Science Summary

Glacier National Park, Montana

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Research and Resources Management Projects
1997-1999

Message from the Superintendent

Language contained in the National Park Service Organic Act of 1916 embraces science as a legitimate use of the national parks. Management policies that have evolved since the creation of the National Park Service have consistently reaffirmed this precept. The legislation creating many National Park Service units specifically identifies scientific research as an appropriate use of park resources. Glacier National Park is a world-class resource and recently was designated a World Heritage Site. The park is also an International Biosphere Reserve and has the distinction of being the world's first International Peace Park through its sharing of a common boundary with Waterton Lakes National Park in Alberta, Canada.

Glacier National Park has a proud legacy of research and scientific accomplishment dating back to the pre-World War II era. Until the mid-1960's most research in the park was carried out by independent and academic scientists. The first park scientist was appointed to the park staff in 1967. His task was to organize a research program and serve as an advocate for science in the park. Many changes and organizational realignments have occurred during the past three decades that have affected the conduct of research in Glacier National Park and throughout the National Park Service.

Results of recent research projects and resources management programs are summarized in this report. Scientific inquiry in the park encompasses a wide range of subjects and technical disciplines. Science plays an important role in guiding sound management of the park's natural and cultural features.

I strongly encourage the participation of academic and independent researchers in the park science program. The park offers an ideal environment for scientific studies, especially those that involve natural resources and ecological processes that are becoming increasingly hard to find intact elsewhere. Glacier National Park affords an ideal control environment for scientists to examine unique biotas and natural processes in an area of the northern Rocky Mountains that has been minimally disturbed.

While independent researchers have always been welcome in Glacier National Park, their contributions assume even greater importance today in light of recent changes that have affected agency science throughout the Department of Interior. I would like to extend a personal welcome to prospective research partners and collaborators who have an interest in conducting scientific studies in the park. Information describing how to go about this is provided on the Glacier National Park web site. Interested persons should point their web browser to: http://www.glacier@nps.gov

I hope you will find this Summary useful and informative.

Pete Hart
Acting Superintendent
Glacier National Park

Introduction

The summaries presented in this report describe research investigations and resources management activities conducted in Glacier National Park during the period 1997-1999. The summations are organized topically according to the scientific discipline that best describes the work. Information for the summaries was derived mainly from Investigators Annual Reports for this period. These are mandatory end-of-year reports required from all Principal Investigators and National Park Service project leaders engaged in science and resources management activities in the park.

Since many of these reports involve multi-year projects, findings from Investigators Annual Reports posted over a span of several years were consolidated into a single narrative summary. The synthesis and reporting of technical information for multi-year projects, some involving changes in team members, inevitably results in some loss of clarity. For example, interim conclusions reported in the initial Annual Report may later be contradicted or modified by new information. Study objectives might also change or become more directed as a project enters its second or third year. The editors attempted to make the most accurate interpretation possible based on the data and information contained in the Investigators Annual Reports.

Persons wishing to obtain a more detailed account of individual projects or wanting to review the original data are encouraged to visit the newly created National Park Service Science Web Site to view the source documents from which this summary was derived. Annual Reports for 2000 were posted too late to be included in this summary, but they may be examined on the national web site for the most up-to-date information about specific projects. Current year (2001) Investigators Annual Reports will be available in the late spring of 2002. The national web site also contains Annual Reports for other National Park Service units. Upon accessing the site's Homepage viewers are prompted to select the name of the park and the reporting year from dialog boxes. The web site address is: http://science.nature.nps.gov/research.

More detailed information about specific studies may also be available as scientific reprints. The Investigators Annual Report remains, however, the best source of general information about research and resources management activities in the parks. Since this information is now available to all persons having Internet access it is unclear whether documents such as this will be printed in the future. Approximately 100 printed copies of the Science Summary are available for limited distribution.

Acknowledgments

Several people assisted in the preparation of this Science Summary. Larry Peterson reviewed and compiled the data from Investigators' Annual Reports (IAR's) posted by Principal Investigators for 1997 and 1998. These reports constitute the principal source of information for the summaries presented here. Larry's participation was supported by a two-year grant from the Glacier Natural History Association (GNHA) whose support was essential and very much appreciated. Ms. LeAnn Simpson, Executive Director of the GNHA, is acknowledged for her role in making this support available. Also, we would like to thank Larry Frederick, former Chief of Interpretation at Glacier National Park (GNP), for his coordination of GNHA support for the task. Dave Eaker from the Public Affairs Office in Glacier National Park (GNP) reviewed the IAR's for 1999 and incorporated findings for that year into summaries for multi-year projects carried over from previous years. Amy Vanderbilt, Public Information Officer at GNP, is acknowledged for making Dave Eaker from her staff available to assist with this work. Dr. Leo Marnell, Senior Scientist at GNP, performed the final editing, updating, and proof reading for the Science Summary.

Contents

Field of Inquiry: **Botany**
Investigators: **Terry McLendon, Shepherd Miller and Tara Williams**

Project Title: **Assessment of Leafy Spurge (*Euphorbia esula*) Control**

Objectives: To compare two methods for controlling Leafy Spurge (*Euphorbia esula*) in a fescue grasssland prairie in Big Prairie, North Fork drainage, Glacier National Park. Two methods were employed: **1)** plants were sprayed with the herbicide Tordon, and **2)** specialized bio-control beetles (*Apthona nigriscutis*) were released near the plants. Control plots with no treatment were also monitored.

Leafy spurge is an extremely prolific noxious weed that poses serious ecological threats to native plant communities. One of these communities is a 30-40 acre fescue grassland prairie in Big Prairie in the North Fork drainage of Glacier National Park. Spurge continues to spread into disturbed sites along roads and along the North Fork floodplain at this location.

Summary: Data were collected in 1997 and 1998 using the point-intercept method. Six 50m x 20 m plots were analyzed; two control plots, two plots treated with the herbicide Tordon, and two plots where bio-control beetles were released. Ten 20 m transects were randomly located in each plot and spurge counted at 10 cm intervals. The data are currently being analyzed.

Field of Inquiry: **Botany**
Investigators: **Raymond Shearer and Jennifer Asebrook**

Project Title: **Conifer Germination along the Lake McDonald Section of the Going-to-the-Sun Road, Glacier National Park**

Objective: To determine the types and relative survival of conifers that germinate along a disturbed roadcut.

Summary: This is a continuation of a conifer germination study that was initiated in 1992 in conjunction with a seedfall study started 5-years earlier (1987–1995). Ten sites comprising four 0.25 m² replicate plots were established in five representative land types along the roadcut. Plots were visited each month from May to October for 7-years to count the conifers that germinated in each of the 40 plots. These data are being analyzed with the conifer seedfall data to compare seedfall with the number of seedlings established (seed to seedling ratio). This ongoing study is a cooperative effort between Glacier National Park and the U.S. Forest Service. Field data collections are continuing and results will be published upon completion of the work.

Field of Inquiry: **Botany**
Investigator: **Peter Lesica**

Project Title: Flora of Glacier National Park

Objectives: The goals of the study are to: **1)** create a baseline inventory of vascular plants in Glacier National Park, **2)** verify and annotate vascular plant specimens in the park herbarium, **3)** complete the park plant collection, **4)** document the occurrence of exotic plants, and **5)** produce a floristic manual for the park.

Summary: I have identified more than 100 plant species new to Glacier National Park. Specimens were collected in 1998-99 for five of these species: *Botrychium crenulatum*, *Sambucus cerulea*, *Rorippa truncata*, *Carex simulat* and *Erigeron lackschewitzii*. Thirty populations of rare plants were located and approximately 450 specimens were collected for the park herbarium. Four populations of "Species of Concern" (National Heritage List) were located. I also located populations of *Lycopodium dendroideum*, *Vaccinium myrtilloides* and *Botrychium paradoxum*; all Species of Concern appearing on the Montana Natural Heritage Program list. I discovered populations of *Conimitella williamsii*, *Arenaria stricta* and *Achillea nobilis*; all first records for the park. A floristic manual for the park is nearing completion.

Field of Inquiry: **Botany/Plant Restoration**
Investigators: **Jennifer M. Asebrook, Shannon F. Kimball, Bonnie E. Lamb, and Beth S. Brenneman**

Project Title: Revegetation Monitoring in Glacier National Park

This investigation involves multiple objectives concerned with mitigation for reconstruction of portions of the Going-To-The-Sun Road in Glacier National Park. The Federal Highway Administration has designated the project as number 303. Research objectives are as follows:

Objective for 303 B: 1): to track the establishment and growth of native seeded species on road shoulders**, 2)** to determine the optimum species selection and seeding rates along road shoulders, and **3)** to determine if the objective has been met for establishment of a turf shoulder that is "durable, maintainable, safe, and able to stand up to heavy automobile and visitor foot traffic".

Objective for 303 C: 1) to determine the mean canopy cover of native and exotic plant species on all land types, **2)** to track the success of seeded and planted material through estimates of canopy cover and density, and **3)** to compare the efficiency and accuracy of the point-intercept method with the ocular-cover estimate method.

Objective for 303 D: 1) to determine the mean canopy cover of native and exotic plant species on all land types, **2)** to determine the density of seeded species on all landtypes; and **3)** to assess the survival and growth of planted trees and shrubs on all landtypes.

Objective for 303 E: 1) to assess the effect of Biosol, an organic mycelium-based fertilizer (6-1-3 + 1% Mg), on subalpine revegetation; and **2)** to determine the survival and canopy cover of planted and seeded material in certain planting units.

Summary for 303 B: Species composition was dominated by exotic species on the road shoulder plots 7 years after revegetation. Exotic grasses including *Phleum pratense*, *Poa pratensis*, and *Poa compressa* were especially prominent. Native grass cover has declined due primarily to decreases of *Bromus carinatus* and *Elymus glaucus*, both short-lived nurse grasses. Given the presence of exotic plants prior to revegetation and continuous disturbances to road shoulders, this condition is not expected to change appreciably. Replanting has, however, allowed some low-growing species of native shrubs and forbs to persist; these include *Linnaea borealis*, *Arctostaphylos uva-ursi*, *Aster laevis*, *Fragaria virginiana*, *Fragaria vesca*, *Solidago canadensis*, and *Achillea millefolium*. Some of the more persistent exotic forbs tend to thrive on road shoulders. These include *Medicago lupulina*, *Melilotus officinale*, *Chrysanthemum leucanthemum*, *Plantago major, Taraxacum officinale* and *Trifolium pratense*. Control of exotic forbs on road shoulders will likely require continued herbicide application. Future field tests should be conducted to assess a better seeding strategy for the success of native grasses.

Summary for 303 C: Six years after revegetation activities were initiated plant restoration objectives are being only partially met. Except for steep slopes, exotic grasses dominated on most plots due to abundant cover of *Phleum pratense* and *Poa pratensis*. Exotic grass and forb cover remains low on steep plots. Native grass cover has diminished overall due primarily to decreases of *Bromus carinatus* and *Elymus glaucus*, both short-lived nurse grasses. Other long-lived native grasses such as *Poa palustris*, *Elymus spicatus*, *Elymus trachycaulus* (ssp. *trachycaulus* and ssp. *subsecundus*) and *Carex rossii* have persisted, especially on steep slopes where native grasses have the highest percent of cover of any lifeform. More persistent exotic species such as *Cirsium arvense*, *Medicago lupulina*, *Melilotus officinale*, *Trifolium* spp., *Taraxacum officinale*, *Verbascum thapsus* and *Prunella vulgaris* are generally becoming more widespread. These findings indicate the need for seeding and planting to maintain a nominal native component on disturbed sites including roadside plant communities. Ocular-estimation was found to be preferable to the point-intercept method for monitoring plant communities on disturbed sites.

