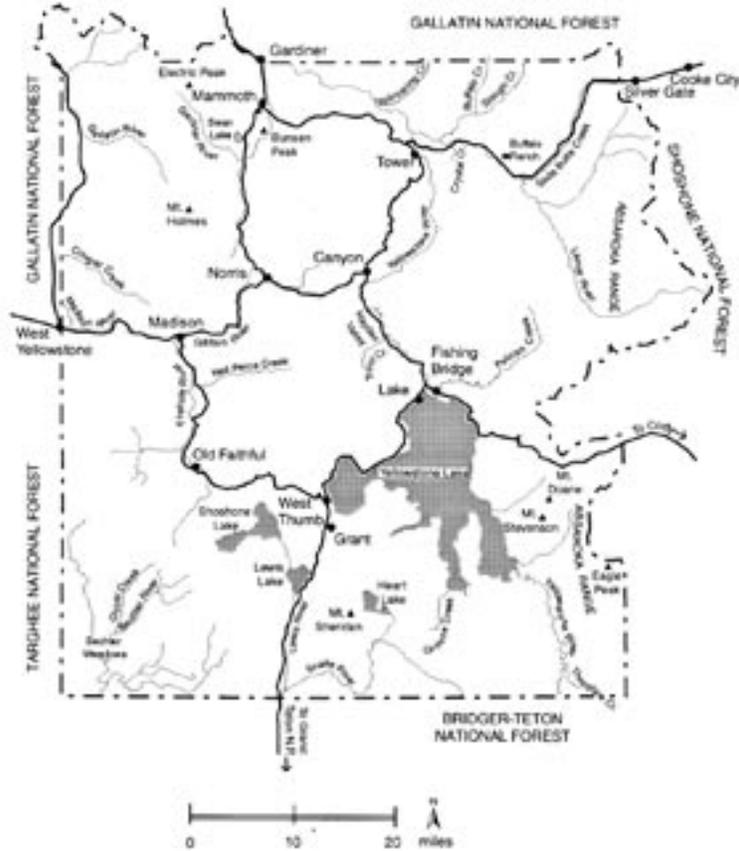


INVESTIGATORS' ANNUAL REPORTS 2001



YELLOWSTONE NATIONAL PARK



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Yellowstone Center for Resources

P.O. Box 168

Yellowstone National Park, Wyoming 82190

November 2003

YCR Investigators' Annual Report: YCR-IAR-2003

Cover: Spire segments found on the floor of Yellowstone Lake at Bridge Bay. Photo courtesy of Dr. Russell Cuhel, University of Wisconsin-Milwaukee.

Acknowledgements: The National Park Service thanks the researchers who have contributed to our knowledge and understanding of Yellowstone. This report was compiled and edited by Christie Hendrix and Virginia Warner.

FOREWORD

Since the dawn of scientific wondering, human inquiry has led to the exploration, and often alteration, of almost everything in our world, at every scale—from the landscape of the moon to the human genome. In the national parks, however, through varying definitions and to varying degrees of success, we have attempted to “preserve natural conditions” for the past 130 years.

Their long-term preservation of natural resources makes parks reservoirs of information of great value to humanity. Today more than ever before, America’s national parks are viewed as more than pleasuring grounds and nature preserves. The NPS’s Natural Resource Challenge urges that in addition to using science as a means to improve park management, parks can and should be centers for broad scientific research and inquiry.

The national parks have long-captured the imagination of scientists, who recognized them as places where we could observe natural processes operating in places that had been less subject to human alteration than most others throughout the nation, and indeed throughout the world. In Yellowstone, those kinds of observed processes have ranged from macro-scale studies of landscape changes affecting the local ecosystem to micro-scale studies of tiny organisms that have the potential to change the lives of people the world over, making the protection of this wilderness relevant and crucial even to those who will never know its aesthetic and recreational wonders.

There are more than 300 index entries in this year’s Investigators’ Annual Report. That is a lot of scientific knowledge to be shared. This report should not be seen as the body of that knowledge, but rather as its skeleton. Contact information is provided so that readers may learn more about the projects and results described here. Project findings are also available on the NPS website (<http://science.nature.nps.gov/permits/index.jsp>).

All persons who wish to conduct their own research in Yellowstone are required to apply for a permit. Information on permitting procedures is available from the Research Permitting Office, Yellowstone Center for Resources, P.O. Box 168, Yellowstone National Park, WY 82190.

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ANIMAL COMMUNITIES

Project title: Epidemiology and Pathogenesis of Brucellosis in Bison of Yellowstone National Park

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Additional investigators: Jack Rhyan, Keith Aune

Objective: Determine the natural course of brucellosis in free-ranging bison; determine modes of transmission; provide information on the prevalence of infection and abortion.

Findings: We removed radiocollars from our research animals fall of 2001. We located a large number of birthsites (42) during the spring of 2001, from both collared and noncollared animals. Bison apparently develop clinical brucellosis during their first pregnancy after exposure to the bacteria. Repeat reproductive failures, induced by brucellosis, appear to be uncommon. The primary route of transmission appears to be through contact with culture positive birthsites and birth products shortly after calving has occurred.

Project title: Bison and Elk Responses to Winter Recreation in YNP

Principal investigator: Dr. Robert Garrott
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Bozeman, MT 59717

Additional investigator: Scott Creel, Amanda Hardy

Objective: This study addresses bison and elk responses to winter recreation in the upper Madison River drainage of Yellowstone National Park. Using data on weather; winter recreation activity; elk and bison distribution, behavior, abundance, and fecal stress hormone (glucocorticoid) levels collected during the winters of 1998–1999 and 1999–2000, we developed models to analyze if variables related to winter recreation contributed to bison and elk distribution, behavior, and stress hormone level responses.

Findings: The distribution models were inconclusive in terms of human activities displacing bison or elk from the road corridor (n = 1811 bison groups and 884 elk groups; R² results for 4 models ranged from 0.10 to <0.01). Behavioral responses increased as distance between human activities and bison (n = 2189 group observations) and elk (n = 1097 group observations) decreased (P < 0.001 for both species). Both species behaviorally responded more often to people off-trail than to people on trails (bison n = 377 group observations, elk n = 220 group observations; P < 0.001 for both species), and human activities afoot prompted proportionately more behavioral responses than human activities on roads. Elk had higher stress hormone levels after exposure to >7,500 cumulative vehicles entering the West Yellowstone gate (n = 987; P = 0.002). Elk residing along the road segment with the greatest amount of oversnow vehicle (OSV) activity had higher stress hormone levels compared to elk residing along the less-traveled road segment (P < 0.001). As the daily number of vehicles entering the West Yellowstone gate increased, elk stress hormone levels increased (P = 0.057) while the probability of bison and elk behaviorally responding to human activities on the road decreased (P = 0.001 for both species). The predictability and frequency of OSV activities facilitated habituation to the majority of winter recreation activities. Abundance estimates indicated populations of wintering bison increased and wintering elk remained stable over 20 years. Despite varying responses to increased winter visitation since the late 1970s, bison and elk winter in the same area each year, coexisting with winter recreation without experiencing declining population numbers.

