

GLOBAL CHANGE RESEARCH IN MOUNTAIN BIOSPHERE RESERVES

Proceedings of the International Launching Workshop
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10–13 November 2003



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12. USA: *Glacier National Park, Biosphere Reserve and GLORIA Site*

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INTRODUCTION

The National Park Service of the United States has 388 designated protected areas and parks that include historic and cultural sites as well as ‘natural resource’ parks set aside for their unique and outstanding natural features. Early efforts to create parks were focused on areas of beauty or unusual features but later efforts increasingly aimed to protect biodiversity and intact ecosystems. Protected areas in the National Park Service are found in nearly all the fifty states from Florida to Alaska, with examples of preserved natural environments ranging from coral reefs to the icy summit of Mt. McKinley in Alaska, at 6,187 m. 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, six years before a national park service was created to oversee the growing number of parks that the US Congress was establishing. Waterton National Park was created by Canada immediately north of the US–Canada border during the same period. In 1932, a joint lobbying effort by private citizens and groups convinced both the United States and Canada to establish the world’s first trans-boundary park to explicitly underscore and symbolize the neighbourly relationship between these two countries. This became the world’s first ‘peace’ park and was named Waterton–Glacier International Peace Park. The combined park is managed collaboratively on many issues but each national park is separately funded and operates under different national statutes and laws. It was, however, jointly named a Biosphere Reserve in 1976 and a World Heritage Site in 1995. There have been recent efforts to significantly increase the size of Waterton National Park by adding publicly owned forests on the western side of the continental divide in British Columbia, Canada. For the purposes of this chapter, I will emphasize the US 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 US–Canada border. It is a 4,082 km² mountain wilderness that straddles the continental divide of North America and contains 175 named summits of up to 3,150 m elevation. 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. Approximately 60 per cent of the Glacier MBR is covered in conifer and deciduous forests. It is managed as a wilderness area, and only the Going-to-the-Sun Road traverses the park over the continental divide. Short roads and nearly 1,000 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. The Glacier MBR is home to 272 bird species, 23 fish species and 63 mammal species that include the endangered or threatened grizzly bear, grey wolf and lynx.

The Glacier MBR is bordered by US Forest Service lands that include large, designated wilderness areas to the south and west. To the east is the Blackfoot Indian Nation reservation that shares Chief Mountain, a sacred site to many Plains Indian tribes. To the north are Waterton National Park in Alberta, Canada, and Crown Forest Lands in British Columbia. Relatively small towns (with populations of around 3,000–12,000) 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 BIOSPHERE

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 displays moderate temperature variation. The eastern side is dominated by a drier, continental climate with frequent strong winds and more extreme temperatures. This is reflected in the vegetation types and plant communities found on the either side of the divide.

The lowest elevation in Glacier MBR is 985 m 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*). Drier sites, or areas that have been historically burned, are dominated by lodgepole pine (*Pinus contorta* var. *latifolia*), a fire-adapted species common throughout the Rocky Mountain western states. Drier forests are more widespread on the eastern side. Deciduous species, such as cottonwood trees (*Populus spp.*), dominate riparian areas and various shrubs are common on slopes where there is frequent disturbance such as snow avalanches. Deciduous trees, such as aspen (*Populus tremuloides*), are also common on the eastern border of the park where they are interspersed with grasslands. Most of the grasslands are found 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, which are important winter ranges for bighorn sheep and other ungulates.

At mid-elevations (2,000 m), the conifer forests are dominated by subalpine fir (*Abies lasiocarpa*), and where the canopy begins to thin 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 an elevation of approximately 2,500 m.

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 per cent of the vegetation communities in this MBR.

For the land surface of this MBR, 34 per cent is lowland, moist, coniferous forest; 16.3 per cent is dry, coniferous forest; 6.6 per cent is deciduous trees and shrubs, 5 per cent is moist, herbaceous vegetation, and 7.1 per cent is dry, herbaceous vegetation. Barren rock, snow and ice cover the remaining 31 per cent of the terrestrial surface.

CHARACTERIZATION OF THE SITE ABOVE THE VEGETATION LINE

The Glacier MBR is a snow-dominated environment with approximately 70 per cent of the annual precipitation falling as snow. Snow covers all elevations of the MBR for four or five months of each year and the highest elevations (2,800–3,000 m) above the vegetation line are snow-free for only two months of the year. According to a remote sensing survey, the area above the vegetation line has approximately eighty perennial snowfields and small alpine glaciers. There are an estimated twenty-seven glaciers remaining. 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 composed of steep cliffs, ridges and headwalls that surround the summits.