Summary for 303 D: Five years after replanting, all plots are generally meeting restoration objectives by having higher native cover than exotic cover. While tree cover remains low and native grasses declined in 1999, native grass cover remains the highest of any lifeform and both shrub and native forb cover are increasing. High native grass cover is due to the persistence or increase of *Elymus glaucus*, *Elymus spicatus*, *Carex* spp., *Festuca idahoensis*, *Stipa nelsonii*, and *Elymus trachycaulus* (ssp. *subsecundus* and ssp. *trachycaulus*). Increasing shrub and native forb cover is due to increases of *Symphoricarpos albus*, *Amelanchier alnifolia*, *Achillea millefolium*, *Erigeron speciosus*, *Penstemon confertus*, *Lathyrus ochroleucus*, *Potentilla gracilis*, *Aster laevis*, and *Solidago canadensis*. Exotic grass and forb cover remain relatively low on this project, particularly on steep slopes, although noxious weed management should continue. While density of most seeded species has increased since seed was applied, density estimates have leveled off at 5-years after replanting.

Planted trees and shrubs continue to have increased mortality. Woody material declined from 59% in 1997 to 51% in 1999. While certain species had higher survival rates than others, particularly *Cornus sericea, Amelanchier alnifolia, and Prunus virginiana,* most species are showing a decline in survival. Surviving trees and shrubs, however, are showing consistent signs of growth 5-years after planting. In addition, woody material planted in the spring tended to have higher survival than the same species planted in the fall. Survival also tended to be higher on steep slopes where there was less competition from other vegetation. These results are similar to another study done on the nearby Coram Experimental Forest.

Summary for 303 E: With 3-years of data, it appears that Biosol application may not have long-term, positive effects on seeded grasses or forbs. Within 2-years after re-seeding, there was higher cover of seeded grasses, particularly *Poa alpina* and *Phleum alpinum*, on Biosol plots. By year three, however, the rate of increase became greater on control plots with differences between the treatments no longer statistically significant. Control plots have always had a higher cover of seeded forbs than Biosol plots. Survival rates of planted material were similar in both control and Biosol plots.

Survival of planted material on this project is exceptionally high, with 88% planted grass survival and 77% planted shrub and forb survival. These are particularly promising results given the short growing season and the harsh environment at the Continental Divide. While canopy cover of seeded material remains fairly low, cover of seeded material did significantly increase in 1999. At present, planted material is providing most of the canopy cover on the project, illustrating the benefits of planting containerized material as part of a revegetation strategy. The combination of seeding and planting resulted in twice the overall grass cover compared to seed alone. Planted forb cover is currently three times as high as seeded forb cover.

Field of Inquiry: **Botany/Plant Restoration**
Investigators: **Dale Wick and Associates**

Project Title: **Native Plant Restoration in Glacier National Park**

Objective: To collect seed and plant material for propagation of site–specific native plants to revegetate disturbed sites throughout Glacier National Park.

Summary: Reconstruction of several segments of the historic Going-to-the-Sun Road and visitor-use activities throughout the park have caused significant site disturbances. Nursery operations involve the collection and propagation of native plant materials (seed and cuttings) to mitigate damage to native vegetation caused by these actvities. The Nursery maintains a diverse base-stock of native plants for each valley or geographic area of the park. The goal is to maintain the genetic integrity and biodiversity of Glacier Park's native plant communities. The facility also provides a place for experimentation and research aimed at developing propagation techniques for a diverse assemblage of native plant species. It is also used as a facility to study of

the phenology of a variety of flora, and for educational activities for visitors, volunteers, school students and staff.

With assistance from many volunteers, the Revegetation Crew and IPM/Hazard Tree crew, the nursery staff successfully produces more than 25,000 plants annually through vegetation propagation and seeding. Approximately 85 native plant species have been propagated from plants or seeds collected from the six ranger subdistricts of Glacier National Park. Nearly 7 kg of cleaned seeds have been obtained during 70 field collections throughout the park. Some of this seed is distributed to private nurseries that grow materials for Glacier Park under contract. Seed is also sent to the Natural Resources Conservation Service, Bridger Plant Materials Center.

Field of Inquiry: **Botany/Plant Restoration**
Investigators: **Dale Wick and Associates**

Project Title: **Cooperative Greenhouse Operation and Environmental Education School District, Glacier National Park**

Objective: To involve students from School District #6 (Columbia Falls, MT) in native plant restoration activities in Glacier National Park.

Summary: In 1991 a cooperative greenhouse was constructed at the Columbia Falls High School, partially funded through a grant obtained by Glacier National Park. Each year local and regional classroom groups visit the park to collect seeds. The seed is cultivated during winters in the greenhouse. Students work with park staff the following spring to revegetate impacted campsites and other disturbed areas in selected campgrounds. This experience provides the students with a sense of ownership and helps them understand the importance of good land stewardship. The program also introduces students to possible career opportunities in resources management, horticulture, biology and related fields.

More than 300 students typically participate in this program each year. Members of the greenhouse staff visit classrooms during the winter for lecture and slide presentations that explain the native plant restoration program in Glacier National Park. Students have assisted in the production of tens of thousands of plants and have participated in dozens of restoration projects throughout the park. Fall seed collection has been curtailed or postponed during recent years due to budget cutbacks at the High School making it difficult for classes to secure bus transportation to the park.

Field of Inquiry: **Botany/Plant Restoration**
Investigators: **Joyce Lapp and Dawn La Fleur**

Project Title: **Native Plant Restoration in Glacier National Park**

Objective: To conduct on-site revegetation of disturbed sites throughout Glacier National Park utilizing site-specific native plant materials.

Summary: Construction and visitor-use activities create disturbances to soils and plant communities at many locations throughout the park. The revegetation program attempts to preserve the genetic integrity of native floral by using indigenous plant materials collected at or near the disturbed site.This work also includes soil stabilization, erosion control, reduction of exotic plant populations and the reintroduction of the native plant materials in such a manner as to successfully blend into the surrounding undisturbed communities. Revegetation crews have successfully rehabilitated dozens of disturbed sites throughout the park with assistance from the park Maintenance Division, subdistrict personnel, nursery crew, IPM/Hazard Tree crew, and AmeriCorp volunteers. Revegetation crews have upgraded backcountry camps and frontcountry campground sites on both the west and east sides of the park. Disturbed lands are treated with restoration techniques including soil scarification, seeding and planting with native species, mulching, fencing, and signing. Tens of thousands of containerized and bare-root plants have been successfully placed at disturbed sites throughout the park. Cooperative efforts with local School District #6 involve students in the native plant propagation program and foster a greater awareness of land restoration issues.

Field of Inquiry: **Botany/Plant Restoration**
Investigator: **Tara Williams**

Project Title: **Restoring Whitebark and Limber Pine Communities**

Objectives: The goal of this program is to initiate a restoration program for whitebark and limber pine in Glacier National Park. Objectives are to: **1)** develop a conservation strategy and action plan in cooperation with park neighbors**, 2)** collect seed to ensure that native stocks are represented in genetic experiments to develop rust resistant trees, **3)** develop protocols for propagating limber pine in nurseries, and **4)** develop natural areas for establishing whitebark and limber pine through small burns or mechanical means.

Summary: There is a growing consensus among scientists and resource managers that whitebark and limber pine will eventually be lost in Glacier National Park without active management intervention. Whitebark pine seeds have been collected for several seasons. Cages installed on four whitebark pine trees in Bighorn Basin in the Two-Medicine area resulted in the collection of 60 cones. In 1997 approximately 1,900 seeds were harvested, 500 of which went to the Glacier

National Park Nursery; 1,391 were transferred to the U.S. Forest Service Nursery at Coeur d'Alene for propagation.

In 1998 60 cages were installed on five trees in Preston Park and 48 cages were installed on seven trees near Old Man Lake. These yielded 240 and 124 cones, respectively. In total, 13,377 seeds were harvested that year; 10,779 seeds from Preston Park and 2,598 seeds from the Old Man Lake site. Approximately 1,200 seeds went to the Glacier National Park nursery and 12,177 seeds were transferred to the U.S. Forest Service nursery at Coeur d'Alene, Idaho for propagation.

Field of Inquiry: Botany/Plant Restoration
Investigators: **Terry McLendon, Shepherd Miller and Tara Williams**

Project Title: **Comparison of the Ecological and Economic Benefits Between Two Revegetation Treatments at Logan Pass, Glacier National Park: Seeding vs. Seeding and Planting**

Objectives: To compare two revegetation schemes for use at Logan Pass: **1)** grass and forb seed mixture only, and **2)** the same species mix with containerized material planted at the prescribed planting ratio of 18 plants/m^2.

Summary: In 1997 34 1m x 1m plots were examined, 15 with the seed mixture only, 15 with the seed mixture and containerized plants, and 4 reference plots. In 1998, 38 plots were analyzed with the addition of four more reference plots. Data were collected using the point intercept method. Comparisons of species diversity and plant canopy cover are to be made after a minimum of three years of data collection. Since it takes more time and money to grow and plant containerized materials in revegetation projects compared to the planting of seed, results of these experiments will indicate the most efficient method for use at Logan Pass. Data analysis is currently in progress.

***Field of Inquiry*: Ecology**
Investigators: **Richard Hauer and Jack Stanford**

***Project Title*: Impacts of Climate Change on Hydrology and Aquatic Biota in the Lake McDonald Watershed, Glacier National Park**

Objective: To gather baseline data on stream discharge, nutrient and sediment loads, temperature regimes and responses of aquatic biota. Emphasis is on aquatic insects and their response to variations in climate. These data are also used for validation of ecosystem models.

Summary: Six stream gauging stations and one weather station collecting hourly average data have been maintained for the past 5years to gather baseline information about stream discharge and temperature. Gauging stations are visited routinely throughout the year to maintain electronic components in a field setting. The equipment is set to average readings taken at

one-hour intervals. Chemical and biological samples are collected according to a specific experimental design and sampling protocol. Thermal loggers have been placed in selected reaches of alpine streams to build an elevational thermal regime profile for the basin.

During the past year the paper, "Assessment of climate change and freshwater ecosystems of the Rocky Mountains, USA and Canada", by F. R. Hauer, was presented to the international peer-review journal Hydrological Processes. Also, the 44th Annual Meeting of the North American Benthological Society met in Kalispell, Montana; one of the meeting's special sessions was organized around the Global Climate Change topic. F. R. Hauer, J. A. Stanford, and W. Lowe presented a paper at the session "Potential effects of global climate change and complex distribution and abundance patterns of macroinvertebrates in northern Rocky Mountain streams." This paper highlighted the results of work done on this project with emphasis on hydropsychid caddisflies. The recently published book Methods in Stream Ecology, edited by Hauer and G. A. Lamberti (Academic Press) cited data from this project.

Field of Inquiry: **Ecology**
Investigator: **David Cairns**

Project Title: **Fine-scale Analysis of Soil Properties at the Alpine Treeline Ecotone**

Objective: To determine fine-scale variability in soil nutrient properties at the alpine treeline ecotone representing different types of treeline environments

Summary: Altogether 140 soil samples were collected from four drainages representing different types of treeline environments in Glacier National Park. Four study sites were representative of a mid-elevation moist treeline environment (Baring Creek basin); a high elevation, moist valley bottom (Preston Park); a high elevation steeply sloped dry location (Apikuni Cirque); and a high elevation gently sloped bowl (Scenic Point). Soils are being analyzed for total nitrogen, total carbon, exchangeable potassium and phosphorus.

Tundra/Krummholz Differences: A primary goal of the project is to catalog the differences between soils found in tundra locations and those collected from beneath the Krummholz canopy. Preliminary statistical analyses of the soil samples indicate that total nitrogen, total carbon and the carbon/nitrogen ratio is higher in Krummholz locations than at the tundra sites. There are no significant differences between Krummholz and tundra for soil phosphorus and potassium.

