	6%	0.63
Kennedy	19%	79%	2%	0.61
Kintla/Bowman	13%	73%	14%	0.66
Lake McDonald	4%	62%	33%	0.76
Nyack	8%	53%	39%	0.77
Quartz/Logging	5%	55%	39%	0.78
Saint Mary	7%	58%	35%	0.76
Swiftcurrent	5%	58%	38%	0.77
Upper Two Medicine	13%	75%	13%	0.66
Waterton	8%	62%	30%	0.73

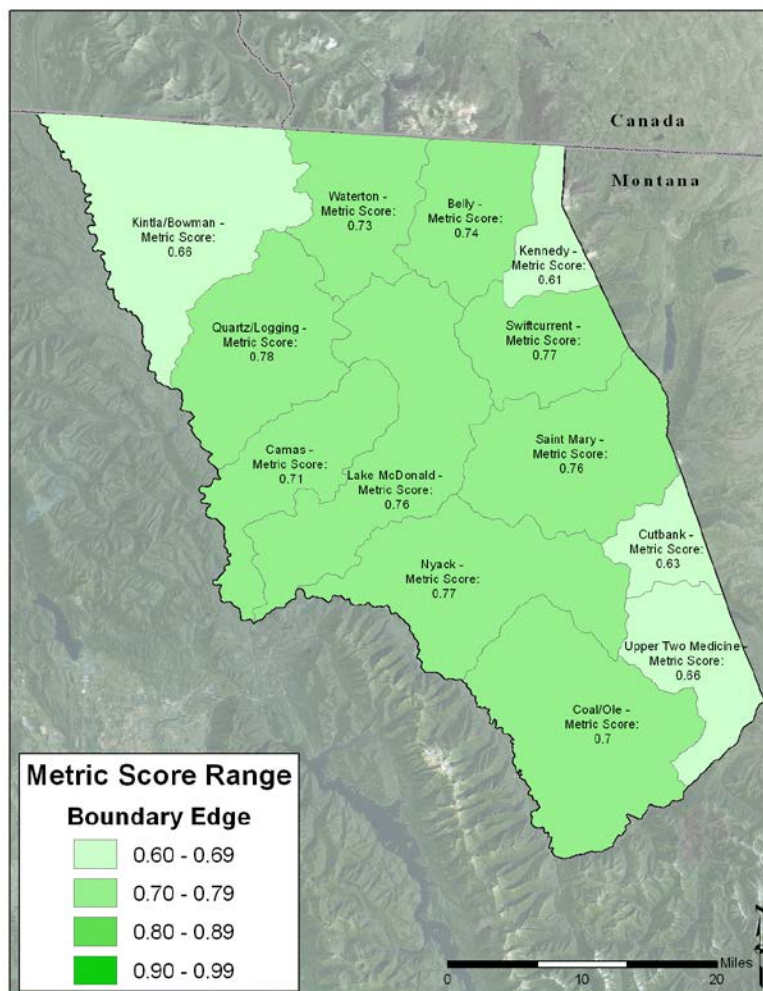


Figure 5.38. Poaching measured by proximity to park boundary edge metric score range.

Human impact ($V_{\text{HUMANDIST}}$)

Watersheds with developed infrastructure including roads, buildings, campsites, and trails scored the lowest with this human disturbance metric (Table 5.54). Due to the numerous roads, lodges, facilities and in-holdings, Lake McDonald scored the lowest. Coal/Ole and Upper Two Medicine were affected by their proximity to major highways and population centers. The range of metric scores by watershed is presented in Figure 5.39.

Table 5.54. The human disturbance metric scores.

Watershed	Human Impact Score
Belly	0.97
Camas	0.82
Coal/Ole	0.86
Cut Bank	0.98
Kennedy	0.89
Kintla/Bowman	0.91
Lake McDonald	0.78
Nyack	0.91
Quartz/Logging	0.93
Saint Mary	0.85
Swiftcurrent	0.92
Upper Two Medicine	0.85
Waterton	0.99

Mammal Condition Index

The mammal index incorporates six significance metrics that measure habitat attributes within each watershed that are necessary to support a healthy population of mammals that the park has deemed important (e.g. bears, goat, sheep, wolves). Additionally, there are two stressor metrics that measures the proximity of these habitats to human infrastructure and the potential exposure of the various watersheds to illegal poaching. Collectively, this index provides an insight of the relative condition of a wide variety of mammals in each of the park's watersheds. The watersheds that scored the lowest generally had limited habitat in one or more of the metrics and increased potential pressure from illegal poaching within the park or harvesting adjacent to the park. The range of index scores by watershed is presented in Table 5.55 and Figure 5.40.

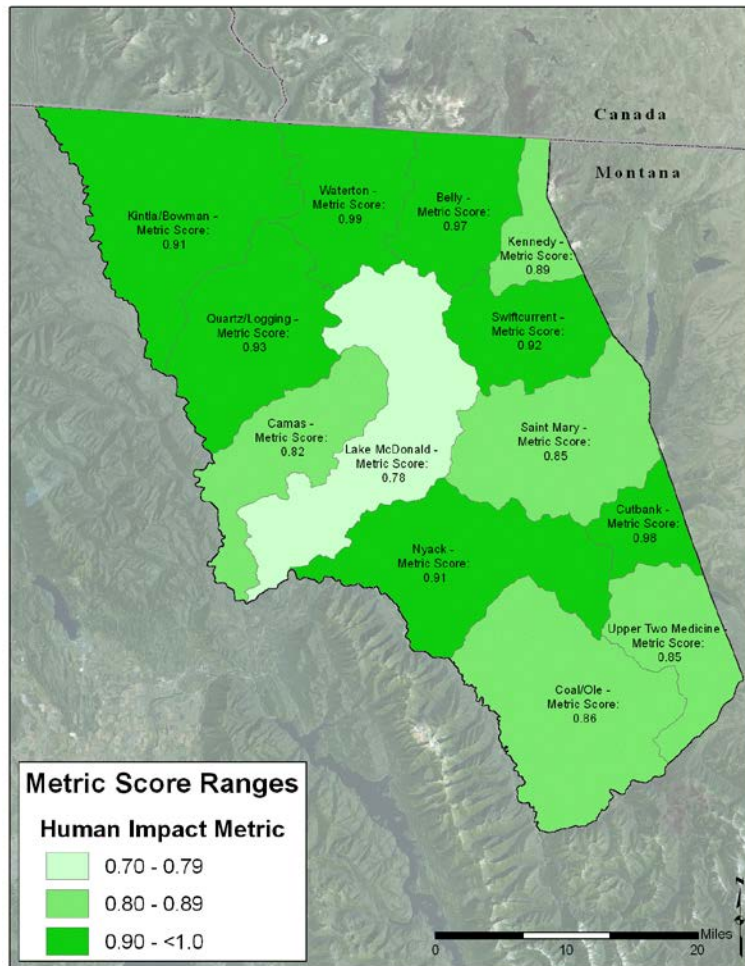


Figure 5.39. Human Impact metric score range.

Table 5.55. The mammal condition index score results.

Watershed	Sheep Escape Terrain	Goat Escape Terrain	Talus	Spruce-Fir Forest	Prey	Snow-Denning	Harvest Poaching	Human Disturbance	Mammal Condition Index
Belly	1.00	1.00	1.00	0.33	0.47	0.89	0.74	0.97	0.86
Camas	0.33	0.33	0.81	0.66	0.73	0.81	0.71	0.82	0.74
Coal/Ole	0.66	1.00	0.90	0.66	0.55	0.86	0.7	0.86	0.80
Cut Bank	0.66	0.66	0.87	0.33	0.42	0.83	0.63	0.98	0.79
Kennedy	0.66	1.00	0.91	0.33	0.42	0.81	0.61	0.89	0.76
Kintla/Bowman	1.00	1.00	0.96	1.00	0.63	0.96	0.66	0.91	0.85
Lake McDonald	0.66	0.66	0.87	1.00	0.65	0.89	0.76	0.78	0.78
Nyack	0.66	0.66	0.87	0.66	0.61	0.90	0.77	0.91	0.83
Quartz/Logging	0.66	0.66	0.86	0.66	0.66	0.86	0.78	0.93	0.84
Saint Mary	1.00	1.00	0.99	0.66	0.47	1.00	0.76	0.85	0.83
Swiftcurrent	1.00	1.00	0.96	0.33	0.47	0.87	0.77	0.92	0.84
Upper Two Medicine	0.66	0.66	0.89	0.33	0.48	0.83	0.66	0.85	0.74
Waterton	0.66	0.66	0.89	0.66	0.48	0.89	0.73	0.99	0.84

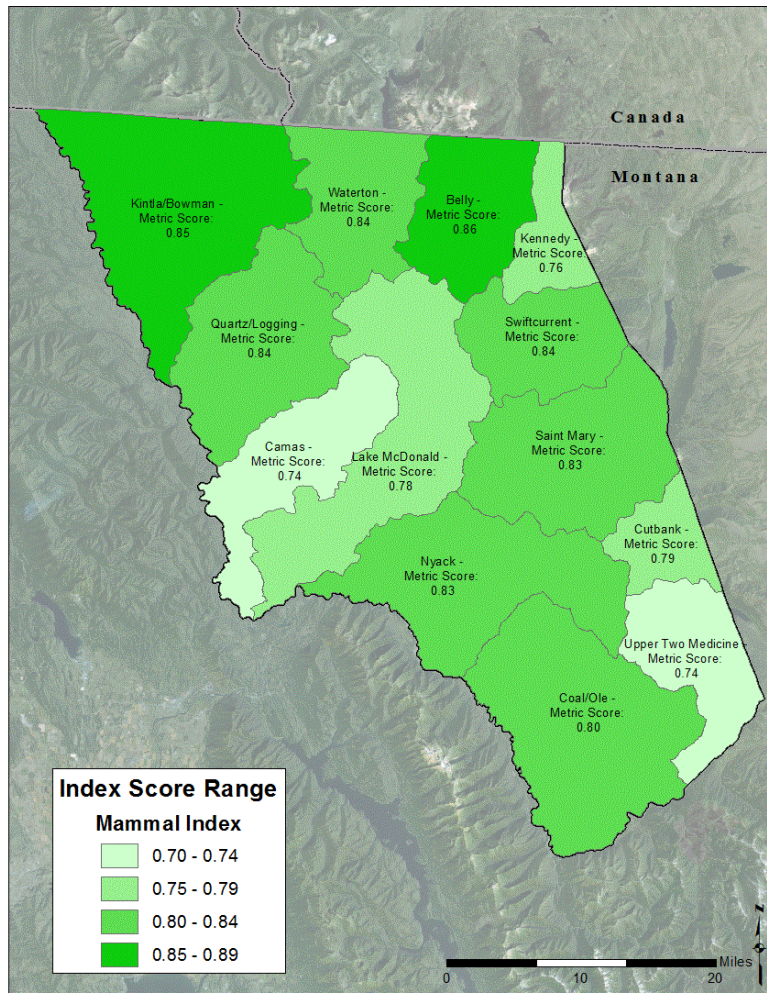


Figure 5.40. Mammal Condition Index score range.

5.6.4 Key Information Gaps and Research Needs

Future threats that may affect GLAC's grizzly bear population, unless adequately mitigated for, include: human-caused mortality due to increasing levels of human presence in and around GLAC; fragmentation across the U.S. Highway 2 corridor; and the possible effects of global warming such as changes in available foods, denning times, snowpack conditions, and fire regimes.

The effect of an expanding human population around GLAC, particularly on the western edge of the park in Flathead County, is one of the biggest future threats to GLAC grizzly bears both from the direct mortality risks and the loss of secure habitat. Between 2000 and 2008, human populations in Flathead and Glacier Counties grew by 18.8% and 0.4% respectively (U.S. Census Bureau 2009). Today, there are an average of 14.6 people per square mile in Flathead County (U.S. Census Bureau 2009) and that number will continue to rise as the population grows to an estimated 111,740 by 2025, an increase of 37,269 people from 2000 (Flathead County 2007a). Construction of new homes within Flathead County has steadily increased since 1970 (Flathead County 2007a) with a corresponding increase in the number of seasonal, cabin-style homes which are often located in rural areas (Flathead

County 2007b). Grizzly bears exhibit a preference to living >10 km from these developed areas (Nelleman et al. 2007) which limits the availability of secure habitat. Some bears have to live in these developed areas and those that do are more likely to have conflicts with humans such as direct mortality from bear-human encounters, food conditioning, and increased chances of habituation (Mattson et al. 1987).

Amplified by the threat of a growing human population around the park is the potential for increased population fragmentation between the GLAC and the Bob Marshall Wilderness complex. As the number of residents increases within the U.S. Highway 2 corridor, traffic volumes will increase and thus, further limit grizzly bear movements and increase the likelihood of bear-vehicle collisions, bear-human conflicts, and human-caused grizzly bear mortality. The effects of this threat may be mitigated through preventive efforts such as safe crossing options and educational outreach programs targeted at residents and user groups.

Climate change may generate a number of threats to GLAC's grizzly bear population in the future as well. Because we cannot decidedly predict exactly how climate change will alter our planet, most of the threats posed to grizzly bears are based on knowledgeable predictions and future-scenario modeling efforts. A few of the foremost possibilities include: shifts in bear foods, reduction in snowpack levels, shifts in denning times, and changes in fire regimes.

Climate change could impact grizzly bears in GLAC by creating either a temporal shift or reduction in their available food sources. Already, as glaciers melt and mean annual temperatures increase, plant communities are beginning to shift their spatial distributions (Rodriguez et al. 2007). If temperatures rise to extreme levels, there is a possibility that high elevation alpine plant communities might disappear entirely, as they have been predicted to do in Britain (Thomas and Morris 1994). However, because grizzly bears are such successful omnivores if these changes are made gradually, they may not have extreme effects.

Another possible influence of climate change is the gradual reduction in snow accumulation within the park as mean cool season temperatures increase and annual precipitation in the form of snow decreases (Karl et al. 2009). Less snowpack means earlier spring runoff times and this would likely shorten the denning season as foods become available earlier. This increased time outside of the den would consequently add to the threat of conflicts with humans. A shortened den season would also offer fewer protections for cubs of the year by increasing the time they are exposed to predators and other environmental influences.

Fire regime changes caused either directly or indirectly by global warming (Miller and Urban 1999) may also impact grizzly bears in the future by drastically altering their habitat. Over the next 60 years, as weather changes triggered by warming take effect, longer fire seasons due to an increased likelihood of fires in the spring and an increased severity of fires in the summer is expected (Nitschke and Innes 2008). Completely new fire regimes would impact the typical availability of bear foods and may, in the long-term, alter the overall habitat suitability for grizzly bears within GLAC by modifying resources on a landscape scale.

Additional and ongoing funding is needed to maintain a radio-collared sample of grizzly bears throughout the NCDE and within GLAC as well as continuing the non-invasive population monitoring pioneered by Kendall. Slowly reproducing, long-lived, wide-roaming species like grizzly bears are particularly vulnerable to human pressures. With data obtained from GPS and VHF radio-collars, we can determine population trend, estimate vital rates (i.e., survival, reproductive success, litter interval, etc.), examine spatial and temporal differences in population traits, assess the potential impacts from climate change on grizzly bear habitat use, and establish if grizzly bears in GLAC are at or near carrying capacity. Continuously monitoring the trend and associated vital rates is fundamental to the successful management of the species so that changes in habitat and population conditions can be detected in time to respond with appropriate management actions. Adequate funding to maintain a radio-collared sample and conduct data analyses are both necessary to understanding the overall status of grizzly bears in the park and how habitat and population conditions may change in the future.

Another information gap associated with GLAC is related to road density data. Currently, road densities within six subunits shared by GLAC and the Blackfoot Tribe on the eastern edge of the park are unknown. While the portions of these subunits that are within GLAC are accounted for and meet the motorized access management standards, they are only a fragment of the overall area within each subunit (<75% GLAC). As previously mentioned, secure habitat with substantial Core area is an essential part of keeping grizzly bears safe from human-related mortalities. Obtaining these missing data for Tribal lands immediately surrounding GLAC will be useful in assessing how secure bear habitat is on the eastern edge of the park and where there is a need for improvement.

In a popular vacation spot like GLAC, it is important to know how various recreational activities are affecting grizzly bears. Little research has been done to document how the level and type of human recreational activities can influence bear behavior. With the exception of White et al. (1999), there is no GLAC-specific information pertaining to the responses bears have to recreational activities within the park. This information will become increasingly important for future management decisions as the number of visitors and residents in the area continues to increase.

Finally, resource managers and others outside the park must recognize that there is no self-contained GLAC grizzly bear population within the park's boundaries. The grizzly bears living within GLAC are individuals belonging to a larger population across the NCDE. Outside influences are critically important factors for the success of the grizzly bears living within the park. Cooperation with surrounding management entities, such as the state of Montana, the Blackfoot Tribe, and Canadian authorities, and the ability to participate meaningfully in their respective decision-making processes is necessary to ensure the health and vitality of grizzly bears whose ranges overlap the Park and the surrounding jurisdictions.

5.7 Focal Area - Vegetation

5.7.1 Summary of Current Conditions

The native plant communities within the boundaries of Glacier National Park are remarkably intact. However, human use in and around the park has resulted in the introduction of non-native invasive plant species and disturbance of native vegetation near developed areas. As documented by the USGS-NPS Vegetation Mapping Program (VMP) (Hop et al. 2007), these disturbed areas make up a small percentage of the park's overall acreage. Less than 10% of the total area within Glacier National Park is classified as "developed" or supports vegetation that has been significantly disturbed. The bulk of the park (approximately 92%) is managed as wilderness, and is indeed proposed as wilderness, lending to the overall protection of native vegetation.

The goals of the park's VMP were to (1) adequately describe and map plant communities of the park and (2) provide useable baseline vegetation information to scientists and NPS resource managers. The project, initiated in 1998 and completed in 2009, has resulted in the production of a list of plant communities (a plant community classification), their ecological description and a map showing their distribution (See Figure 3.6).

The VMP project is useful in summarizing current conditions of Glacier's vegetation because it allows quantitative analysis of the relative abundance of developed and markedly disturbed areas. Updates are needed to account for several large fires that have taken place since the original aerial photography. The map and associated metadata provide a broad overview of current vegetation, broken into units that indicate and define land cover at relatively coarse resolution (1.25 acres). Fine scale identification of, for example, patches of weeds within a small polygon of native vegetation was beyond the scope of that project. The detail and extent of the VMP for the park provided the basis for many of the vegetation based metrics used throughout this condition assessment. Metrics like the alpine habitat for the bird assessment, and spruce-fir habitat for the mammal assessment were derived from these data. However, an assessment of the entire vegetation of the park was limited to a few key disturbance attributes. Several of the ideal vegetation assessment attributes such as rare plants, seedling viability, or management plans, are not at a scale appropriate for this watershed scale assessment, but are indirectly addressed in this section. Three metrics: non-native invasive plants, grazing trespass, and human disturbance are spatially appropriate to apply the vegetation condition assessment.

Non-native Invasive Plant Species

The invasion of non-native species into native plant communities is considered to be one of the most serious threats to the park's native vegetation (Lange 1991). Invasive non-native plant species are primarily confined to open, non-forested areas at low to mid-elevation. While 126 introduced species have been documented, only 4 non-native species occur in the subalpine zone, and none have been observed above treeline (Lesica 2002). Most (60%) are confined to disturbed areas, such as along roads or near developed areas (Lesica 2002). Non-native species known to invade native plant communities and replace existing native vegetation in the park are: spotted knapweed (*Centaurea*

maculosa), leafy spurge (*Euphorbia esula*), St. Johnswort (*Hypericum perforatum*), meadow hawkweed (*Hieracium caespitosum*), orange hawkweed (*Hieracium auranticum*), oxeye daisy (*Leucanthemum vulgare*), Tansy Ragwort (*Senecio jacobaea*), houndstongue (*Cynoglossum officinale*), Tall Buttercup (*Ranunculus acris*), cheatgrass (*Bromus tectorum*), Dalmatian toadflax (*Linaria dalmatica*), yellow toadflax (*Linaria vulgaris*), and sulphur cinquefoil (*Potentilla recta*).

Grazing Trespass

Trespass grazing occurs frequently along the eastern border of Glacier National Park. The park boundary is not entirely fenced, nor is it demarcated by a major river, as it is on the park's western and southern borders. Adjacent land owners on the Blackfeet Indian Reservation often use their property as grazing range, and livestock freely wander in and out of the park. Open grasslands and aspen woodlands are especially affected.

Livestock use impacts the park's native vegetation in several ways. Cows use native plants for forage, negatively influencing the health of individual plants through heavy, repeated browsing. Heavy grazing also results in trampling and uprooting of native vegetation, particularly when the soil is moist in the spring. Non-native invasive plant species can also be spread by livestock migrating in and out of Glacier National Park.

Human Disturbance

In Glacier National Park a number of different types of recreation have the potential to affect vegetation negatively. Driving, hiking, boating, and camping, as well as NPS-approved projects that involve ground disturbance may increase disturbance to sensitive species, and increase the occurrence of tolerant and non-native species. Road traffic along the Going-to-the-Sun road and other roads in the park are a large source of invasive species located along the road bank.

5.7.2 Methods: Vegetation

Non-native Invasive Plant Species (V_{WEED})

Infestations of invasive non-native plant species in the park are monitored and actively managed, especially Montana listed noxious weeds. Control measures have been only partially successful in slowing the spread of some species. Only a major, sustained effort, backed by adequate funding, will restore some impacted systems to their natural state, although complete restoration is impossible in many sites. Efforts to identify significant populations of non-native invasive plant species within the park's boundaries have resulted in the assembly of a GIS layer (2006_infest.shp) showing the locations of these populations. In addition to mapped occurrences, extensive supplementary data exists which describes infested areas and treatments taken. The following weed metric was developed using the 2006 noxious weed spatial data:

$$V_{\text{WEED}} = 1 - \frac{\text{The total number of mapped invasive species sites per watershed}}{\text{total for all watersheds (relative sites)}}$$

Grazing Trespass (V_{GRAZE})

Illegal grazing of livestock has impacted the eastern grasslands of Glacier National Park since its designation, and continues to be problematic. The 2006 mapping data indicate extensive trespass along the eastern boundary of the park (trespass_extent_2006.shp, GLAC data). In 2007, all of these portions were fenced (livestock_fences_2007.shp, GLAC data). While it would be ideal to provide protection through fencing the entire eastern boundary (Shea et al 2009), this has proven to be impractical from a funding and staffing standpoint. Shea and colleagues indicated that alternative methods (i.e. communicating with landowners and lease holders) have failed to reduce this threat.

The following series of formulas was used to evaluate grazing trespass on land within the park, based on documented occurrences of trespass and preventive methods of eliminating problem livestock. If there is no documented grazing trespass, the watershed received a score of 1.0:

Step 1: $1 - \frac{\text{the total acreage of mapped grazing trespass per watershed}}{\text{total for all watersheds (relative sites)}}$

Step 2: The above results are subtracted from 1 to obtain the remaining points necessary to raise the score to 100% and this sum is multiplied by the percent of the grazing areas that are currently fenced. This sum is added to the results in Step 1. If the area is 100% fenced then the score will be 1.0 if is partially fenced or not fenced at all the score will be lower.

Human Disturbance ($V_{\text{HUMANDIST}}$)

This metric estimates the *risk* to vegetation communities by using a surrogate measure of impact from the area proximal to human use based on the proximity to roads, railroads, buildings and campsites, and trails. A raster based assessment was developed using five raster datasets (or shape files converted to raster) available from the park: park's roads geo-database, railways from the BNSF geo-database, trails (trails_20050501.shp), buildings (building2006.shp), and camp sites (campsites.shp). For consistency, the same buffers area applied to roads, railroads, campsites, structures, and trails are applied for the analysis of avian, mammals, and vegetation ecological condition assessment. The buffers was applied to the various types of roads found in or near the park: Roads-1 are paved major highways (2-mile buffer), Roads-2 are primary paved roads within the park (1-mile buffer), Roads-3 are secondary paved roads within the park (0.5 miles buffer), and Roads-4 are the park's gravel or two-track roads (0.25-mile buffer). Buffers were also applied to the railroad (2 miles), building and campsites (0.25 miles), and tails (300 feet). Although the park has requested that all analysis effort was to be completed in English units, raster analysis was completed in metric units to correspond to potential future Landsat data format. Therefore, each raster layer was established with a 30-meter grid and the human infrastructure was buffered and corresponding buffer grid was scored following the criteria in Table 5.56. If the cell was less than or equal to the Euclidean buffer distance and greater than the previous buffer distance the cells received the assigned cell score. If greater than the max distance then the cell score was 1.0. The layers were then superimposed and the lowest of each layer's cell score was assigned to the final cell layer. The cell scores were then averaged for each watershed.