Project title: Predator–Prey Dynamics in a Wolf–Ungulate System

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Additional investigator: Rose Jaffe, Eric Bergman, Doug Smith, Kerry Murphy

Objective: The goals of the study are to quantify wolf predation rates, and prey selection, and to assess wolf predation impacts on the ungulate populations in the Madison, Firehole, and Gibbon drainages of Yellowstone National Park. Wolf spatial dynamic data are being collected on four scales in order to model how different factors (prey distribution, prey abundance, landscape features, snow pack and temporal trends) affect landscape use. Specific objectives include: 1) estimating winter ungulate abundance and composition, 2) estimating the amount of predation ungulates are subjected to over time (wolf days); 3) describing prey selection patterns; 4) describing temporal patterns in kill rates, both within and between winters, 5) estimating ungulate offtake by wolves according to species, sex, and age class, 6) describing recolonization patterns of the prey system based on wolf home range variation between winters, 7) determining wolf core use areas within the study area, 8) assessing factors that influence localized wolf movements, and 9) finding wolf kill sites and assessing which features influence their location.

Findings: Predation and spatial data is still being collected. Data has been systematically collected between November and May since 1998. Daily ground telemetry and snow tracking of wolves is performed to determine wolf distribution, abundance, and to locate kills. Necropsies are performed to ascertain the species, sex and age classes of kills. Locations of kills are recorded to examine kill distribution. The amount of data collected is determined by daily wolf activity. One hundred sixty definite and 31 probable wolf kills have been located during the study for a total of 187 kills. The species/sex/age breakdown of wolf kills has been 97 elk calves, 61 cow elk, 11 bull elk, 2 unknown adult elk, 15 bison calves, 1 cow bison and 1 unknown bison. An analytical method was developed to estimate smoothed kill rates across time using a moving window average and a weighting scheme to account for undetected kills. When applied to 1998–1999 and 1999–2000 winter data, this technique indicated that approximately 30% of the wolf kills were undetected. Estimated kill rates (kills/100 wolf days) calculated for 1998–1999 and 1999–2000 nearly doubled from fall to spring each winter, and were nearly twice as high the first year (11.8) as the second year (6.5). Differences between the 1998–1999 and 1999–2000 winters included snow pack, above average in 1998–1999 versus below average in 1999–2000, and wolf pack size, 7 and 13 animals. Estimated elk calf offtake was 20–25%, the highest among prey types. Wolves were triangulated from the ground 51, 88 and 145 times during each of the 1998–1999, 1999–2000 and 2000–2001 winters, respectively. The distribution of locations changed between winters, with the Gibbon drainage progressively becoming more included across the three winters. Wolf snow tracking was consistent across the winters of 1998–1999, 1999–2000, and 2000–2001, with 300 km, 302 km, and 341 km of tracks collected respectively. Distribution of tracks across the study area changed between winters, with an expansion of space used over the three years. The spatial distribution of kill sites has also been variable across the three winters.

Project title: Determining Bison Response to Mock Vaccination Approaches for Evaluating the Feasibility of a Remote Bison Vaccination Program in Yellowstone National Park: Phase I

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Additional investigators: McCrea Cobb, Mark Biel, John A. Mack, Travis Wyman

Objective: The primary purpose of Phase I is to determine the closest distance that park staff can safely approach bison on foot, horseback, snowmobile, and by vehicle during each of the four sampling seasons, while simultaneously minimizing stimulation of bison flight or aggressive responses. The bison management plan calls for YNP to be vaccinating bison with a remote delivery device before the third and final step of management actions outlined in the Record of Decision (ROD) will be initiated. Consequently, park managers must know 1) how effectively NPS staff can approach wild bison and not subject themselves to unnecessary safety hazards, 2) whether similar

methods of approach can be used throughout the park, and 3) whether biologists or technicians can approach wild bison to distances close enough to deliver a vaccine using current ballistic technology.

Findings: We observed a total of 6,303 bison over 208 individual approach sequences. In general, the initial reaction of bison to observers was minimal. The most prominent behavior when bison were first encountered was feeding and resting. There were no initial aggressive reactions. Initial attention/alarm reactions were only seen in two survey areas within the Madison/Firehole (4.35%). Bison in Yellowstone's northern range show more diverse activity at all stops than bison in the other survey areas including a greater percentage of anxiety responses such as ambling and running away.

Flight reactions occurred quite often in the northern range. From 42 total approaches in the northern range, flight reactions occurred 28 or 67% of the time. By comparison, in the Madison/Firehole area, out of 97 total approaches, flights occurred 29 or 30% of the time. In the Hayden Valley area and other areas, findings were similar to Madison/Firehole.

During the approaches, a sense of minimum or average minimum safe distances humans can approach bison was determined. There was, however, a great deal of variation. Generally, if a crew successfully approached to within 100 meters, they could also get to within 75 meters 100% of the time. Once at 75, 50 meters was attainable over half the time. There were times, however, when observers could not get to within 100 meters. We determined no pattern that can be used in future approaches to predict bison behavior a priori with any absolute certainty. Feasibility of a remote vaccination program is not simply how close humans can get to bison, but how safely, efficiently, and reasonably the remote vaccination process can be implemented.

The key point is that bison are not pushed into moving or behaving in a certain way but persuaded to do so. We believe this concept is the key to future successful approach and vaccination operations.

Pressure is defined by the following five determinants: 1) Distance (smaller the distance = the greater the pressure), 2) Location of Observers (Observers close together = more pressure), 3) Number of Observers (more observers = more pressure), 4) Predators in Area (Predators = Pressure), 5) Climate and Topography (Increase in environmental variables = more pressure).

Pressure release is as important as pressure applied. These two concepts in conjunction will influence bison behavior. An example of a pressure release is lateral movements. When maneuvering around bison, expert and timely application of lateral movements combined with direct movements influence bison group dynamics.

Parkwide it appears that bison can be approached to within 100 meters 92% of the time on foot and 87% of the time by horseback. The current remote delivery technology suggests that the B.T.I. compressed air rifle can deliver vaccines to distances as far out as 50 meters. If the technology improves enough to successfully deliver a vaccine that penetrates the skin of a bison calf or yearling at 50 meters, this study shows that vaccinating eligible individuals could be successful at least 68% of the time. By selecting an appropriate transportation mode relative to the location within the park and combining that with selective timing throughout the year, the frequency of successful approaches would be even greater.

The one caveat at this stage of investigation is that there appears to be a difference in approach distance expectations on the northern range of Yellowstone. A chi square test comparing observations of approach on the northern range and observations in the central portion of the park indicates a probability of less than 0.1% that approachability in these two areas are equal. Consequently, alternate strategies for

getting close to bison on the northern range may need to be developed.

Project title: Fecundity and Fawn Mortality of Northern Yellowstone Pronghorn

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Objective: Assess pregnancy status of all collared females. Capture fawns to record birth date, mass, and foot length, to attach a solar powered ear tag transmitter, and to obtain a two-gram tissue sample. Monitor fawns to record date of death and probable cause. In August, map locations of pronghorn groups, and count males, females, and fawns.

Findings: Twenty collared females were present in August 2000, and all were present at the start of the field season in May 2001. One female was killed by coyotes in early June and another was found dead in the Yellowstone River on November 10.

Of 20 females, we saw 18 in late stages of pregnancy. One female (795) was not pregnant for the third year in a row. Status of the other female (193) was uncertain. The minimum pregnancy rate is $18/20 = 90\%$. We obtained good estimates of the birthing dates of the 18 pregnant females that gave birth between May 21 and June 20. The median birth date was May 30. We weighed nine fawns born to six different females. Mean adjusted birth mass (Mass at capture - [days age at capture x 0.2446]) was 2.95 kg.