Inter-basin Variability: Since the soil samples were collected from four different types of treeline environments, it was possible to evaluate differences in soil nutrients among the four environments. Preliminary analyses of the data indicate that there are significant differences among the four treeline sites. Nitrogen and carbon values were highest at the Baring Creek and Preston Park sites. These sites are the most heavily vegetated. The Baring Creek site also had the highest potassium values and the second highest phosphorus values. This suggests the Baring Creek site is not limited by soil nutrients. The most nutrient-poor site was Scenic Point, although

high potassium values were present. This was unexpected since the Apikuni Cirque site is the least vegetated of the four sites.

Geo-statistical Analysis: Relative geographic coordinates of the sampling locations were recorded. Plotting of relative locations allows for geo-statistical analyses to be conducted. Variability of soil characteristics over space can also be calculated. The Principal Investigator is currently doing the geo-statistical analysis, but results are not yet available.

Field of Inquiry: Ecology
Coordinator: **Daniel Fagre**

Project Title: **Global Change Research Program**

Objective: To determine how the Glacier National Park mountain ecosystem will respond to global environmental change.

Summary: Our focus for the past 7-years has been to determine how the Glacier National Park mountain ecosystem will respond to global environmental change. We first had to establish how major ecosystem components are influenced by current and past climatic patterns. Developing computer-based ecosystem models that simulate ecosystem outputs was instrumental in reaching an understanding of basic mountain system behavior. Computer model estimates of outputs, such as stream discharge, compared favorably with real-time monitoring of several streams in the Lake McDonald watershed. We applied the model to new research questions and used it to assess future possible scenarios. Much of our past work is summarized by Drs. Joseph White and Steve Running and collaborators in a recent Ecological Applications publication.

Forest Modeling

During the past year we have continued development of ecological modeling capabilities. Progress was made in integrating all model components within the same programming language for more seamless operation. The simulated interaction of future climate and fire management scenarios at Glacier demonstrated that different landscape patterns are likely to dominate in future years, influencing ecosystem processes and vulnerability to external stressors. Differences in landscape metrics, such as contagion and average polygon size, reflected a future trend towards smaller, homogeneous habitat patches as a result of more frequent stand-replacing fires. The implications of altered landscape patterns were examined for several key wildlife species by incorporating habitat modules that included a number of vegetation categories and key resources. Other simulated ecosystem responses include increased vulnerability to change for the eastern half of Glacier National Park as a result of more erratic weather patterns (e.g. increased interannual variability).

Watershed Research

Seven years of monitoring and investigations into aquatic system responses to climate change have been summarized. Since 1992 we have recorded the lowest spring discharge and second highest spring discharge of the past 30 years (based on SNOTEL records),

thereby capturing much of the high interannual variance in this system. We have also documented an unusual run-off event in late fall and its impacts on the biota. Such "spring discharges" in fall are forecast to become more frequent under some climate change scenarios. In addition to the eight primary stream monitoring sites, we also collected detailed stream temperature recordings from over 20 other sites located along the a continuum ranging from the lowland valleys to the alpine zone. Ten additional temperature-recording devices were placed in alpine zones and floodplains. These efforts have underscored the thermal complexity present in this watershed and the complicated spatial changes that would occur under future climate changes. These stream/wetland complexes possess diverse temperature regimes and are concentrated zones of biogeochemical cycling. Diverse aquatic faunal assemblages containing some rare species occur in these zones. Many of these species have very specific habitat requirements and respond quickly to thermal changes.

We have identified over 200 species of aquatic insects distributed among streams and wetlands along the elevation gradient of the McDonald and St. Mary basins in Glacier National Park. Stream species tend to express distinct Gaussian longitudinal distribution and abundance patterns characterized by discreet, species-specific distribution ranges. We have good information about species distributions along the stream continuum; however, we know much less about the thermally complex stream/wetland systems of the alpine and floodplains. These sites appear to be most sensitive to hydrologic and thermal variation driven by climatic change.

Atmospheric Research

A Brewer spectrophotometer was installed at St. Mary in August 1997 and the first year of data indicated peak levels of ozone and UV-B radiation during July and August. This effort is part of the PRIMENet network, a program for monitoring impacts of atmospheric stressors on natural resources. These data will be part of the first long-term national assessment of UV-B radiation patterns associated with thinning ozone layers in the upper atmosphere. Locally, these data can be related to changes in amphibian populations, which may be sensitive to UV-B increases. USGS scientists conducted specific examinations of amphibian habitats with a portable spectrophotometer at several ponds during recent summers.

Photographic Documentation

The Glacier National Park archives contain approximately 12,000 historic photographs dating back to the late 1800's. Many of these photographs are of glaciers, snowfields, alpine meadows, treeline, and avalanche paths that have changed in response to climate shifts. During summer 1998, Karen Holzer and Lisa McKeon returned to the exact locations from which selected historic photographs were taken and took new photographs to document the extent of change. Both the old and new photographs were digitally scanned and cropped so that exact comparisons could be made between photographs. This project is ongoing but completed comparisons already have visually underscored the dynamic nature of some mountain features.

Spatial changes in Alpine Vegetation Patterns

Fritz Klasner concluded his M.S. at Oregon State University with a paper analyzing a 46-year

history of alpine treeline changes using sequential aerial photography. Elevational changes in

treeline did not occur but the transition from trees to tundra became more abrupt because Krummholz patches filled existing spaces. Additionally, more Krummholz became upright patch forests and increased stand density. Areas with trails had more Krummholz fragmentation than those with no trails but, overall, the impact of trails was not significant compared to climate change.

Continuing Research Activities

A paper summarizing glacier recessions in Glacier National Park was completed by Carl Key for a satellite atlas of the world's glaciers. In addition to our repeat photography efforts, we also contracted for new aerial photography of the glaciers in order to gain updated information about the size and number of remaining glaciers.

We continue to record snow amounts and characteristics ahead of the snowplows during the annual clearing of the Going-To-The-Sun Road over Logan Pass. These data will be used to test the effectiveness of a snow model, MTSNOW, for predicting year-to-year variation in snow density and hardness. We have also statistically analyzed existing data to look at long-term trends.

Lake-ice formation, thickness, and melt out are being monitored as indicators of long-term changes. Snowpack is monitored on an elevational gradient on both sides of the Continental Divide for long-term trends and development of snow models. Mountain meteorology at high elevation sites is monitored year-round in support of other studies.

The Future

The first 7-year phase of Global Change funding was concluded in September 1998. A national competition for new research projects was conducted by the USGS last summer. Several of our proposed projects were funded for the next 5-years. Our research at Glacier National Park will be extended to the North Cascades and Olympic National Parks to compare mountain ecosystem responses to climate change along a gradient from maritime (Olympic National Park) to continental (Glacier National Park) conditions. Additional research projects will focus on alpine treeline dynamics and the interaction of amphibian metapopulation dynamics with UV-B exposure in mountain habitats.

Field of Inquiry: **Ecology**

Investigators: **Daniel Fagre, George Malanson, David Butler, Steven Walsh, David Cairns and Daniel Brown**

Project Title: **Invasibility of Tundra in the Northern Rocky Mountains**

Objective: To assess the sensitivity of alpine tundra to invasion by woody species from treeline in the Northern Rocky Mountains.

Summary: This project was initiated at Glacier National Park during the summer 1999 field season after several months spent establishing cooperative agreements between the USGS and five universities. Graduate students were hired, equipment purchased, and logistics such as housing were arranged. Positive Systems Inc. was contracted to make photographic overflights of tundra environments in the park. Flights were carried out with simultaneous ground-truthing activities during a period of excellent late summer weather. All principal investigators spent part of the summer in the field at the Lee Ridge site with their graduate students and assistants. Fifteen scientists collected data for different components of the project.

Modeling. We plan to develop models of tree-species invasiveness and growth in response to causal mechanisms, especially those related to hydrology. The models will be validated at multiple spatial and temporal scales. Results will allow the interpretation of past and ongoing changes at and above treeline in the wildlands of the western US. The sensitivity of tundra to invasion is significant because many large tracts of land having wildlife and recreation values exist just above the treeline ecotone. The sensitivity of the ecotone and its use as an indicator of climatic change has been debated. What the debates overlook, however, is that we should expect a highly nonlinear response because the ecotone is likely a balance of opposing positive feedbacks. Such positive feedback switches are likely to have produced a system that can have a critical point and is subject to small or large periods of change with incremental climatic change.

The core model will be a mechanistic tree establishment and growth model based on modifications to, and integration between, two existing types of models; biogeochemical cycling models (FOREST-BGC) and forest gap models (FORSKA). We have a modified version of FOREST-BGC, ATE-BGC (Alpine Treeline Ecotone-BGC) that was developed specifically to include treeline ecotone processes such as needle abrasion and frost desiccation. FORSKA will be modified to represent mat Krummholz growth form as well as upright trees. The two models will be integrated by using ATE-BGC to identify the potential productivity of sites that will be used as site quality in FORSKA instead of empirically fitted curves as is usual in gap models.

Field of Inquiry: Ecology
Investigator: **Ernest Hartley**

Project Title: **Visitor Impact on Subalpine Dry Meadow and Wet Meadow Vegetation: A 30-Year Study**

Objective: To determine the qualitative and quantitative relationships between human activities (primarily trampling effects) and the condition of alpine and subalpine vegetation in the Logan Pass region of the Park.

Summary: Vegetation changes in response to clipping and various intensities of trampling, physical and physiological condition of plants, and physical properties of soils were studied in experimental plots established three decades ago in dry and wet meadow plant communities. Trailside vegetation was mapped to measure the long-term effects of off-trail trampling, the primary experimental treatment. Data were collected on plant community composition, species cover, flowering characteristics, height of plants, root carbohydrate content, soil compaction and soil temperature.

Thirty years after treatment visual and statistical differences between control plots and treated subplots were still evident from both flower count and species cover data. Total vegetation cover for all species combined in dry meadow plots was significant at the 5% level. Fifteen species remained significantly altered after 30 years of recovery time. Seven plant species showed variable degrees of recovery. Preliminary conclusions suggest that the clipping treatment has a longer-term negative impact on the plants than the trampling treatments, although the effects are species-specific. Recovery of subalpine dry meadow vegetation from visitor trampling, as measured at Logan Pass, is a slow process. The plant community within treatment plots has not yet returned to pretreatment conditions. Recovery will undoubtedly require several more decades.

Field of Inquiry: Ecology
Investigators: **Jack Stanford, Sandra Tardiff and Allison Young**

Project Title: **Grizzly Bear Digging in Subalpine Meadows**

Objectives: 1) to determine the effect of bear digging on spatial patterns of soil nitrogen availability and plant community patches, and **2)** to determine the effect of digging on glacier lily (*Erythronium grandiflorum*) physiology.

Summary: Previous work in Glacier National Park by the senior investigator showed that glacier lilies colonizing dig areas were larger and produced more seeds than plants in undisturbed areas. We collected data from sampling grids set up at Logan Pass and Fifty Mountain. We measured soil ammonium, nitrate and phosphate using ion exchange resin bags. Glacier lily density and seed production was also measured at each point. Initial geostatistical analysis of soil variables showed no spatial autocorrelation over the distances sampled in the grids. Additional analyses of

data are ongoing. We applied low concentrations of fertilizer to five small plots in digs and five plots in undisturbed areas to verify physiological responses the lilies to increased nitrogen availability from digging. Preliminary analysis of the data confirmed increased plant-available nitrogen through a variety of physiological measures in glacier lilies.