Table 5.56. Human disturbance ($V_{\text{HUMANDIST}}$) metric scoring assigned to the appropriate raster cells.

Raster	Total Buffer size (mile)	Total Buffer size (m)	Raster Cell Score Assigned to Buffer Distances (m)									
			0	0.1	0.2	0.3	0.4	0.5	0.6	0.7	0.8	0.9
Road 1	2.00	3218	50	402	754	1106	1458	1810	2162	2515	2867	3219
Road 2	1.00	1609	50	223	397	570	743	916	1090	1263	1436	1609
Road 3	0.50	805	50	134	218	302	385	469	553	637	721	805
Road 4	0.25	402	50	89	128	167	207	246	285	324	363	402
Railroad	2.00	3218	50	402	754	1106	1458	1810	2162	2515	2867	3219
Building	0.25	402	50	89	128	167	207	246	285	324	363	402
Trail	300 (ft)	~90	-	-	-	-	-	-	-	30	60	90

Calculation of Total Score

The final index is intended to capture a combination of each of the above metrics to represent the general condition of each watershed to support a healthy mammal population. By necessity, the index is a simplification of the complex elements necessary to maintain vegetation populations. However the collection of these metrics into an index provides insight of the relative condition of human and domestic animal impacts and invasive species of each of the park's watersheds. As with all models in the assessment it provides a score for a watershed derived from the diversity of the habitat and proximity to human activity that is relative to other watersheds in the park only. The Vegetation Condition Index is as follows:

$$\text{Vegetation Condition} = ((V_{\text{WEED}} * V_{\text{HUMANDIST}}) + V_{\text{GRAZE}})/2$$

5.7.3 Vegetation Results

Three metrics were used to assess the health of vegetation condition among different watersheds within the park. As the entire park has a very healthy vegetation community these metrics measure potential threats to the vegetation condition.

Non-native Invasive Plant Species (V_{WEED})

Non-native invasive plant species generally occur near areas of human concentration, high road and trail density and areas of grazing. Kintla/Bowman, Lake McDonald and Saint Mary have the highest number of observed non-native plants and, therefore, the lowest metric scores (Table 5.57 and Figure 5.41).

Table 5.57. Non-native plant species metric scoring.

Watershed	Weed Survey Count	Metric score
Belly	36	0.96
Camas	73	0.92
Coal/Ole	83	0.91
Cut Bank	10	0.99
Kennedy	3	1.00
Kintla/Bowman	156	0.83

Watershed	Weed Survey Count	Metric score
Lake McDonald	163	0.83
Nyack	83	0.91
Quartz/Logging	48	0.95
Saint Mary	117	0.88
Swiftcurrent	96	0.90
Upper Two Medicine	62	0.93
Waterton	12	0.99

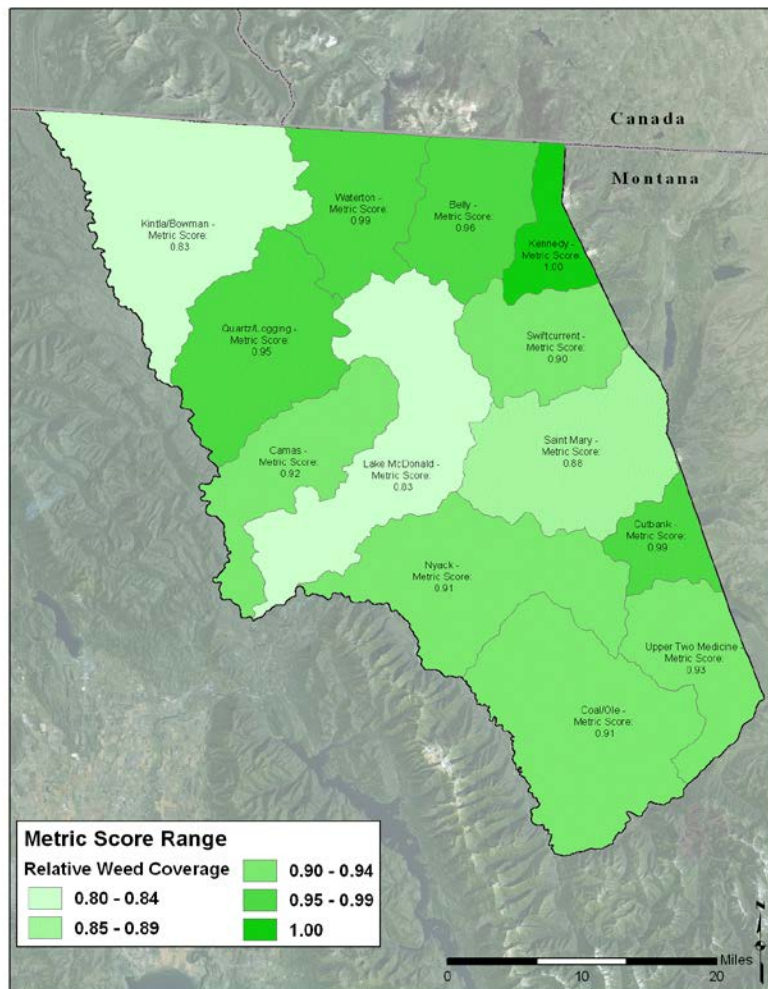


Figure 5.41. Range of weed metric scores within GLAC.

Human disturbance ($V_{\text{HUMANDIST}}$)

Watersheds with developed infrastructure including roads, buildings, campsites, and trails scored the lowest with this human disturbance metric (Table 5.58). Due to the numerous roads, lodges, facilities and in-holdings, Lake McDonald scored the lowest. Coal/Ole and Upper Two Medicine were affected by their proximity to major highways and population centers. More detailed locations of

problem locations for this are provided in Appendix C. The range of metric scores by watershed is presented in Figure 5.42.

Table 5.58. The human impact metric score in each watershed in Glacier National Park.

Watershed	Human Impact Score
Belly	0.97
Camas	0.82
Coal/Ole	0.86
Cut Bank	0.98
Kennedy	0.89
Kintla/Bowman	0.91
Lake McDonald	0.78
Nyack	0.91
Quartz/Logging	0.93
Saint Mary	0.85
Swiftcurrent	0.92
Upper Two Medicine	0.85
Waterton	0.99

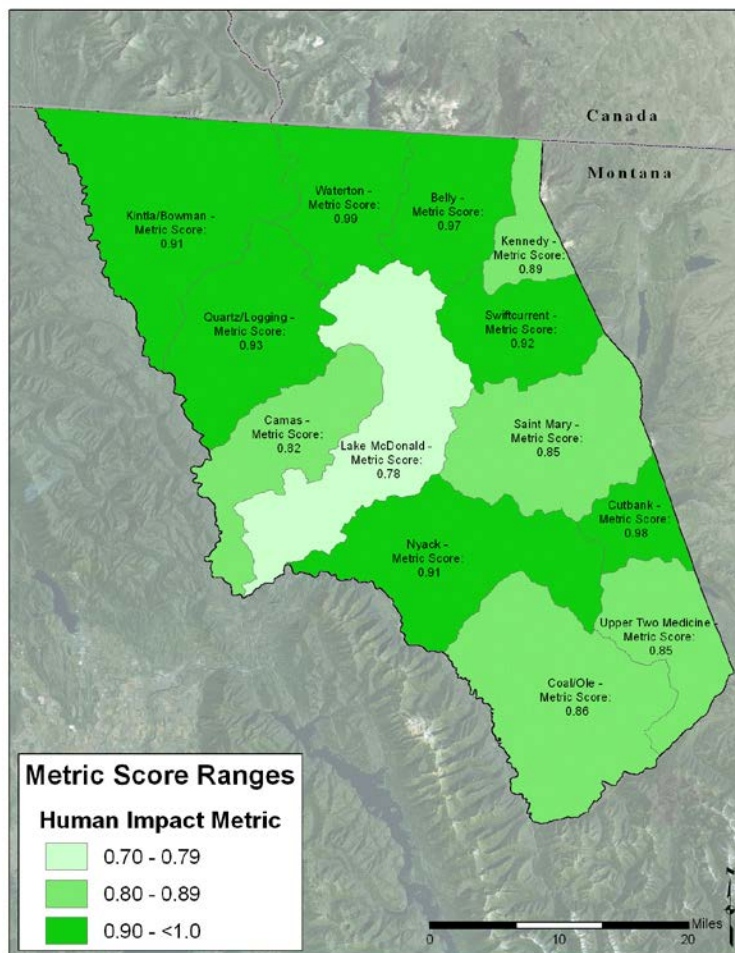


Figure 5.42. Range of human impact within GLAC.

Grazing Trespass (V_{GRAZE})

Historic grazing trespass has been observed in the park as late as 2011. In 2007 extensions were added to existing property fencing was installed in areas where the trespass had occurred. However, this exclusion fencing is not continuous nor is it feasible to have a continuous fence in all areas along the park's eastern boundary where grazing leases exist (see Appendix C). As a result, further trespass does occur and the continued motoring of illegal trespass and the reliability of the fencing is recommended. Table 5.59 and Figure 5.43 provide the results of the grazing assessment in the park.

Table 5.59. Grazing trespass, percent of preventative fencing, and related metric scoring.

Watershed	Total 2006 Grazing Trespass Acreage	Percent of Fencing along Boundary of Trespass Areas	Metric score
Belly	661	0	0.95
Camas	0	N/A	1.00
Coal/Ole	0	N/A	1.00
Cut Bank	1849	91	0.99
Kennedy	2868	100	1.00
Kintla/Bowman	0	N/A	1.00
Lake McDonald	0	N/A	1.00
Nyack	0	N/A	1.00
Quartz/Logging	0	N/A	1.00
Saint Mary	208	75	1.00
Swiftcurrent	3292	100	1.00
Upper Two Medicine	3497	70	0.92
Waterton	0	N/A	1.00

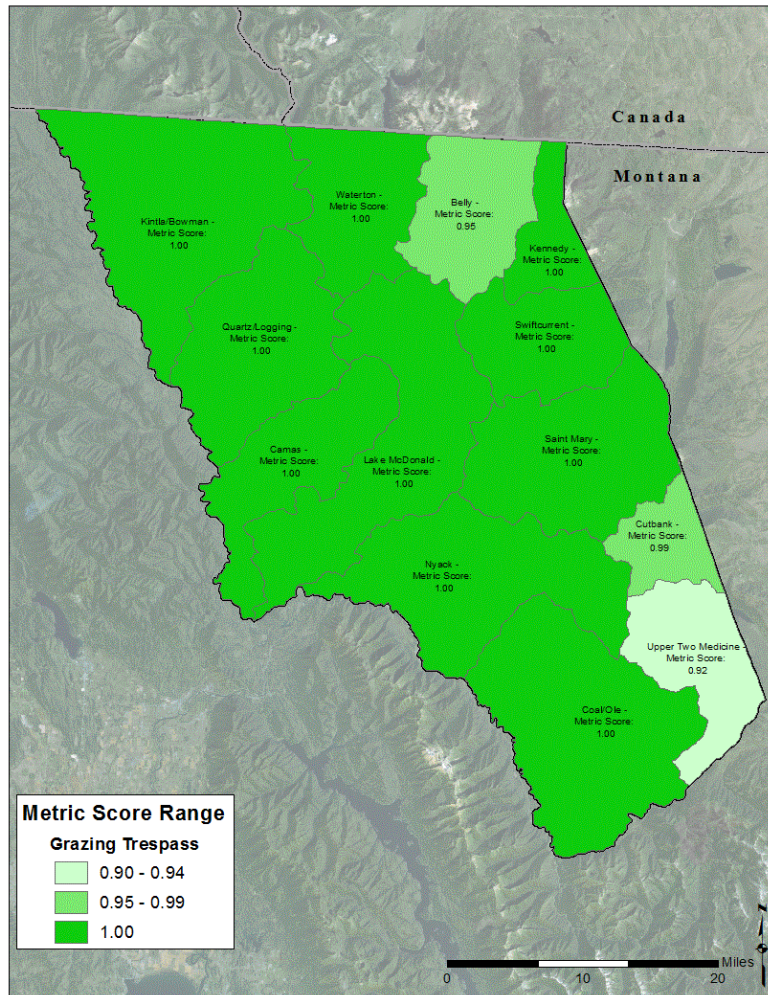


Figure 5.43. Range of grazing trespass metric scores along the eastern boarder of GLAC.

Vegetation Condition

Vegetation condition is an important attribute for many of the metrics used throughout all of the park's ecological condition assessment indices presented above. The condition index presented here only captures divergence from ideal conditions as measured by three stressor metrics that assess non-native species, grazing, and potential disturbance from human concentration. As a result, Kintla/Bowman, Camas, Lake McDonald and other watersheds that scored in the lower range have higher concentration of human interaction than other watersheds (Table 5.60 and Figure 5.44).

Table 5.60. Vegetation condition metric and final index scores.

Watershed	Exotic Species Metric	Human Disturbance Metric	Grazing Trespass Metric	Index score
Belly	0.96	0.97	0.95	0.94
Camas	0.92	0.82	1.00	0.88
Coal/Ole	0.91	0.86	1.00	0.89
Cut Bank	0.99	0.98	0.99	0.98
Kennedy	1.00	0.89	1.00	0.95
Kintla/Bowman	0.83	0.91	1.00	0.88
Lake McDonald	0.83	0.78	1.00	0.82
Nyack	0.91	0.91	1.00	0.91
Quartz/Logging	0.95	0.93	1.00	0.94
Saint Mary	0.88	0.85	1.00	0.87
Swiftcurrent	0.90	0.92	1.00	0.91
Upper Two Medicine	0.93	0.85	0.92	0.86
Waterton	0.99	0.99	1.00	0.99

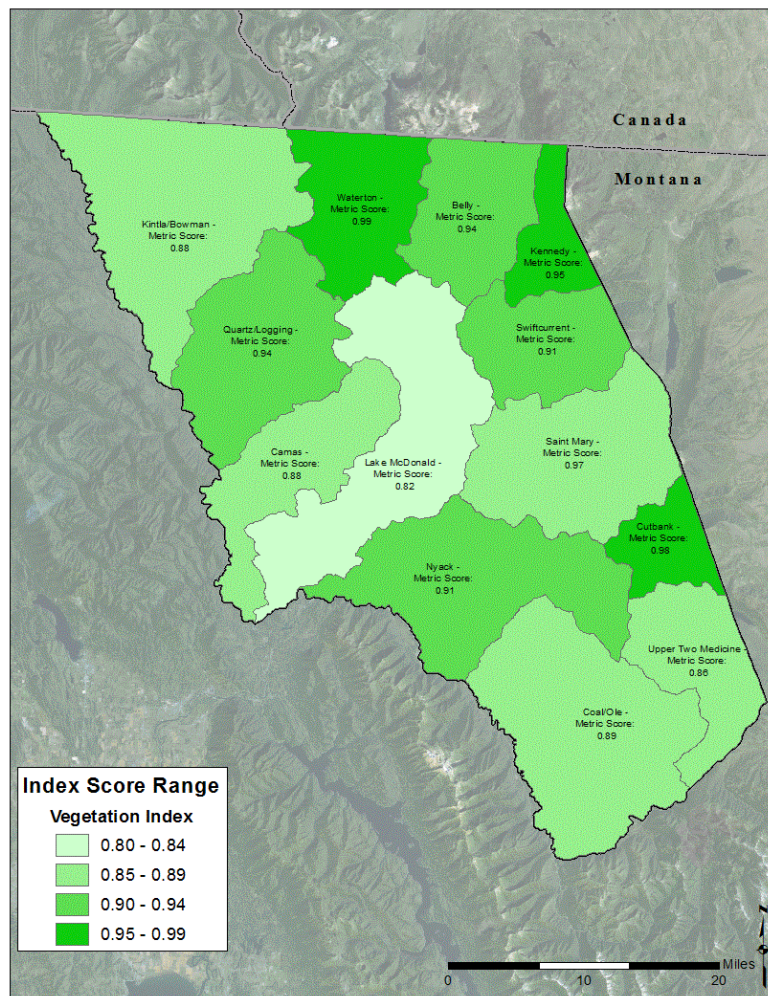


Figure 5.44. Vegetation condition index range of within GLAC.

5.7.4 Assessment of availability and gaps in monitoring data

Grasslands

Grasslands make up a small percentage of the terrestrial vegetation in the park and were therefore not included in this watershed scale assessment. However, they play an important role in the overall ecological health and diversity of the entire ecosystem. Grasslands provide important forage and habitat for ungulates native to the park, such as deer, elk, and bighorn sheep (Shea et al. 2009). These ungulates, in turn, provide food for carnivores, some of which are federally listed, such as grizzly bear. Carnivores also use the meadows for vegetative components of their diets (Shea et al. 2009).

Grasslands east of the Continental Divide in Glacier National Park have been the focus of the Glacier National Park Eastside Grasslands Ecology Project (EGEP) which was aimed at studying specific composition and distribution of these grasslands. The goals of this project were (Shea et al. 2009):

1. To determine plant species composition in each of the numerous meadow systems and to classify the grassland communities on the east side of the park.
2. To monitor the presence and status of exotic plant species, and to place surveyed sites in a matrix based on current ecological integrity, severity of current or potential threat to ecological integrity, and potential of the sites to respond to management treatment.
3. To establish permanent vegetation plots that may be used again in the future for comparative analysis.
4. To document wildlife utilization of grasslands and establish a baseline for determining relationships with vegetative conditions, comparison with historical records, and future monitoring. The assessment focused on elk, bighorn sheep, neotropical migratory birds, and small mammals.
5. To determine the initial condition of undisturbed grasslands, identify what changes (if any) have occurred over the last 100 years, assess the amount of damage caused by those changes, and clarify the rate and direction of change to help forecast expected future conditions.

The EGEP final report (Shea et al. 2009) meets all of the above goals and recommends specific actions for reducing threats to specific native grassland communities. The report provides crucial information in assessing the overall ecological health of Glacier National Park's native grasslands.

Whitebark and Limber Pine Woodlands

Whitebark pine (*Pinus albicaulis*) and limber pine (*Pinus flexilis*) communities are ecologically important for a variety of reasons. Their seeds are used for food by many wildlife species, including the federally listed grizzly bear. The trees also strongly influence patterns of vegetation establishment by acting as a pioneer species on harsh, exposed sites. In doing so they create sheltered microsites

where other plant species can successfully establish. They further enhance the proliferation of vegetation by accumulating snow, thereby increasing soil moisture during snowmelt periods.

Whitebark and limber pine communities once flourished across subalpine slopes within Glacier National Park, but have been severely impacted by an epidemic of white pine blister rust (*Cronartium ribicola*) over the last century. The disease specifically affects five-needle pines. Although western white pine (*Pinus monticola*) occurs in the park, the disease is most severe and widespread in limber and whitebark pine. The mortality rate of whitebark pine within the park, due to blister rust infection, is approximately 45%, with at least 73% infection in the remaining live trees (Kendall and Keane 2001). Kendall et al. (1996) estimate the park's limber pine mortality at 39%, with 78% infection in the remaining live trees.

Some whitebark and limber pine trees within the park appear to be resistant to blister rust. Seeds were harvested from these trees, starting in 1997 and continuing to date, with the intention of propagating and replanting potentially disease-resistant seeds and seedlings. In 2002, park scientists initiated a project to monitor the success of replanted seeds and seedlings. Some seeds were planted directly into subalpine habitats where whitebark and limber pine communities once flourished, while others were grown in a horticultural setting, and then reestablished on subalpine slopes as seedlings, most often in recently burned sites in existing or potential habitat. The success of seedling establishment is actively monitored by park scientists. Although the success of this project is important, the data was not included in the condition assessment because the temporal and spatial scale of the data was not conducive to the watershed scale assessment here.

Rare Plants

Glacier National Park provides habitat for 73 species of rare and/or sensitive plants. The presence of so many of these unique species is indicative of the overall ecological health of the park's terrestrial vegetation and the success of current management directives.

Plant species of special concern are tracked by the Montana Natural Heritage Program in coordination with park scientists. Locations of these species are distributed throughout the park and occur in every major vegetation zone. Funding in recent years has enabled the park to establish long-term monitoring plots in seven fen communities each with two or more rare plant populations included in the monitoring. Field crews have also surveyed more than 60 rare plant populations, collected habitat data and mapped their extent with GPS. More than a dozen new rare plant populations were found and documented, and a few historical records were verified. The data has been submitted to the Montana Natural Heritage Program, and a relational database for storing data has been developed. In addition, a rare plant field guide was developed and printed.

Non-native Invasive Plant Species

In 1991 an integrated weed management program was initiated, based on National Park Service policy. This policy mandates the control of invasive plant species if they (1) displace native flora, (2) interrupt ecological processes, and/or (3) interfere with the interpretation of a natural scene. The park

has actively managed and monitored areas where non-native invasive plant species are a persistent problem. The park maintains an Exotics database which is updated yearly to survey non-native invasive plants and to track treatments. Management includes the application of herbicides in front country areas where appropriate. Herbicides are used on large infestations as well as smaller populations that are more easily contained. Priorities for treatment are dependent upon the species, the invaded habitat, extent of infestation, and possibility of containment. Herbicide use is currently not permitted in the backcountry of Glacier National Park; hand-pulling and mechanical controls are the only methods employed in these sites. Bio-control agents have been used in the past but their effectiveness in significantly reducing the number or size of invasive plant populations has been limited.

Grazing Trespass

Park staff and resource managers try to monitor grazing trespass; however resources are limited, making it difficult to adequately patrol the entire eastern boundary. Documented occurrences of livestock trespass are recorded by the park, and the information entered into a database. The park does make a concerted effort to maintain the sections of existing fence throughout the field season.

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Appendix A. Climate Information

This appendix contains a more detailed summary of the current and forecasted climatic conditions of Glacier National Park (GLAC) than appears in the main body of the text. All referenced literature in this appendix is provided in the reference section above.

Introduction

Due to the predicted changes in climate from continued greenhouse gas emissions (Intergovernmental Panel on Climate Change; IPCC 2007), climate change has become a stressor of great focus and concern within GLAC. In fact, the continuing disappearance of GLAC's glaciers is one of the most notable and widely cited changes within the national park system. Models suggest that some of the largest glaciers will likely be gone by 2030 and of the estimated 150 glaciers existing within the park in 1850, only 25 glaciers larger than 25 acres remain (U.S. Department of the Interior Geological Survey; USGS 2010). Although the shrinking and disappearance of glaciers is the most noticeable direct effect of increasing temperatures, other critical climate change impacts include possible transformations in the park's snowpack and water resources, increased disturbance frequency and severity, both in terms of fire and insect outbreaks, and changes in growing seasons and vegetation dynamics.

The current climate of GLAC is distinguished by its location on the Continental Divide where it sits on the boundary between maritime and continental climates (Finklin 1986, Carrara 1989). The seasonal cycle is defined by long winters and short summers (Finklin 1986). Pacific maritime air masses often dominate the western side of the park bringing significant snowfall in the winter (Carrara 1989). In contrast, the park's east side is more dominated by dry continental air masses resulting in cold winters and dry, sunny summers (Rockwell 2007). Both sides of the park usually experience minimum precipitation during July and August (Finklin 1986). The wettest times of year are in the winter, especially for the western side, and in late spring from April to June (Carrara 1989). Given the rugged topography of the landscape, many microclimates exist and temperature/precipitation regimes can change drastically over just a short distance.

