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Glacier National Park Biosphere Reserve: Its Suitability for the Mountain Research Initiative

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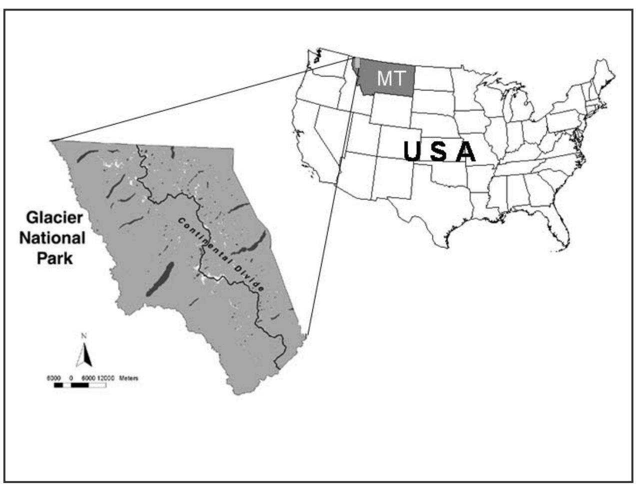
Introduction

The National Park Service of the United States has 388 designated protected areas and parks. These include historic and cultural sites as well as "natural resource" parks that are set aside for their unique and outstanding natural features. Early efforts to create natural resource parks were focused on areas of beauty or with unusual features but later efforts increasingly aimed to protect biodiversity and intact ecosystems. Protected areas in the National Park Service are in nearly all of the 50 states from Florida to Alaska and preserve examples of natural environments ranging from coral reefs to the icy summit of 6187 m Mt. McKinley in Alaska. Many of the larger parks have been designated as Biosphere Reserves under the United Nations Educational, Scientific and Cultural Organization (UNESCO) Man and the Biosphere Programme.

The area now managed as Glacier National Park was first set aside as a forest reserve in 1897 and then designated as a national park in 1910 (Glacier National Park 2002). This occurred six years before the National Park Service was created in 1916 to oversee the growing number of parks that the U.S. Congress was establishing. Waterton Lakes National Park was created immediately north of the U.S.-Canada border by Canada during the same period. In 1932, a joint lobbying effort by private citizens and groups convinced both the U.S. and Canada to establish the world's first transboundary park to explicitly underscore and symbolize the neighborly relationship between these two countries. This became the world's first "peace" park. Waterton-Glacier International Peace Park is managed collaboratively on many issues but each component national park is separately funded and operates under different national statutes and laws. Waterton-Glacier International Peace Park was, however, named a Biosphere Reserve in 1976 and a World Heritage Site in 1995. There have been recent efforts to greatly increase the size of Waterton Lakes National Park by adding publicly owned forests on the western side of the continental divide in British Columbia, Canada. For the purposes of this paper, I will emphasize the U.S. portion of the Waterton-Glacier International Peace Park and refer to it as the Glacier Mountain Biosphere Reserve (MBR).