Field of Inquiry: Ecology
Investigators: **Jack Stanford, Bonnie Ellis and Chris Frissel**

Project Title: Ecology of the Nyack Floodplain

Objectives: Study objectives are to: **1)** describe and model ground water flow paths that feed spring brooks and other wetland features associated with the riparian zone in the Nyack flood plain (Middle Fork, Flathead River), **2)** describe and model biophysical responses within these hydrogeomorphic features, and **3)** determine if comparable hydrogeomorphis features and biophysical responses exist in the flood plains of the Nyack Creek corridor.

Summary: Investigations have been in progress at the Nyack site for more than a decade and the project remains ongoing. Measurements are continuing in the well-grid on the Floodplain and reconnaissance of the Nyack Creek corridor is in progress. We obtained a complete set of stereo photos to compare with photos obtained during previous on-site studies. We have determined that flooding and the deposition of woody debris interacts with the legacy of gravel and cobble deposition to influence the position of the main river channel. Spring brooks and other flood plain wetlands reflect the legacy of this cut and fill alluvation process. Biodiversity of the river corridor is substantially elevated by the presence of dynamic flood plain habitats. We have developed an initial computer model that describes water movement from the river through the interstitial environments of the flood plain and into riparian wetlands. Over the next several years we will continue to measure biophysical processes to refine and validate this model. We intend to install more wells on the Nyack Floodplain for greater resolution of interstitial flow paths and to use less removable piezometers to examine hydrologic processes in the Nyack Creek corridor.

Field of Inquiry: **Ecology**
Investigators: **Thomas S. Bansak and Jack A. Stanford.**

Project Title: **The Influence of Vertical Hydraulic Exchange on Habitat Heterogeneity and Surficial Primary Production on a Large Alluvial Floodplain**

Objectives: To examine the effects of vertical hydraulic exchange on habitat conditions at different ecotone types throughout the floodplain, and to assess the influence of habitat condition on surficial primary production.

Summary: The Nyack floodplain of the Middle Fork, Flathead River, is an ideal site for this work because it is a pristine floodplain characterized by high volume hyporheic flow through highly porous glaciofluvial sediments. Sites with neutral vertical exchange were selected in the

main channel above and below, and in the center of the floodplain. Additional sites were established in zones of regional down and upwelling. Upwelling sites were selected near the heads of four floodplain springbrooks (two within Glacier National Park). Physical measurements were performed and chemical variables were determined from samples collected monthly at each of the sites from April through December beginning in 1997. These variables included depth, current velocity, temperature, substrate size, and water chemistry. Algal biomass (chlorophyll and ash free dry mass) samples were collected at each site throughout the growing season (August through November) most years.

Results from this work suggest that vertical hydraulic exchange does, in fact, influence physical and chemical conditions throughout the flood plain and contribute to habitat diversity. At upwelling sites the thermal regime was more moderate causing physical and chemical conditions to be less variable over time than neutral and downwelling sites. Additionally, upwelling hyporheic water had significantly higher concentrations of soluble reactive phosphorus, the limiting nutrient on the flood plain.

The higher concentrations of soluble reactive phosphorus at upwelling sites appear to contribute to increased algal production. Analysis of variance demonstrated significantly greater chlorophyll (2-20X) and ash free dry mass (2-10X) at upwelling sites (both within springbrooks and within the main channel) compared to downwelling and most neutral sites.

Field of Inquiry: **Ecology**
Investigator: **John Vogler**

Project Title: **Spatial Variation in Soil Condition and Vegetation on Trampled Sites in Glacier National Park, Montana**

Objective: To examine and quantify variations in vegetation and soil conditions on anthropogenically-disturbed sites on the east side of Glacier National Park.

Summary: Only the first stage of the project has been completed. Sites were stratified according to disturbance type, elevation, aspect and surficial geology. Canonical correspondence analysis will be employed to determine factors responsible for diversity in vegetation. Exotic plant species will be identified. Soil properties within and between various soil types was also examined. Sample sites included the Grinnell Glacier picnic area, Preston Park, old St. Mary Bridge, Ptarmigan Campsite, Cut Bank Corral, Dawson Pass, Piegan Pass, Old Poia Lake Campground and Gunsight Lake Campground. Detailed soil data and vegetation inventories for each site are currently available. Analysis of the other data is in progress.

Field of Inquiry: Ecology
Investigator: **Katherine Kendall**

Project Title: Status and Distribution of Whitebark and Limber Pine in Glacier, Yellowstone and Grand Teton National Parks

Objective: To sample and map whitebark pine communities in the greater Glacier-Waterton ecosystem. The information will be combined with data collected at other locales to assess the status of whitebark pine throughout the central and northern Rocky Mountains

Summary: Nearly half the whitebark pine trees in Glacier National Park are dead. Of the remaining live trees, 85% are infected with rust and more than a third of their cone-bearing crowns are dead. Moving south in the Rockies to southern Montana and Wyoming, whitebark pine health improves as the climate becomes drier. In the Gallatin National Forest and Yellowstone and Grand Teton National Parks, approximately 7% of the whitebark pines are dead and 5% of the live trees are infected with rust. The highest infection rates (up to 44%) were found in the Teton Range where conditions are moister than in neighboring areas to the north.

Limber pine has also suffered heavy mortality and blister rust infection in northwest Montana and southern Alberta. On average about a third of the limber pine is dead and 90% of the remaining live trees are infected with rust. Limber pine health improves to the south. In Southwest Montana, northwest Wyoming, and adjoining areas of Idaho, limber pine mortality and incidence of rust is low to moderate with few hot spots of heavy infection. No rust has been found on limber pine in Craters of the Moon National Monument in southern Idaho.

Field of Inquiry: Ecology

Investigators: Stephen Corn and Daniel Fagre

Project Title: PRIMENet Ultraviolet Radiation/Amphibian Populations Research

Objectives: To determine if a relationship exists between ultraviolet (UV) radiation and the distribution of amphibian populations. A secondary goal is to determine if the distribution of breeding sites is consistent with metapopulation theory. We also conducted stream surveys to further define the distribution of the tailed frog (*Ascaphus truei*) in Glacier National Park.

Summary: Summer 1999 was the first season of surveys in Glacier National Park for the Parks Research and Intensive Monitoring of Ecosystems Network (PRIMENet) ultraviolet/amphibian populations study. We surveyed 89 wetlands in the Camas-Dutch drainage and 36 wetlands in the Two Medicine drainage. The long-toed salamander *(Ambystoma macrodactylum*), found at 43% of wetlands, was the most common amphibian. The spotted frog (*Rana luteiventris*) bred at 22% of wetlands surveyed, and the boreal toad (*Bufo boreas*) bred at 9% of wetlands surveyed. Surveys for the tailed frog revealed 12 new localities, but only five of these were breeding sites. The current distribution of tailed frogs in Glacier National Park is still poorly defined.

Field of Inquiry: Ecology
Investigator: **Stephen Barrett**

Project Title: Fire History in the Hudson Bay Drainage of Glacier National Park

Objective: To describe fire history in the Hudson Bay Drainage of Glacier National Park.

Summary: Fires were frequent in the Waterton-Glacier ecosystem before about 1940. In the Hudson Bay study area, stand-replacing fires predominated and occurred at mean intervals of about 140 years at the stand level. Small to moderate size mixed severity fires were also common in low-elevation dry stands, occurring about every 50 years at the stand level. Small to moderate size mixed severity fires were also common in low-elevation dry stands, occurring about every 50 years on an average. These fires were important for recycling adjacent aspen groves and grasslands. Despite extended periods of drought recent fire suppression has promoted a sharp decline in fire frequency. Lightning ignitions in the Hudson Bay Drainage and west side of the Continental Divide occasionally cause large fires. Some of these may be related to climatic anomalies such as drought conditions coinciding with periods of severe fire weather (Johnson et al. 1990, Johnson and Larsen 1991, Barrett et al. (in press). Lightning ignitions are infrequent on the east side, but humans have historically caused fires there, especially in low-elevation terrain. Fuel buildups during the fire exclusion period have contributed to shifting-stand fire regimes and reductions in landscape diversity. Prescribed fires near timberline zones might reduce current fire hazards and help perpetuate some fire dependent communities.

Field of Inquiry: **Ecology**
Investigators: **Richard Hauer and J. J. Giersch**

Project Title: Effects of Climate Change on Hydrologic Systems and Associated Biota

Objective: To understand and predict the effects of climate change on hydrologic processes and resulting impacts on cold water ecosystems.

Summary: This project is part of the Global Climate Change Operations and Conceptual Research Plan for Glacier National Park. The research is focused in the McDonald Basin in the west-central portion of the park.

Current Climate Models predict that the climate will change globally during the next century. Anticipated changes are expected to have major impacts on regional freshwater ecosystems. Findings to date indicate that climate-induced variations in hydrologic input and nutrient loading have occurred in response to interannual variation in hydrologic regimes. Predictable shifts in the distribution and abundance of aquatic biota have occurred. We conducted a detailed spatial analysis of current velocity, substratum size, sestonic carbon and nitrogen, thermal regimes, and changing abundance of dominant species of the macroinvertebrate community along a mountain stream gradient. This work demonstrated that macroinvertebrate distribution and abundance is highly correlated with stream elevation and thermal characteristics. Water quality, water quantity

and thermal dynamics are attributes that could have significant effects on the diverse and often fragile biota of freshwater habitats characteristic of the northern Rocky Mountain Ecoregion.

Field of Inquiry: **Ecology**
Investigators: **Richard Hauer and J. J. Giersch**

Project Title: **Effects of Climate Change on Biodiversity in High Elevation Alpine Streams**

Objective: To identify and catalog benthic insects to create a database for future reference in climate change research.

Summary: Macroinvertebrate communities were sampled with Surber and modified kick nets in first-order alpine streams between 1,900-2,300m elevation at Logan Pass and near Kootenai Pass in Glacier National Park. These streams are moderately high gradient and contain extensive bedrock. Water sources included snowmelt, remnant ice fields, springs, seeps, and colluvium. Adult insects were collected by standard sweep methods near terrestrial vegetation. Chironomidae and the rare trichopterans *Allomyia vifosa* and *A. hector* dominated headwater areas of snowmelt-driven streams. Spring-fed streams with associated fens were dominated by *Allomyia* spp. The hypogean amphipod *Stygobromus* sp. was found in shallow gravels at the Logan Creek springhead. Several species of Simmullidae and Rhyacophilidae were found in the macroinvertebrate assemblage.

We also found many rare species, including many new Montana records. New larval associations included *Rhyacophila donali, R. glaciera,* and *R. rickeri*. The stonefly, *Lednia tumana,* known only from alpine streams in Glacier National Park, was found in cold snowmelt streams and in springs with maximum summer afternoon temperatures seldom exceeding 15°C. Species assemblages increased in complexity downstream to include Heptageniidae, several additional species of Rhyacophila and the large predatory stonefly *Megarcys watertoni.*

Field of Inquiry: **Ecology**
Investigator: **Terry McLendon**

Project Title: **Development of a Prototype Ecological Monitoring Program**

Objective: To evaluate selected revegetation/restoration projects in Glacier National Park and apply the EDYS model.

Summary: A vegetation monitoring design was incorporated into two revegetation/restoration projects in 1997. One involved roadside revegetation in a subalpine tundra community, and the other a grassland restoration/exotic plant control project in a fescue prairie. Park personnel collected data following these protocols from 1997-1999. These data have been summarized and statistical analyses are in progress. A final report will be prepared upon completion of field work planned for the summer of 2000. The report will evaluate the success of both projects. The EDYS model has been specially adapted for the fescue site based primarily on information contained in the literature. Site-specific data will be used to optimize the model for tundra in 2000. Additional data will be gathered from the grassland site during summer 2000 to validate the model and create a final version for that application. The completed models will serve as management tools for revegetation and restoration project decision-making.