DEMOGRAPHIC AND ECONOMIC CHARACTERIZATION OF THE BIOSPHERE RESERVE (INCLUDING LAND USES)

The cultural history of the MBR dates back at least 10,000 years and includes the prehistoric and historic use of the land by Native Americans and their contemporary descendants. The first Europeans to explore the area were fur trappers in the 1730s. By the 1880s, a few transitory mining camps and hunting expeditions were begun but economic development did not start until 1892 when the arrival of the Great Northern Railway spurred homesteaders to claim land within the future park boundaries. The railway company was instrumental to the development of the tourist industry for the fledgling park and a number of hotels and backcountry chalets were constructed. The National Park Service purchased most of the private homes after the park was created but approximately thirty 'in holdings' still exist. These homes are used as summer homes as most businesses and services are closed during the winter months. Tourism is the only economic activity within the MBR and only a few National Park employees reside permanently within the park. The MBR maintains several visitor centres, numerous campgrounds, roads and trails, it also provides law enforcement and search and rescue services. Licensed concessionaires provide hotel lodgings, park guides and other facilities within the MBR boundaries. There are 1.7 million visitors annually and numerous hotels, restaurants, shops and services have been established outside the MBR to cater to their needs, primarily between the months of June and September. Winter use has increased over the last decade but remains less than 20 per cent of the total number of visits yearly. 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 per cent increase in the population of the nearby valley during the past ten years as retirees and others move into the area. Most of these newcomers are encouraged 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.

ONGOING GLOBAL CHANGE PROGRAMMES AND RESEARCH PROJECTS

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 twentieth century. In 1967, a full-time scientist was hired as a member of the park's staff and a research division eventually formed as more scientists joined. In 1990 the Glacier MBR successfully competed to host a global change research programme sponsored by the National Park Service as part of the US Global Change Research Program newly created by Congress. A global change research coordinator was hired and over the past thirteen years a diversity of research projects have been initiated with numerous collaborators from other federal agencies, universities, non-government organizations, and from other countries. After several reorganizations, global change research at the Glacier MBR is now conducted through the US Geological Survey, the primary research arm of the Department of the Interior. Funding levels range from \$235,000–\$595,000 annually and have been greatly leveraged through partnerships, graduate student programmes, and the use of interns to increase the research intensity on addressing how mountain ecosystems respond to climate change. Currently, the Glacier MBR global change programme employs an ecologist, two physical scientists and a biological technician working on site on a full-time basis. Active partnerships currently exist with nineteen scientists at eleven universities and five federal agencies with partial or full support to seven graduate students. A similar level of collaboration has existed during the thirteen years of the programme. The programme and individual projects are periodically renewed through intense competition so the future of the Glacier MBR global change research is not assured.

CURRENT ACTIVITIES

Climate

A network of remote, automated climate stations has been placed at sixteen (mostly) high-elevation sites within the Glacier MBR for various periods to monitor trends and to provide data for parameterizing purposes and for improving computer models. These augment long-term, permanent climate stations, with data going back to 1896, at low elevations in the MBR and in the adjoining valleys. Real-time access capabilities are a recent addition with radio links to hosted websites. Nine 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 (with triple redundant

sensors) and a spectrophotometer have recently been added by other agencies. Historic climate data have been compiled and statistically reviewed from nearby sites and a comprehensive regional climate database is nearing completion. Through collaborators, a climate extrapolation process has been developed that provides proxy climate data for mountainous terrain at a 30 m resolution for the past eighteen years.

Snow

Since 1993, monthly snow depth and snow water equivalence measurements have been taken at 110 sites within two 500 km² watersheds. 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. 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 has been initiated on forest canopy cover interception of snow. As snow controls a great number of ecosystem processes in Glacier MBR, these research activities all aim to translate the impact of past and future climate change on the spatial and temporal dynamics of snow.

Snow Chemistry

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

Snow Avalanches

Up to 50 per cent of some high elevation watersheds in the Glacier MBR show the impacts of snow avalanches on vegetation. The magnitude and frequency of likely avalanches will be affected by shifts in snow deposition induced by climate change. Research projects are testing the effectiveness of remote sensing technologies for detecting and measuring snow avalanche impacts on 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 programme 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.

Glaciers

Small alpine glaciers are rapidly disappearing in the Glacier MBR. Historic data on recession have been captured and analysed in geographic information systems, and chronosequences have been produced that show over 72 per cent of the largest glaciers have disappeared over the past century. Geospatial modeling techniques were applied that suggest that all glaciers will disappear by 2030. 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 and the re-establishment of stream gages to measure glacier discharge. Consequences of glacier disappearance for downstream fauna have also been assessed.

Alpine Studies

A suite of ongoing research projects aims to assess rates of change, and those mechanisms controlling change, in high elevation environments near the alpine treeline ecotone. New remote sensing data sources at 1-m resolution and spatial analysis techniques are improving plant community classification as well as characterizing spatial patterns of tree invasion into alpine tundra. Cellular automata examine the strength of various positive and negative feedback in establishing trees and creating observed spatial patterns. Climate monitoring and modeling at several spatial scales examine the role of wind, snow, soil depth, microtopography and tree patch modification of microclimates in determining size, shape and distribution of tree 'fingers' and islands in the alpine tundra. Soil nutrient distribution, carbon balance modeling, 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 in order to look at climatic pulses over the past 480 years, relating these to the timing and extent of alpine processes. 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. 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 has joined the GLORIA (Global Observation and Research in Alpine Areas) worldwide network that identifies suitable summits for long-term monitoring of alpine vegetation change in response to climatic variability. Two summits were established and inventoried during the summer of 2003 and an additional two summits will complete the study in 2004.