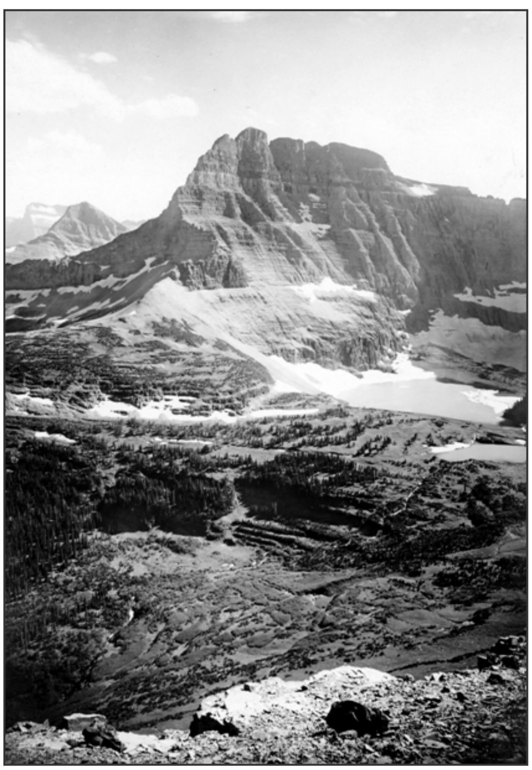
Location and Description

The Glacier MBR is in the northern Rocky Mountains of northwestern Montana, USA, along the U.S.-Canada border. Glacier MBR is a 4082 km^2 mountain wilderness that straddles the continental divide of North America and contains 175 named summits of up to 3150 m elevation (Glacier National Park 2002). It contains 762 lakes as deep as 150 m and 563 streams and rivers. Sedimentary rock layers that are as old as 1.3 billion years have been dramatically reshaped by repeated glaciation to form relatively flat bottomed valleys, steep headwalls, numerous cirque basins and pyramidal peaks (Rockwell 2002). Approximately 60% of the Glacier MBR is covered in conifer and deciduous forests. Managed as a wilderness area, only the Going-to-the-Sun Road traverses the park over the continental divide. Short roads and nearly 1000 km of trails provide access to the majority of the MBR's landscape. There are approximately 1,270 vascular plant species, 880 mosses and lichens, and 130 non-native plant species (Glacier National Park 2002). The Glacier MBR is home to 272 bird species, 23 fish species and 63 mammal species that include the endangered or threatened grizzly bear, gray wolf and lynx.

The Glacier MBR is bordered by U.S. Forest Service lands that include large, designated wilderness areas to the south and west. To the east is the Blackfeet Indian Nation reservation that shares Chief Mountain, a sacred site for many Plains Indian Tribes, with the Glacier MBR. To the north are Waterton Lakes National Park in Alberta, Canada, and Crown Forest Lands in British Columbia. Relatively small towns (approximately 3,000-12,000 population size) lie outside the MBR in nearby valleys but much of the region is undeveloped or mostly natural landscapes. This region has been described as the "Crown of the Continent Ecosystem" in recognition of its interconnected and intact characteristics.

Vegetation Zones in the Glacier Mountain Biosphere Reserve

Climatic regimes are distinctly different on the eastern and western sides of the MBR owing to the continental divide that bisects this landscape. The western side is strongly influenced by maritime moisture from the Pacific Ocean and has moderate temperature variation (Finklin 1986). The eastern side is dominated by a drier, continental climate with frequent strong winds and more extreme temperatures. This is reflected in the types of vegetation and plant communities found on the two sides of the divide.



The lowest elevation in the MBR is 985m on the western side where moist coniferous forests are common on valley bottoms and lower slopes. These forests are dominated by western red cedar (*Thuja plicata*), mountain hemlock (*Tsuga heterophylla)*, western larch (*Larix occidentalis*), and Engelmann spruce(*Picea engelmannii*) (Lescia 2002). Drier sites, or areas that have historically burned, are dominated by lodgepole pine ((*Pinus contorta* var. *latifolia*), a fire-adapted species common throughout the Rocky Mountain states. Drier forests are more widespread on the eastern side. Deciduous species, such as cottonwood trees (*Populus spp*.), dominate riparian areas. Various shrubs are common on slopes where there is frequent disturbance such as from snow avalanches. Deciduous trees, such as aspen (*Populus tremuloides*), also are common on the eastern border of the park where they are interspersed with grasslands. Most of the grasslands are on the eastern side and at low elevations where they merge with the Great Plains of central North America. However, there are some high elevation grasslands on ridges from the east-facing mountains that are important winter range for bighorn sheep and other ungulates.

At mid-elevations (2000 m), the conifer forests are dominated by subalpine fir (*Abies lasiocarpa*) and the canopy begins to thin (Lesica 2002). Subalpine meadows and high-elevation wetlands are interspersed with patchy subalpine fir forests. Higher still, krummholz forms of subalpine fir become common and soon give way to alpine tundra at approximately 2500m. The treeline, or alpine treeline ecotone, is greatly influenced by the diverse topography and geomorphic dynamics. Consequently, the variation in treeline elevation is greater than for other mountain areas. Alpine tundra represents less than 3% of the vegetation communities in this MBR.