Field of Inquiry: **Ecology**

Investigators: **George Malanson, Daniel G. Brown, David R. Butler, David M. Cairns and Stephen J. Walsh**

Project Title: **Pattern and Process at Alpine Treeline**

Objectives: To create a simulation model for Krummholz vegetation based on existing mechanistic (e.g., FOREST-BGC) and semi-mechanistic (e.g., FORSKA) models for conifer growth; to characterize the structure of Krummholz forms and the feedbacks of the vegetation on the local environment; and to characterize the radiometric characteristics of Krummholz.

Summary: Lee Ridge shows evidence of a least three stages of tree advance into tundra. On the lower elevation section of the ridge, linear patterns in the trees indicate that the forest has developed from fingers that advanced upslope into tundra. Preliminary tree-ring evidence indicate that this advance was initiated in the mid-19th century. Higher on the ridge fingers of trees have advanced into tundra. Tree-rings indicate that these fingers formed early in the 20th century. Scattered seedling/saplings of tree species are advancing into tundra; tree-rings indicate a pulse of establishment c. 20 years ago. The fingers of trees on Lee Ridge affect local wind patterns. Wind at the downwind tips of the fingers was consistently lower than wind between fingers as measured at seedling height of 20 cm. We were unable to detect a difference in soil development along the axis of the tree fingers. We did, however, find evidence of acolian deposition of fine sediment within the fingers. Leaf area index (LAF) data have been used to apply spectral unmixing to Landsat Thematic Mapper pixels to estimate the percent trees in each pixel. LAF information has enhanced our understanding of empirical relationships between LAI and the normalized difference vegetation index. It has improved our ability to estimate and map LAI from the TM images. The model will be used to assess the importance of local positive feedbacks and seed rain as potential responses to climatic change.

Field of Inquiry: **Ecology**
Investigator: **Kristopher Peterson**

Project Title: **Identification and Prioritization of Whitebark Pine Habitat for Prescribed Fire in Glacier National Park**

Objective: To reintroduce fire to whitebark pine habitats to facilitate their restoration and recovery.

Summary: Approximately 87,000 acres of seral whitebark pine habitat were identified in Glacier National Park, the majority occurring east side of the Continental Divide (70,000 acres). Future burn sites are being identified and prioritized based on ecological attributes and fire

management considerations (i.e., previous fire history, accessibility of area, size of habitat, etc.). This project is part of the continuing fire management program in Glacier National Park.

Field of Inquiry: **Ecology**
Investigator: **Carl H. Key**

Project Title: **Mountain Landscape Diversity and Ecology in the Rocky Mountains**

Objectives: To evaluate landscape diversity in National Parks and surrounding public lands; and to determine landscape disturbance trends and assess their role in shaping natural communities.

Summary: We have documented spatial and temporal trends of glacial recession in the region and characterized conditions of the "Little Ice Age" across the Rocky Mountain Region from Canada to Colorado. An accurate chronology was revealed by patterns of neoglacial advances and retreat. A field-oriented fire severity rating system was developed and a remote sensing model for burn severity was created for assessment, mapping and monitoring of large forested areas at moderate resolution. Methods were developed for meso-scale monitoring of grasslands on the east side of the park and for identifying disturbances and patterns of change in the grasslands. We also developed new approaches for modeling forest fuels. This will facilitate application of the FARSITE fire-spread model for compliance with the Interagency Joint Fire Sciences guidelines.

Development of a satellite data archive continued with the addition of 9 Landsat TM scenes and 28 Landsat MSS scenes to the Park's GIS. The archive provides over 25 years coverage to quantify annual and seasonal landscape changes within the greater Glacier ecosystem. Computer programs were written to handle unusual formats of pre-1980 datasets. A database of available remote sensing sources was updated, including details about sampling dates, sensor types, and quality and ownership of instruments.

GIS datasets of six glaciers were created to assess glacial trends and identify potential impacts of melting on stream flows and temperatures. Historic maps, aerial photos and documents were digitized to represent glacier terminus positions in time-series from 1850 to 1994. Aerial photos of glaciers were obtained in 1993 and new terminus positions were mapped. Reductions in the size of glaciers ranged from 62% to 87%. Melt rates were highest from the 1920s through the mid-1940s, a regionally warm-dry period. Recession continues since glaciers have not yet reached equilibrium with today's climate. Overlay of digitized Little Ice Age moraines for 11 glaciers indicated positions of mid-19th Century termini and the magnitude of retreat since that time. Non-glaciated basins contribute significantly less water to streams than glaciated basins where timing and extent of run-off is buffered. Current rates of glacial retreat imply future reductions in stream flow that will likely have secondary influences on stream organisms and other ecosystem properties.

An unsupervised spectral classification of a 1995 Landsat TM scene was completed using iterative clustering and a unique band combination to define the status of perennial ice and snow.

The classification resolved the current extent of glaciers in and around Glacier National Park. Only about 36 sq km of perennial ice and snow remains in the region, almost all of it contained within the park. A regional chronology was compiled for the "Little Ice Age" and the "Medieval Warm Period" to provide a time-frame for assessing climate changes during the last millennium. Relative age and extent of glacier maxima within the period were compared along a latitudinal gradient spanning the Rocky Mountains. Evidence was developed from dated moraines and proxy measures such as tree-ring chronologies and lake sediment cores. These data were used to quantify latitudinal variation in conditions and magnitude and the duration of cooling and warming periods. The evidence suggests that several climatic drivers are responsible for transformations currently occurring throughout the Rocky Mountains.

Remote sensing of burn severity was initiated on 17,000 acres of the Adair Ridge and Starvation fires from 1994. Four Landsat TM scenes (spring and fall scenes from 1994 and 1995) were rectified and standardized to permit direct radiometric comparison between pre- and post-fire dates. Several indices were tested as correlates to burn severity. This led to development of a new index, the normalized burn ratio (NBR), which provided optimum discrimination of severity levels. A new burn severity rating system was also developed to measure fire effects in the field. Aerial overflights and ground sampling were completed on 88 plots to facilitate the interpretation of remote sensing data and to validate models. Results provided a distinct fire perimeter and showed mottled patterns over a range of severity. This contrasted with forest canopy replacement that dominated the 30,000-acre Red Bench Fire in 1988. In most areas vegetative recovery from the 1994 fires is expected to be rapid, and the mosaic of fire-created openings should enhance forest habitat.

To implement the FARSITE, a real-time fire growth model, a first-generation fuel model was developed through the use of Landsat TM multi-spectral classification data. Fifteen fuel types were identified and mapped over the northwest quarter of the park. An opportunity to test the dataset occurred during a 10,000-acre fire in the fall of 1998. Preliminary review compared FARSITE simulations to actual fire behavior. Good performance was observed suggesting suitability of the fuel classification. Validation and refinement of the fuel model is planned.

Five high elevation weather stations were installed to monitor mountain climatology and provide validation of climate models. We also established protocols for year-round sampling and post-processing. Several weather stations suffered winter damage and required repair. We created aggregate daily/hourly datasets spanning 3-years and acquired datasets that were developed from regional climate stations maintained at other locations by the National Park Service, National Weather Service, and the Bureau of Land Management. All datasets were corrected and calibrated; summary statistics and preliminary correlations were developed from the data. These data should reveal temporal and spatial factors (i.e., lapse rates) that will enhance our understanding of how climate is influenced by mountainous terrain.

Field of Inquiry: **Environmental Monitoring**
Investigators: **K. C. Donnelly and Shannon Garcia**

Project Title: **Remediation and Risk Assessment of Contaminated Soils**

Objective: To collect soil samples and conifer needles near Many Glacier and Bowman Lake in Glacier National Park. The samples are to be used as background (i.e., control) samples for comparison with needles obtained in other locations throughout the United States.

Summary: Conifer needles collected from the two study sites have been extracted and analyzed for chemical constituents. The needles contained only trace levels of chlorinate dibenzo-p-dioxins. These findings indicate conifer needles sampled from remote areas of Glacier National Park reflect true natural “background levels” of chemical constituents and are ideally suited for use as controls for comparisons with contaminated media .

Field of Inquiry: **Environmental Monitoring**
Investigators: **K. C. Donnelly and Shannon S. Garcia**

Project Title: **Genotoxicity Monitoring of Pristine Soils**

Objective: To compare mutagenicity data derived from pristine soils (baseline values) collected from a remote area with soil mutagenicity at Superfund sites.

Summary: Four soil samples were collected from two sites in Glacier National Park; near Bowman Lake and in the vicinity of Grinnell Glacier (Red Rock Falls). The samples were extracted with hexane:acetone. When tested with strain TA98 in the Usalmonellau/microsome assay, three of the four samples were nonmutagenic without metabolic activation (did not produce a doubling of revertants at two consecutive doses). One sample did elicit a positive response without metabolic activation and revealed 254 and 133 net revertants at the two highest doses. This sample was also positive with metabolic activation. Overall, metabolic activation had little impact on the mutagenicity data. Aliquots from these are currently undergoing chemical analyses. Results are expected to reveal what natural mutagens exist in pristine soils.

Field of Inquiry: **Environmental Monitoring**
Investigator: **David Clow**

Project Title: **Survey of High-Altitude Lake Chemistry in National Parks in the Western United States**

Objective: To conduct a survey of the chemistry of alpine/subalpine lakes in seven national parks in the western United States. The data will be compared to a previous lake chemistry survey done in 1985 to see if there have been significant changes in water quality since the mid-1980's.

Summary: Findings from this work will provide a reference database for measuring the sensitivity of remote wilderness lakes to acidic deposition and climate change. Chemical surveys were conducted for 72 high-altitude lakes in seven national parks in the western United States during fall 1999. Lakes in three California parks (Sequoia/Kings Canyon, Yosemite, and Lassen Volcanic) and in Rocky Mountain National Park (Colorado) were dilute. Median specific conductances were less than 12 µS/cm and median alkalinities were less than 75 µeq/L. Specific conductances and alkalinities generally were substantially higher in Grand Teton and Yellowstone National Parks (Wyoming), and Glacier National Park (Montana), probably due to the prevalence of more reactive bedrock types. Concentrations of base cations and alkalinity were lowest in lakes in the alpine zone because of minimal vegetation and soil development and rapid turnover rates. These conditions make alpine lakes highly sensitive to atmospheric deposition of pollutants.

Field of Inquiry: **Geology**
Investigator: **Brian R. Pratt**

Project Title: **Sedimentology of Selected Units in the Mesoproterozoic**

Objective: To understand the depositional environment of selected units in the Belt Supergroup, sedimentary rocks of the Mesoproterozoic age (c. 1.5 Ga) in Glacier National Park and surrounding environs. and so on.

Summary: I have been specifically interested in the effects of Precambrian earthquakes that shook the sediment during deposition. This work is being expanded to embrace the sedimentary environment in general, including provenance and geochemistry of the terrigenous sediment, paleoclimate, bathymetry, paleocurrents and water chemistry. The project is a long-term effort that has been carried on intermittently for almost a decade. Papers have been published on the Altyn Formation and the Helena (Siyeh) Formation. Two of these papers deal with the enigmatic molar-tooth structure and synersis cracks, which should be of interest to park interpretive programs since several new theories are presented. Others papers are in preparation. Copies of completed papers have been furnished to park staff. The Appekunny and Grinnell formations will be investigated during the 2001 field season.