Of the nine fawns captured, six were male and three were female. In the late summer count of 26 surviving fawns, 13 were male and 13 were female. One of nine (11%) of the ear-tagged fawns survived to August. Overall, six of the 36 (17%) fawns born to the 18 collared females were alive in early August. The median age of death of fawns was five days. In early August, we counted 93 adult females and with them 26 fawns. Ten of the 26 fawns were in the pronghorn group at Carbella, north of the park.

One adult female (163) was found dead and partly eaten by coyotes six days after the normal birth of her fawns. One adult female (884) was found in the Yellowstone River near Gardiner. This female was estimated to be 3–6 years of age when captured in 1989, so it is unlikely that her death was age related.

ANTHROPOLOGY

Project title: People and Nature: Yellowstone as Landscape

Principal investigator: Dr. Raymond Fenio

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Objective: This research will provide an ethnographic study of a National Park. The descriptive data provided by ethnography are not easily assembled by other methods. By living in a place and observing, as well as talking with the people who visit, work, and reside within it provides a greater depth of understanding. In discovering what people do when they experience Yellowstone, what they expect and how these expectations shape their attitudes about parks, wilderness and recreation, this research should provide a valuable contribution to park management and hopefully encourage and invite thoughtful dialogue over what culture and nature means and their relative value in emerging policy.

Findings: This research is ongoing. However, some interviews have been conducted with visitors and employees. Observations about what visitors actually do have been recorded but without any results or conclusions at this time.

ARCHEOLOGY

Project title: Archeological Investigations in Yellowstone National Park

Principal investigator: Dr. Leslie Davis

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Additional investigators: Ann Johnson, Brian Reeves

Objective: Conduct National Register testing at selected sites to determine research potential and to investigate qualities of a traditional aboriginal ford; continue inventory of rivers and streams in the park; and conduct archeological inventory in support of the trails program.

Findings: The past year was again busy, with 1,200 acres inventoried and 49 new sites. Volunteer John Reynolds entered catalog data on 1,800 archeological specimens or groups of specimens. Inventory on backcountry trail segments proposed for reconstruction were inventoried at Shoshone Lake, South Boundary, Fan Creek, Heart Lake/Outlet Creek, and Pelican Creek. Seven new sites were documented. The long term project to inventory waterways in the park continued at lower Lamar River/lower Slough Creek and blocking up areas on the Yellowstone river.

National Register testing was accomplished for sites on both sides of the Yellowstone River at the Bannock Trail ford at Tower Falls. However, the archeological data of this ford does not meet expectations of a traditional ford, which we suggest should have evidence of many groups camping and staging, probably on both sides of the river as people were getting ready to cross or drying out afterwards. While there are suitable terraces on both sides of the river at this location, the terraces contain limited evidence of pre-historic use. There was no evidence for use during early historic or Late Prehistoric times.

There are physical reasons this may not have been a favored ford. The Yellowstone River roars through a steep, relatively narrow canyon that would be difficult to ford until high water was over. Additionally, the path up (or down) the eastern bank is very difficult, being steep and sandy.

Aubrey Haines in *The Yellowstone Story* documents use of the Bannock Trail near Tower by various explorers, and Wayne Replogle in his book on Yellowstone's Bannock Indian Trails very clearly says that (writing in the early 1950s) he could see evidence of the trail in this area. We believe these sources of information to be reliable. As we can find no trace today, 50 years later, may suggest limited use and that this area may not be a traditional ford. The evidence seen by Replogle may represent use of this route at a late date as Indians tried to avoid identification by the Cavalry or other whites. Interestingly, testing of the archaeological sites did not identify evidence of historic or protohistoric use.

Three sites on another prominent creek were tested, including the one at the ford. Here, the archaeological materials on both sides of the ford are plentiful and represent long use, both temporally and intensively, of this locality. All traffic in this area is channeled to this ford as the creek earns its name annually and this is the best place to cross it. The sites up the creek from the ford are smaller with fewer compo-

nents at each, probably representing groups traveling up and down Hellroaring Creek with shorter stays due to more limited resources. This testing has allowed us to put the two sites at the ford into perspective and to see their relative importance.

Project title: Geochemical Investigations of Obsidian Source Material

Principal investigator: Mr. Kenneth Cannon
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Additional investigators: Richard E. Hughes

Objective: To collect provenance and geochemical data on geologic sources of toolstone quality obsidian. This database will be used to compare geochemical data of artifacts for discerning aboriginal use of obsidian sources. This information will be useful in determining patterns of lithic procurement and land use in the Greater Yellowstone Ecosystem and beyond.

Findings: Funding has been sought for 2002 through the National Center for Technology Transfer.

Project title: Chemical Analysis of Obsidian Sources and Artifacts from the Northwest and Great Plains

Principal investigator: Dr. Michael D. Glascock
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Additional investigator: Craig E. Skinner

Objective: Continue to expand chemical database of obsidian sources in Yellowstone National Park and surrounding areas. Utilize the database to establish the provenance of obsidian artifacts found in the Great Plains, etc.

Findings: Dr. Michael D. Glascock and Mr. Craig Skinner are continuing their research project on the characterization of obsidian sources in Yellowstone National Park and the surrounding region. We recently acquired additional source materials from sources on the Idaho–Wyoming border and added these to our database following analysis by NAA and XRF. Dr. Glascock collaborated

with Dr. Brian Molyneaux on the analysis of obsidian artifacts from Devils Tower. About 50% of the obsidian artifacts were sourced to Obsidian Cliff, but other sources in Idaho such as Malad and Bear Gulch, and Mineral Mountain (a source in south-central Utah) were also identified. Dr. Molyneaux used these results to write a chapter entitled “Exploring the Landscapes of Long Distance Exchange: Evidence from Obsidian Cliffs and Devils Tower, Wyoming” for an edited volume entitled “Geochemical Evidence for Long-Distance Exchange,” edited by Dr. Michael D. Glascock. Dr. Glascock and Mr. Skinner plan to continue our research on the study of obsidian sources in the Yellowstone region. A publication of the entire project is possible in 2003.

Project title: Parkwide Road Improvement—Data Recovery

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Additional investigators: Paul Sanders, David Eckles

Objective: Data recovery efforts were conducted at the historic Tower Soldier Station (48YE163) to mitigate potential effects from proposed highway construction.

Findings: Four 1x1 m units were excavated at the site that was occupied from 1903 to 1907. Excavation unit 1 investigated a potential historic trash pit, but found it to be a natural depression, possibly a tree tip-up. Excavation units 2 through 4 investigated the Officers Quarters location. Deteriorated wood flooring was found in units 3 and 4 that represent the south wall of the former 10 x 12 foot structure. A few nails, metal and glass fragments and one butchered medium-sized mammal bone were recovered from the excavation units. A few prehistoric artifacts were also recovered, indicative of an earlier prehistoric occupation. No significant materials were found in the area of proposed construction, although materials outside of the proposed construction area continue to hold additional research potential.

BOTANY

Project title: Physiology of Thermotolerant Plants in Yellowstone Park

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AB 119

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Additional investigator: Thamir Al-Niemi

Objective: To use flowering plants seemingly adapted to geothermally modified environments of Yellowstone as model organisms for the study of stress physiology mechanisms.

Findings: In 2001, individuals of the species *Dichanthelium lanuginosum* were collected from several study sites within YNP and used for both protein and genetic analyses. Two basic findings are as follows. First, the expression of at least two classes of heat shock proteins is detectable in root extracts from plants on warm soils. Secondly, preliminary genetic analyses suggest that sub-populations of plants may exist along soil temperature gradients within a relatively small area.