Climate warming trends have become increasingly evident in the general western Montana region within which GLAC resides. Using observations from 9 U.S. Historic Climatology Network (USHCN) weather stations within the region, Pederson et al. (2010) recently found that the annual average temperature in western Montana increased 2.39 °F (1.33 °C) over the 20th century. More importantly, Pederson et al. (2010) analyzed trends in ecologically critical temperature thresholds from 1900-2006. They found that the average annual number of days with daily minimum temperatures (T_{min}) below freezing decreased around 16 days while the annual number of extremely hot days with a daily maximum temperature (T_{max}) $\geq 90^{\circ}\text{F}$ (32.2°C) increased threefold. The annual number of extremely cold days where T_{min} was $\leq 0^{\circ}\text{F}$ (-17.8°C) also decreased from an average of 20 days from 1895-1980 to an average of 14 days from 1981-2006. Lastly, the Pederson et al. study, along with another analysis of two weather stations in the region (Caprio et al. 2008), revealed an annual asymmetry in the warming trends with the greatest warming seen in the late winter to early spring and the least in the fall.

The western Montana temperature trends documented by Pederson et al. (2010) are similar to those found throughout the American West over the past century (e.g.- Groisman et al. 2004, Mote et al. 2005, Knowles et al. 2006, Bonfils et al. 2008). Consequently, multiple independent analyses have documented possible climate warming impacts in the American West including changes in: snowpack (Mote et al. 2005), the proportion of precipitation falling as rain instead of snow (Knowles et al. 2006), the timing of stream flow runoff (Stewart et al. 2005), wildfire activity (Westerling 2006), insect outbreaks (Raffa et al. 2008), and tree mortality rates (van Mantgem et al. 2009). Given these current changes and predictions of continued and intensified warming (IPCC 2007), understanding the effects of climate change within GLAC has become of critical importance. Park managers will need the capacity to properly manage the changing GLAC landscape, yet the interactions between climate warming and ecosystem processes at the scale of a region like GLAC are not yet well understood. Therefore, the objective of this study was to start to provide a clearer picture of possible future climate change impacts across the GLAC landscape with a focus on analyzing projected changes in temperature and precipitation and subsequent impacts on the park's growing season and vegetation productivity.

Downscaling Climate Projections

To assess the impacts of future climate change in GLAC, future climate projections, produced through the use of global climate models (GCMs), are required. GCMs are physically-based complex mathematical representations of the planet's atmosphere, ocean, atmosphere, land, and ice. GCM simulations of future climate were conducted for the 21st century climate under different greenhouse gas emission scenarios defined by the IPCC Special Report on Emission Scenarios (SRES; Nakicenovic et al. 2000). The different SRES scenarios contain a wide range of socioeconomic settings leading to various future levels of greenhouse gas emissions. Simulation results from the B1, A1B, and A2 scenarios are the most commonly analyzed and they have become the standard low, medium, and high future emission scenarios, respectively (Ray et al. 2008). Each scenario is a plausible storyline of future human activity and considers factors such as economic and population growth, degree of adoption of new technologies and energy sources, and land-use change. For instance, the B1 scenario assumes a more globally based focus on economic and environmental solutions and a quicker adoption of cleaner and efficient technologies. In contrast, the A2 scenario assumes a more fragmented world with slower technology development and adoption. For this study, the version of the SRES scenarios used, projects CO₂ concentrations by 2100 to be 549 parts per million (ppm) in the B1 scenario, 717 ppm in the A1B scenario, and 856 ppm in the A2 scenario (<http://www.ipcc-data.org/ancillary/tar-isam.txt>).

While GCM projections are useful for analyzing future climate change at continental and global scales, they are much more limited when directly applied to smaller regions and landscapes such as GLAC. The typical horizontal grid size of GCMs is over 200 km and, in turn, most GCMs represent GLAC with less than a single grid cell. Due to this coarse resolution, GCM projections are especially limited in the topographically complex landscape of GLAC where physiographic features frequently drive rapid changes in temperature and precipitation over relatively small spatial scales (Christensen et al. 2007). GCMs can often represent regional storm tracks and synoptic weather conditions, but cannot capture many local climate-forcing factors such as elevation lapse rates, cold air inversions,

and solar radiation variations (Daly 2006, Christensen et al. 2007). These landscape-scale variations in meteorological variables even present a challenge for modeling current and past ecosystem changes across heterogeneous landscapes (Daly et al. 2008).

Therefore, to properly assess landscape-scale ecological processes and impacts in the complex terrain of GLAC, the derivation of finer-scale spatial climate datasets from both historical observations and future climate projections is required. The method of refining coarse GCM data to drive ecosystem and hydrology models at finer scales is often termed downscaling (Hamlet et al. 2010). Various downscaling methods have been developed to better capture climate-forcing factors and are divided into two main classes: statistical methods and dynamical regional climate model (RCM) methods.

Due to its simplicity and previous use in conducting non-spatial ecosystem simulations for future climate projections in the U.S. Northern Rockies (Boisvenue and Running 2010), the delta statistical method was used to downscale GCM projections to GLAC. To capture small-scale climate variability, the delta method simply adds on regional GCM projections to a high resolution spatial historical climatology. In other words, a historical spatial climatology is repeated into the future, but is modified by general projections of temperature and precipitation. This produces future spatial climate patterns that are consistent with historically observed fine-scale climate variability and seasonal cycles.

As a baseline for the delta downscaling method, a spatial climatology grid covering the 1970 – 2009 time period was created for GLAC at a 30-arcsec (around 800 m) resolution. The dataset was produced at a daily time step to support more advanced ecosystem modeling. Daily values of Tmax, Tmin, and precipitation were estimated for each grid cell using a statistical interpolation of daily weather station data. To account for the complex topography of GLAC and its effect on temperature and precipitation, daily interpolated values were modified based on monthly gridded climate data from the PRISM dataset (Parameter-elevation Regressions on Independent Slopes Model; Daly et al. 2002, 2008). PRISM is a commonly used historical climate dataset available for the conterminous U.S. that statistically models climate-forcing physiographic factors such as elevation, topographic position (i.e.- susceptibility to cold air drainage), rain shadows, and coastal proximity at several different scales. In addition to Tmax, Tmin, and precipitation, daily day length, solar radiation, and humidity were also estimated for each grid cell using an established bioclimatology model (Running and Nemani 1987). Ultimately, a 1970-2009 climate time series was produced for each grid cell (around 7,200 total) within GLAC.

Future climate projections were obtained from an analysis of 20 GCMs completed for the general Pacific Northwest region by the Climate Impacts Group (CIG) at the University of Washington (Mote and Salathé 2009). The 20 GCMs were examined by CIG for possible biases in modeling 20th century Pacific Northwest climate and, based on the results of this analysis, were statistically combined to provide single composite 21st century projections of temperature and precipitation for the A1B and B1 scenarios. Since projections for the A2 scenario were not provided, B1 was considered the low emission scenario and A1B the higher emission scenario.

Although raw GCM data can be used to provide future monthly or even daily projections of meteorological variables, this is usually a case of false precision (i.e.- do we really know what the weather will be like on December 14, 2100?). Therefore, the CIG Pacific Northwest projections were directed at 30-year time windows, the recommended minimum amount of time that should be used to quantify a region's climate. Projected seasonal changes in temperature and precipitation (DJF, MAM, JJA, SON), in relation to a 1980s (1970-1999 mean) baseline, were given for the 2020s (2010 - 2039 mean), the 2040s (2030 - 2069 mean) and the 2080s (2070 - 2099 mean). In descriptions below, these 30-year time windows will simply be referred to as the 1980s, 2020s, 2040s, and 2080s.

At the 30-year timescale, the CIG Pacific Northwest projections show increases in temperature in all seasons for both the B1 and A1B emission scenarios (Figure A-1). In the 2020s, both emission scenarios show similar trends in temperature, but by the 2080s, higher temperature increases are in seen in the A1B scenario due to increased radiative forcing from higher greenhouse gas emissions. Summer (JJA) consistently displays the largest increases in temperature.

In contrast to temperature, the future projections in Pacific Northwest precipitation are not as clear. This is the result of a large range of projections given by the different GCM models with some models projecting a wetter climate and others projecting drier conditions. Therefore, the CIG bias-corrected composite of 20 GCM projections indicates only slight changes in total annual precipitation for both scenarios and all future time windows. While the range of total annual precipitation projections is large, a majority of GCMs do consistently project a decrease in summer precipitation and an increase in winter precipitation for the Pacific Northwest (Figure A-1; Mote and Salathé 2009).

Using the described delta method, the CIG Pacific Northwest projections were applied to the GLAC historical climatology to generate a 1970 - 2100 daily time step climate time series for each grid cell and emission scenario consisting of the following daily variables: Tmax, Tmin, precipitation, day length, solar radiation, and humidity. Instead of simply cycling the historical climate data into the future, a stochastic weather generator was used to randomly generate values for each day and grid cell based on the day's historical variability in temperature and precipitation. The projected changes in temperature and precipitation were then applied to these randomly generated values. This avoids possible artifacts produced by cycling through the same 30-year sequence of daily weather, yet maintained the historical temporal and spatial climate patterns seen within GLAC.

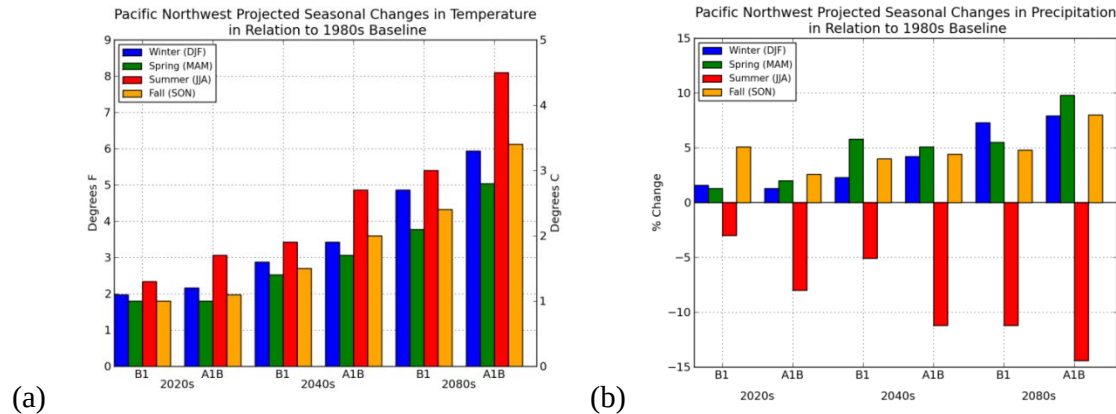


Figure A-1: Projected seasonal changes in Pacific Northwest temperature (a) and precipitation (b) in relation to a 1980s (1970-1999) baseline. Projections are generated from an analysis of outputs from 20 GCM models for the area between 124° and 111° west longitude and 41.5° to 49.5° north latitude as conducted by the Climate Impacts Group at the University of Washington (Mote and Salathé 2009).

Ecosystem Modeling

To analyze possible ecosystem changes in GLAC in relation to the future climate projections, ecosystem modeling was performed with Biome-BGC, a computer model that simulates fluxes of carbon, water, and nitrogen through terrestrial ecosystems. Biome-BGC models both energy and water balances (including snowpack) and variables related to plant growth and decomposition. The model has been successfully applied to many ecosystems, including a variety of forest types (e.g.- Thornton et al. 2002, Migliavacca et al. 2009, Ueyama et al. 2010), agricultural fields (e.g.- Wang et al. 2005, Di Vittorio et al. 2010), and heterogeneous landscapes (e.g.- Turner et al. 2007). Biome-BGC is considered a “big-leaf” model since it represents a site with a single leaf layer and does not simulate individual trees or species. To more realistically simulate snowpack changes, the simple snowmelt model within Biome-BGC was replaced with an improved model described by Coughlan and Running (1997).

To model ecosystem changes at a grid cell on the generated GLAC climate grid, Biome-BGC required inputs related to the characteristics of the site, the type of vegetation being simulated in addition to the daily meteorological data. The appropriate vegetation type of each grid cell was determined using the National Landcover Database 2001 (NLCD 2001) spatial dataset (Homer et al. 2004). NLCD vegetation classes were aggregated and simplified to grass, deciduous broadleaf forest (DBF), evergreen needleleaf forest (ENF), and shrub. Grid cells specified as non-vegetated were not modeled for ecosystem changes.

Site-specific Biome-BGC input requirements included soil texture and depth; site albedo; nitrogen inputs, including fixation and deposition; atmospheric carbon dioxide concentration, and elevation. Soil texture and depth were taken from Miller and White’s (1998) gridded continental United States soil dataset based on State Soil Geographic Database (STATSGO) data. Elevation was determined from the Advanced Spaceborne Thermal Emission and Reflection Radiometer (ASTER) Global

Digital Elevation Model (GDEM) (<http://asterweb.jpl.nasa.gov/gdem.asp>). Nitrogen deposition was estimated as a function of annual precipitation using data from the National Atmospheric Deposition Program Glacier National Park-Fire Weather Station (NADP/NTN Monitoring Location MT05). Historical atmospheric carbon dioxide (CO₂) concentrations were based on the Mauna Loa CO₂ curve (Dr. Pieter Tans, NOAA/ESRL; www.esrl.noaa.gov/gmd/ccgg/trends/). Future carbon dioxide concentrations were taken from the decadal values reported for the B1 and A1B scenarios (<http://www.ipcc-data.org/ancillary/tar-isam.txt>).

Once the vegetation type and site-specific variables were defined for each grid cell, Biome-BGC was run from 1970 – 2100 for both the B1 and A1B scenarios. Initial site conditions for 1970 were determined through what is defined as a spin-up, a several thousand year model run that brings the site into a steady-state condition (i.e.- carbon inputs equals outputs) with current climate based on continually cycling through the 1970 - 2009 historical climate time series. A spin-up is necessary to isolate and analyze the effects of a changing climate on ecosystem properties and avoid artificial trends simply caused by the modeled site not being in equilibrium with the current climate.

Variables Analyzed

All input datasets used in the modeling procedure and subsequent output variables are summarized in Table A-1. In discussions below, model output results for the main climate and ecosystem-related variables are aggregated to the four main time windows: the 1980s baseline, the 2020s, the 2040s, and the 2080s. Results are summarized and discussed both in reference to geographic maps and in relation to land cover and elevation classes (Figure A-2). At the scale of an area like GLAC, elevation is likely one of the most important topographic factors resulting in spatial patterns of temperature and precipitation (Daly et al. 2002, 2008) and, in turn, patterns of ecosystem properties.

Table A-1: Summary of input data used in climate interpolation and Biome-BGC modeling for 1970 – 2100 time period, and resulting output variables. All output variables were generated at a daily time step for each 30-arcsec (around 800m) grid cell within GLAC.

Input Data		
Description	Dataset Name(s)	Reference(s)/Link(s)
Weather station daily Tmin, Tmax, precipitation (1970-2009)	NOAA COOP Network, NOAA NCDC GSOD, NRCS SNOTEL Network	www.ncdc.noaa.gov/CDO/cdo/ www.wcc.nrcs.usda.gov/snow/
Gridded monthly terrain-informed Tmin, Tmax, precipitation (1970-2009)	PRISM	www.prism.oregonstate.edu/ Daly et al. 2002, 2008
GCM Regional Temperature and Precipitation Projections	CIG Pacific Northwest climate projections	cses.washington.edu/cig/res/ia/waccia.shtml Mote and Salathé 2009
Past/Current CO2 Concentrations	NOAA/ESRL Mauna Loa CO2 curve	www.esrl.noaa.gov/gmd/ccgg/trends/ Dr. Pieter Tans
Future CO2 Concentration Scenarios	IPCC SRES Emission Scenarios	www.ipcc-data.org/ancillary/tar-isam.txt Nakicenovic 2000
Land Cover	NLCD 2001	www.mrlc.gov/ Homer et al. 2004
Soil texture and depth	CONUS-Soil	www.soilinfo.psu.edu/index.cgi?soil_data&conus Miller and White 1998
Nitrogen Deposition	NADP Glacier National Park Fire Weather Station (MT05)	nadp.sws.uiuc.edu/sites/siteinfo.asp?id=MT05&net=NTN
Temperature (Tmin,Tmax,Tday)	°F	Daily minimum, maximum, and average daytime temperatures
Precipitation	Inches	Daily precipitation amount

Input Data		
Description	Dataset Name(s)	Reference(s)/Link(s)
Solar Radiation	Watts/m2	Daily average instantaneous shortwave flux density
Humidity (Vapor Pressure Deficit)	Pascals	Daily difference between actual air moisture and saturated air moisture
From Biome-BGC Modeling	Units	Description
Growing Season	Days, Year Day	Growing season length, start year day, and end year day
Summer Water Stress	Days	Number of days of summer vegetation water stress
Day of Complete Snowmelt	Year Day	First Day of year with no snow on the ground
Net Primary Productivity (NPP)	Kg Carbon m-2year-1 or day-1	Measure of vegetation productivity
Total Onsite Carbon	Kg Carbon m-2	Total site carbon in vegetation, litter, and soil

While it is well-known that the eastern slopes of GLAC are drier and that there is a clear east-west ecological gradient within the park (Walsh et al. 2009), averaged weather station data indicate no large differences in precipitation between the eastern and western sides (Finklin 1986). Therefore, the PRISM historical climate dataset does not display a strong east-west precipitation gradient at the scale of the park since it relies largely on weather station data to model topographic effects. Other possible drying factors, such as periodic warm Chinook winds on the eastern side (Selkowitz et al. 2002), are not accounted for in the climate dataset or the Biome-BGC ecosystem model. In consequence, the results of this study likely do not capture possible differences in vegetation response between the eastern and western sides and are, thus, not presented in this context. Additionally, since evergreen needle forests (ENF) dominate 63% of the area in GLAC, ecosystem-related variables are summarized only for this land cover.

With the downscaled 1970 - 2100 spatial climatology grid created for the B1 and A1B scenarios, changes in the mean annual climate variables were visualized for the 2020s, 2040s, and 2080s (Figure A-3). Projected temperature changes were then analyzed to see if they would result in parts of GLAC crossing critical temperature thresholds. One particularly meaningful threshold that was analyzed was the freezing point at 32°F (0°C). This threshold is especially critical in the fall and

spring when T_{min} trends above or below freezing could significantly impact snowpack dynamics, freeze/thaw patterns and biological processes (Pederson et al. 2010).

Elevation and Land Cover Classes

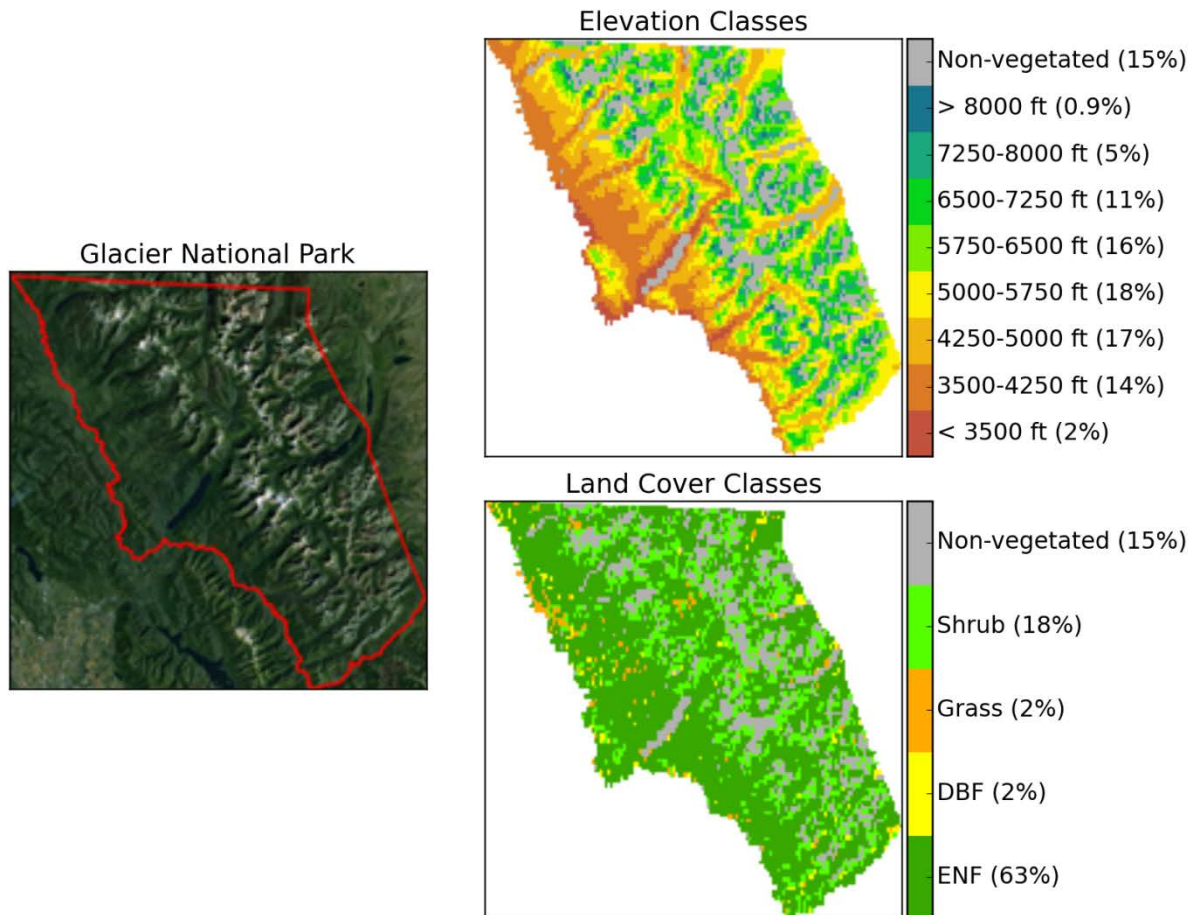


Figure A-2: GLAC maps of elevation and land cover classes used in modeling and analysis. Percentages to right of class labels display percent of the landscape area occupied by that class. Elevation data: ASTER GDEM. Land Cover Data: NLCD 2001.

Glacier National Park
Annual Average Daily Minimum Temperature

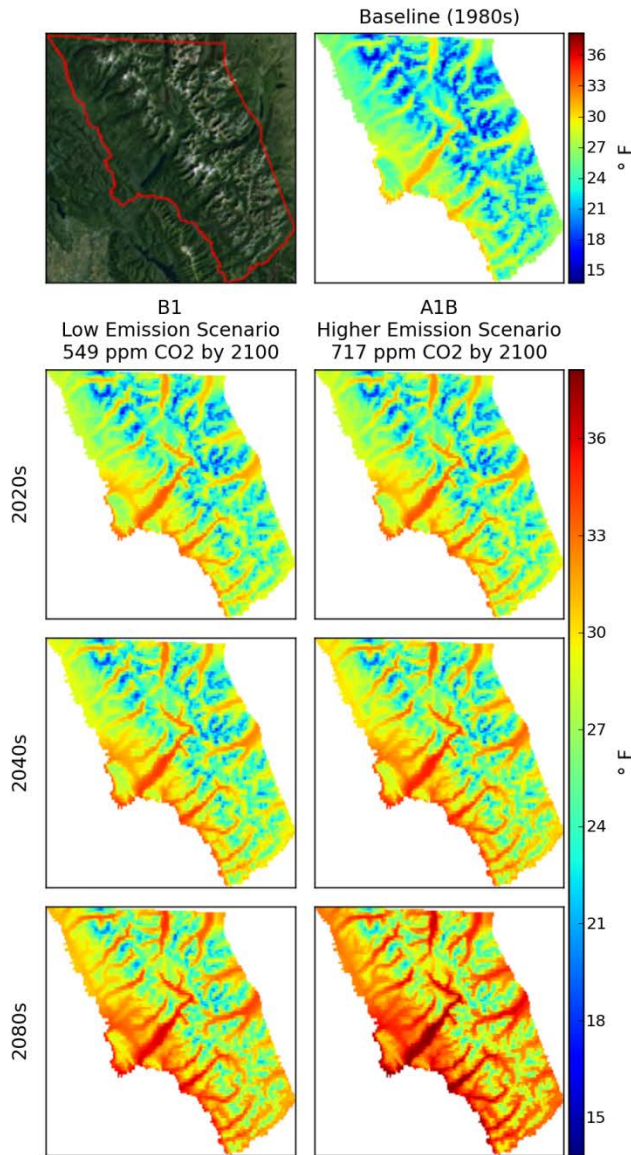


Figure A-3: GLAC example maps of annual average daily Tmin for the B1 and A1B emission scenarios in the 2020s, 2040s, and 2080s. Changes in temperature are downscaled to a 30-arcsec (around 800 m) resolution from general Pacific Northwest projections given by Mote and Salathé (2009). Other climate variables generated at this resolution included Tmax, precipitation, day length, solar radiation, and humidity.