Field of Inquiry: **Geology**
Investigator: **Julie Bartley**

Project Title: **Geochemistry of the Helena Formation, Glacier National Park**

Objective: To understand the depositional history and associated geochemical changes in the Helena Formation during the Mesoproterozoic

Summary: The Mesoproterozoic was an interval of earth history that spanned from 1600 million years (Ma) before present to 1000 Ma. This six hundred million year time-period witnessed critical changes in ocean chemistry, atmospheric oxidation, global tectonic reorganization, and the evolution of biological life-forms. Until recently the Mesoproterozoic has been poorly studied due to the scarcity of accessible localities. The Helena Formation provides one of the best exposures of Mesoproterozoic carbonates in the United States. Previous research by other workers suggests that the Helena Formation was deposited in a restricted basin and that increasing restriction upward in the unit resulted in distinctive geochemical change. We tested this hypothesis by examining the C-isotope geochemistry of carbonates and organic carbon from rocks of the Helena Formation.

We conducted reconnaissance fieldwork in the summer of 1999 and collected 40 samples for isotopic analysis. The stratigraphy of the Helena, examined at three localities (Lunch Creek, Siyeh Bend, and Grinnell Glacier) is inconsistent with an upward increase in basin restriction. Carbon isotopic analysis of organic carbon and carbonate carbon samples, although incomplete, also fails to support the hypothesis of basin restriction. We argue that a more plausible explanation for the observed geochemical change within the Helena Formation was a global change in the isotopic composition of marine carbonate at the time of deposition of Helena Formation carbonates.

Field of Inquiry: **Geology/Paleontology**
Investigator: **Mary R. Dawson**

Project Title: **Paleontological and Geological Investigations in Glacier National Park**

Objective: To conduct Paleontological/geological investigations at several sites in Glacier National Park.

Summary: Paleomagnetic sampling was concentrated in the Coal Creek drainage. The most complete section of the formation is along this tributary of the Middle Fork of the Flathead River. John Kappelman of the University of Texas and his associates collected most of their data at this locale. They investigated the full thickness of the section along Coal Creek, encompassing the lowest strata in the formation upward to recent Pleistocene deposits. Included in the section are a radiometric date (46.2+/-0.4ma), a vertebrate fossil locality (correlated as Uintan middle Eocene) and numerous fossil mollusk localities. Sites were also sampled along the main channel Middle Fork around a fossil gastropod bed that can be effectively used as a marker horizon in Kishenehn deposits on the Middle Fork. The paleomagnetic cores are currently being processed at the Paleomagnetics Laboratory, University of Texas.

Paleontological prospecting was also undertaken along the Middle and North Forks of the Flathead River. The most productive sites along the Middle Fork were M2 and Kuhn's Point. The former produced a number of jaws, including an agamid lizard (cf. *Tinosaurus*) that is new to the local fauna, and an antiacodontid artiodactyl, also unknown in the locality. The latter is important in providing a close biostratigraphic match to the Coal Creek vertebrate locality. A nearly complete turtle shell was discovered at the Kuhn's Point site. This is significant because turtles are rare in the Kishenehn Formation. Both M2 and Kuhn's Point are middle Eocene (Uintan) in age.

Prospecting was also done on the North Fork below the mouth of Kintla Creek. A Park Ranger found a nearly complete horse jaw (cf. *Mesohippus*) in this locality. The horse jaw and several gastropods, found in the same locality, could provide important new biostratigraphic and environmental information on these strata in the Oligocene part of the formation. Fossil bearing matrix for screen washing was collected from the titanothere locality along Coal Creek, the Middle Fork localities M2 and Paola siding, and the Foolhen locality on the North Fork. These samples are currently being processed.

Field of Inquiry: **Geomorphology**
Investigators: **Forest Wilkerson and Ginger Schmid**

Project Title: **Spatial and Temporal Characteristics of Debris Flows in Glacier National Park**

Objective: To identify the processes that lead to the initiation, transport, and deposition of debris flows within Glacier National Park.

Summary: Debris flows are a fairly common occurrence, but they appear to be restricted to the leading initiator of these events. A multiple scale approach was used to define the geomorphology of individual debris flows. Debris flow attributes were incorporated into a Geographic Information System database to better define the role of basin wide processes such as snow loading, slope angle and hydrologic input. It does not appear that intense rainfall events are necessary to initiate flows. This is best illustrated by the recording of major flow events in 1995 and 1996. At present, debris flows mainly impact park trails. There is no evidence that permanent structures are presently threatened. Monitoring will continue for at least one more field season.

Field of Inquiry: Geomorphology
Investigator: **George Malanson**

Project Title: 20th Century Landscape Change

Objectives: To assess the nature and extent of recent changes in cultural, ecological and geomorphological features and understand the relationships between these entities.

Summary: The study involves examination of time-series photographs. Change in natural features appears to be scale-dependent. Except for the removal of buildings and the retreat of large glaciers, little change is evident. Patterns of vegetation and landforms remained largely unchanged over the past 80+ years. Exceptions occur in active geomorphis areas (e.g., at Slide Lake).

Field of Inquiry: **Geomorphology**
Investigators: **Ross Meentemeyer and David R. Butler**

Project Title: The Geomorphic and Environmental Significance of Beaver Ponds as Sediment Traps in Mountainous Terrain

Objectives: To quantify the effectiveness of beaver ponds as sediment traps and understand their role in regulating sediment yields to drainage catchments; and to quantify the effect of beaver ponds on downstream flow velocity and discharge.

Summary: Preliminary results indicate that beaver ponds do indeed trap sediment. Older ponds have accumulated significantly more sediment than younger ponds. Rates of sedimentation have not yet been determined. Beaver ponds retard downstream flow velocity and absorb a significant amount of stream discharge energy.

Field of Inquiry: **Sociology/Recreation**
Investigators: **Naoki Amako and Charles C. Harris**

Project Title: **Impacts of Recreational Activities: Factors Limiting the Success of Leave-No-Trace Education Practices in Glacier National Park**

Objectives: Goals of this study are to: 1) determine how successfully Leave-No-Trace (LNT) practices have been implemented, 2) assess the levels of prior and acquired knowledge about LNT practices among backcountry users, and 3) identify the barriers to successful implementation of the LNT program.

Summary: A national program called Leave-No-Trace (LNT) was initiated by the U.S. Forest Service to increase public awareness about the fragility of natural environments and encourage responsible outdoor recreation practices. The goal is to teach minimum impact outdoor skills and foster an ethic aimed at reducing impacts on the experiences of other public land users.

We surveyed park visitors to identify personal beliefs, situational factors, and subjective norms. We also sought to identify possible barriers to successful implementation of LNT practices in Glacier National Park. Of 607 individuals interviewed 407 agreed to participate in the survey. The ratio between day hikers and the overnight users was 53:47. Results from the self-report indicate that compliance with practices related to personal hygiene, that is wastewater treatment and disposal of human waste, was only marginally successful. Proper LNT practices were perceived to be unimportant and requiring of too much effort. Books and magazines were the most frequently identified information sources and were rated "most important" as sources of guidance for LNT instruction. It is hoped that results of the survey will allow park managers to refine and improve the success of the LNT program. Survey results are still under analysis.

Field of Inquiry: **Wildlife Biology**
Investigator: **Maurice Hornocker**

Project Title: **Cougar-Wolf Interaction in the North Fork of the Flathead River, Montana**

Objective: To document the relationship between cougars and wolves and learn how they partition certain resources in areas of overlap in the North Fork region of Glacier National Park.

Summary: The locations and seasonal movements of cougars were plotted from 587 ground and 1,376 aerial observations. Concurrently 164 ground and 471 aerial observations were recorded for wolves. Simultaneous location data are currently being compiled into a database for nearest-neighbor presence/absence and home range analyses.

A total of 150 ungulate carcasses have been investigated since winter 1993. Seventy-three of the ungulate mortalities were categorized as probable or positive cougar kills. Cougars and wolves mostly killed white-tailed deer during winters. Cougar and wolf scats were collected for food habits analysis and are currently being catalogued.

Three cougars were killed during interactions with wolves and one apparently perished during an encounter with a bear. During winter months we documented four cases (5%) in which wolves displaced cougars off ungulate carcasses (n=73) and 23 instances (27%) where wolf sign was located at ungulate carcasses (n=86). Tracks at most of these sites indicated feeding behavior typically associated with cougars. Bear sign was present at 9 of 25 cougar kill sites (36%) during winters in the Kintla Lake area of Glacier National Park. The Kintla Lakes region is the only cougar winter range where winter bear activity was documented.

Field of Inquiry: **Wildlife Biology**
Investigators: **Wendy Arjo, Robert Ream and Dan Pletscher**

Project Title: **Effects of Wolf Colonization on Coyote Behavior, Movements and Food Habits**

Objective: To study spatial relationships of wolves and coyotes and determine the effects of wolves on the movements, behavior and food habits of coyotes.

Summary: Coyotes and wolves were trapped during the spring (May-June); only coyotes were trapped in the fall (Sept-Oct). A single member from the South Camas wolf pack was captured and collared (a 3-year old female). No wolves from the North Camas pack were captured. Four coyotes were captured, two males and two females. All of the coyotes were captured outside of Glacier National Park. To date we have captured 18 coyotes, 9 males and 9 females. Six of these were captured in Glacier National Park. Data on locations and movements of the animals are currently being analyzed.

Field of Inquiry: Wildlife Biology

Investigators: **Katherine Kendall, Dave Schirokauer, Kris Peterson and Lisette Waits**

Project Title: **DNA Fingerprinting to Monitor Grizzly Bear Populations in the Greater Glacier Area**

Objectives: Project objectives are to: **1)** obtain minimum counts and density estimates of grizzly and black bear populations in the Greater Glacier Area using non-invasive genetic methods, **2)** model the statistical power of non-intrusive sampling strategies and develop a protocol for monitoring long-term bear population trends, **3)** assess genetic diversity and the degree of relatedness among grizzly and black bear populations, and **4**) evaluate the effects of age, diet, and sample storage technique on fecal DNA extraction success. We will determine the feasibility of using DNA from hair found on rub-trees to identify bears and evaluate the effects of specimen storage time and preservation methods on DNA extraction rates from hair samples.

Summary: A study area of 8,100 km² (2 million acres) was established where 126 8 x 8 km (64 km²) grid cells were identified for placement of traps. Trapping was carried out during five 2-week trap sessions. Some 620 hair traps were placed in the field; samples were retrieved between May 19th and August 12th, 1998. Approximately 7,200 hair samples were collected that year. Hair was found at 80% of the traps where the average number of hair samples per trap site was 14. Forty percent of the samples had 5 or more hair follicles. Preliminary results of sampling indicate that DNA was extracted from 90-100% of the hair samples (N=300).

Eight hundred miles of trail were surveyed between June 1 and October 9. Thirteen hundred hair samples were collected from rub trees along trails. Seven hundred scat samples were collected from trails.

Hair

We have evaluated the difference between the use of silica at room temperature vs. –20 C freezer storage in preservation of hair/DNA samples. We have also begun to compare DNA amplification success and error rates for time points from one week to one year.

Scat

We have almost finished testing drying methods: oven, silica, freeze drying and microwaving. We have begun testing preservation methods: oven & -20 C freeze, oven & silica beads at room temperature, ethanol and lysis buffer.

Extraction

We have developed a new more effective DNA extraction protocol.

As of February 2000, bear species was identified from 2,268 hair samples and 530 records obtained during sign surveys. These samples yield a 35:65 brown (grizzly) to black bear ratio for hair trapping and an 81:19 ratio for sign survey; 573 (81%) of the brown bear hair trap samples provided complete genotypes. Rub tree samples yielded 222 complete genotypes of 372 brown bear samples (60% success). The 795 recorded genotypes identified 205 individual brown bears: 117 unique to hair traps, 54 unique to sign survey, and 34 found in both types of sampling. As expected, bear behavior was biased according to gender. The ratio of male to female samples using rub trees on trails was 80:20; the hair trapping gender ratio was 50:50. Overall a fairly balanced 58:42 male to female ratio was represented in the data.