Project title: Birds, Bees, Butterflies, and Botany

Principal investigator: Dr. Peg Steuneberg

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Additional investigators: Heidi Gough, Lee Krumholz, Sam Webb, Jesse Dillon, Amy Dahl, Sue Fishbain

Objective: To teach the basics of botanical illustration following the conventions of scientific illustration.

Findings: N/A

Project title: Yellowstone Flora

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Objective: The vascular plant flora of Yellowstone, even though investigated for approximately 120 years, is not completely known. The primary focus of this project is to improve the current knowledge of the flora of the park through in-depth collecting, especially of areas in the park that have not been previously studied. This includes inventory of the occurrence and range of native taxa and also involves the documentation of the arrival and spread of exotic species. In addition, collection of specimens for the Yellowstone herbarium will improve the value of the facility for both NPS personnel and outside researchers.

Findings: Ongoing inventory of vascular plants and collection for the Yellowstone National Park Herbarium (YELLO). Four species of vascular plants previously not reported as occurring within the park were discovered. One taxa, *Oxytropis deflexa* (Pall.) DC. var. *foliolosa* (Hook.) Barneby, is a native species that was located apparently for the first time within the park. The other three species, *Trifolium dubium* Sibthorp, *Ambrosia psilostachya* DC., and a *Cerastium* of which the correct identification is still pending, are all exotic taxa that have become recently established within the park. Additionally, a population of *Atriplex canescens* (Pursh) Nutt. was discovered in the park. Previous reports of this species were based on misidentifications or specimens that the material was so limited that a definitive identification was uncertain.

Project title: Evolution and Habitat Requirements of *Agrostis rossiae* Vasey, a Grass Endemic to Thermal Soils in Yellowstone National Park

Principal investigator: Dr. Steven Darwin

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Additional investigators: Michael Tercek

Objective: *Agrostis rossiae* ("Ross's Bentgrass") is a grass that is endemic to thermal areas in southern Yellowstone. Previous studies have shown that *Agrostis* species are able to rapidly differentiate into genetically distinct populations when specialized soil conditions are present. These genetic differ-

ences are maintained by strong natural selection despite continued cross-pollination between the populations. The goals of my study are as follows: 1) to use genetic markers to determine whether *A. rossiae* is a valid taxon that is distinct from other co-occurring *Agrostis* species and therefore worthy of special protection, 2) to determine the evolutionary history of *A. rossiae*, find its sister taxon (closest relative), and determine whether it is monophyletic, i.e. has evolved only one time or more than once in response to geothermal habitats, and 3) to determine its habitat requirements, discover which ecological factors are responsible for its restricted distribution.

Findings: With considerable help from the Yellowstone GIS lab, I have completed mapping of all known *A. rossiae* populations. Collection of field data (soil temperature, soil moisture, seed collection, other sampling) continues. These data are being used to design growth chamber experiments that are conducted at Tulane University. Genetic data collection should be completed by May 2002. The entire research project should be completed by December, 2002. For additional information send email to mtercek@tulane.edu or visit <http://agrostis.topcities.com>.

Project title: Vascular Flora of the Greater Yellowstone Area

Principal investigator: Mr. Erwin Evert
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 Park Ridge, IL 60068

Objective: To collect vascular plant specimens as vouchers for distribution maps to be included in the investigator's "Flora of the Greater Yellowstone Area."

Findings: Four species known previously in Yellowstone National Park only from one or two other locations: *Gymnosteris parvula*, Hayden Valley; *Carex brevior*, Seven Mile Hole; *Rubus acaulis*, one mile west of Cascade Lake; *Pyrola picta* var. *dentata*, Elephant Back Mountain.

Project title: Aspen Regeneration in Northern Yellowstone National Park

Principal investigator: Dr. William J. Ripple
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Additional investigators: Eric J. Larsen, Douglas W. Smith, Roy Renkin

Objective: Our objective was to measure aspen regenerative success on YNP's northern range.

Findings: Based on trophic cascades theory, we hypothesized that wolves may displace elk from some areas of the northern range, thus allowing more robust aspen regeneration in areas of higher wolf presence. Using radio telemetry data on wolves, we assigned a probability of wolf presence in each of our sampled aspen stands. Permanent 1 x 20 m belt transects (plots) were established in the aspen stands, marked with both a metal identification tag on a large-stemmed aspen tree and nails in the ground at 3, 5, 10, and 20 m from the starting point.

Our second set of field data was collected from our 112 aspen plots during August of 2001. Aspen overstory density and diameter at breast height (DBH) were recorded. Sucker density, heights, and whether the suckers had been browsed the previous winter were recorded. The number of elk pellet groups was recorded for each plot. The generalized habitat type of each aspen stand was recorded using the categories of mesic upland steppe, xeric upland steppe, and wet meadow/riparian. The aspect, slope, elevation, and recent fire history of each stand were recorded. Findings from our previous field research were published in the December 2001 issue of *Biological Conservation*.

ECOLOGY

Project title: The Ecological Relationship Between a Rocky Mountain Threatened Species and a Great Plains Agricultural Pest

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Reno, NV 89557

Additional investigator: Hillary L. Robison

Objectives: 1) To determine where army cutworm moths (*Euxoa auxiliaris*) (ACMs) originate. Pressures on ACM subpopulations, either natural (e.g., weather patterns) or human-caused (e.g., pesticides, habitat conversion), may affect moth recruitment and the numbers of adults reaching high elevation sites, where they are a critical food source for the threatened Greater Yellowstone Ecosystem grizzly bear (*Ursus arctos horribilis*). 2) To determine if ACMs harbor agricultural pesticide residues in their tissues. Resulting pesticide magnification in grizzly bears that forage heavily on moths may have detrimental physiological or developmental side effects. 3) To elucidate the effects of weather on ACM migration from Great Plains agricultural areas to ACM aggregation sites in the Rocky Mountains. 4) To determine whether ACMs from different Great Plains origins are interbreeding in high elevation sites prior to their return to agricultural areas. If ACM subpopulations do not interbreed, unfavorable conditions in specific Great Plains areas may impact moth numbers in high elevation.

Findings: To date, army cutworm moths (*Euxoa auxiliaris*) (ACMs) have been collected for genetic and reproductive analyses from a total of 11 high elevation sites, including nine sites in Wyoming, one site in Washington, and one site in New Mexico. ACMs have been collected from 39 low elevation sites in Montana, Wyoming, Nebraska, and South Dakota. The sampling effort comprises a 360-degree radius around the high elevation study areas.

ACMs were collected for pesticide residue analysis during the 1999 and 2001 field seasons. Analyses of these ACMs showed no biologically significant traces of pesticides in the ACMs. Genetic analyses on the ACMs are performed in the Laboratory for Ecological and Evolutionary Genetics at the University of Nevada, Reno. Each of these several thousand ACMs must be individually keyed out to species and then their DNA may be extracted. A genomic DNA library was developed for the ACM. This library was screened for microsatellite loci and primers were developed to amplify these loci in polymerase chain reactions (PCRs). PCRs are being optimized for these loci, and analysis of the variability at these loci is beginning. Analysis of the variability at these loci will aid in determining whether ACMs interbreed in high elevations and in determining their Great Plains origins.