For the land surface of this MBR, 34% is in lowland, moist coniferous forest, 16.3% in dry, coniferous forest, 6.6% in deciduous trees and shrubs, 5% in moist, herbaceous vegetation, and 7.1% in dry, herbaceous vegetation. Barren rock, snow and ice cover the remaining 31% of the terrestrial surface (Glacier National Park 2002).

Characterization of the Glacier Mountain Biosphere Reserve above the vegetation line

The Glacier MBR is a snow dominated environment with approximately 70% of the annual precipitation falling as snow (Finklin 1986). Snow covers all elevations of the MBR for 4-5 months of each year and the highest elevations (2800-3000m) above the vegetation line are free of snow for only 2 months each year. The area above the vegetation line has approximately 80 perennial snowfields and an estimated 27 small alpine glaciers remaining, based on a remote sensing survey (Key et al. 2002). Rock and snow avalanches, debris flows, solifluction lobes, patterned ground, talus slopes and frost-shattered rock above the vegetation line all reflect cold, harsh conditions that prevent or slow plant colonization. Much of the terrain above the vegetation line is comprised of steep cliffs, ridges and sharp summits.

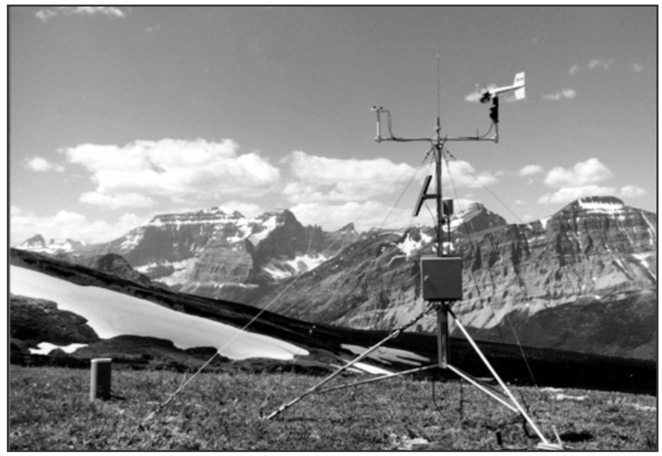
Demographic and economic characterization of the mountain biosphere reserve

The cultural history of the MBR dates to at least 10,000 years ago and includes prehistoric and historic use by Native Americans and their contemporary descendents (Long 2002). The first Europeans to explore the area were fur trappers in the 1790s. By the 1880s, a few transitory mining camps and hunting expeditions began to occur but economic development did not begin until 1892 when the arrival of the Great Northern Railway spurred homesteaders to claim land within the future park boundaries. The railroad company was instrumental in developing a tourist industry for the fledgling park and constructed a number of hotels and backcountry chalets (Rockwell 2002). The National Park Service purchased most of the private homes after the park was created but approximately 30 “in holdings” still exist. These homes are used primarily as summer homes as most businesses and services are closed during the winter. The tourist industry is the only economic activity within the MBR and only a few National Park employees reside within the park permanently. The MBR maintains several visitor centers, numerous campgrounds, roads and trails, and provides law enforcement and search and rescue. Licensed concessioners provide the hotel, guiding and other services within the MBR boundaries. The MBR is visited by 1.7 million people each year and numerous hotels, restaurants, shops and services have been established outside the MBR to cater to their needs, primarily between June and September each year (Glacier National Park 2002). Winter use has increased during the past 10 years but remains less than 20% of the total visitation for the MBR. The MBR generates significant economic activity for the region, estimated at $1.1 million per day in tourist-based revenues. In addition, there has been a 26% increase in the population of the nearby valley during the past 10 years as retirees and others move into the area (National Parks Conservation Association 2003). Most of these newcomers are motivated by the presence of the MBR. The role of the MBR in driving demographic and economic patterns in the region has increased as other activities, such as mining, manufacturing and timber harvest, have decreased (Travis et al. 2002).