Forests, Fire, and Ecosystem Modeling

Since its inception, integrated ecosystem modeling has been a cornerstone of the global change research programme at Glacier MBR. 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 programmes that include: extensive fire histories of the MBR, a network of over 200 forest study plots, a decade of hydrologic monitoring, and updated vegetation mapping. The models have been used to examine and project the ecological consequences of different climatic scenarios for a period of up to 500 years into the future. 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. Since 1993, daily discharge and temperature and frequent water chemistry and biological inventories have been monitored at one 500 km² watershed. This data has been used to parameterize and validate ecosystem models, and determine the relative contribution of the MBR to regional rivers; it has 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 on floodplain dynamics through hydrologic and landscape changes that interact 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.

Regional Scaling

Recognizing that 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 analysed for the Crown of the Continent Ecosystem, described earlier, that encompasses other relatively unaltered mountain landscapes along approximately 400 km of the spine of the Rocky Mountains in Canada. The US 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. This 800 km transect spans three distinct mountain ranges and a variety of land uses, and modeling studies will be used to respond to 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 United States, and to find common, and different, responses of mountain ecosystems to climate change. 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, Glacier MBR is part of the GLORIA network (as described above), as well as the World Network of Biosphere Reserves (WNBR), it will also participate in the UNESCO–MRI (Mountain Research Initiative) Global Change Research in Mountain Biosphere Reserves project.

AVAILABILITY OF CLIMATE, VEGETATION, HYDROLOGICAL, ECONOMIC AND DEMOGRAPHIC DATA

Climate data was first systematically collected in 1896 in the nearby town of Kalispell, Flathead Valley. Since 1896, additional weather stations have been established around the perimeter of Glacier MBR as part of the US National Weather Service. The first climate data within the MBR was collected in 1913, but more reliable data has been acquired since 1932. A growing network of climate data stations (as previously described) has provided for more complete spatial coverage, and additional sensors and instruments have been added. Climatic data products (for instance, DAYMET) provide geospatial extrapolation of climate variables, and several web-based data clearinghouses ensure that access to climate data is easier than ever before.

A land cover map for Glacier MBR was first produced in 1898 as part of a forest resources inventory. Other contributions to the vegetation database include: improved mapping, a 1936 vegetation survey, analysis of the first aerial photos in 1945, establishment of a herbarium and museum collections, creation of a naturalist division in Glacier MBR, programmes to control infectious plant diseases (for example, blister rust), independent research projects, and a comprehensive baseline map in 1968. A number of botanists and plant ecologists have devoted

much of their careers to improved understanding of the biodiversity and ecology of vegetation in Glacier MBR, and a comprehensive floristic summary was recently published. Following 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, seasonal staff and a native plant nursery manager have been resident for over ten years. Numerous university collaborators continue to study fire history, grasslands, alpine vegetation dynamics and other topics.

Hydrological data include the US Geological Survey gauging stations on major rivers, which are part of a national network of many thousands of stations, from which real-time data can be accessed from the web. In Glacier MBR, they have been augmented by automated gauging stations located on streams in two watersheds so as to provide more finely scaled data. These stations are downloaded several times per year and a decade-long database of the daily discharge has now been collected. Another recent addition is the Hydrologic Benchmark Network site with periodic water quality sampling and additional instrumentation to measure conductivity. Several surveys have been made of lakes to detect regional changes in water quality, 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 hydrological data for both surface and ground waters covering at least ten years.

Economic and demographic data has been recorded in Glacier MBR ever since the area was first proposed as a park. The data is kept in a museum collection that contains over 361,000 catalogued 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 day. Most of the privately held properties within the MBR have been purchased by the National Park Service and have been included in the public land base. There are virtually no permanent residents in the MBR but several small communities live just beyond its border; the largest of these numbers 300 people but larger communities of 3,000 inhabitants are found 24 km away. Annual reports, filed by the MBR superintendent, describe detailed budgets, contracting activities and financial impacts on local businesses. The county government has maintained 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* 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. Its size, relatively pristine condition, and the natural landscapes around it suggest that many of the documented changes can be attributed to climatic change rather than local disturbances. Glacier MBR has a diversity of biological communities, a variety of physical indicators of climatic change (for instance, glaciers), strong environmental gradients and two distinct climatic regimes. Furthermore, its position in North America provides 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 increasingly organized. Management issues which are likely to become more important to Glacier MBR in coming years include developing responses to extreme climate fluctuations (for example, 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, which may undermine ecosystem resilience in the face of continuing global change.