Project title: Collection and Use of Plaster Castings of Animal Tracks to Teach Wildlife Ecology to College and K-12 Students

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Additional investigators: Bruce D. Eshelman

Objective: We propose to collect plaster casts of animal tracks that we find along the Lamar River and Soda Butte Creek. This exercise will be conducted during a three credit field course offered through the University of Wisconsin–Whitewater for college students and K–12 educators. We wish to introduce wildlife management techniques such as track interpretation. Participants will be asked to identify tracks (to genus and species if possible), interpret any behavior suggested by the tracks and prepare plaster castings. Many of the participants are, or plan to become K–12 teachers, and these techniques will be useful in outdoor education. Selected castings will be used for later testing of the participants during course exams. Selected castings will also be displayed in a comparative and interpretive collection at the University of Wisconsin–Whitewater, Biology Museum. The castings will also be used in the University of Wisconsin–Whitewater Outreach Program for K–12 schools and local Scout troops. The castings are used to make latex negatives for duplication of the original. These duplicates are then used in lectures about wildlife ecology and Yellowstone National Park given by Dr. Clokey. Each year, 10–20 duplicate castings are made and distributed to a K–12 class during the lecture. All castings are for educational purposes only and are not for sale (they are marked with the collection location, animal and a statement saying not for sale). Participants in the course are allowed to keep duplicates of castings and are told that they are to be used for educational purposes only. We collect within 200 yards of established trails. We are discreet and clean up all plaster and material. We are aware of and respect the rights and interest of other users.

Findings: Tracks of coyote, wolf, grizzly bear, bison, pronghorn and raven were studied along the Lamar River and Soda Butte Creek. About 7–10 plaster casts were made for the bear and wolf tracks each and two casts were made for each of the other species. Selected castings were used for educational purposes at the University of Wisconsin–Whitewater Museum (we kept several good wolf tracks and one good bear track for the University display). Students in the course were allowed to keep duplicates of the bear and wolf tracks. We plan to continue teaching the course until 2005 and will seek permission to collect similar tracks at the same locations each year.

Project title: The Sustainability of Grazing Ecosystems

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Additional investigators: Peter Groffman

Objective: Examine the effects of grazing mammals on grassland primary production and nutrient cycling.

Findings: In 1998, we established 10 grassland sites in the park ranging widely in elevation, seasonal use by ungulates, plant production, and soil conditions. At each site, we established permanent exclosures to create an ungrazed treatment. Since 1999, we have measured aboveground and belowground production inside and outside the exclosures at each of the sites to determine the effect of grazing on grassland production. In addition, in 2001, we measured in situ net N mineralization inside and outside exclosures at six of the sites.

Plant production data from 1999 indicate that ungulates increased both aboveground and belowground production. Belowground production was stimulated seven times more than aboveground production. Data from 2000 and 2001 are currently being analyzed. In addition, soil extractions from 2001 to examine the effects of grazers on N mineralization have not been analyzed.

Project title: The Impact of Climate Change on Alpine Plant and Insect Diversity in the Rocky Mountains

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Additional investigators: Eric DeChaine

Objectives: The goals of this study are to determine the impact of climate change on the biological diversity of alpine plants and insects in the Rocky Mountains and the degree to which national parks may conserve this diversity. These objectives will be accomplished by inferring the shared phylogeographic history of alpine plants and insects through genetic analysis of the geographic structure and history of populations of plant-insect associations throughout the Rockies. This analysis will not only reveal how historic climate change affected population structure, but also permits

the identification of national parks that harbor relatively high levels of diversity.

First, it must be determined whether independent taxa share a common history. The null hypothesis is that the phylogeographic history of each species is unique. The null predicts no concordance in the timing of diversification events or topography among area cladograms for the different taxa. The alternative hypothesis is that independent taxa share a common history and predicts that co-distributed species will have similar area cladograms.

The shared history of taxa will be used to estimate how extrinsic factors contributed to the distribution and diversity of these co-distributed organisms. The null hypothesis is that there is no geographic structure to the distribution of diversity. This hypothesis predicts that geographic lineages are distributed randomly on a phylogenetic tree. Analysis of the historic shifts in the distributions of alpine habitats suggests an alternative hypothesis that the southern Rockies served as a refuge and harbored species for longer periods of time than northern portions of the modern range. This hypothesis predicts that lineages in northern populations will be more recently derived than southern populations and only a fraction of the diversity present in the south will be represented in the north.

The study taxa: In order to acquire a representative sample of the alpine community and incorporate interspecific interactions into the examination of how climate change affected biological diversity, this study will analyze the phylogenetic histories of three specialized plant-insect interactions. These associations 1) range from the southern Rockies where the effects of habitat fragmentation due to climate change are most severe to northern areas that were completely covered by Pleistocene ice sheets, 2) are predominantly influenced by climate, 3) are abundant and play integral roles in the alpine community, 4) are relatively easy to find and collect, and 5) include taxa for which molecular techniques are well developed. Herbaceous plants and insects have been shown to be excellent bio-indicators of climate and environmental change.

Two pairs of alpine plant–butterfly associations will be used to estimate the geographic distribution of biological diversity. The study organisms are 1) the yellow stonecrop *Sedum lanceolatum* (*Crassulaceae*) and the Rocky Mountain Apollo *Parnassius phoebus* (*Papilionidae*) and 2) the alpine clover *Trifolium dasyphyllum* (*Fabaceae*) and Mead’s sulfur *Colias meadii* (*Pieridae*). Though the associations are relatively specific, variation in host use occurs throughout each species’ range.

Findings: Specimens of *Sedum lanceolatum*, *Parnassius phoebus*, *Trifolium dasyphyllum*, and *Colias meadii* were collected from 22 alpine sites throughout the Rocky Mountains, including Glacier National Park, the Greater Yellowstone Ecosystem, Rocky Mountain National Park, and the southern Rockies of Colorado. In Glacier National Park specimens were collected at 1) Numa Peak, 2) Gunsight Mountain, 3) Triple Divide Peak, and 4) Dawson Pass. In the Greater Yellowstone Ecosystem, the alpine sites in Yellowstone National Park were on 5) Amethyst Peak and 6) Mt. Washburn, while in Grand Teton National Park, specimens were collected from 7) Moose Mountain and 8) Static Peak. Organisms were collected from alpine tundra in Rocky Mountain National Park on 9) Sundance Mountain and 10) Long’s Peak. Specimens were also collected from eastern slope sites in Idaho, including 11) Hyndman Peak and 12) Borah Peak, and from potential southern refugia sites in Colorado including: 13) the American Basin, 14) San Luis Peak, 15) Humboldt Peak, 16) Iron Nipple, 17) Mt. Democrat, 18) Mt. Elbert, 19) Mt. Shavano, 20) Quandary Peak, 21) Maroon Pass, and 22) Pike’s Peak.

In order to obtain an accurate estimate of genetic variation and thus population history, it is necessary to sample DNA from many individuals of each population. Twenty to thirty specimens of each species were collected at each site. Sites were accessed on foot. Butterflies were collected with a

net and stored in glassine envelopes. To preserve the organisms and their natural environment, only parts of plants were collected. Leaves were sampled by hand from approximately thirty individuals of each species and stored in plastic bags. Specimens were carried out of the field, transported on ice, and stored at 80°C at the University of Colorado, Boulder.

Methods for assessing evolutionary histories and diversity: Nuclear as well as mitochondrial (mtDNA, insect) or chloroplast (cpDNA, plant) DNA was sequenced, in order to develop phylogenetic trees. DNA was extracted from the insects and amplified with specific primers for the mitochondrial Cytochrome Oxidase I. DNA was extracted from the plants and amplified with specific primers for the chloroplast intergenic spacers between trnL and trnF and between trnL and trnT.