On-going global change programmes and research projects in the mountain biosphere reserve

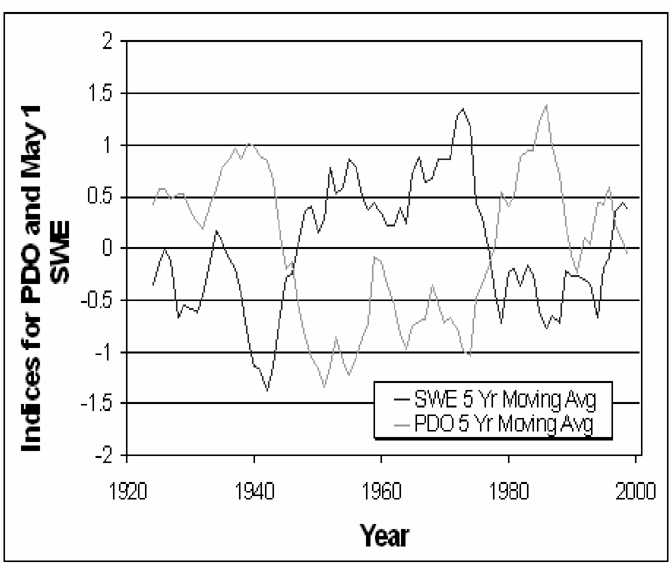
Scientists were prominent among the early supporters of Glacier National Park’s creation and various scientists played roles in exploration, management and research during the first half of the 20th century. In 1967 a full-time scientist was hired onto the park’s staff and a research division eventually was formed as more scientists were added (Martinka 1992). In 1990 the Glacier MBR successfully competed to host a global change research program sponsored by the National Park Service as part of the U.S. Global Change Research Program, newly created by Congress. A global change research coordinator was hired and, over the past 13 years, a diversity of research projects has been initiated with numerous collaborators from other federal agencies, universities, non-government organizations, and from other countries. After several reorganizations, the global change research at the Glacier MBR is now conducted through the U.S. Geological Survey, the primary research arm of the Department of the Interior. Funding levels have ranged from $235,000 - $595,000 per year and have been greatly leveraged through partnerships, graduate student programs, and the use of interns to increase the research intensity in addressing how mountain ecosystems respond to climate change. Currently, the Glacier MBR global change programme has an ecologist, two physical scientists and a biological technician working full-time. Active partnerships currently exist with 19 scientists at 11 universities and 5 federal agencies with partial or full support to 7 graduate students. A similar level of collaboration has existed for the 13 years of the programme. The programme and individual projects are periodically renewed through intense competition. Therefore, the future of the Glacier MBR global change research is not necessarily assured.

Current Activities



Climate – A network of remote, automated climate stations has been placed at 16 (mostly) high elevation sites within the Glacier MBR for various lengths of time to monitor trends and to provide data for parameterizing and improving computer models (Fagre et al. 1997). These augment long-term, permanent climate stations at low elevations in the MBR and in adjoining valleys that provide with data from 1896 to the present. Real-time access capabilities have recently been added with radio links to hosted websites (http://www.wrh.noaa.gov/cgi-bin/Missoula/msoobs?site=LOGPS&type=4&src=lcl). Ten climate stations are currently maintained and additional sensors have been added to two snow monitoring sites (SNOTEL) operated by another federal agency. A high-precision Climate Reference Network station (that has triple redundant sensors) and a spectrophotometer recently have been added by other agencies. Historic climate data have been compiled and statistically reviewed from nearby sites. A regional comprehensive climate database is nearing completion. Through collaborators, a climate extrapolation process was developed that provides proxy climate data for mountainous terrain at a 30 m resolution for the past 18 years (Thornton et al. 1997).

Snow – Monthly snow depth and snow water equivalence measurements are made at 110 sites within two 500 km^2 watersheds since 1993 (Fagre et al. 2002). This spatially distributed dataset augments daily data collected at a single site since 1979 and annual data collected from seven sites since 1922. Maximum snowpack accumulation trends have been correlated with sea surface temperature anomalies in the Pacific Ocean that have consistent multi-decadal patterns (Selkowitz et al. 2002). A trend toward later maximum snowpack accumulation has been noted along with earlier snowmelt, potentially creating more intense spring run-off and flooding. Several models of snow distribution in complex topography have been devised and tested and a new study of forest



canopy cover interception of snow has been initiated. Because snow controls so many ecosystem processes in the Glacier MBR, these research activities all aim to translate the impact of past and future climate change on snow spatial and temporal dynamics.