Biome-BGC results were examined for changes in ENF vegetation productivity and overall carbon stocks. At a high level, plants have several basic requirements that provide the foundation for photosynthesis: water, a specific range of temperatures, carbon dioxide, and sunlight (Boisvenue and

Running 2010). While there are many other factors (e.g.-soil nutrients), a change in any one of these basic requirements will affect a plant's photosynthetic capacity (i.e.-productivity). In GLAC, ENF vegetation productively is largely constrained by sunlight, water, and minimum temperature (Jolly et al. 2005). Winters in GLAC bring cold temperatures and shorter day lengths that end the growing season and induce vegetation dormancy. These two constraints are released in the spring and summer, but during the dry summer months, water availability can significantly restrict growth if precipitation and/or melt water runoff are low. Climate change could have a significant effect on water balances and seasonal temperature cycles. Therefore, it was important to analyze how the projected changes in temperature and precipitation could affect these two constraints and, in turn, ENF vegetation productivity.

Impacts to vegetation temperature limitations were assessed by analyzing changes in overall growing season length, and the year days on which the growing season started and ended. The beginning of the annual growing season at a site was defined as the first seven consecutive days that ENF vegetation was photosynthetically active while the end of the growing season was defined as the last seven consecutive days that the vegetation was photosynthetically active.

Changes in water constraints were quantified using a daily vegetation water stress index (WSI) based on results from the Biome-BGC ecosystem model runs. The daily WSI ranges from zero to one and represents the degree to which vegetation productivity is constrained by both humidity and soil moisture. A WSI value of zero represents unconstrained productivity while a value of one represents completely constrained productively due to very low humidity and/or soil moisture levels. The summation of daily WSI values over a specific season or year can be equated to the number of days of water stress experienced by vegetation during that time period. For instance, a cumulative daily WSI value of 30 over the summer implies that vegetation experienced 30 days of water stress. Since increases in summer water stress during the height of the growing season could have a strong impact on GLAC vegetation productivity, WSI results were analyzed based on changes in cumulative summer WSI values.

Effects on ENF vegetation productivity and carbon accumulation trajectories were determined by examining trends in Net Primary Productivity (NPP), Net Ecosystem Exchange (NEE), and total carbon stocks (amount of onsite carbon within vegetation, litter, and soil). NPP is the net uptake of carbon by vegetation and equals gross photosynthesis minus plant autotrophic respiration (AR). Conversely, NEE characterizes the net carbon exchange from an entire ecosystem area (i.e.—if an area is a carbon source or sink), and, in the Biome-BGC model, is calculated by subtracting heterotrophic respiration (HR) and fire carbon losses from NPP. The HR component within NEE represents the carbon released by organic matter decomposition performed by soil microorganisms. NPP and NEE are both defined and given in carbon mass per area per unit time.

Results and Discussion

Temperature Threshold Trends

In the 1980s baseline, 100% of GLAC had an average fall and spring daily T_{min} below freezing with overall averages of 25.6°F (-3.6°C) and 23.3°F (-4.8°C), respectively (Figure A-4, Figure A-5). While the portion of GLAC with a fall average T_{min} below freezing declined in the 2020s and

2040s, more significant declines were not seen until the 2080s when only 48% of the park was less than freezing in the warmer A1B scenario and 70% in the B1 scenario. The percentage of locations below freezing in the spring declined slightly, but the decreases in area were small and only a few lower elevation valleys crossed the freezing threshold.

Compared to the average values of fall and spring T_{min} within the park, average winter daily T_{max} values appeared to be more susceptible to crossing the freezing threshold (Figure A-6). In the 1980s baseline, 93% of the park landscape displayed an average winter T_{max} below freezing with an overall average of 27.1°F (-2.7°C). In comparison, in the 2020s, 77% of the landscape was below freezing in the warmer A1B scenario and 78% in the B1 scenario. By the 2080s, only 38% of the park was below freezing in the A1B scenario and 46% in the B1 scenario.

As evident in the summary maps (Figure A-4, Figure A-5, Figure A-6), the spatial patterns of areas above and below the freezing thresholds in the different scenarios and time windows were noticeably a function of elevation and its influence on temperature. For example, average daily winter T_{max} for vegetated areas below 5750 ft was above freezing by the 2080s, but the average winter T_{max} for areas higher than 5750 ft remained at or below freezing (Figure A-7). In fact, overall average fall and spring T_{min} and winter T_{max} for vegetated areas above 5750 ft remained at or below freezing in both scenarios and all future time windows. Nevertheless, the projected increases in temperature resulted in an upward movement of the general elevation at which the crossing of freezing thresholds occurred (Figure A-7).

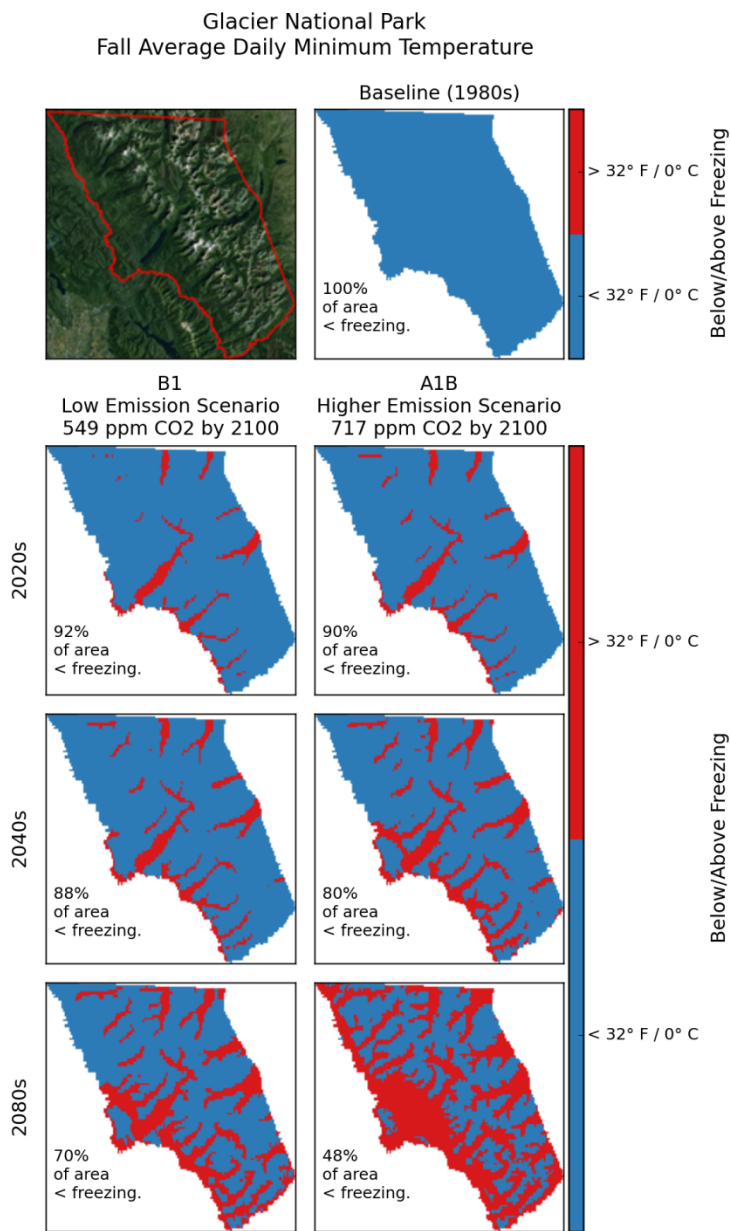


Figure A-4: GLAC maps of fall (SON) average daily Tmin below/above freezing threshold for the B1 and A1B emission scenarios in the 2020s, 2040s, and 2080s. Changes in temperature are downscaled from general Pacific Northwest projections given by Mote and Salathé (2009).

Glacier National Park
Spring Average Daily Minimum Temperature

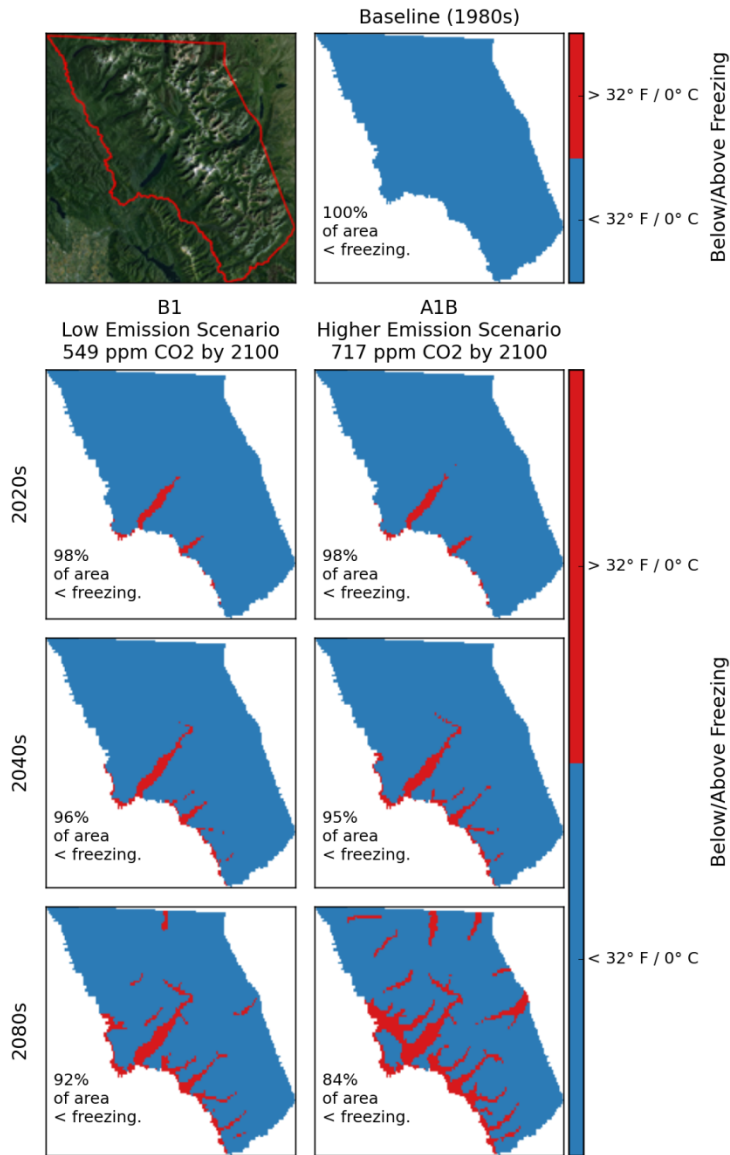


Figure A-5: GLAC maps of spring (MAM) average daily Tmin below/above freezing threshold for the B1 and A1B emission scenarios in the 2020s, 2040s, and 2080s. Changes in temperature are downscaled from general Pacific Northwest projections given by Mote and Salathé (2009).

Glacier National Park
Winter Average Daily Maximum Temperature

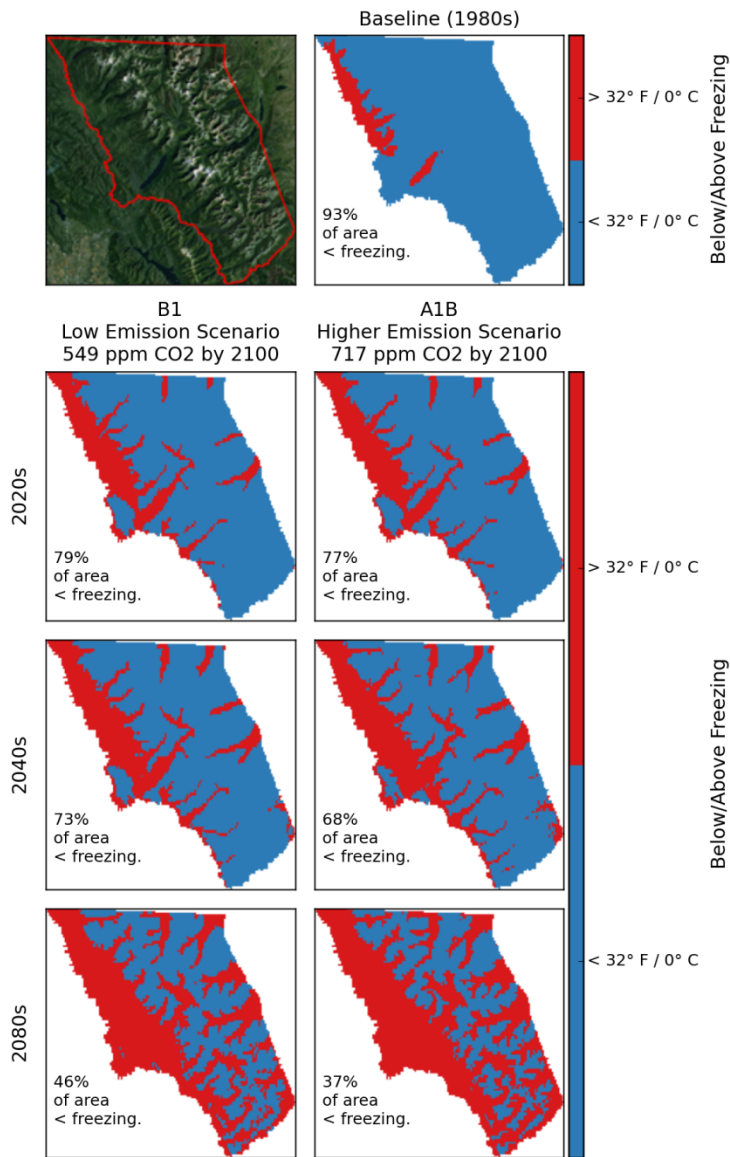


Figure A-6: GLAC maps of winter (DJF) average daily Tmax below/above freezing threshold for the B1 and A1B emission scenarios in the 2020s, 2040s, and 2080s. Changes in temperature are downscaled from general Pacific Northwest projections given by Mote and Salathé (2009).

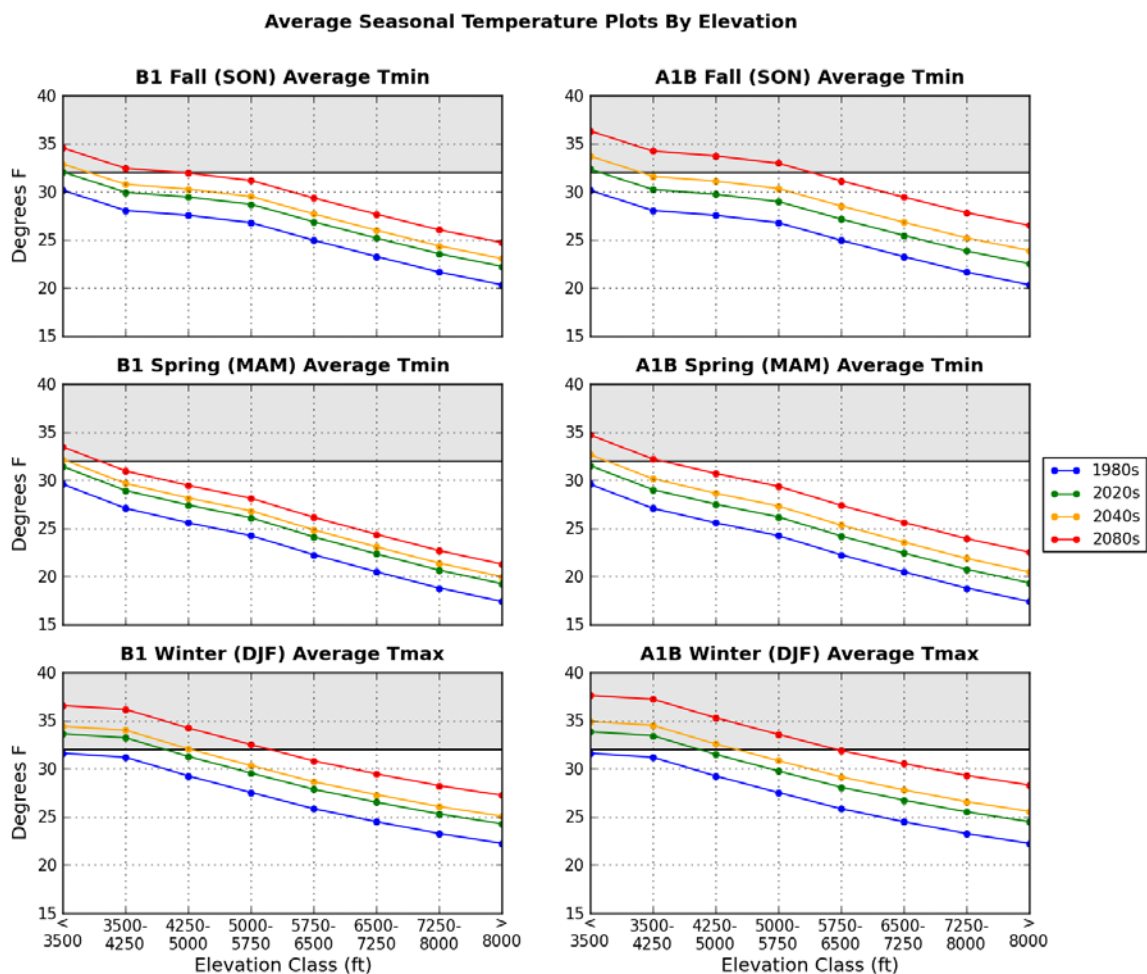


Figure A-7: Plots of fall (SON) average daily Tmin, spring (MAM) average daily Tmin, and winter (DJF) average daily Tmax by 750 ft elevation classes for the B1 and A1B scenarios. Shaded regions represent temperatures above the freezing point threshold. Only vegetated sites are considered in the calculation of the average for each elevation class.

Vegetation-Related Trends

As would be expected, in the baseline 1980s, evergreen needle-leaf forests (ENF) in lower warmer elevations had a longer average growing season than the colder higher elevations. In all future time windows, growing season length increased across all elevations signifying a releasing of temperature constraints with the growing season increasing by over a month in some areas by the 2080s (Figure A-8). However, the change in growing season length was not uniform. For instance, elevations from 5750 to 8000 ft. displayed less than a 5 day increase in growing season length in the 2020s while some lower elevations had more than a 10 day increase.

The start of the growing season occurred earlier at all elevations (Figure A-9), but the changes to the end of growing season were much more variable (Figure A-10). In both scenarios and all future time windows, the average year day of the end of growing season actually occurred earlier in the year for

forests between 5750 and 8000 ft. Since changes in growing season were based not only on climate data, but the actual physiological response of the ENF land cover, the earlier termination of the growing season in some areas was likely the result of ENF vegetation becoming dormant in late summer instead of fall in response to more limited water availability. Still, the earlier start of the growing season at all elevations was enough to compensate in these instances and resulted in the increased growing season lengths described earlier (Figure A-8).

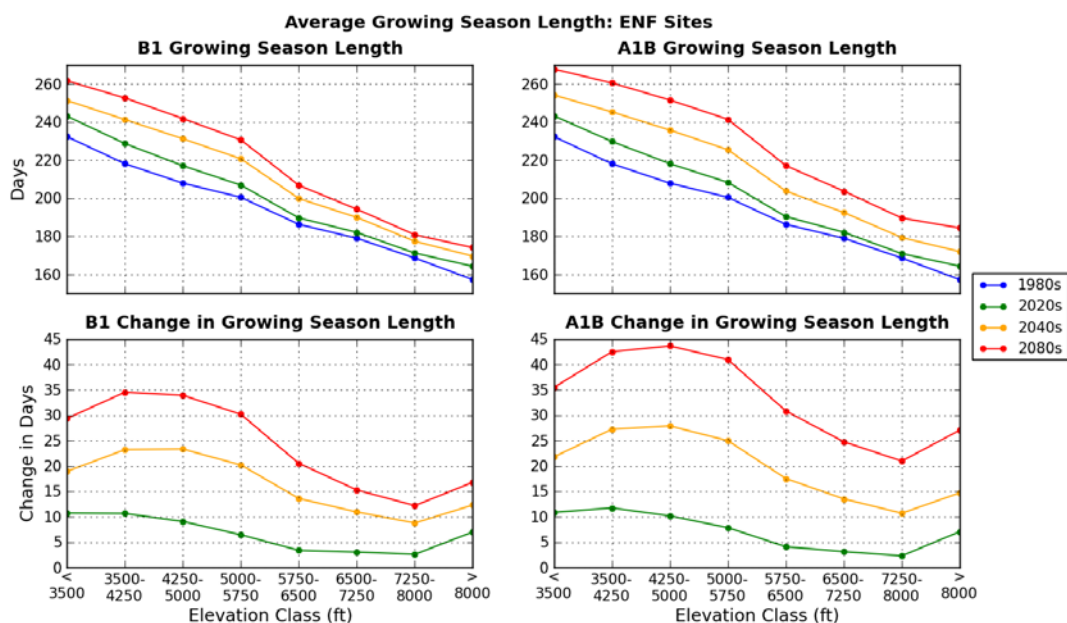


Figure A-8: Plots of annual average ENF growing season length and change in growing season length by 750 ft elevation classes for the B1 and A1B scenarios. Each dot is the average of all sites falling within the specified elevation class.

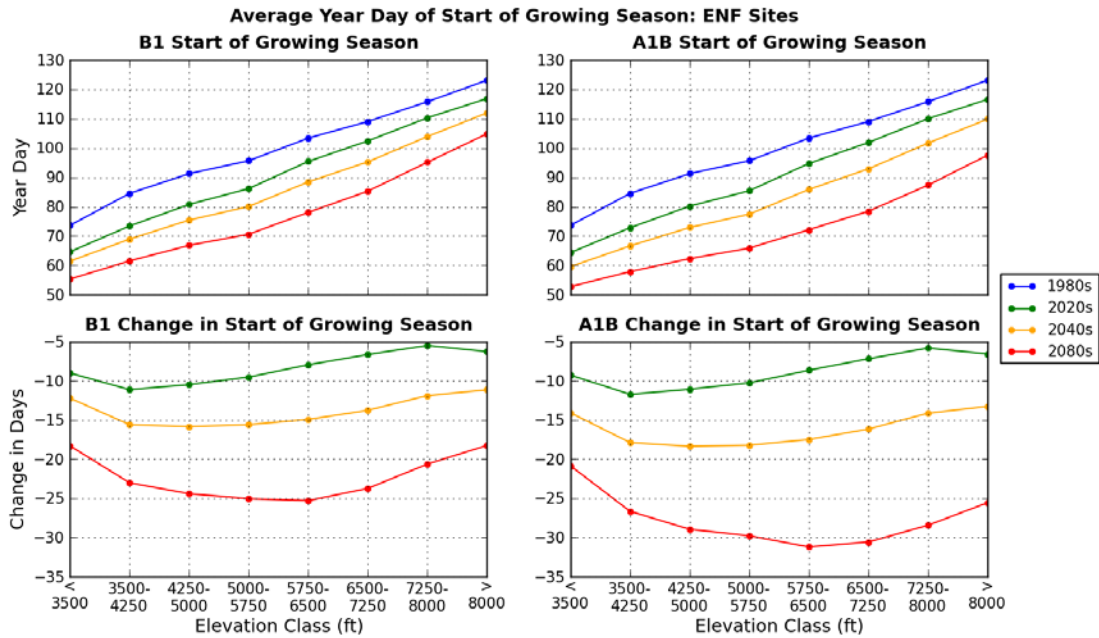


Figure A-9: Plots of annual average year day of the start of the ENF growing season and change in days by 750 ft. elevation classes for the B1 and A1B scenarios. Each dot is the average of all sites falling within the specified elevation class.