Phylogenetic trees and nested clades were generated from DNA sequence polymorphisms to infer hypothetical evolutionary relationships among haplotypes (unique genetic sequences) within each species.

Results to date: The strength of the historic signal between the herbivorous insect and its host-plant suggest that biotic factors may be responsible for evolution in these organisms, and that there is a strong potential for co-evolution. Importantly, these findings point to ecological and evolutionary stability of the alpine community. Preliminary analysis revealed significant co-divergence of the host plant (*Sedum*) and the herbivore (*Parnassius*) based on topology-based tests (using TreeMap).

A preliminary nested clade analysis reveals a geographic distinction between southern Colorado and northern haplotypes; however, too few individuals from each population have been sequenced at this juncture for a rigorous geographic analysis of the clades. This pattern is also evident from the plot of genetic variation with latitude. Though only a few individuals from each population have been analyzed, these data agree with the general trend of rapid northward expansion following deglaciation and contrast the findings of other alpine studies.

Together, these preliminary findings support the hypothesis that alpine communities persist in southern refugia and northern were re-colonized following glacial retreat.

**Project title: Northern Range Small Mammal Study:
Populations Responding to Vegetation Change**

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Additional investigators: Mitchel Hannon

Objective: 1) Provide a continued, long term monitoring effort on the small mammals of Yellowstone's northern range to determine how populations respond to habitat changing events such as fire. 2) Evaluate the spatial and temporal distribution of small mammal species by developing improved and refined landscape (habitat) models that predict their distribution and abundance. 3) Re-assess the small mammal prey base in relation to the predators present in the northern range. 4) Monitor recolonization of small mammals and vegetation in habitats affected by the fires of 1988 (13 and 14 years later).

Findings: The data collected from last summer's field work has not been analyzed yet. We will complete analysis of the trapping data upon completion of the project after the summer of 2002. General trends that we observed over the course of the field work last summer were a reduction in vole population numbers, possibly as a result of drier conditions. We will examine these types of demographic relationships once we have the full data set collected.

Project title: Effects of Winter Range on a Pronghorn Population in Yellowstone National Park

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Additional investigators: Vanna Boccadori

Objective: Describe seasonal movement patterns and distributional shifts in the pronghorn population. Model current patterns of landscape use on the pronghorn winter range. Relate patterns of seasonal landscape use with assessments of adult female pronghorn survival and recruitment.

Findings: The population contains two subgroups, based on migratory strategy with respect to the winter range. A non-migratory segment remains on the winter range year-round, a migratory segment summers from Blacktail Plateau to Lamar Valley, then returns to the winter range in the fall. There also has been movement out of the park to Carbella, where a herd has remained for the past 22 months. Selection among cover types on the winter range is occurring. Winter diet is comprised mostly of browse, with rabbitbrush being the most abundant plant type. Fawn doe ratios during the summer months are consistently lower for the non-migratory herd than for the migratory herd. There is a precipitous decline in fawn doe ratios from August to November. The herd on private land at Carbella has a fawn doe ratio of 1:1. The project is near completion. A final report to the park is expected in May 2002.

Project title: Causes for Habitat Selection of Uinta Ground Squirrel

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Objective: The Uinta Ground Squirrel is commonly found in both grassland and sagebrush habitats. The objective of this study is to determine what effects this change in vegetative structure has on individuals living within these habitats. The Uinta ground squirrel defends itself against predators by visually scanning its surroundings and assessing the danger while it forages above ground. Individuals within grasslands have a clear line of sight while scanning, typically allowing them ample time to spot an oncoming predator and retreat below ground. In the taller sagebrush, however, the individual's view is obscured, reducing predator detection ability. We seek to determine what effect this change in vegetative structure has on the individual's behavior, survival probability and baseline stress level. We will determine how the individual's behavior has changed in response to the taller vegetation by trapping individuals in Sherman live traps and placing a unique design on their back using commercial hair dye. This will allow us to observe known individuals and compile time budgets for each individual for comparison between populations in the two habitats. Through repeated trapping over the course of the summer long field season we will be able to determine survival of individuals and also determine the general health of individuals by documenting their weight gain over the course of the field season. Finally, we will retrieve fecal samples from the traps to determine the level of the stress hormone corticosterone that is found in the animal. This will allow us to determine if the reduced scanning ability has a negative physiological effect, which may effect survival probability. We anticipate finding an increase in vigilance behavior and stress hormone level as a result of the obscured surroundings within the sagebrush habitat and a possible reduction in survival probability due to the negative effects of stress and reduced predator scanning and avoidance ability.

Findings: At this time, we have not completed any statistical analysis of the data collected over the summer of 2001. We did collect a great deal of behavioral data as well as fecal samples for the stress hormone tests from individuals across age and sex classifications. We caught a total of 294 animals between the five field sites in the northern range. The general impression we have after this initial field season is that the individuals living within the sagebrush habitat are more wary of intruders than the relatively less wary individuals in the grassland. They demonstrated uneasiness with every sound and movement, while individuals in the grassland were seemingly relaxed unless directly rushed at by predators. Ultimately, they seemed far more secure and relaxed than their sagebrush conspecifics. We have not completed any stress tests, but our samples are being preserved in deep freeze until we can complete the tests in fall 2002. We anxiously await the results of our statistical analysis, which we will complete following our second and final field season in summer 2002.

Project title: Effects of 1998 Fires on Ecology of Coyotes in Yellowstone National Park: Baseline Succeeding Wolf Recovery

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Additional investigators: Jennifer Sheldon

Objective: Document long-term effects of the 1988 fires on the population dynamics and behavioral ecology of coyotes. Document the long-term impacts of wolf restoration on coyote populations and coyote behavioral ecology, including effects on coyote prey abundance, and competitor species. Continue long-term monitoring of coyote populations by adherence to those objectives listed in previous reports and peer-reviewed publications, including: pack size, individual identification, social class, pack location, mortality, loss rate, litter size, vocalizations, scent-marking, predation on small mammals and ungulates (and neonates), interactions with other species including ungulates, interactions with scavengers at carcasses, and radio-tracking.

Findings: This long-term project began phase III in 2001 (Phase I: pre-wolf, Phase II: wolf colonization, Phase III: wolf establishment). Each six-year phase provides a new segment of a rare long-term ecological study. The long-term impact of fires (during Phase I) was an indirect effect via the small mammal prey base but now these effects are diminishing. A variety of significant demographic and behavioral effects of wolves on coyotes continue to occur. Currently, 33 resident adult coyotes occupy the Lamar Valley and Little America study areas, with a much reduced population present on the Blacktail Plateau study area. The demographic and social disruption of resident coyotes in the central Lamar Valley that occurred during the initial wolf colonization period from 1995 to 1999 (and 1997 to present in Blacktail) was to a great extent replicated in the Little America area in the year 2000 and 2001, as the Druid wolf pack extended its use area to cover this portion of the coyote study area. Effects on coyotes included increased mortality and disappearance rates, high turnover of alpha pairs, extreme fluidity in home range boundaries and social composition, and a variety of other behavioral responses. Three manuscripts are currently in preparation this year, which delineate specifics of demographic, spatial, and mortality-related aspects of the study.

Project title: Sagebrush Ecology and Ungulate Relationships

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Objective: To 1) determine the current status of the sagebrush-shrub community on the northern Yellowstone mule deer winter range, 2) determine the importance of the sagebrush-shrub community to wintering mule deer and elk, 3) describe the effect of human-caused and natural fire, including interactions with browsing, on sagebrush ecology on the northern Yellowstone winter range, and 4) determine what management techniques can be implemented to preserve or enhance mule deer and elk habitats associated with sagebrush-shrub communities.