During the 1999 field season scat collection and preservation techniques were modified based on lab optimization experiments. Currently, only scats collected from the 1999 season are being processed to maximize extraction rates and minimize costs. To date, 487 of 1,822 collected scats have been successfully extracted. Of these, 232 samples were from brown bears. Genotyping of scat samples has just begun. Currently, only seven bears have been fully genotyped. However, these genotypes have not been compared yet to those identified from hair samples. It is, therefore, unclear whether these bears were previously identified.

Field of Inquiry: Wildlife Biology

Investigators: Ed Bangs, Joe Fontaine, Diane Boyd and Tom Meier

Project Title: Rocky Mountain Wolf Recovery Program

Objective: To collect information about the status, distribution, and management of recovering wolf populations in the Northern Rocky Mountains of northwestern Montana, central Idaho, and the Greater Yellowstone Ecosystem.

Summary: Summary for calendar year 1999:

Northwestern Montana: The wolf population is greater than 63 wolves dispersed among six packs. Five packs were classified as breeding packs. The wolf population along the west side of Glacier National Park comprised five animals and no reproduction occurred in the park during 1999. Four wolves were captured and radio collared in the park in May 1999, but only one of the transmitters was still being tracked at the end of the reporting period.

Central Idaho: The wolf population is approximately 141 wolves in 10 breeding packs.

Greater Yellowstone Ecosystem: The wolf population is approximately 118 wolves in eight breeding packs.

Field of Inquiry: Wildlife Biology

Investigators: **John Waller and Chris Servheeen**

Project Title: **Effects of High-Speed Highways on Grizzly Bear Movements, Mortality, Habitat-use, and Habitat Fragmentation**

Objectives: To investigate the effects of the US Highway 2 transportation corridor on the ecology of resident grizzly bears; to make inferences about the present and future connectivity between Glacier National Park and the Bob Marshall Wilderness complex.

Summary: During the spring of 1998 grizzly bears were captured in the U.S. Highway 2 corridor. They were fitted with VHF radio collars and their movements monitored until the denning season. New generation GPS collars were attached to bears that frequently moved across the highway. The collars provided accurate bear locations every hour enabling us to precisely track bear movements. The goal is to relate bear responses to changes in highway traffic patterns.

In spring 1999 Telonics Generation II "store-on-board" collars were attached to five adult female grizzlies; three in Glacier National Park and two in Wyoming. The 2100 g collars report a position hourly 24 times each day. The terrain in the study area is very rugged with elevations ranging from 1,200 m to over 3,000 m. Lower elevations are densely forested. The collars were equipped with automatic release mechanisms that caused them to fall off on a pre-programmed date. Collars were retrieved and the data downloaded to a computer. The collar has a simultaneous VHF beacon that allows concurrent aerial and ground tracking. All deployed collars and six not attached to bears released properly as programmed. Four of the five collars placed on bears functioned properly. One failed to collect data due to an internal fault. The 3D fix-rate (the most accurate location class) was 60%. The collar GPS unit functioned for 114 days before battery failure; the VHF beacon uses a separate power supply and reportedly will run for 18 months. Each of the four attached collars was recorded at more than 1,600 locations. We have not performed accuracy tests, but the manufacturer advertises 15 m mean error differentially corrected. Initial inspection of known locations suggests accuracy is very good. Recent literature indicates that successful fix rate will be lower in areas of steep topography and heavy canopy cover. The extent of this bias must be estimated in each study area. The project will continue through the 2001 field season.

Field of Inquiry: **Wildlife Biology/Entomology**
Investigators: **Kim Keating, Michael Ivie, George Markin and Donna Ivie**

Project Title: **Evaluating Impacts of an Introduced Biological Control Agent, the Seven-spotted Ladybird Beetle, (*Coccinella septempunctata*), on Native *Coccinella* in Natural Areas of the Northern Rocky Mountains**

Objectives: Study objectives are to: **1**) document the occurrence and extent of spread of *Coccinella septempunctata* (C-7) in northern Rocky Mountain national parks, **2)** estimate and compare historical vs. contemporary relative abundances of Coccinella species in these areas, **3)** identify species of *Coccinella* that may have been impacted by invasions of C-7, **4)** provide

baseline data for assessing impacts of other exotic ladybird beetles (particularly *Harmonia axyridis*) that are known to be expanding their range; these could significantly impact native species, and **5)** identify appropriate research and/or management responses in light of the above findings.

Summary: In 1999 704 specimens of six *Coccinella* species were collected in Glacier National Park (GNP) and curated at Montana State University. Also, 138 historical specimens were examined from various museums. The exotic *C. septempunctata* (C-7) comprised 81% of the post-invasion (post-1989) specimens. Relative abundances of native species declined significantly ($P < 0.05$) following invasion by C-7. These included C. *novemnotata* (8.7% pre-invasion vs. 0.4% post-invasion), *C. trasnversoguttata* (38.4% vs. 7.1%), *C. trifasciata* (31.2% vs. 10.7%), C. monticola (8.7% vs. 0.1%), and *C. alta* (13.0% vs. 0.3%). We conclude that C-7 has had a major adverse impact on native *Coccinella* in Glacier National Park. Results from other northern Rocky Mountain parks are consistent with this conclusion. A final report is in preparation.

Field of Inquiry: **Wildlife Biology/ Entomology**
Investigators: **Chris Wheat and Ward B. Watt**

Project Title: **Biogeography and Evolutionary History of the Alpine Butterfly, *Colias meadii,* in the Rocky Mountains**

Objective: Objectives of this study are to: **1)** document the locations of resident populations of *C. meadii*, **2)** assess the quality of habitats used by this butterfly species, **3)** collect *C. meadii* specimens for genetic analysis to determine the relationship of these populations to those north and south along the Rocky Mountains.

Summary: Only three specimens of *Colias* were collected in the park, all north of the Going-To-The-Sun Road. The small number is attributed to delayed spring conditions which produced a late eclosion date. *Colias* was just beginning to emerge during the sampling period. Habitats at the collection sites were generally good which suggests that a large resident population could be potentially be supported.

Record numbers for the three specimens are:

CWW612 *Colias meadii elis*
CWW613 *Colias meadii elis*
CWW614 *Colias meadii elis*
Specimens are currently stored at –80C and are awaiting analysis.

Field of Inquiry: **Wildlife Biology/Entomology**
Investigator: **Steve Kohler**

Project Title: **Butterflies of Montana**

Objectives: To provide: **1)** a list of butterfly species (*Lepidoptera, Whopalocera*) occurring in Montana, **2)** a guide to the identification of State species, **3)** illustrations, both dorsal and ventral aspects, of the male and female of each species, **4)** maps showing the distribution of each species in the State, **5)** records of collection localities and dates, and **6)** life history and food plant information.

Summary: Throughout Montana 90 new county records were established for 56 different species. Two field trips were made to high altitude sites in Glacier National Park in July of 1998, but no new distributional data was obtained. After completion of field studies and publication of results, specimens will be deposited in a major natural history museum. Specimens collected in Glacier National Park will be deposited in the park museum.

Field of Inquiry: **Wildlife Biology/Herpetology**

Investigators: **Mark Thompson and Anthony Russell**

Project Title: **Phylogeography of the Long-toed Salamander (*Ambystoma macrodactylum)***

Objective: To investigate the phylogeography of the long-toed salamander near the northern limit of its mountain range.

Summary: Phylogeography refers to the observed relationship between genetic relatedness and the geographic distribution of plants and animals. Co-investigation of biogeography and population genetics permits the historical influences on organisms to be inferred from their current genetic assortment. Ancestral patterns of descent (phylogeny) can be deduced, based upon maternal inheritance and the gradual change of mitochondrial DNA. We are examining changes in an intergenic spacer region from the mitochondrial genome that is ubiquitous among the salamander Family Ambystomatidae.

The long-toed salamander is indigenous to western North America and occurs from the Peace River region of western Canada south to California. The intergenic spacer region is a rapidly evolving gene and, therefore, is ideal for the study of interpopulation genetics. We are currently sequencing this gene and comparing the amounts and types of changes from sampled regions. Greater amounts of change reflect greater lengths of time in breeding separation. By linking the more closely related groups an approximation can be made of historical migration routes. The current investigation asks what impact geological influences have had on the breeding behavior, genetic attributes, and migratory dynamics following the long-toed salamander's northern postglacial range expansion. This study is the first of its kind in this region and has potential to reveal significant historical and biological information about this region. By examining unique genetically identifiable groups we hope to facilitate management decisions affecting the long-toed salamander and its habitat.

The preliminary data elicits interesting questions which merit further investigation. The genetics are highly variable and cluster geographically by similarity among the populations examined thus far. Our sampling has extended from Southern Montana, along the western border of Alberta and into Northeastern British Columbia. We have clustered, by similarity, the genetic groups from sampled locations and compared them geographically. Waterton Lakes, the Bow Valley region, and Montana's populations exhibit a close historical affinity by virtue of their genetic similarity. Northern British Columbia and Northern Alberta's salamander populations are genetically distinct from their southern relatives. Results from an independent investigation, using allozymes, support our findings. This suggests that current subspecies designations may be incorrectly assigned. Alberta's northern populations, more closely related to populations in British Columbia, should be classified as a single subspecies, *Ambystoma macrodactylum columbianum*. Southern Alberta's populations share an affinity with Montana's populations and should retain their current status as *Ambystoma macrodactylum krausei.* It seems likely that salamanders from Montana traversed north, subsequent to the last glaciation period, to propagate current populations in southern Alberta. However, it should be noted that there is some disagreement between the two data sets and we are proceeding with our investigation.

Field of Inquiry: **Wildlife Biology/Fisheries**
Investigator: **Bill Michels**

Project Title: **St. Mary River Fishery Study**

Objective: To gather definitive information on fish-community composition; bull trout population structure, status, and limiting factors; bull trout habitat-use and seasonal movements; and westslope cutthroat trout status in the Saint Mary Drainage, Montana.

Summary: Large (>400 mm) adult migratory bull trout were found in Kennedy Creek, Boulder Creek and Lee Creek east of the Continental Divide in Glacier National Park. Significant numbers of juvenile bull trout were also present in these streams. A small waterfall on Otatso Creek at the park boundary prevents passage of migrant fish upstream. However, resident bull trout populations occur in Otatso Creek and in the Slide Lakes upstream from the barrier. Many bull trout (25-572 mm) were captured in stream reaches above, between, and below the Slide lakes. Seven adult bull trout captured in Kennedy Creek. One fish collected from Boulder Creek had previously been captured and tagged at the fish traps during their outmigration.

Cutthroat x rainbow trout hybrids and mountain whitefish were also captured in Kennedy,

Otatso, Boulder and Lee Creeks. A few brook trout were encountered in Kennedy and Boulder

Creeks.

Wild Creek supports a population of small (55-186 mm) cutthroat trout. No other species was captured. These fish appeared to be westslope cutthroat trout; a sample was retained for later genetic analysis. A barrier exists on Wild Creek approximately 0.5 miles above the park boundary beyond which no fish were observed.

Despite extensive electrofishing along Divide Creek only two cutthroat trout (220 & 280 mm) were captured, both near the park boundary. No barriers to the upstream movement of fish were encountered.

Fish traps were installed on Kennedy, Otatso, Boulder and Divide Creeks in 1998 to capture migratory bull trout. These are known bull trout spawning streams. The traps provided information about the status and movements of bull trout that use tributary streams. Trapping also provided critical information about the movements of bull trout between the Saint Mary River and several tributary streams. Traps were installed in late August and operated until mid-October 1998. Thirteen (6-Kennedy, 3-Otatso, 4-Boulder) adult bull trout (>1250 g) captured in the traps were surgically implanted with 400-day radio transmitters. Tracking of tagged fish provided definitive information on home ranges and locations of feeding, wintering and spawning habitats.