Snow chemistry – Atmospheric deposition has been monitored at a single, low elevation site in the Glacier MBR since 1980 as part of a national network. Orographic uplift brings tremendous snow amounts to the higher elevations of the MBR. Up to nine months of atmospheric deposition is contained in the annual snowpack at high elevations and released during spring melt. Because climate change will affect the timing and amount of snow, a series of research projects have examined the spatial distribution of major ion snow chemistry in the Glacier MBR since 1998 with respect to elevation and the different climatic regimes on either side of the continental divide (Fagre et al. 2000). These studies are nested within a larger scale study of the Rocky Mountains. Two projects recently have evaluated the presence of persistent organic pesticide residues in snow. These residues may be transported from as far as southeast Asia and the atmospheric transport system may be greatly affected by climate change.

Snow Avalanches – Up to 50% of some high elevation watersheds in the Glacier MBR show the impacts of snow avalanches on vegetation. The magnitude and frequency of snow avalanches likely will be affected by climate change-induced shifts in snow deposition. Research projects are testing the effectiveness of remote sensing technologies for detecting and measuring snow avalanche impacts to plant communities, estimating the movement of carbon within the ecosystem (including carbon inputs to aquatic systems), compiling historic avalanche frequency and establishing statistical correlations to precursor meteorological conditions, developing Intelligent Sensor Array approaches for collecting avalanche data, and increasing our understanding of wet-slab avalanches. Some of this information is being collected through an avalanche hazard forecasting program for the alpine section of the road that traverses the MBR over the continental divide. Safety and engineering standards will be influenced by long-term changes in snow avalanche potential. The regional economy is directly affected by changes in road closures due to snow avalanches. Thus, for this MBR, changes in snow avalanche frequency and magnitude are a direct and measurable consequence of climatic change.

Grinnell Glacier

Glaciers – Small, alpine glaciers are rapidly disappearing in the Glacier MBR. Historic data on recession have been captured and analyzed in geographic information systems. Chronosequences have been produced to show that over 72% of the largest glaciers have disappeared during the past century (Key et al. 2002). Geospatial modeling techniques were applied and suggest that all glaciers will be gone by 2030 (Hall and Fagre 2003). Repeat photography, utilizing the 18,000 images from the Glacier MBR archives, has provided visual evidence of glacial recession to diverse audiences. Website and ftp access to these images has proved to be critical in communicating the impacts of climate change on a MBR such as Glacier. Ongoing studies include various remote sensing efforts to monitor changes in ice area, use of ground-penetrating radar to determine volumetric changes, global positioning system surveys to measure ice margins, and re-establishment of stream gages to measure glacier discharge. Consequences of glacier disappearance for downstream fauna also have been assessed.

Alpine studies – A suite of ongoing research projects aims to assess rates of change, and mechanisms controlling change, in high elevation environments near the alpine treeline ecotone (http://www.nrel.colostate.edu/brd_global_change/proj_10_tundra.html). New 1-m resolution remote sensing data sources and spatial analysis techniques are improving plant community classification and characterizing spatial patterns of alpine tundra (Walsh et al. 2003). Cellular automata examine the strength of various positive and negative feedbacks in establishing trees and creating observed spatial patterns (Alftine and Malanson 2004). Climate monitoring and modeling at several spatial scales examine the role of wind, snow (Geddes and Brown submitted), soil depth, microtopography and tree patch modification of microclimates in determining size, shape and distribution of tree "fingers" and islands in the alpine tundra (Butler et al. 2003, Malanson et al. 2000). Soil nutrient distribution, carbon balance modeling (Cairns and Malanson 1998), disturbance by animals and the underlying template of treads and risers resulting from patterned ground are being evaluated as drivers of pace and pattern in tundra invasion by trees. The Post-Little Ice Age history of tree colonization is being tied to instrument records of climatic trends and modeled snow deposition. Paleoclimatic data are being reconstructed from tree-rings to look at climatic pulses for the past 480 years and relate these to the timing and extent of alpine processes (Pederson et al. submitted). Approximately 200 plots, used in an earlier vegetation classification study, are being monitored for long-term changes in species composition and cover in alpine tundra areas throughout the MBR. Responses to climatic change in the alpine zone are being separated from disturbances caused by changing levels of human use (Klasner and Fagre 2002). Repeat photography is being used to visually document changes in the alpine areas and digital aerial photography has documented the expansion in area, and increases in biomass, of the alpine treeline ecotone. These integrated studies will collectively allow us to understand and predict the degree and direction of change in alpine areas of the MBR as continuing global changes are manifested.