Findings: Mule deer utilize the several sagebrush habitat types in the boundary line area as key wintering types. They use the four woody sagebrush and three rabbitbrush heavily as browse, although they display a decided preference among taxa on winter range. None of the sagebrush have reestablished.

Project title: Ecology and Distribution of Red Fox (*Vulpes vulpes*) in Northern Yellowstone

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Additional investigator: Robert Fuhrmann, Keith van Etten

Objective: 1) Determine long-term trends in habitat use of northern Yellowstone's red fox and the potential influence of changing prey abundance, climate, and distributional shifts by coyotes, and 2) examine the genetic variability of red fox subpopulations according to three elevational zones.

Findings: The distribution, morphology, and habitat use of red fox was examined in the northern Yellowstone ecosystem. Morphological and genetic samples were collected on live-captured and dead foxes to identify the presence and distribution of potential red fox subspecies across an elevational gradient. Examination of 22 red foxes indicated shorter tail length above 7,200 feet. Other parameters indicated trends of beneficial adaptations to climatically harsh environments at high elevations. At elevations above 7,200 feet, there was significantly higher frequency of a light gray coat color morph. Genetic analysis indicated that foxes above 7,200 feet were genetical isolated from lower elevations yet no geographic barrier exists. Habitat use was evaluated by snow-tracking fox using GPS and GIS technologies. Foxes were distributed across the study area in a wide range of forest cover types. Results show that red fox prefer forested and forest-edge habitats. Foxes significantly selected habitats that were less than 25 meters from an ecotone (structural edge). They preferred mesic sedge meadows and spruce-fir habitats at low angle slopes with a wide range in aspect. Lower elevational populations on the northern range were less specific in their selection of habitats and foraged mostly in mesic meadows and sagebrush. Above 7,200 feet, foxes preferred spruce-fir forests and foraged in mesic meadows and in spruce-fir and old-aged lodgepole forests. The mountain red fox that inhabits northern Yellowstone should be classified as a forest carnivore and is quite possibly a new subspecies of mountain fox, indigenous to North America. Field work continued in winter 2001/2002 to re-survey transects covered in 1994 and 1995. One manuscript was submitted in 2001 and another is planned for 2002.

Project title: Above- and Below-ground Carbon Allocation in Developing and Mature Lodgepole Pine Forests in Yellowstone National Park

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Objective: Fire and landscape variables interact to produce a mosaic of different vegetation types. The resulting spatial heterogeneity in tree density, herbaceous cover, and species composition that has been observed in Yellowstone National Park will influence primary production and carbon storage for many years. Therefore to determine the long-term effects of fire on carbon release and storage during succession, we must understand how processes differ among sites as a function of community structure. The research we are conducting focuses on the effects of differences in growth-form composition (i.e., relative abundance of trees and herbaceous plants) on above- and belowground carbon dynamics following the 1988 fires in Yellowstone National Park.

The overarching objectives are to answer two questions: 1) How do above- and belowground carbon storage and flux values differ in 12-yr-old post-fire stands with different proportions of trees and herbaceous plants? 2) How do above- and belowground carbon storage and flux values in stands burned 12 years ago differ from comparable values in nearby mature forests with similar soils?

Answering these questions will enable us to look more holistically at the effects of differences in growth-form composition carbon allocation across the Yellowstone landscape where lodgepole pine (*Pinus contorta* var. *latifolia*) is the dominant species.

Findings: A 3 1/2-month field season during the summer of 2001 allowed us to complete the field phase of our research, which encompassed 11 months of field work in Yellowstone NP over the last 3 years. Specific field accomplishments included: 1) sampled soil CO₂ efflux rates early in the summer when soils were saturated from melting snowpack and soil temperatures were still relatively low; 2) conducted a comparison of our IRGA (EGM-2, PP-systems) with the recognized standard (LICOR-6400) for sampling soil CO₂ efflux; 3) harvested the belowground portions of 45 trees to be used in the creation of allometric equations for estimating coarse root biomass in developing lodgepole pine trees; 4) completed data collection for above-ground net primary productivity estimation; 5) collected litter trap samples for estimating winter litterfall rates; 6) collected ion-exchange resin bags that were placed in the field during September of 2000; 7) harvested the above-ground portion of 5 mature lodgepole pine trees for validation of existing allometrics; 8) resampled soil, litter and root carbon pools to provide estimates of changes in these compartments.

All lab work has now been completed and we are currently analyzing our data and preparing manuscripts. We expect that three manuscripts will be submitted to peer reviewed journals within the next 6 months and that one dissertation will be completed as well. Copies of all documents will be sent to Yellowstone NP Research Office.

Project title: Graduate Program in Science Education, Classes in Geology and Ecology

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Objective: Educate graduate-level students in teaching and ecology coursework.

Findings: No research was conducted. All projects were of an educational nature.

Project title: Validation of High Resolution Hyperspectral Data for Stream and Riparian Habitat Analysis

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Additional investigators: Joseph Boardman, Andrew Marcus, Wayne Minshall, Richard Aspinall, Don Despain, Kerry Halligan

Objective: The objectives of this Hyperspectral EOCAP Project are twofold. First, the project seeks to test the application of airborne hyperspectral imagery to riparian and in-stream ecological and environmental studies and monitoring. Second, using experience gleaned from these application tests, we are defining the unique and common requirements of hyperspectral data for operational commercial and scientific uses in the area of stream and habitat analysis.

Findings: Our results fall into these two broad categories: specific stream study application results and more general conclusions about commercial hyperspectral data requirements. We are documenting which specific stream ecology variables can best be measured from airborne hyperspectral sensors, and which stream parameters are not amenable to hyperspectral determination. Through acquisition of the field and airborne data, development of experimental protocols, analysis and processing of the hyperspectral data and documentation of the results we are building the case for stream and riparian studies using hyperspectral data. Furthermore, we are discovering, often through the process of trial-and-error, numerous critical gaps and deficiencies that exist in current systems that hinder the commercialization of hyperspectral data for riparian studies.

In 2001, hyperspectral data sets collected in 1999–2000 1–m, 5–m, and 8–m Probe-1 (128 channels) and 2–m and 17–m AVIRIS data (224 channels) were analyzed. Extensive ground-truth data were

collected along the Soda Butte and Cache Creek study sites. Six main classes of ecological parameters that we seek to study and classify are: 1) stream morphological units, 2) stream Department and flow regime, 3) substrate particle size, 4) in-stream algae chlorophyll levels, 5) woody debris, 6) heavy metals and associated mine tailings in fluvial sediments, and 7) riparian vegetation community mapping including individual species identification of willow, sedge, cottonwood, aspen, upland grasses, rushes, alder, sagebrush, and conifer species.

These six main classes of variables span the range from relatively easy to extremely difficult, in terms of hyperspectral measurement. Each ecological variable has its own degree of hyperspectral leverage, or observability in the hyperspectral data. Furthermore, key issues such as spatial and spectral resolution, noise level, geometric fidelity, geopositioning accuracy and timeliness of data delivery and processing affect each specific application differently. Using multiple spatial and spectral resolutions, and multitemporal data sets, we are investigating and documenting the complex interplay between instrument and data parameters and the usefulness and accuracy of the derived ecological products.