A total of 167 bull trout (160-690 mm) was captured in the fish traps in 1998 compared to only 99 (156-720 mm) in 1997. Forty-four (6 <300 mm, 38 >300 mm) bull trout were captured in the Kennedy Creek trap compared to 33 in 1997. Thirty-six (17 <300 mm, 19 >300 mm) bull trout were captured in the Otatso Creek trap compared to 17 in 1997. Eighty-seven (23 <300 mm, 64 >300 mm) bull trout were captured in the Boulder Creek trap in 1998 compared to only 47 in

1997. No bull trout were captured in the Divide Creek trap in 1998 compared to two (both >300 mm) in 1997. Mountain whitefish, cutthroat X rainbow hybrids, brook trout, mountain, whitefish, longnose suckers, longnose dace, and sculpins were also captured in the traps.

Seven adult bull trout captured in 1998 in the Kennedy Creek trap, 5 from the Otatso Creek trap, and 7 caught in the Boulder Creek trap were recaptured fish tagged in 1997. Seven adult bull trout captured in 1998 at the Kennedy Creek trap and 5 captured in the Boulder Creek trap were recaptures of fish tagged in 1997 during electrofishing surveys upstream from the traps.

Fall redd counts for bull trout were conducted in Kennedy, Boulder, and Otatso Creeks. Kennedy and Boulder Creeks showed an appreciable increase in the number of bull trout redds counted in 1998 compared to 1997. The count in Kennedy Creek increased from 23 redds in 1997 to 37 in 1998. Boulder Creek showed an increase from 12 redds in 1997 to 42 in 1998. The time of redd counts in Boulder Creek, however, was nearly a month later in 1997. Although adult migrant bull trout are believed to spawn in Otatso Creek, no redds were identified in this stream in 1997 or 1998.

Field of Inquiry: **Wildlife Biology/Fisheries**
Investigator: **Terry Clayton**

Project Title: **East Side Bull Trout Monitoring Study**

Objective: To obtain biological information about bull trout populations in the Glacier-Waterton Parks region east of the Continental Divide.

Summary: Bull trout populations in the northwestern United States and western Canada are seriously threatened by environmental disturbances. Bull trout are currently listed as *Threatened* under the Endangered Species Act in the United States. East of the Continental Divide bull trout are occur only in the Hudson Bay Drainage; they are absent from the upper Missouri River headwaters. In the United States the native range of the bull trout includes the Waterton River, St. Mary River and Belly River drainages, all of which originate in Glacier National Park and flow into Canada. The St. Mary River flows through the Blackfeet Indian Reservation before leaving the United States. In Canada the Belly River flows through Waterton Lakes National

Park and the Blood Indian Reservation. Results are pending for DNA analysis, population estimation, redd counts, and radio tracking data.

Field of Inquiry: **Wildlife Biology/Ornithology**
Investigator: **James Larison**

Project Title: **Heavy Metals Contamination in White-tailed Ptarmigan in the Alpine Zone of Glacier National Park**

Objectives: 1) To determine if trace metal contaminants are affecting the health and/or reproductive success of white-tailed ptarmigan (*Lagopus leucurus*) living in the "ore belt" region of the Northern Rocky Mountains; and **2)** to assess the physiological condition of birds stressed by the presence of several heavy metals.

Summary: Four independent populations of white-tailed ptarmigan have been identified; (a) Logon Pass (Glacier National Park, Montana), (b) Mount Evans, Colorado; (c) Animas Creek, Colorado; and (d) Mineral Creek, Colorado. Surface waters were assayed for metal contaminants in the summer and winter ranges of each population and soils were tested in the wintering habitats of the Colorado populations. Preferred food items of each population have also been determined. Approximately 0.5 g of axial covert feathers were taken from 275 birds sampled from all locations. Samples are currently being analyzed for Cd, Hg, Pb, Al, Co, Cu, Zn, Cr, As, V, Mg, Mn, K, P, Ca and Se. Preliminary indications are that birds living in the Rocky Mountain "ore belt" are contaminated with a variety of potentially toxic metals. In some cases contaminant levels appear to be high enough to cause injury or mortality.

Field of Inquiry: **Wildlife Biology/Ornithology**
Investigators: **David Benson and Richard E. Johnson**

Project Title: **Mating Behavior of the White-Tailed Ptarmigan**

Objective, Part 1: To examine the causes and consequences of monogamy in the evolution of white-tailed ptarmigan. We propose to test three predictive hypotheses about white-tailed Ptarmigan mating behavior:

Hypotheses. **1)** Monogamy should evolve when males are less successful with two mates than with one. Therefore, since monogamy has evolved in white-tailed ptarmigan, polygamous males will have a lower reproductive output than monogamous males; **2)** Extra-pair copulation (EPC) is part of the mixed reproductive strategy rather than a specialized reproductive behavior adopted by one subset of the population. Thus territorial mated-males will be more successful in their use of EPC to increase their paternity than unmated non-territorial males,

3) There should be a direct relationship between intensity of mate guarding by the male and willingness to accept EPC by the female in a mated pair. Females, which readily accept EPC, will be guarded more closely than females who do not readily accept EPC.

Objectives, Part 2: 1) To describe late summer movements of white-tailed ptarmigan that breed in Logan Pass, Lunch Creek and the Morning Eagle Falls study areas, **2)** to describe breeding and post breeding (late summer) habitats used by ptarmigans from Logan Pass, Lunch Creek, and Morning Eagle Falls areas, and **3)** to correlate conditions of habitat with late summer movements of ptarmigan.

Summary: Initial analysis indicates white-tailed ptarmigan in Logan Pass occupy substantially reduced home ranges in the late summer. Habitat variables related to microclimate (i.e., open water, soil moisture, distance to water, distance to snow, etc.) rather than food, herbaceous cover, dwarf willow, distance to willow, or predation appear to influence late-summer range reductions of ptarmigan in the Logan Pass area.

Field of Inquiry: **Wildlife Biology/Ornithology**
Investigators: **Jay Sumner and Kurt Schmidt**

Project Title: **Survey of Cliff-Nesting Raptors and Alpine Ecotone Wildlife in Glacier National Park**

Objectives: 1) To survey cliff-nesting raptors at 26 designated backcountry sites, visit other potential nest sites, verify nest locations, document productivity and habitat information, and record sightings of other wildlife species; and **2)** to determine nest productivity of raptor species throughout the park as required in the Glacier National Park Resource Management Plan.

Summary: We located 13 active raptor eyries during the 1998 field season: six golden eagle (*Aquila chrysaetos*), four prairie falcon (*Falco mexicanus*), two bald eagle (*Haliaetus leucocephalus*) and one osprey (*Pandion haliaetus*). Two bald eagle nests and one golden eagle nest had already been located during previous surveys and were being monitored by National Park Service biologists. The Poia Lake prairie falcon nesting cliff was also known, but the eyrie had not previously been located.

1998: We observed or heard young birds at the Sentinel Mountain and Wynn Mountain prairie falcon eyries, but could not locate the eyrie. We saw three prairie falcon nestlings at the Sofa Mt/Cave Valley Cirque Eyrie on July 1. Prairie falcons called and dove at us, and we observed the adults exchange prey at the Kennedy/Yellow Mt. Eyrie on June 2. The golden eagles at Boulder Lake fledged at least one young. We observed two 7-week-old nestlings at the Heavy Runner golden eagle nest on July 21. We were unable to count young before fledging at the four remaining golden eagle nests, or at the two bald eagle nests and the osprey nest visited in May and early June.

We saw more golden eagles (62% of 134 raptor observations) than any other raptor. Prairie falcons and bald eagles, also common, comprised 10% and 9% of all raptor observations, respectively. We observed osprey, sharp-shinned hawks (*Accipiter striatus*), red-tailed hawks (*Buteo jamaicensis*), and northern goshawks (*Accipiter gentilis*), each at frequencies between 3% and 5%. We made single observations of the American kestrel (*Falco sparverius*), merlin (*Falco columbarus*), great-horned owl (*Bubo virginianus*), saw-whet owl (*Aegolius acadicus*), short-eared owl (*Asio flammeus*), northern harrier (*Circus cyaneus*), and broad winged hawk (*Buteo platypterus*).

1999: We located one active prairie falcon eyrie and four active golden eagle nesting areas. Golden eagles comprised 34% of all sightings. Prairie falcons and sharp-shinned hawks were also common, comprising 22% and 13% of all sightings, respectively.

Field of Inquiry: **Wildlife Biology/Ornithology**
Investigators: **Brett Walker, Suzanne A. Cox, John E. Lundblad, Erick P. Greene and Byron V. Weckworth**

Project Title: **Distribution, Breeding, Demographics and Taxonomic Status of Timberline Sparrows in Glacier National Park**

Objectives: 1) to determine whether analysis of pre-pairing song recordings of timberline sparrows (*Spizella taverneri*) could be used to estimate adult male survival and recruitment, **2)** record, capture, measure, photograph and collect feather samples from male sparrows at five locations in the park, and **3)** survey additional habitats and document breeding status at each location.

Summary: The timberline sparrow was recently confirmed breeding in the park. We were unable to assess the usefulness of pre-pairing songs for monitoring demographics because most males were paired up and had stopped singing pre-pairing "short" songs when we arrived on June 9. However, we successfully captured 28 males and one female at five locations and we obtained morphological data, feather samples, qualitative habitat information and song recordings. Plumage features, morphology, habitat use and acoustic structure of vocalizations support the original identification of the Glacier Park population as timberline sparrows rather than Brewer's sparrows (*S. breweri)*. We located an additional 110+ territorial males in 1999. Combined with 1998 data, this suggests that in any given year at least 200-250 pairs of timberline sparrows breed at 26 or more locations in the park. Genetic analyses of feather samples are scheduled for April-June 2000.

Field of Inquiry: **Wildlife Biology/ Ornithology**
Investigators: **Paul Hendricks and James D. Reichel**

Project Title: **Harlequin Duck Investigations**

Objectives: Study objectives are to: **1)** capture and band adult ducks during spring pairing season and capture adult females and/or broods during mid-summer brood season, **2)** document sightings of previously marked individuals, and **3)** survey streams in northwestern Montana to gather additional productivity data and document their use by Harlequin ducks.

Summary: The spring of 1997 was poor for Harlequin duck pair surveys due to heavy and late-laying snowpack. Spring pair surveys were not conducted in Glacier National Park due to high water. Spring pair surveys were conducted only on the Lower Clark Fork.

A park-wide total of 15 ducks were captured and banded during the August brood survey, including three recaptures of adult females, each with a brood. One of these was the first bird in the park banded as a juvenile that had subsequently been observed with a brood of its own. Total ducks captured included two new adult females, three recaptured females and 10 young of the year. One recaptured female with a brood of two was captured on the Waterton River; the remainder were captured on McDonald Creek.

Banding on streams outside of Glacier National Park resulted in the capture of five adult females ducks (two previously banded) and 18 young of the year in five broods. Blood was sampled from all birds (n=38) captured in and out of the park. Genetic analyses from blood samples are being done at the University of California, Davis.

For all streams surveyed in August (including Glacier National Park), brood sizes (n = 10) were: two broods of 6, a single brood of 5, two broods of 4, two broods of 3 and three broods of 2 Harlequin ducklings. Reproduction was documented on 7 of 10 streams surveyed. Three adult female ducks (from the 1995 cohort) were observed this year on their natal streams without broods. Female Harlequins rarely breed successfully before their third year so it is anticipated that more females from the 1995 cohort will be observed next year with broods.