GLORIA - The Glacier MBR also has joined the GLORIA (Global Observation and Research in Alpine Areas) worldwide network and has identified suitable summits for long-term monitoring of alpine vegetation change in response to climatic variability (Grabherr et al. 2000). Two summits were established and inventoried during the summer of 2003 and an additional two summits will be completed in 2004.

Forests, fire, and ecosystem modeling – Integrated ecosystem modeling has been a cornerstone of the global change research programme at the Glacier MBR since its inception (Fagre et al. 2004). An evolving system of modeling has successfully accounted for the major processes of biogeochemical cycling, hydrology, forest succession and disturbances such as fire. These models have been validated using a variety of monitoring programs that include extensive fire histories of the MBR, a network of forest study plots (over 200), a decade of hydrologic monitoring, and updated vegetation mapping. The models have been used to examine ecological consequences of different climatic scenarios for up to 500 years into the future (Keane et al. 1996, White et al. 1998). Results, such as an increase in grasslands on the eastern side of the

MBR under a likely future scenario, are mapped and conveyed to managers and the public using a variety of visualization technologies.

Hydrology – As the water towers of the world, mountains provide significant benefits to humans and downstream ecosystems through stream and river discharge. Daily discharge and temperature, and frequent water chemistry and biological inventories, have been monitored in one 500 km^2 watershed since 1993 (Hauer et al. 2002). These data have been used to parameterize and validate ecosystem models, have determined relative contribution of the MBR to regional rivers, and have been related to climatic and snowpack trends so that future climate changes can be translated into changes in regional water supply.

Floodplains – Riverine floodplains are major nodes of biocomplexity and biogeochemical cycling in mountains but relatively few intact floodplains exist for study. Past and future climatic change will directly impact floodplain dynamics through hydrologic and landscape changes interacting in complex ways. A major ongoing effort with other collaborators is a multidisciplinary investigation of one floodplain that will result in a coupled terrestrial-aquatic model with which we can assess relative impacts of climate change (http://www.umt.edu/flbs/Research/Biocomplexity.htm).

Regional Scaling – Recognizing that the Glacier MBR is not a discrete ecosystem and that the surrounding landscapes provide critical inputs, we have expanded the spatial scale of the research programme several times. Regional snow and climatic datasets have been analyzed for the Crown of the Continent Ecosystem described earlier that encompasses other relatively unaltered mountain landscapes for approximately 400 km along the spine of the Rocky Mountains in Canada and the U.S. Ecosystem modeling and monitoring, including three years of intensive field studies, have been extended along a transect from the Glacier MBR to the Pacific Ocean and includes two other national parks, Olympic and North Cascades (Fagre and Peterson 2002). This 800 km transect spans three distinct mountain ranges and a variety of land uses and modeling studies will be used to answer questions concerning the interaction of climatic change and growing human populations in mountain regions. The Western Mountain Initiative has been conceptually described and proposed to link existing mountain research programmes across all the mountain areas of the western U.S. and find common, and different, responses of mountain ecosystems to climate change (http://www.cfr.washington.edu/research.fme/wmi/). These mountain programmes are geographically well distributed across the different mountain ranges and include both arid and temperate rainforest extremes in climate and vegetation communities. Finally, the Glacier MBR has joined GLORIA (above), is in the Biosphere Reserve network, and will participate in global scale mountain research through the Mountain Research Initiative.