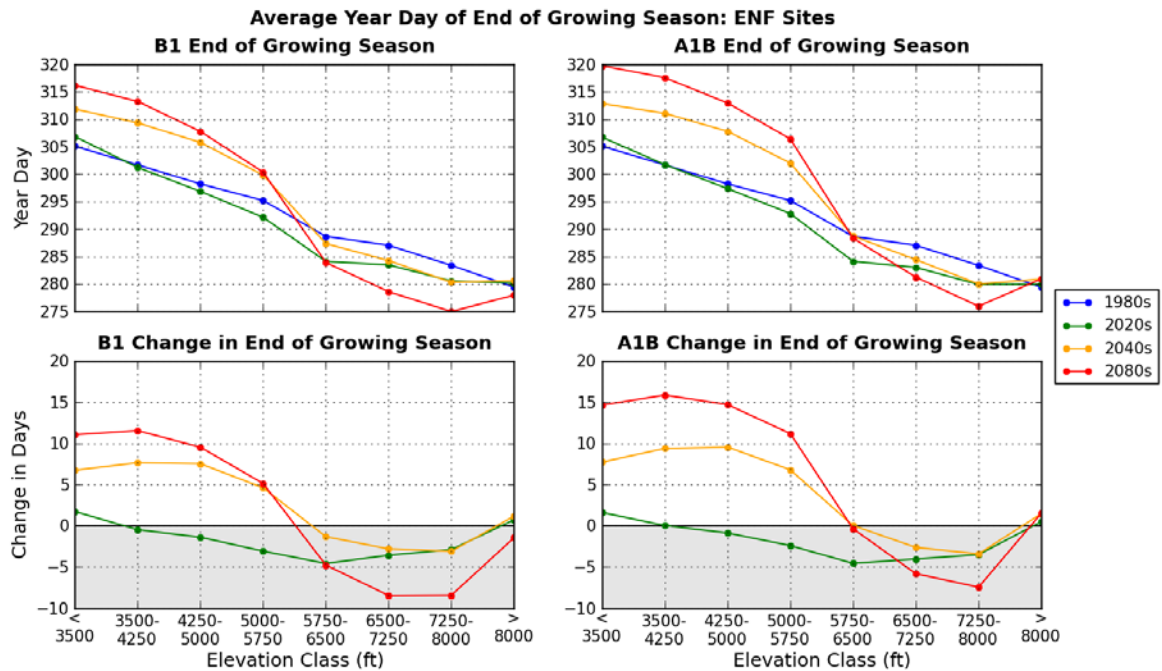


Figure A-10: Plots of annual average year day of the end of the ENF growing season and change in days by 750 ft. elevation classes for the B1 and A1B scenarios. Each dot is the average of all sites falling within the specified elevation class. Shaded regions represent negative changes (i.e. - end of growing season occurring earlier in the year).

Although the projected warmer temperatures resulted in potentially longer ENF growing seasons, increases in summer water stress were also evident in all elevations (Figure A-11). Similar to growing season length, summer water stress was clearly a function of elevation with colder higher elevations experiencing much less water stress than the lower elevations. Increases in water stress were also not uniform as the very lowest elevations (< 3500 ft) and highest elevations (> 8000 ft) exhibited lower relative increases than the other elevations. Greater increases in summer water stress were evident in the warmer A1B scenario, especially by the 2080s where the number of days of summer water stress increased by almost a month in some ENF areas between 5750 and 8000 ft. (Figure A-11).

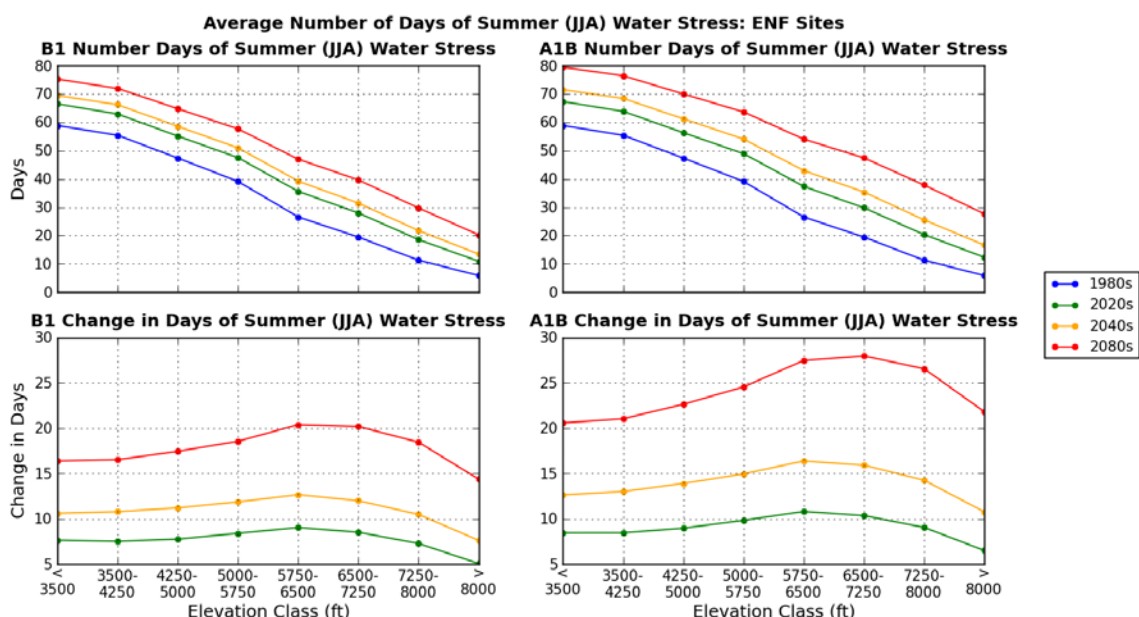


Figure A-11: Plots of average number of days of ENF summer (JJA) water stress and change in summer water stress by 750 ft. elevation classes for the B1 and A1B scenarios. Each dot is the average of all sites falling within the specified elevation class.

The concurrent changes observed in summer water stress and ENF growing season length are indicative of a significant release of vegetation temperature constraints, but a tightening of summer water constraints. In this context, the vegetation net primary productivity (NPP) trends and spatial patterns modeled by Biome-BGC helped to reveal how these two constraints could balance each other across the different elevations. In the 1980s baseline, average NPP of the ENF land cover increased with elevation, but then decreased in areas > 8000 ft where colder temperatures likely limit growth (Figure A-12). In the 2020s, average ENF productivity stayed about the same or decreased as compared to the 1980s except for the higher elevations where cold temperature limitations were most significantly released. In the 2040s, the highest elevations continued to exhibit greater productivity increases with a 14% increase in average NPP for elevations > 8000 ft. However, as compared to the 2040s, productivity for even the highest elevations decreased in the 2080s.

While annual NPP reflects the amount of carbon uptake by vegetation, it is not representative of the full carbon balance of a site (i.e.-if a site is a carbon source or sink) as it does not include the carbon released by decomposition or disturbances such as wildfire. Like plant photosynthesis, decomposition rates are strongly affected by changes in temperature and moisture (Chapin et al. 2002). Therefore, trajectories of future total onsite carbon (carbon in vegetation, litter, and soil) were more indicative of consistent trends in net ecosystem exchange (NEE) and of which elevations were trending towards becoming carbon sinks or sources (Figure A-13). Similar to the pattern seen in NPP in the 1980s baseline, average total onsite carbon (measured as annual max total carbon) in the ENF land cover increased with elevation up until the highest elevations where it started to decrease. In the 2020s, both scenarios showed slight increases in overall average total carbon at all elevations. In the warmer A1B scenario, by the 2040s and 2080s, however, slight decreases in total carbon were evident except for the higher elevations. While total carbon also increased at the higher elevations in the B1 scenario in the 2040s and 2080s, total carbon remained approximately flat at mid and low elevations instead of decreasing.

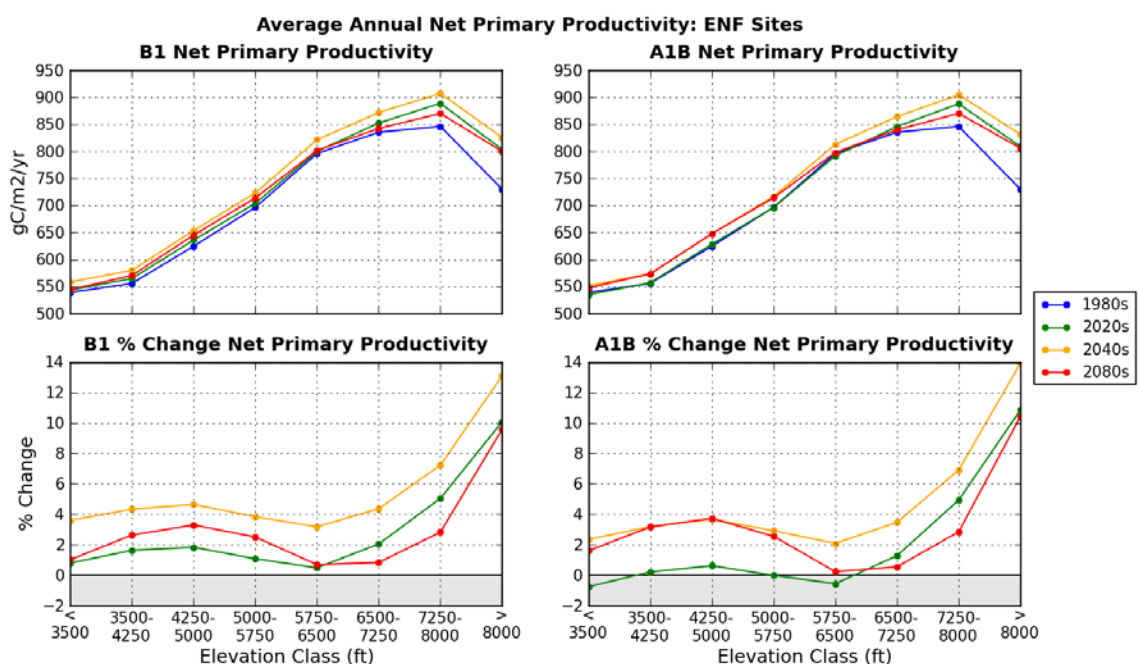


Figure A-12: Plots of ENF average annual net primary productivity (NPP) and percent change in NPP by 750 ft. elevation classes for the B1 and A1B scenarios. Each dot is the average of all sites falling within the specified elevation class. Shaded regions represent relative decreases.

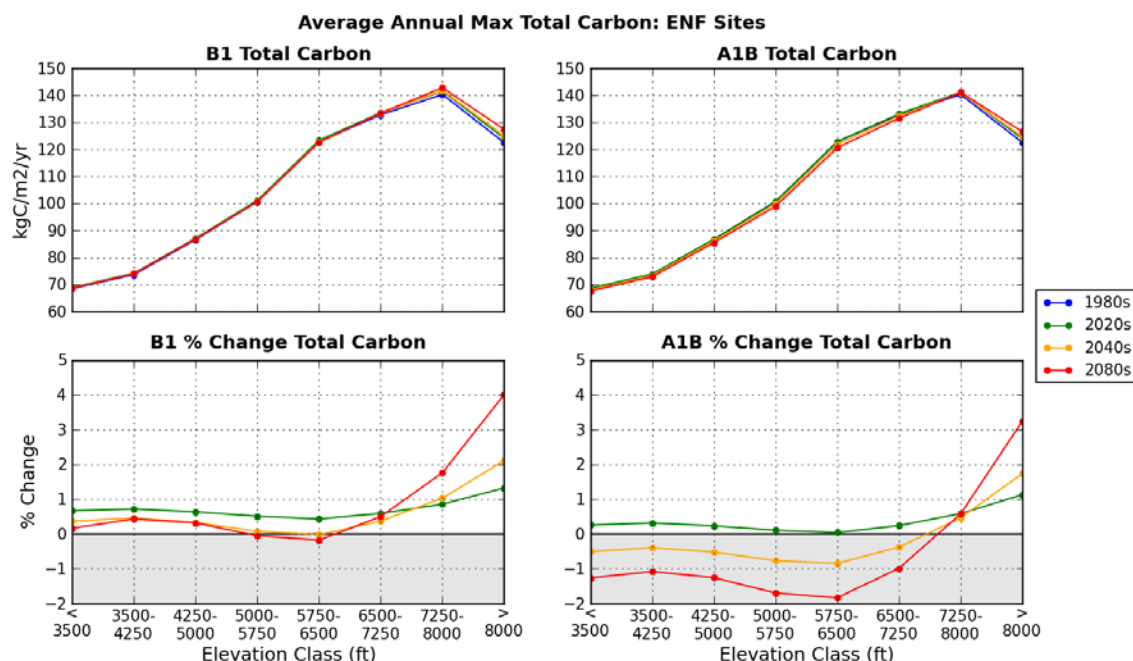


Figure A-13: Plots of ENF average annual max total onsite carbon and percent change in average annual max total onsite carbon by 750 ft. elevation classes for the B1 and A1B scenarios. Shaded regions represent relative decreases.

Overall, except for the highest temperature-limited elevations, potential increases in ENF productivity and total carbon storage resulting from longer growing seasons appeared to be largely offset by increases in summer water stress. In fact, the relative change in the overall average NPP of the ENF land cover never exceeded 5% in any of the future time windows or scenarios (Figure A-14). Additionally, average increases in total carbon were minimal in the B1 scenario and the warmer A1B scenario actually resulted in most ENF areas trending towards becoming carbon sources instead of sinks. Given the large forested areas of GLAC, it is important understand the mechanisms behind this trend. For instance, why did increased temperatures and longer growing seasons in the A1B scenario result in slight decreases in carbon uptake within most of the ENF areas? Contrastingly, why did the highest ENF elevations have significantly larger increases in productivity?

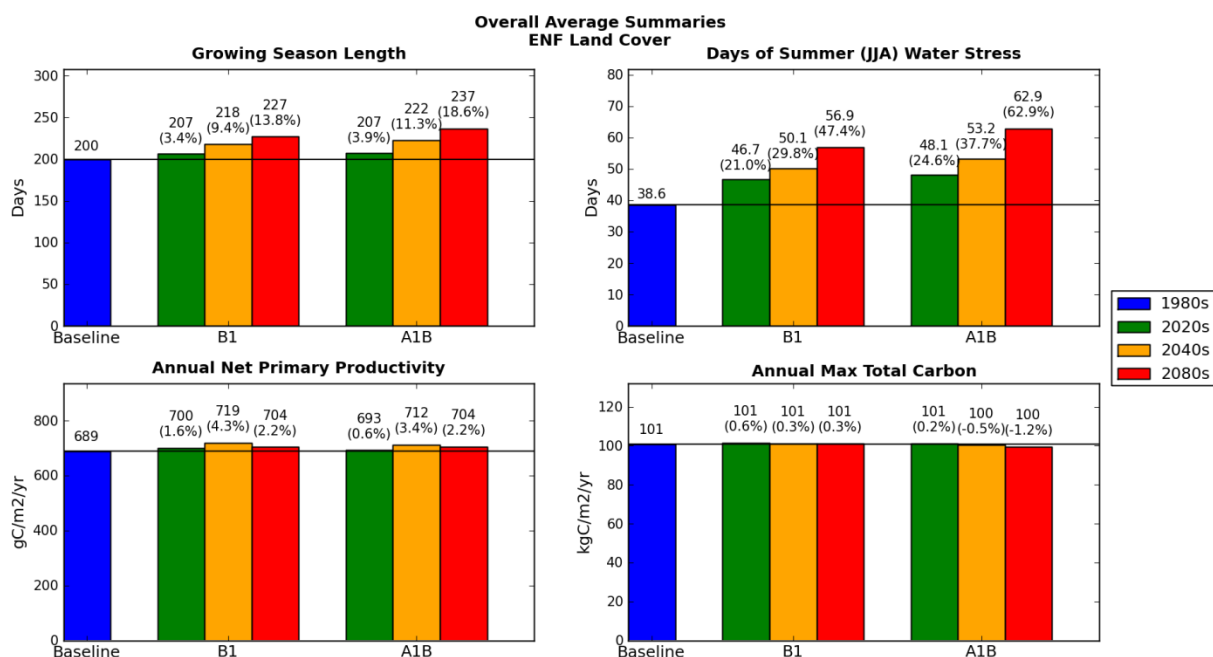


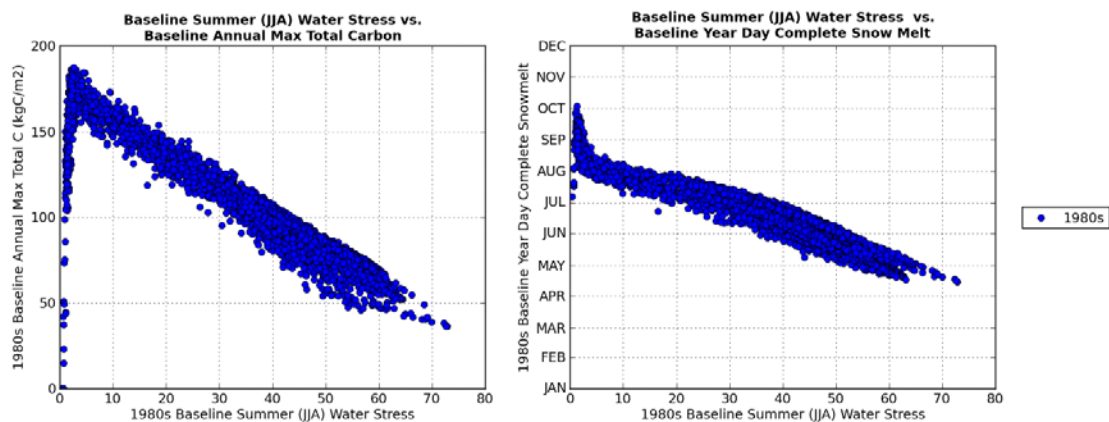
Figure A-14: Overall ENF average values for growing season length, number of days of summer water stress, annual NPP, and annual max total onsite carbon. Top numbers above bars are actual values while percentage numbers are percent change from the 1980s baseline value. Horizontal lines show baseline value.

In the 1980s baseline, the total carbon at an ENF site was found to be strongly related to the average number of days of summer water stress experienced, except for a few low productivity sites that had almost no water stress (Figure A-15). These ENF sites with little water stress and lower productivity were found at the colder higher elevations where low temperatures limited growth. Nonetheless, the strong relationship between summer water stress and total carbon suggests that forest productivity across most of the GLAC landscape is more strongly water-limited than temperature-limited. In turn, the magnitude of summer water stress at an ENF site in the 1980s baseline was found to relate strongest to the site's average year day of complete snow melt, therefore implying that areas receiving snowmelt longer into the dry season (i.e.-July and August) are able to maintain higher levels of productivity (Figure A-15). Consequently, as also found by Tague et al. (2009), the degree of change in water stress and, in turn, ENF vegetation productivity was based both on the baseline timing of melt in relation to the dry season and the magnitude of the change in melt timing. For instance, those ENF sites obtaining snowmelt until August in the baseline displayed the largest increases in water stress because earlier snowmelt timing subjected the sites to water stress during the driest part of the season (Figure A-15). Sites having a baseline snowmelt timing much earlier in the year had less increases in water stress because snowmelt in the 1980s was already largely depleted before the dry season. Additionally, colder sites still able to maintain snowmelt through much of dry season despite increases in temperature experienced smaller increases in water stress.

Differences in the seasonal patterns of ENF vegetation productivity, water stress, and snowmelt along the ENF elevation gradient further revealed how the response of ENF areas within GLAC

could be highly dependent on currently limiting factors. The average ENF seasonal cycles of daily productivity, water stress, and snowmelt for a low (< 3500 ft), mid (5750-6500 ft), and high (> 8000 ft) elevation class are shown in Figure A-16 for the 1980s, 2020s, 2040s, and 2080s (A1B scenario). In the 1980s baseline, the low elevation displayed a negative NPP (i.e.-net loss of carbon) during July and August which indicates a photosynthesis shutdown due to water stress. In contrast, NPP remained above zero during the entire growing season at the mid and high elevations. At all three elevations, increases in temperature in the 2020s, 2040s, and 2080s caused NPP to increase earlier in the spring, peak higher and earlier during the summer, but then decline faster and earlier, especially at the mid-elevation.

(a)



(b)

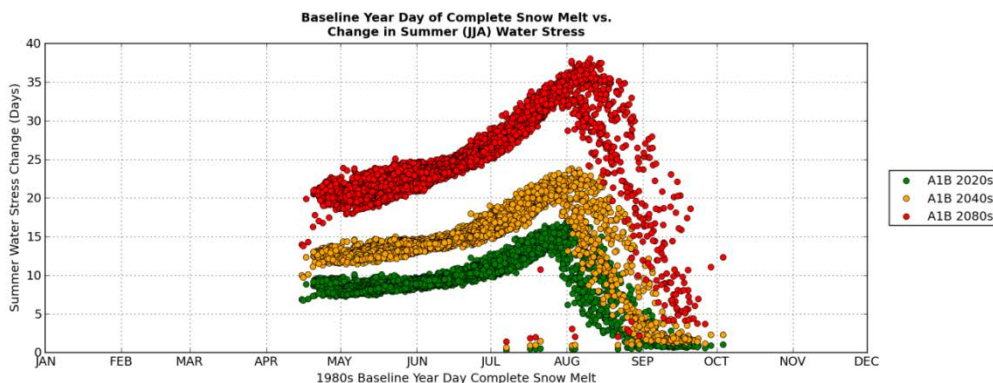


Figure A-15: Scatterplots of 1980s baseline relationships between summer (JJA) water stress, total onsite carbon, and year day of complete snowmelt for ENF land cover (a) and scatterplot of relationship between baseline year day of complete snowmelt and change in summer water stress days in the A1B scenario for the 2020s, 2040s, and 2080s for the ENF land cover.

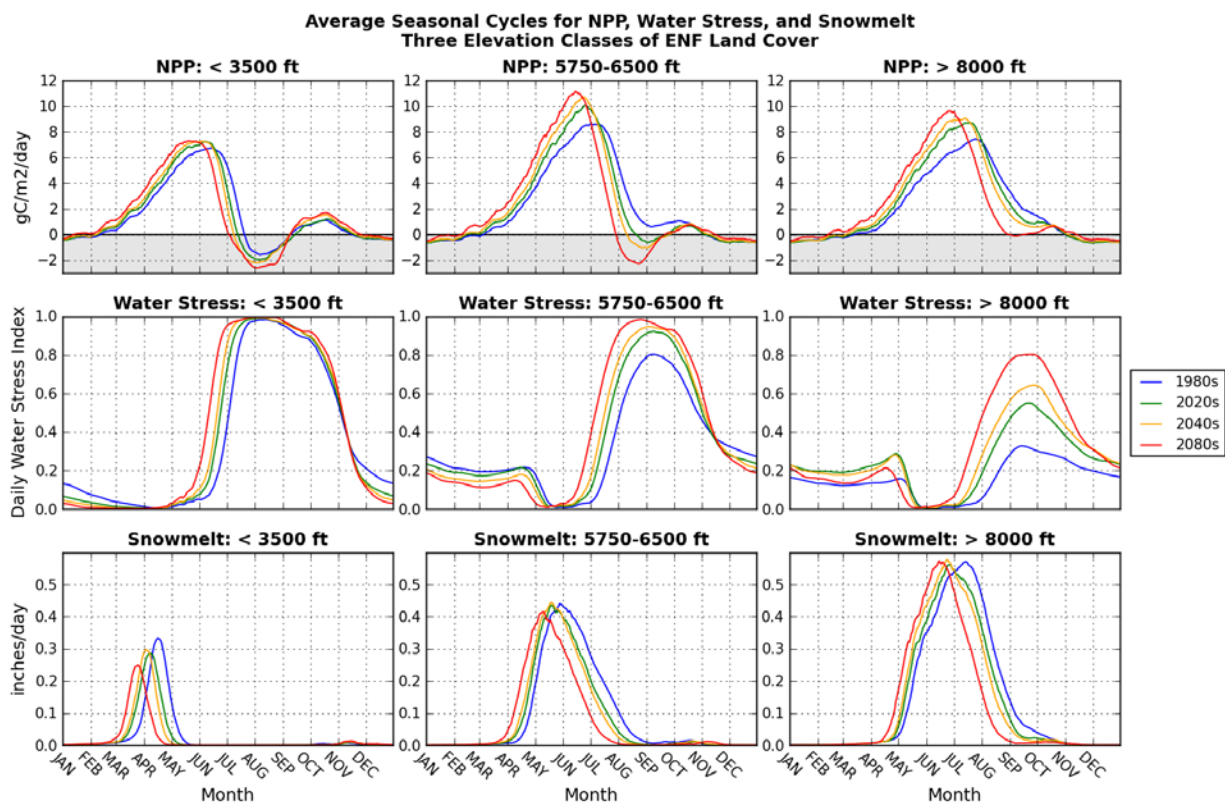


Figure A-16: Average seasonal cycles for NPP, waster stress, and snowmelt for ENF land cover sites at low-elevation (< 3500 ft), mid-elevation (5750 - 6500 ft), and high-elevation (> 8000 ft) for the 1980s baseline, 2020s, 2040s, and 2080s. For clarity, only values for the A1B scenario are displayed. Curves are smoothed with a 15-day running mean. Shaded region in NPP plots represents negative NPP values (i.e. - loss of carbon).