Availability of climate, vegetation, hydrological, economic and demographic data for the Glacier Mountain Biosphere Reserve

Climate data were first systematically collected in 1896 in the nearby town of Kalispell in the Flathead Valley. Since 1896, additional weather stations were established around the perimeter of the Glacier MBR as part of the U.S. National Weather Service. The first climate data collected within the Glacier MBR occurred in 1913 but reliable data date back to 1932. A growing network of climate data stations (described earlier) has provided for more complete spatial coverage and additional sensors and instruments have been added. Climatic data products (e.g. DAYMET) provide geospatial extrapolation of climate variables and several web-based data clearinghouses make access to climate data easier than ever before.

A land cover map for the Glacier MBR was first produced in 1898 as part of a forest resources inventory. Improved mapping, a 1936 vegetation survey, analysis of the first aerial photos in 1945, establishment of an herbarium and museum collections, creation of a naturalist division in the Glacier MBR, programs to control infectious plant diseases (e.g. blister rust), independent research projects, and a comprehensive baseline map in 1968 all contributed to the vegetation database. A number of botanists and plant ecologists have devoted much of their careers to better understanding the biodiversity and ecology of Glacier MBR vegetation and a comprehensive floristic summary was recently published as a book (Lescia 2002). After a four-year effort, a detailed vegetation classification and digital map is nearing completion for the entire park using combinations of aerial photography, remote sensing, and extensive ground truthing. A full-time plant ecologist with seasonal staff and a native plant nursery manager and staff have been resident for over 10 years. Numerous university collaborators continue studying fire history, grasslands, alpine vegetation dynamics and other topics.

Hydrological data include the U.S. Geological Survey gaging stations on major rivers, that are part of a national network of many thousands of stations, from which real-time data can be accessed from the web. Within the Glacier MBR, these are augmented by automated gaging stations that are located on streams within two watersheds to provide more finely scaled data. These stations are downloaded several times per year and a decade-long database of daily discharge has now been accumulated. Another recent addition is the Hydrologic Benchmark Network site with periodic water quality sampling and additional instrumentation such as for measuring conductivity. Several surveys have been made of lakes for detecting changes in water quality regionally and a five-year baseline for water quality was established for four backcountry lakes in the MBR. Finally, the intensive floodplain study described earlier has hydrologic data for both surface and ground waters for at least ten years.

Economic and demographic data pertaining to the Glacier MBR have been recorded since the area was first proposed as a park and are kept in a museum collection that contains over 361,000 cataloged archival items and a park library with over 15,000 titles. Several administrative histories and a number of books have been published that describe, among other topics, the economics of the tourism industry from 1910 to the present. Most of the privately held properties within the MBR have been purchased by the National Park Service and added to the public land base. Virtually no people are permanent full-time residents of the MBR but several small communities exist just outside the MBR border. The largest of these is 300 people but larger communities of 3,000 people are 24 km away. Annual reports are filed by the MBR superintendent that describe in detail the budgets, contracting activities, and financial impacts on local businesses. The county government maintains demographic and economic information for the areas adjoining the MBR for the past 100 years and there have been several recent analyses of population and economic growth to guide community decision-making. A recent summary entitled “Gateway to Glacier” (National Parks Conservation Association 2003) specifically examines the economic impact of the MBR on the regional economy and the increasing interdependence between them.

Summary

The Glacier MBR is an excellent place to assess the impacts of global changes on mountain ecosystems. Because of its size, relatively pristine condition, and the natural landscapes around it, many of the documented changes can be attributed to climatic change rather than local disturbances. The Glacier MBR has a diversity of biological communities, a variety of physical indicators of climatic change (e.g. glaciers), strong environmental gradients, two distinct climatic regimes, and is positioned in North America to provide opportunities to scale up research studies from local to continental scales. The Glacier MBR has a relatively robust science infrastructure, a history of studies to draw from, and access to a rapidly increasing wealth of data that are becoming better organized. Management issues that likely will become more important to the Glacier MBR in coming years include developing responses to extreme climate swings (e.g. drought and forest fires followed by heavy snowpacks and floods), shifting expectations of the MBR by the public and politicians, and rapidly increasing regional landscape fragmentation that may undermine ecosystem resilience in the face of continuing global change.

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