The seasonal cycles of water stress for the low and mid elevation were similar - water stress was low but above zero in the winter, decreased to almost zero when the snowpack started to melt in the spring, and then increased significantly in the summer when snowmelt started to decline. At the high elevation, water stress remained low but slightly elevated through May, quickly decreased to zero when snowmelt increased, and remained low through much of dry season. In all cases, warming caused water stress to increase earlier in the spring and early summer, peak higher, and stay higher throughout more of the growing season.

In total, the seasonal patterns of productivity at these different elevations show that increased temperatures and enhanced spring precipitation increased spring and early summer productivity, but greatly decreased overall summer productivity, especially at the low and mid elevations. In consequence, by the 2080s, total annual NPP only increased by 1.6% in the low elevation and 0.23% at the mid elevation. In contrast, at the high elevation, low temperatures were more limiting in the baseline and warming greatly increased NPP by 13.92% in the 2040s. However, even at the colder high elevation, changes in snowmelt timing caused water stress to increase enough that by the 2080s, NPP had declined to only be 10.43% higher than the baseline.

Conclusion

Summary

This climate change impact study examined possible long term impacts to vegetation productivity within GLAC from the 1980s to the 2020s, 2040s, and 2080s. Composite mean projections of Pacific Northwest temperature and precipitation from an ensemble of GCMs were downscaled to GLAC at 30-arcsec (around 800 meters) resolution for the B1 and A1B emission scenarios. The downscaled projections were used to drive the Biome-BGC ecosystem model to analyze possible specific impacts to seasonal temperature thresholds, growing seasons, vegetation water stress and productivity, and overall carbon sink/source trends. Different impacts and trends were compared along elevation gradients of ENF land cover.

Average winter Tmax temperatures within GLAC appeared to be most susceptible to moving above freezing, thus signifying possible impacts to biological processes and freeze/thaw cycles (Pederson et al. 2010). Areas above 5750 ft were least likely to move above key freezing thresholds given the specific projected changes in temperature. Nevertheless, the projected increases in temperature resulted in an upward movement of the general elevation at which the crossing of freezing thresholds occurred.

Earlier snowmelt timing appeared to have a substantial impact on conifer forest productivity and summer water stress, largely offsetting increases in growing season length, especially at the lower and mid-elevations within the park. Colder higher elevation forested areas exhibited greater relative increases in productivity due to the releasing of temperature constraints and longer growing seasons. These productivity patterns are largely consistent with other modeling and observational studies. In the northern Rockies, a comparable but less extensive simulation analysis (Boisvenue and Running 2010) found productivity increases resulting from longer growing seasons to be largely offset by increased water stress with some sites additionally displaying a decline in total carbon stocks. Long term observational analysis of ecosystem CO₂ exchanges at a site in the Colorado Rocky Mountains also found years with longer growing seasons to be correlated with overall lower rates of forest CO₂ uptake and rates of annual carbon sequestration to be highly dependent on snowmelt timing and availability (Monson et al. 2002, Sacks et al. 2006). Similarly, in a modeling study of a snow-dominated watershed in Yosemite National Park (Tague et al. 2009), the effects of temperature increases on productivity at a site were highly dependent on the shift in timing of snowmelt relative to the growing season. Lastly, Douglas-fir tree ring and growth studies along elevation gradients in the Pacific Northwest have also shown annual growth at mid and low elevations to be more dependent on water availability than temperature and negatively correlated with warmer growing season temperatures (Case and Peterson 2005, Littell et al. 2008).

Limitations and Assumptions

As with all simulation studies involving climate projections and the modeling of ecosystem impacts, there are necessary uncertainties and limitations (Littell et al. 2010). For instance, the downscaling of GCM projections to GLAC made several simplifying assumptions. Despite capturing general spatial climate patterns, the downscaling method used did not maintain the exact projection trends produced by the GCMs nor did it account for possible changes in climate variability (Mote and Salathé 2009).

Furthermore, it was assumed that every area in GLAC would experience the same change in temperature and precipitation. In complex topography, there will likely be great variation in the degree of change. For instance, mountain ridges more coupled to the free-atmosphere may experience greater temperature changes than convergent basins and depressions (Dobrowski 2010). Additionally, while the downscaled climate grid was at a much finer scale than GCM outputs, many important microclimate and fine-scale biophysical factors were likely still not captured and there wasn't an obvious climate gradient between the western and eastern sides of the park. However, downscaling climate projections to even finer scales is likely inappropriate given the uncertainties involved (Wiens and Bachelet 2010).

Projections of temperature and precipitation were also limited to a single composite mean of GCM projections for the B1 and A1B scenarios. Due to the extreme importance of precipitation in mediating vegetation response to warming temperatures in GLAC, future work should incorporate an ensemble of precipitation projections to better assess thresholds and the buffering of temperature-induced impacts. Nevertheless, the simplicity of the downscaling methods used and the easy comparison to historical observations made the methods a good choice for an initial assessment of future climate change impacts before undertaking more complicated regional climate modeling.

Similar to the downscaled projections, given the inherent complexity of terrestrial ecosystems, ecosystem models like Biome-BGC cannot fully represent the entire set of processes governing vegetation dynamics. Simplifying assumptions are necessary to scale models to regional levels and every model differs depending on its specific objective (Waring and Running 2007). As a model of ecosystem biogeochemical cycles, Biome-BGC was designed to simulate fluxes of carbon, nitrogen, and water through terrestrial ecosystems. In contrast, other ecosystem models may focus more on simulating vegetation distributions or recruitment and mortality processes (Waring and Running 2007).

In view of the main objectives of the Biome-BGC model and the simplifications necessary for larger scale applications, Biome-BGC had several assumptions and limitations when applied to the GLAC landscape. A limitation of key importance is that Biome-BGC did not model large-scale disturbances such as stand replacing wildfire and insect outbreaks. Under a warming climate, increases in the frequency and extent of disturbance will likely have a strong effect on GLAC vegetation dynamics and could play an even larger role in changes in ecosystem structure and function than the actual direct effects of temperature and precipitation (Littell et al. 2010). Still, the modeled impacts to snowmelt timing and increases in water stress are strongly indicative of greater probability of severe wildfire (Westerling 2006), increased forest vulnerability to insect outbreaks (Raffa et al. 2008), and drought-induced mortality (van Mantgem et al. 2009). At almost all forested sites, despite modest increases in overall annual productivity, summer water stress was substantially intensified.

Biome-BGC also did not consider changes in species composition, vegetation distribution, land use, or movement in timberlines (i.e. - the land cover is static). Similarly, to isolate the effects of a changing climate for subsequent analysis, Biome-BGC assumed all stands to be old growth and in steady state with current climate. In reality, the GLAC landscape consists of a mosaic of forested areas with different stand ages and time since disturbance. All of these factors impact the carbon

exchanges and trends for a specific site (Boisvenue and Running 2010). Lastly, Biome-BGC considered sites in isolation and did not model stream flow or hydrologic drainage from higher elevations to lower valleys. This could have caused the initial state of some GLAC valley areas to appear too dry and less dependent on snowpack.

In the context of these limitations, the results of this modeling exercise should not be used as predictions of impacts to specific sites within the park. The results should be considered as a best guess hypothesis of how ecosystems will respond along elevation gradients within GLAC based on possible future temperature and precipitation scenarios. For instance, the results are not fine enough to capture biophysical gradients between Lake McDonald and Saint Mary Lake and the differences in ecosystem response between the two sites. On the other hand, the results do indicate how a high elevation forest in GLAC could respond differently than a mid-elevation forest.

Final Conclusions

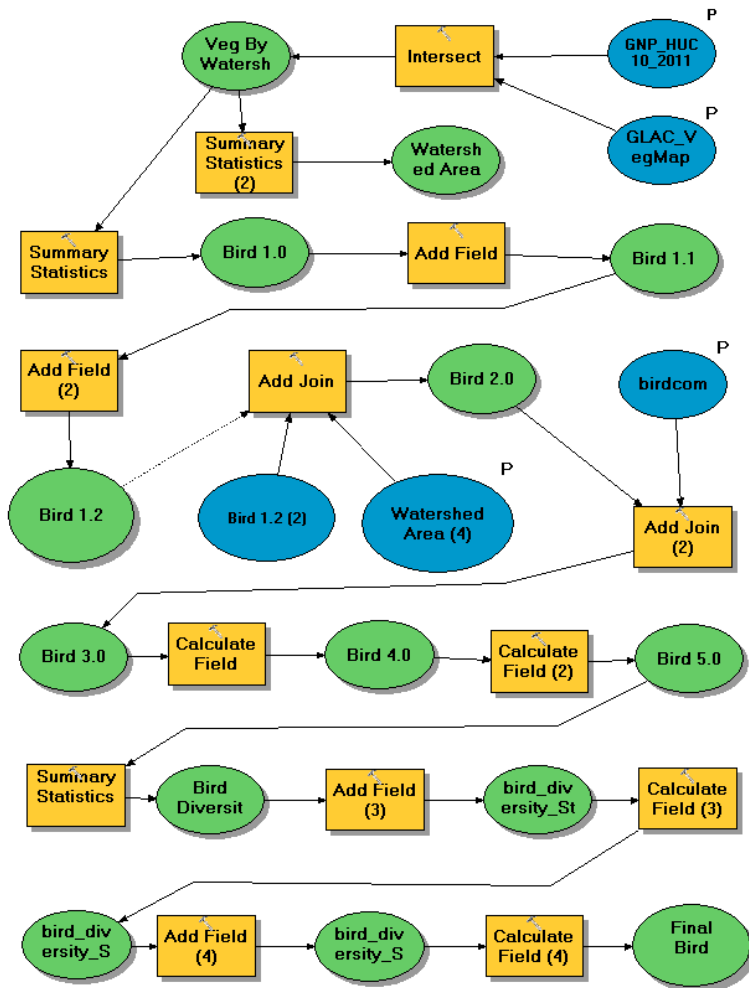
Despite the limitations evident, this modeling exercise served as a valuable exploration of the possible impacts to GLAC resulting from different temperature and precipitation projections. Ecosystem modeling with Biome-BGC allowed for a better understanding of likely vegetation productivity trends and of the key factors involved in vegetation response to a changing climate. Water availability from snowmelt was found to be the most significant limiting factor of forest productivity across the GLAC landscape. In turn, the magnitude of temperature-induced changes in snowmelt timing mediated how different areas of the landscape responded to increased temperatures and longer growing seasons. With more consistent projections of decreased summer precipitation during the already dry summer months, it is highly unlikely that summer rains will compensate for changes in snowmelt inputs. As discussed by Boisvenue and Running (2010), it is not only the amount of precipitation that will drive trends in ecosystem response, but also the timing and form.

Therefore, while the importance of snowpack for forests in the American West is certainly well known, this study further revealed its critical role within GLAC. In turn, given the simplified representations of hydrology and snowpack within Biome-BGC, future work should look to incorporate more advanced hydrology models and assess a wide range of different precipitation scenarios. Along with more representative hydrology, research should be geared to understanding different factors mediating changes in temperature and water availability not only along elevation gradients, but also within diverse physiographic settings and microclimates (e.g.—south versus north-facing slopes, convergent valleys versus ridge tops; Dobrowski 2010). Such understanding is critical to projecting changes at scales more relevant to management (Littell et al. 2010) and identifying which areas of the landscape are most vulnerable or more likely to buffer the effects of increasing temperatures (Dobrowski 2010).

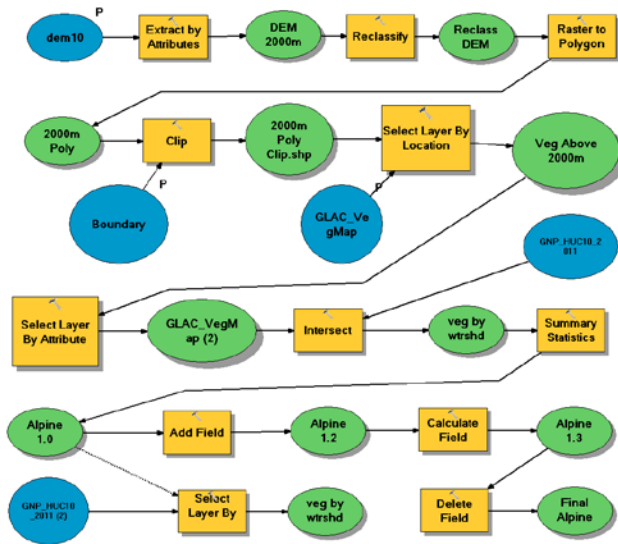
Ultimately, as shown by this study, predicted changes in climate from greenhouse gas emissions will likely have a strong effect on both hydrologic and ecosystem dynamics within GLAC even negating large-scale disturbances. Further interdisciplinary research will be critical for informing sound adaptation strategies and management frameworks capable of addressing the changing landscape.

Appendix B. GIS Models

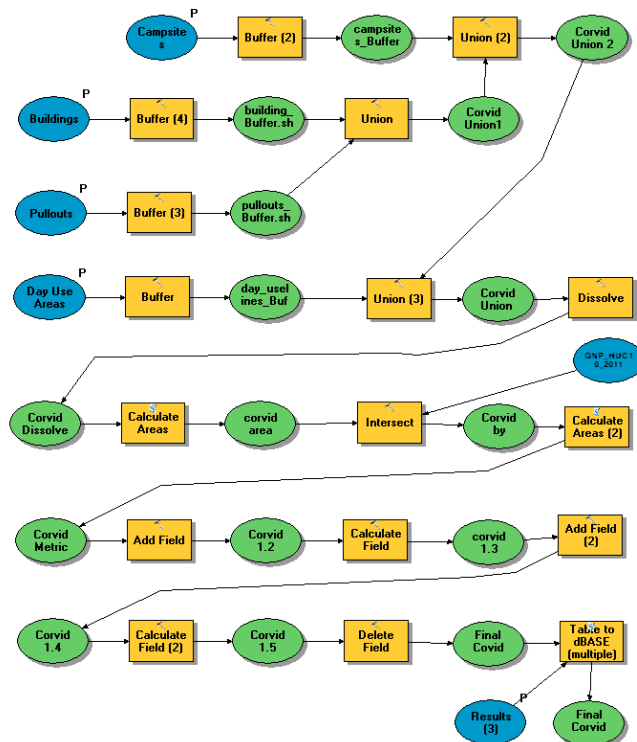
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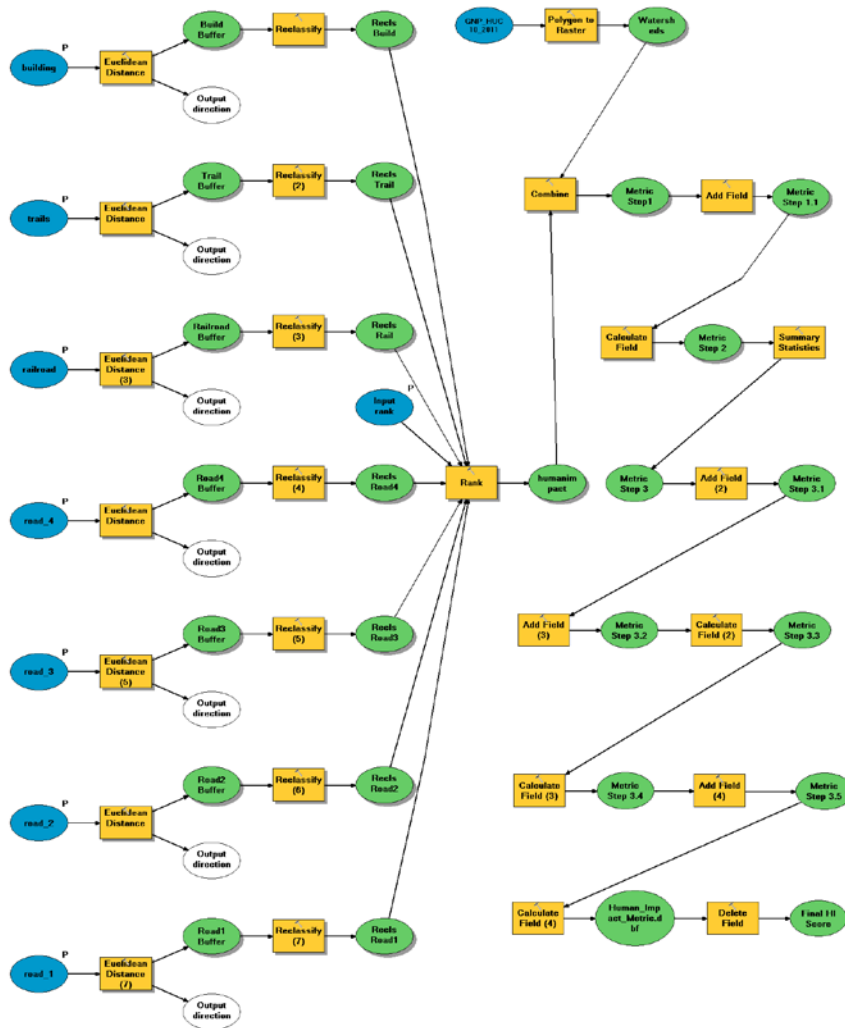
Alpine Habitat Metric



Corvid Model Metric



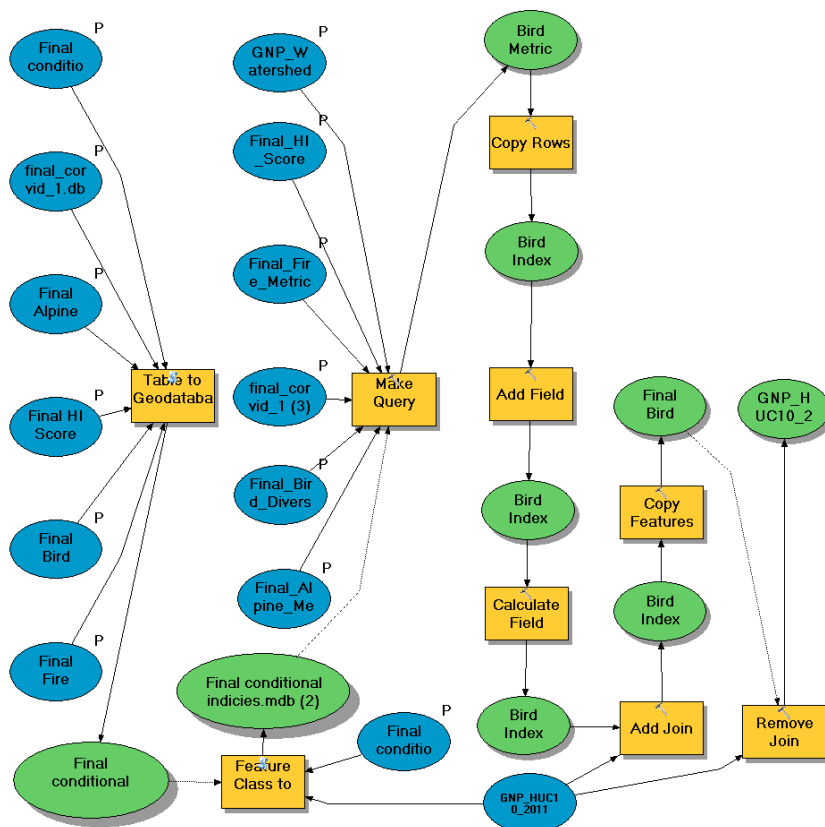
Human Impact Metric



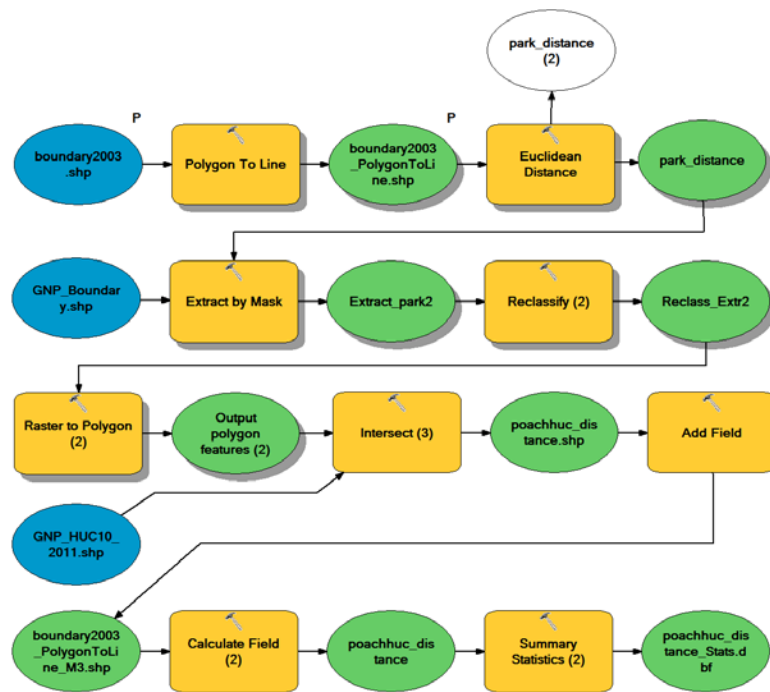
Fire Model



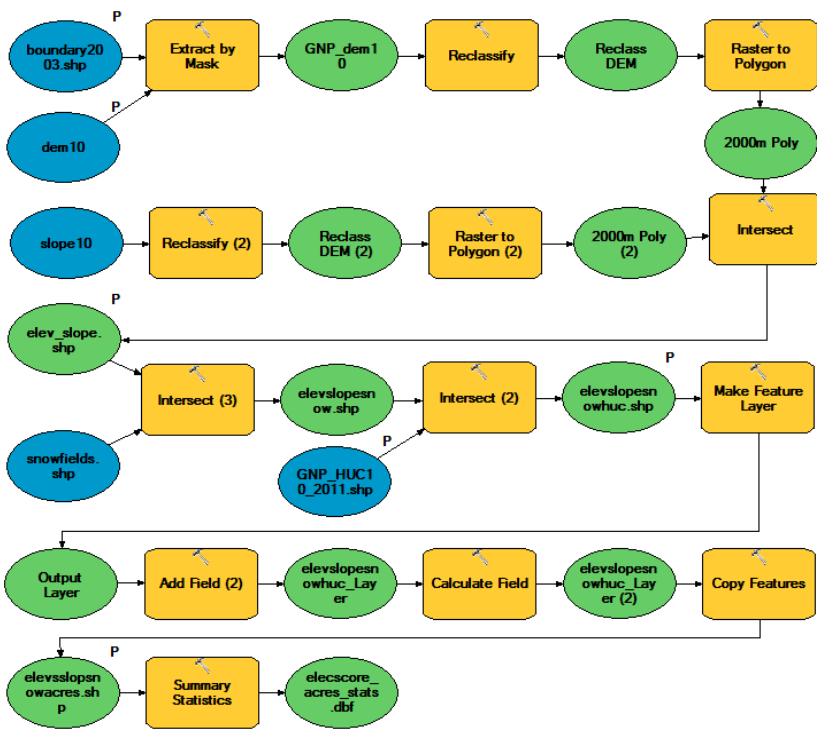
Final Bird Index



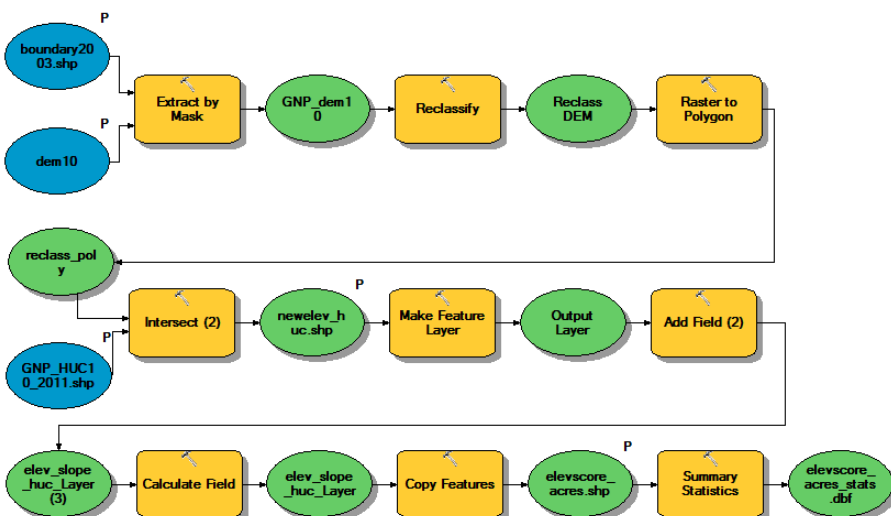
Boundary Edge



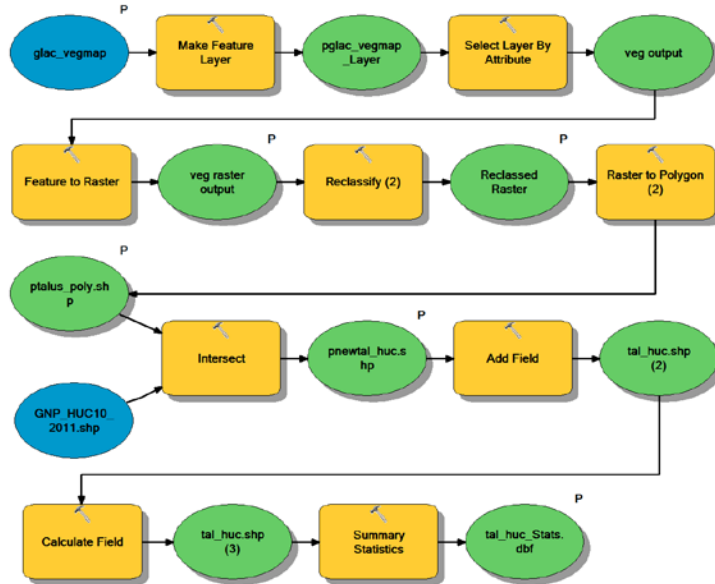
Elevation



Prey



Talus

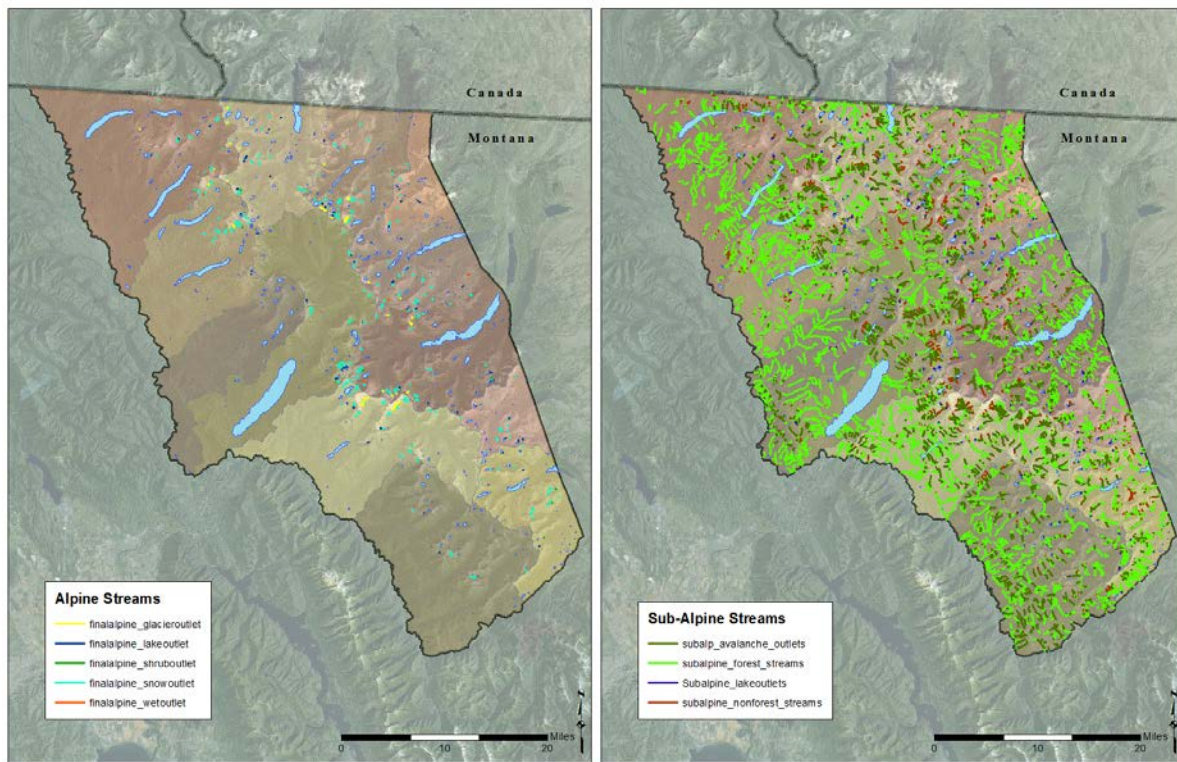


A. Instructions for computing road density per watershed using ArcGIS

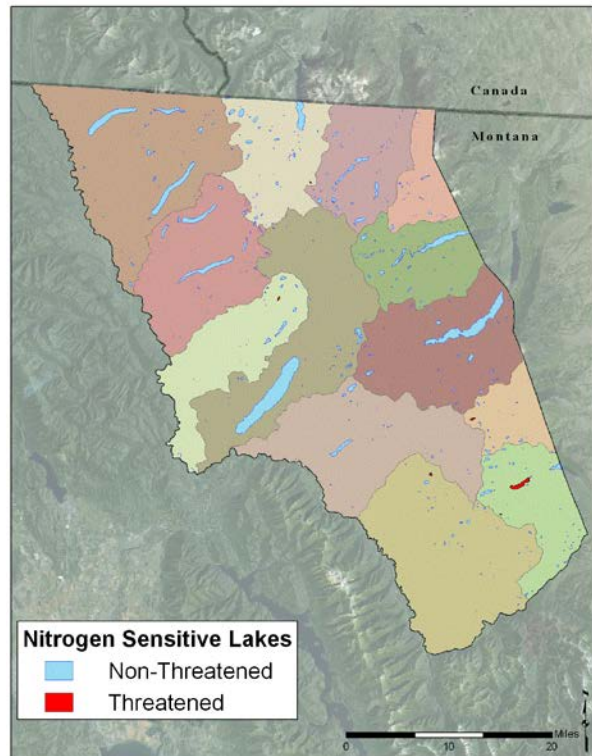
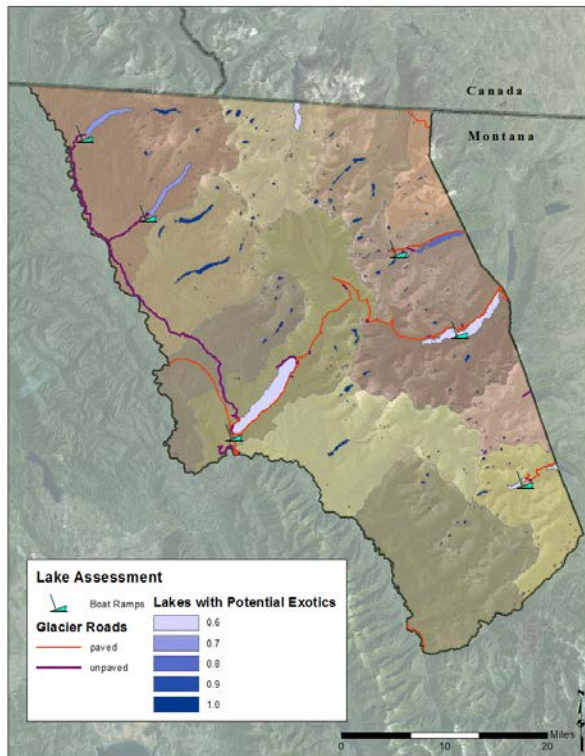
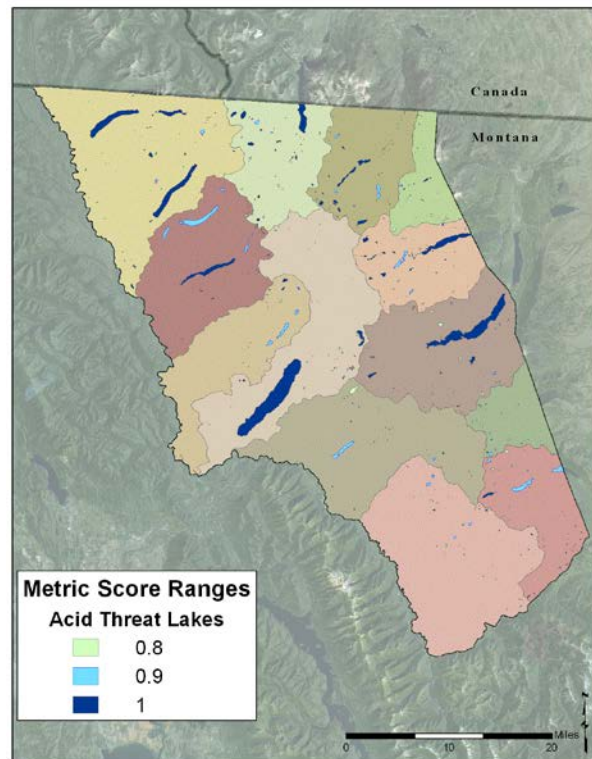
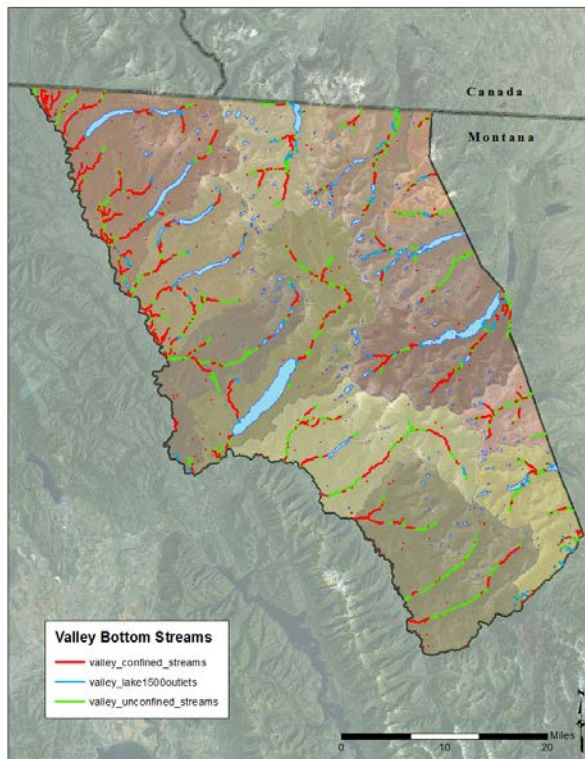
- 1) Two types of data are required in coverage, shapefile or Geodatabase format.
 - a. Roads layer
 - b. Watershed/HUC layer
- 2) Create a Personal Geodatabase called RoadsHUC (ArcCatalog > right click in folder > New > Personal Geodatabase)
- 3) Import roads layer and HUC layer into the Geodatabase (ArcCatalog > right click on layer > Export > Coverage to Geodatabase)
- 4) Intersect the roads and HUC layer (ArcMAP > Tools > Geoprocessing Wizard > Intersect)
- 5) Export the intersection attribute table to an Excel spreadsheet. (ArcMap > Add intersection layer > Open attribute table > Options > Export > Export to .dbf file outside of the Geodatabase)
- 6) Open .dbf file in Excel worksheet
- 7) Remove all extraneous data from spreadsheet and format cells
- 8) Put data in a PivotTable (Data > PivotTable > Wizard – HUC number goes in Row and Shape_Length goes into Data)
- 9) Add HUC areas to the spreadsheet and order sequentially (same as pivot table).
- 10) Compute density $(\text{Length}/1000)/(\text{Area}/10000\text{L})$

Appendix C. Raw Images

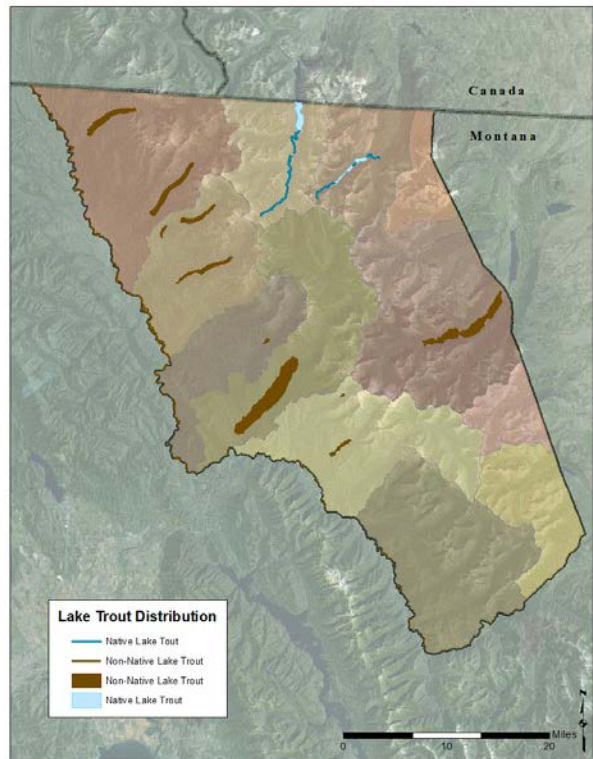
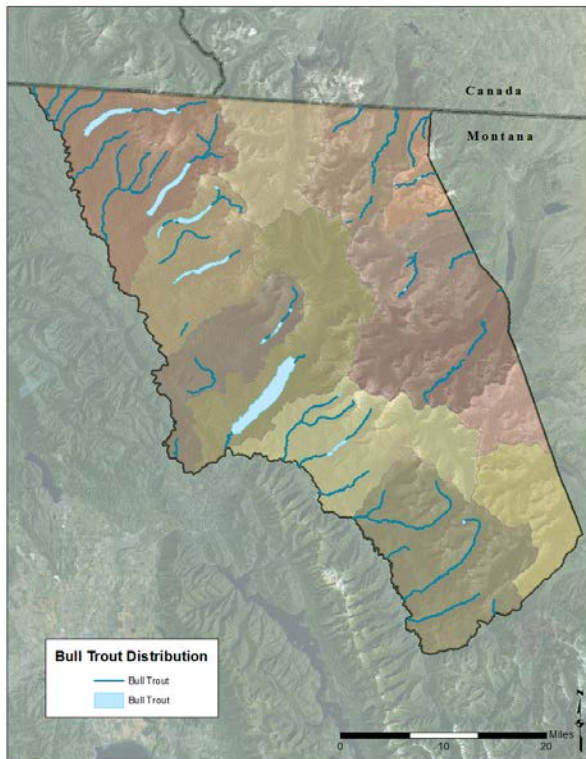
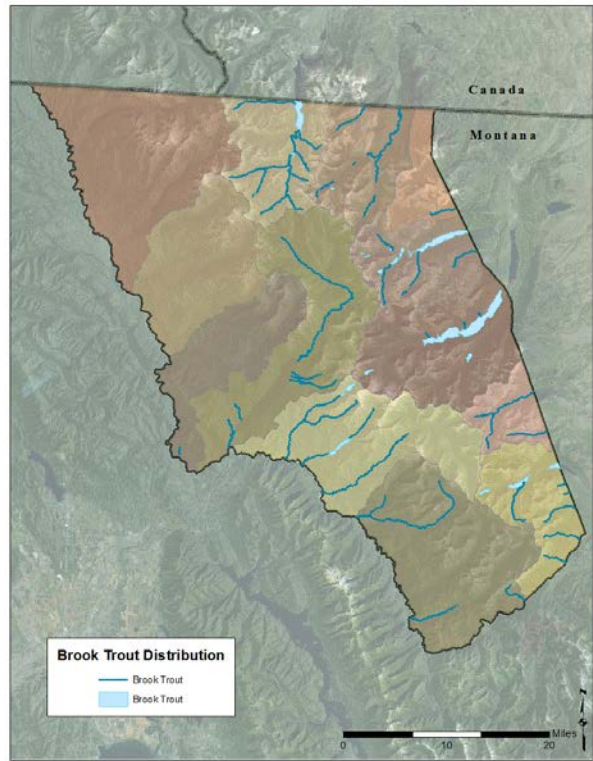
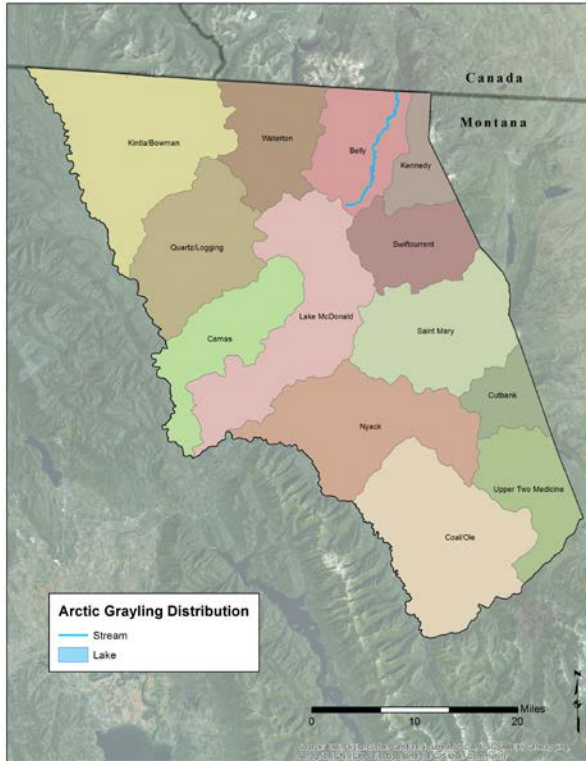
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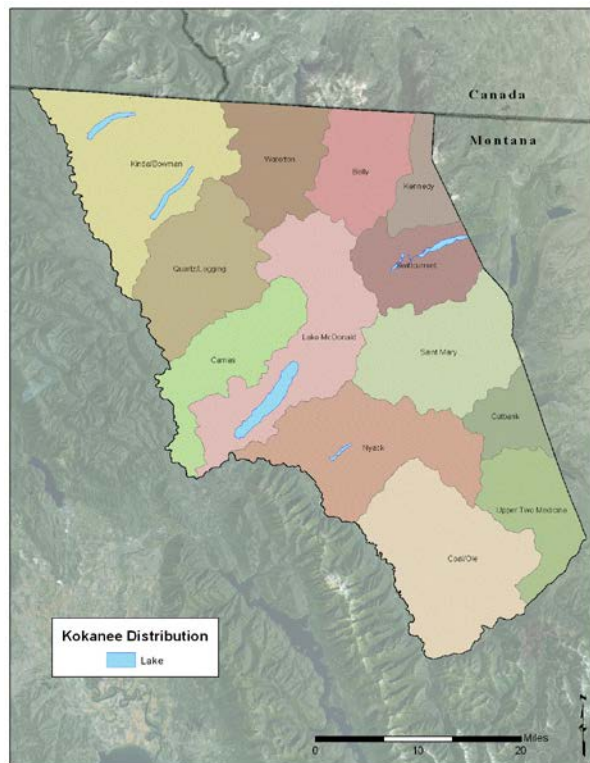
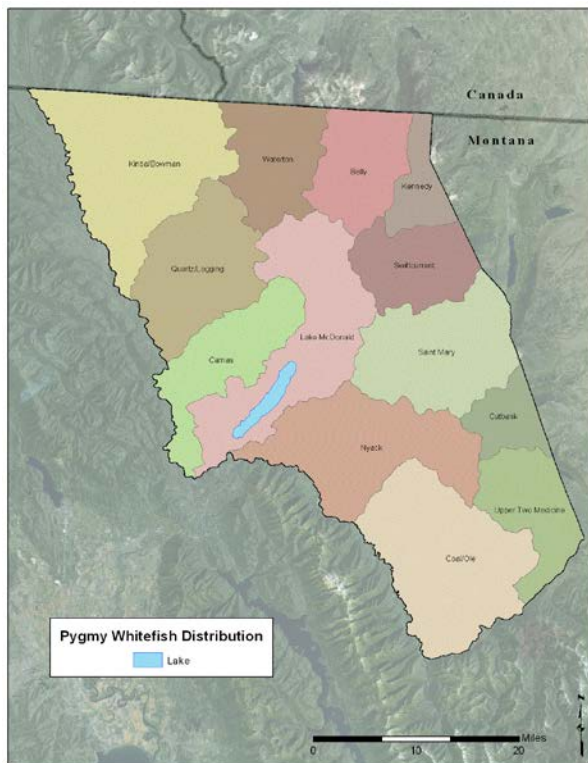
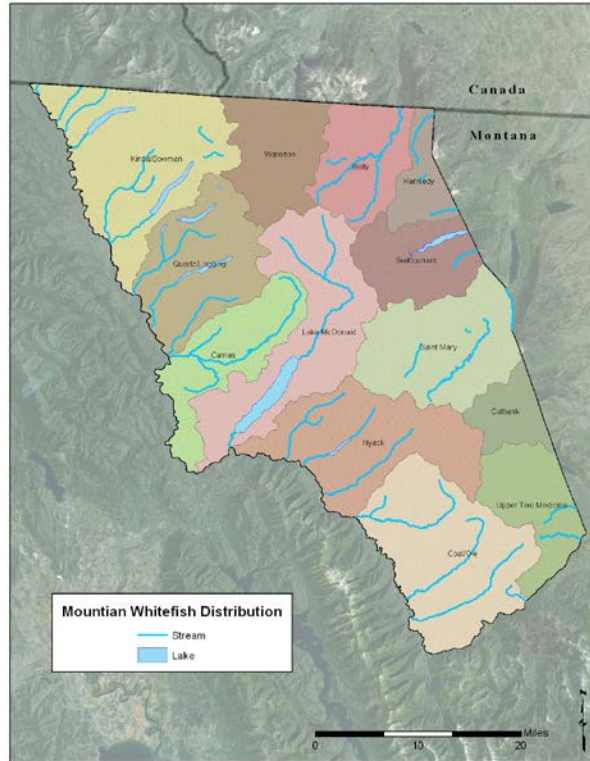
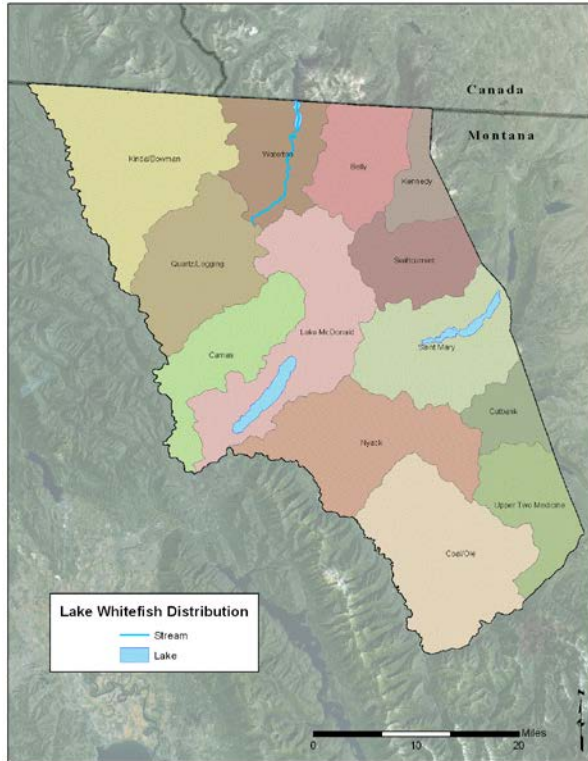


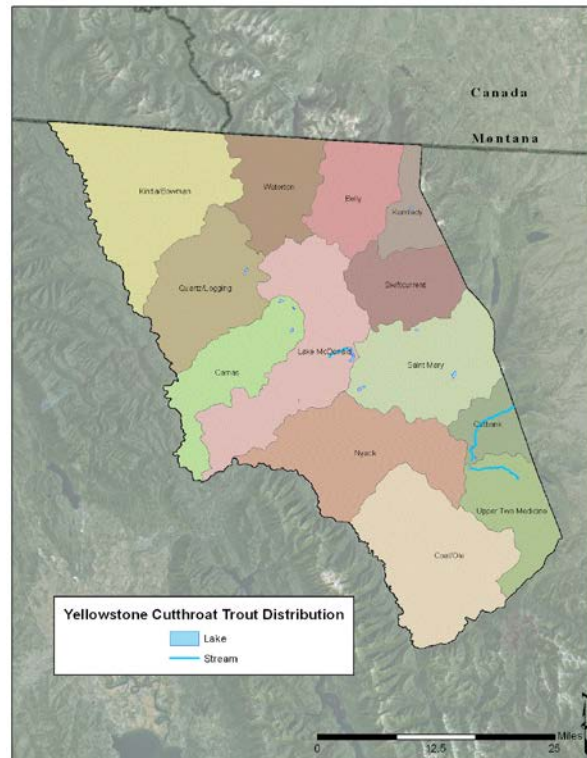
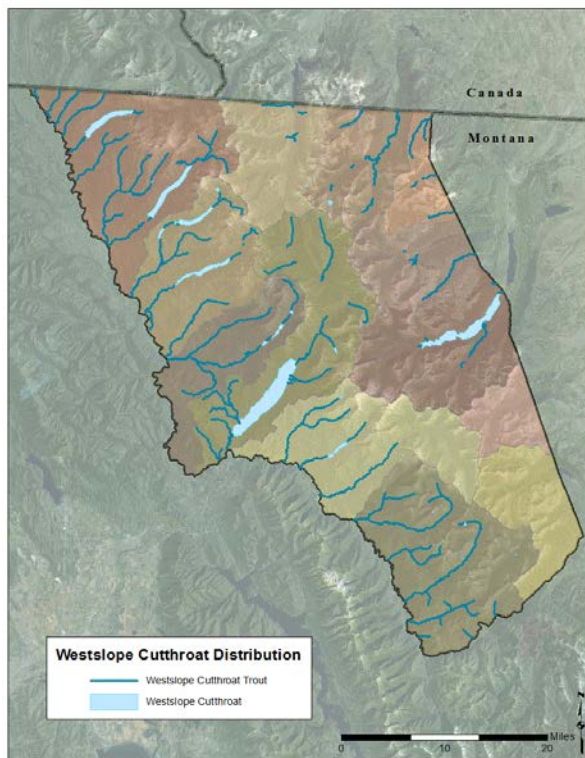
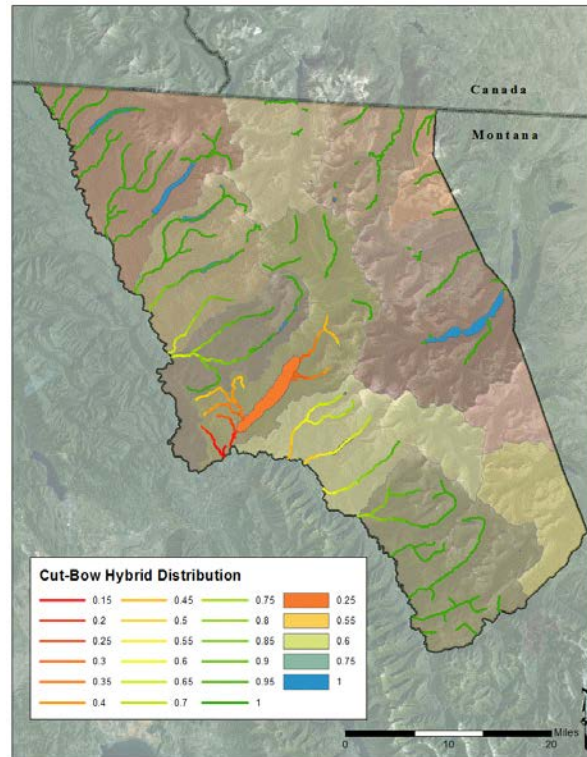
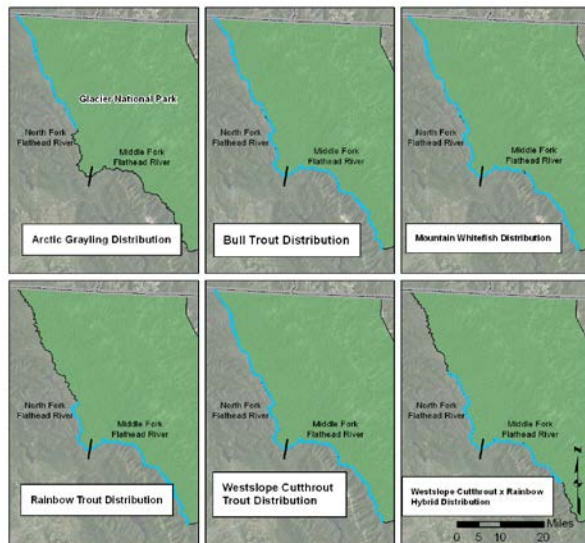
Lake



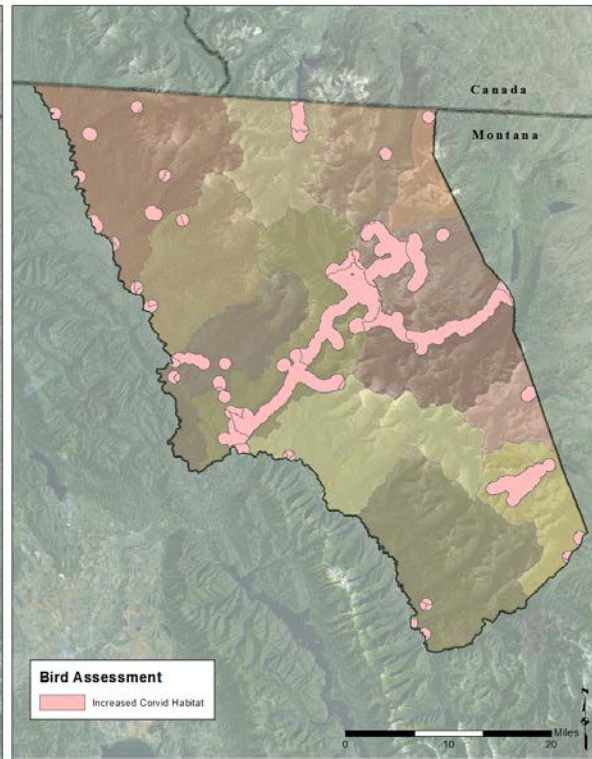
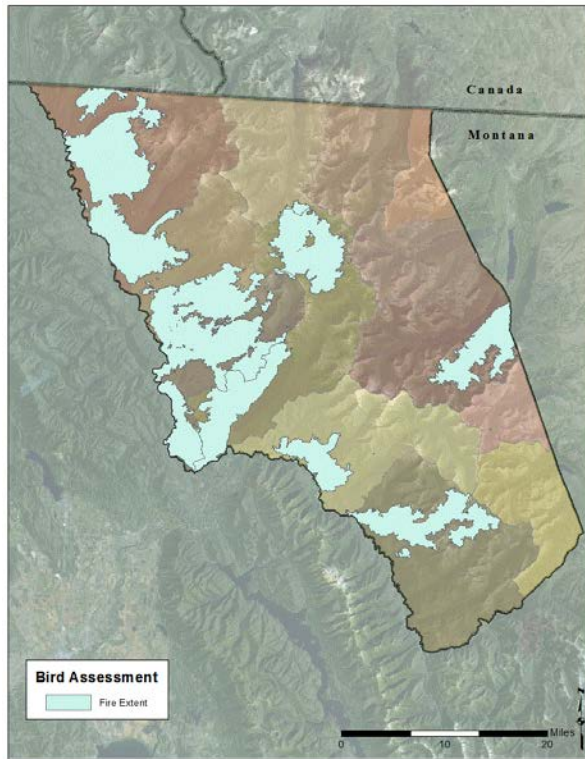
Fish Distribution



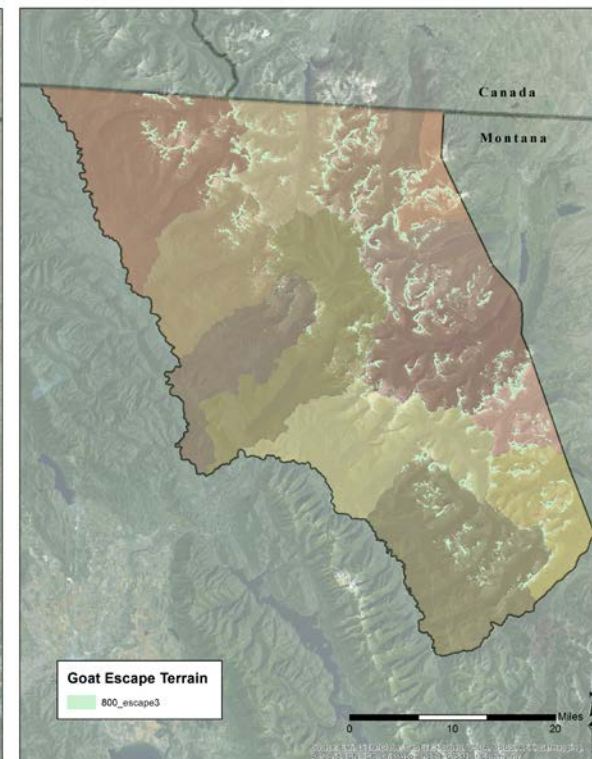
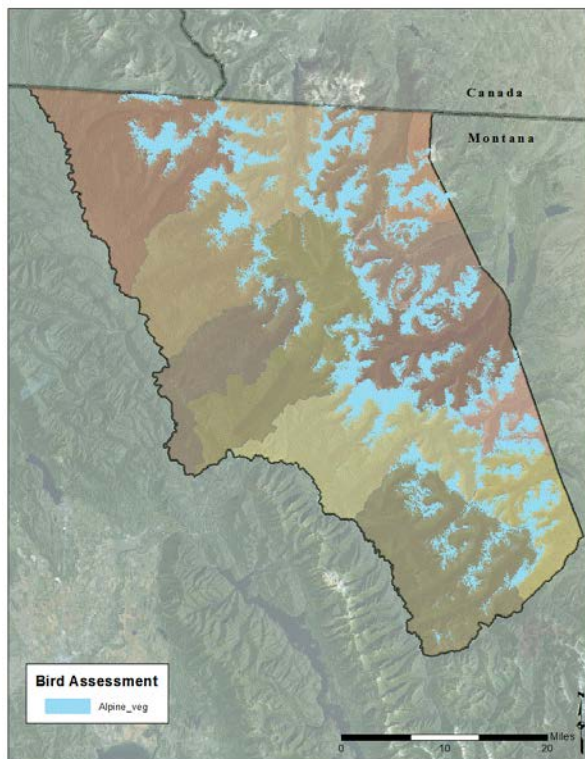


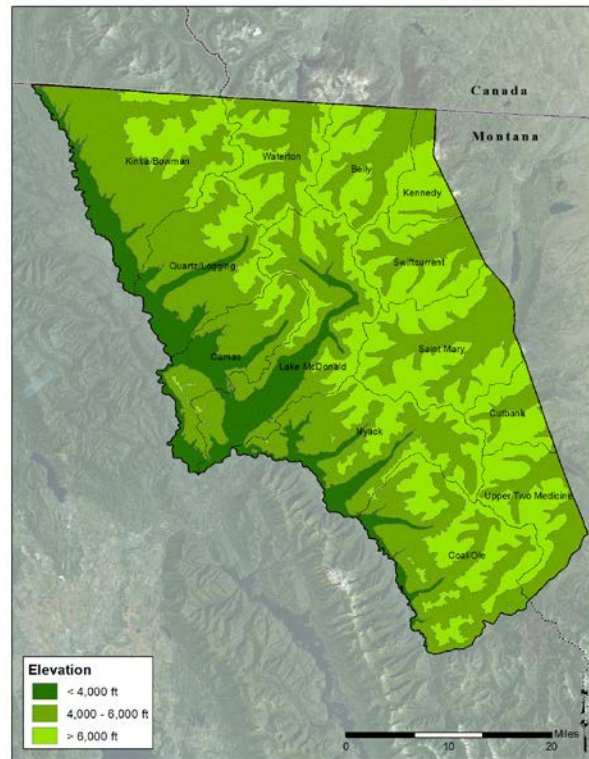
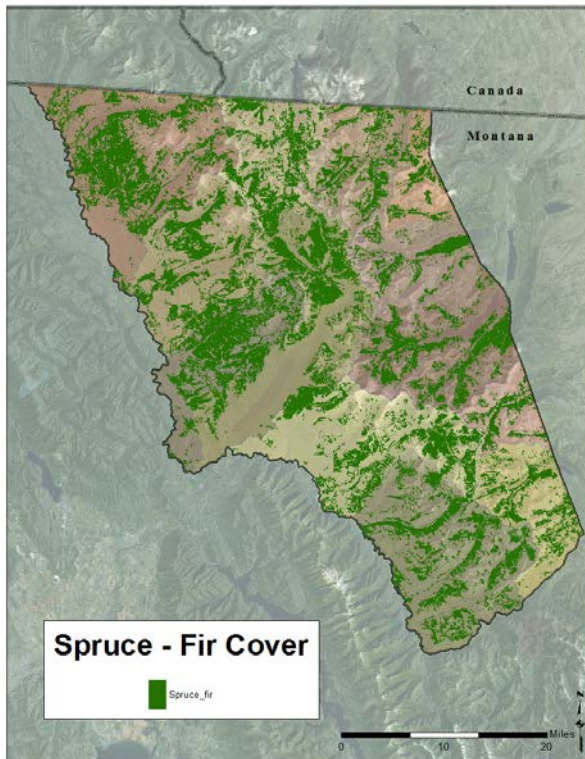
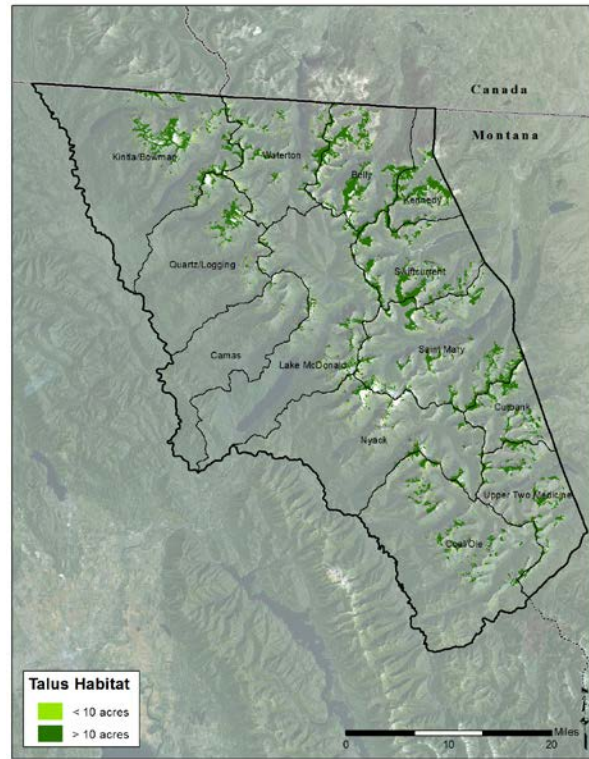
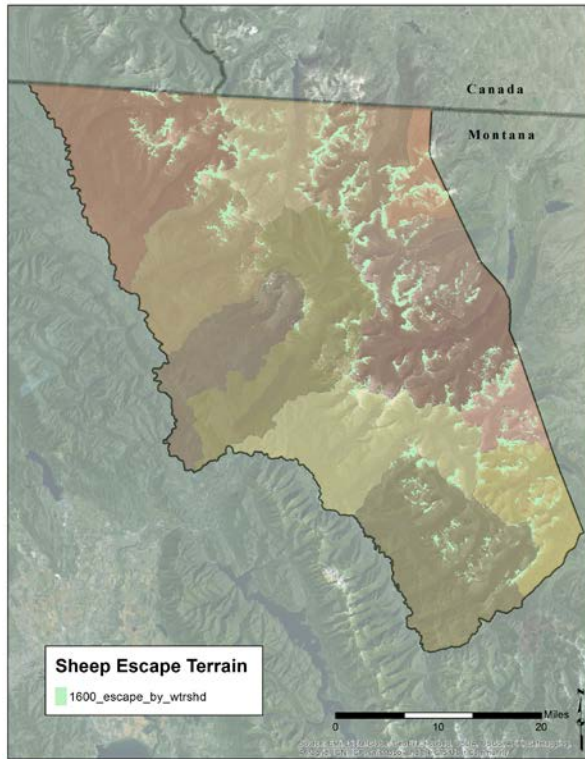


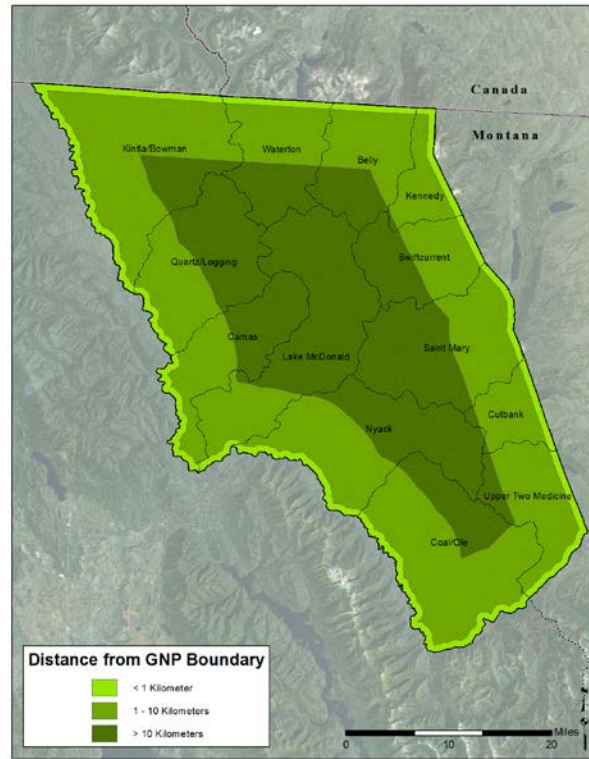
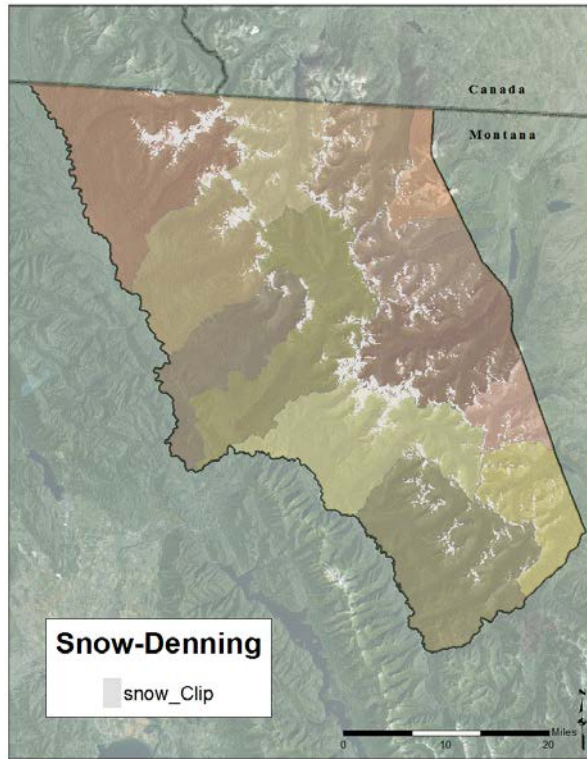
Bird Distribution



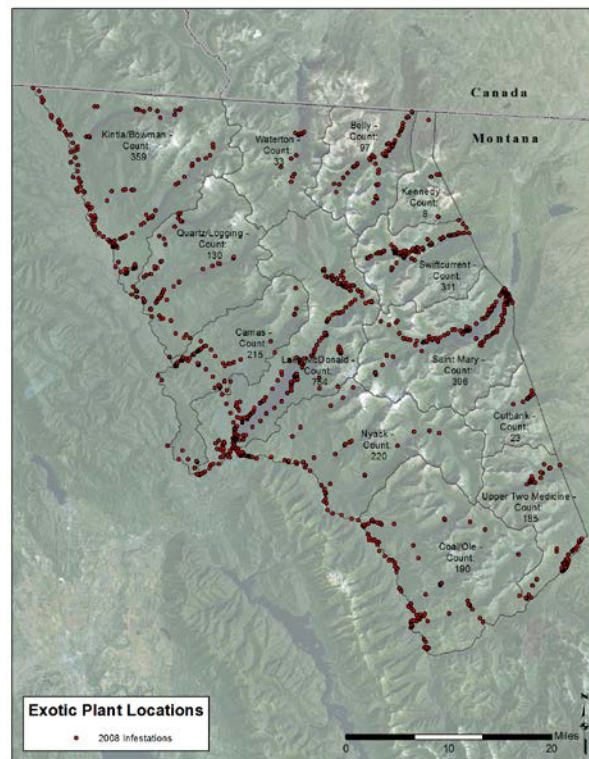
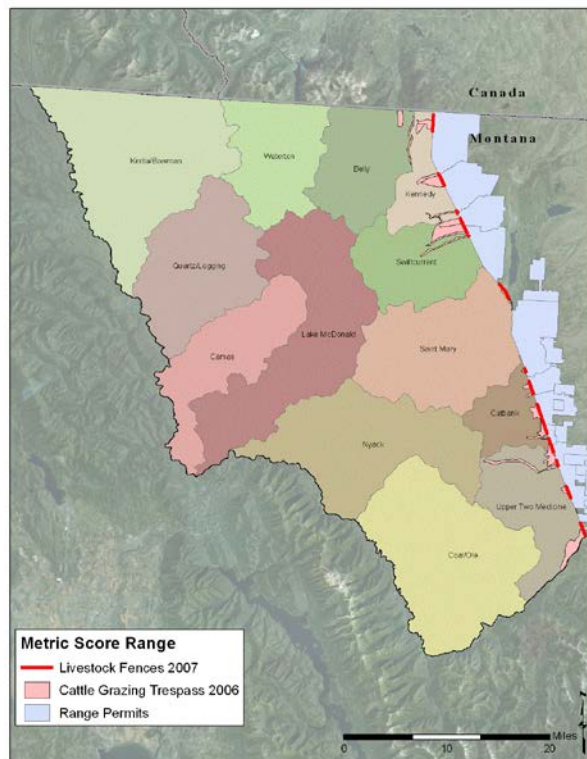
Mammal Data



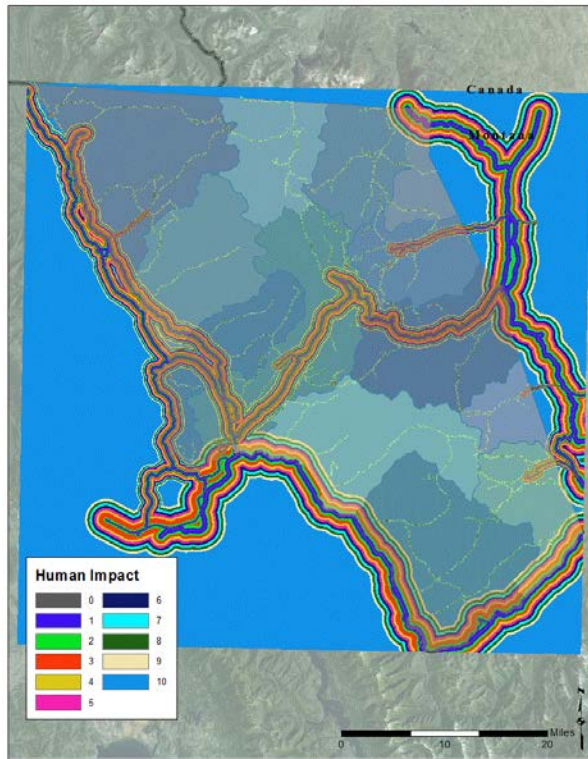




Vegetation



Human Disturbance



The Department of the Interior protects and manages the nation's natural resources and cultural heritage; provides scientific and other information about those resources; and honors its special responsibilities to American Indians, Alaska Natives, and affiliated Island Communities.

NPS 117/128359, April 2015

National Park Service
U.S. Department of the Interior



Natural Resource Stewardship and Science
1201 Oakridge Drive, Suite 150
Fort Collins, CO 80525

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