While spectral contrasts exist among classes and species of vegetation, and even exist among subclasses of a single type, they are subtle and change throughout the growing season. Unlike the small spatial scale and rapidly time-varying nature of the in-stream parameters, the riparian vegetation is distributed in broader units that generally persist from one season to the next. Successful mapping of these plant species rests heavily on correlation of field spectrometry with airborne data. This particular application lends itself to a multi-temporal approach, leveraging the different spectral trajectories of the plant communities throughout the growing season. Initial investigations of the airborne data show tremendous spectral diversity in the riparian vegetation. Empirical spectral analysis indicates that more than a dozen spectrally unique vegetation classes can be mapped. Current efforts involve matching field mapping with the aircraft data results.

Throughout our EOCAP project we are focusing on our dual hyperspectral objectives: developing convincing case study demonstrations of the hyperspectral measurement of important stream and riparian ecology parameters and documenting and developing the common and unique requirements of operational systems to perform these studies in the future. Specifically, we are collecting a laundry list of needs and requirements for commercial systems for hyperspectral stream studies. This list documents specific spatial, spectral, and radiometric design requirements. In addition we are addressing the more mundane, yet critical, aspects of operational acquisition and application including the timely delivery of data and products and its long-term use and archiving. Our initial results from our first field season are very encouraging and productive, both in terms of the development of tantalizing case studies and the frustration involved with finding and documenting technology gaps and shortcomings. Final report of Phase II is now available and we are working on numerous manuscripts. As of April 1, 2002, five have been submitted for publication.

Project title: Cougar-Wolf Interactions in Yellowstone National Park: Competition, Demographics, and Spatial Relationships

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Additional investigators: Maurice Hornocker, Howard Quigley

Objective: 1) Document the characteristics of the cougar population, including population size, survival, cause-specific mortality, natality; and compare results with pre-wolf data on cougar population characteristics in the Northern Greater Yellowstone Area. 2) Assess the effects of cougar predation on elk and mule deer populations as influenced by the presence of wolves. 3) Assess competition and resource partitioning between cougars and wolves by comparing species' spatial and temporal habitat use patterns and prey utilization characteristics. 4) Quantify spatial and temporal interactions between cougars and wolves. 5) Communicate research findings to state and federal agencies and the general public through annual technical reports, research updates, and presentations.

Findings: Hornocker Wildlife Institute (HWI) personnel captured and radio-collared a total of 45 cougars (March 1998 through March 2001) in and adjacent to areas used by 35–60 wolves within three packs on the Northern Yellowstone Study Area (NYSA), the Yellowstone Wolf Restoration program. Researchers associated with both HWI and Yellowstone National Park (YNP) conducted aerial and ground monitoring of radioinstrumented animals.

Field crews searched 1208.7 km to 1621.3 km (755 mi to 1013 mi) of track transect during winters 1998–2001 to conduct cougar sign surveys and provide an estimate of cougar population size. A minimum of 21–22 adult and subadult cougars was present on the NYSA during the 1998–2001 winter seasons. Fourteen resident adults (3 males; 11 females) and 9 of 11 kittens in five family groups are currently being monitored on the NYSA.

Eight adult females produced thirteen litters of 2–4 kittens resulting in 33 offspring documented during March 1998 to August 2001. Thirteen cougar deaths were documented. The deaths included all four of female F107's kittens, which were killed by the Druid wolf pack in two separate events occurring near a cow elk killed by F107. Four cougars were killed by other cougars, one died from unknown causes, one fell off a cliff while attempting to kill a bighorn sheep, one was legally harvested during the Montana cougar hunting season, and 1 cougar kitten was killed by a black bear. Thirteen cougars have dispersed to areas adjacent to and beyond the NYSA.

Weekly aerial flights were scheduled in conjunction with wolf location flights to obtain simultaneous cougar–wolf locations. Through intensive ground monitoring, we documented 202 positive and probable cougar kills. Prey included 140 elk, 38 mule deer, 2 bighorn sheep, 1 antelope, 7 coyotes, 6 marmots, 4 porcupines, 1 red squirrel, 1 blue grouse, 1 red fox, and 1 golden eagle.

A collaborative study of Feline Immunodeficiency Virus prevalence and evolution related to cougar population dynamics continued in 2000–2001. Collaborators in this study include the University of Montana, University of Wyoming, and the Hornocker Wildlife Institute. The Hornocker Wildlife Institute was also involved in collaborative studies on cougar–wolf–grizzly bear–human hunter interactions in the Greater Yellowstone Area, and cougar stress hormone detection in feces with the University of Idaho.

Project title: Multi-trophic Level Responses to the Addition of a Top Carnivore

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Objective: This study is examining the ecological changes associated with re-establishment of wolves in Yellowstone National Park in 1995 and 1996. Species representing three important trophic levels—wolves, elk, and woody vegetation—are the focus of the research. The specific areas of interest are: 1) spatial and temporal patterns of abundance of the newly introduced top carnivore (gray wolf), the dominant herbivore (elk), and woody vegetation on YNP's northern range, and 2) mechanisms underlying trophic dynamics, especially predation rate of wolves and herbivory use by elk on woody vegetation.

Findings: In 2001, 13 radiocollared elk died: 6 were taken by hunters (46% of total mortalities), 1 by a cougar (8%), 4 by wolves (31%), and 2 died of unknown causes (15%). All but one of these mortalities occurred during the winter. An additional 2 elk died due to possible capture-related complications (stress-induced myopathy).

Based on data from GPS-collared elk and also from regular VHF tracking of the collared animals, we documented the current major migration routes of the northern elk herd. Elk travel from their wintering grounds on the northern range to areas as far south as Lewis Lake, east to the eastern border of the park, and north onto the Buffalo Plateau. A small number of elk remain on the northern range even during the summer. Of those that migrated, most elk return to the winter range in mid-October through mid-November, usually in response to snowfall. Migration generally occurs along the obvious large drainages or major ridgelines.

The migratory patterns of the herd segment that summers in the Lewis Lake area were not well-known based on data from 2000, but because of our larger sample of radiocollared elk in 2001, and because of the continued aerial tracking of these animals, new information on their movements was found. These long-distance travelers migrate via the Washburn range/Carnelian Creek region and, remarkably, they can make their 70-kilometer journey between the northern range and the Lewis Lake area in less than four days. All of the elk returned to the northern range by late November, except for one of the elk that summered by Lewis Lake. This animal remained near the South Entrance as late as December 14, when her GPS collar dropped off as programmed.

A preliminary analysis of habitat selection by elk was done to compare pre-1988 fire/pre-wolf, post-1988 fire/pre-wolf, and 2000–early 2001 post-wolf periods. A herd-wide, landscape-scale model of summertime habitat selection showed elk selected for areas of higher elevation, intermediate slope, and southeast to northeast aspects. Elk also selected for grass–forb communities and burned forested areas and they selected against areas of mature conifer forest.

Comparing pre-wolf and post-wolf habitat use, the only major difference detected thus far between these time periods was that elk currently select higher elevations during the summer. This difference could be a result of elk moving to higher elevations away from high wolf-use areas while wolves are centered around their denning areas at lower elevations in the early summer period; however, it could equally be attributed to the drought conditions of the past several years. Dry climatic conditions have left relatively little forage at the lower elevations, possibly pushing elk to the cooler, moister ridgetops.

A preliminary population reconstruction effort for the northern Yellowstone elk herd resulted in minimum number alive (MNA) estimates of 10,856 elk in 1995, 10,625 elk in 1996, 8,280 elk in 1997, 7,228 elk in 1998, 5,676 elk in 1999, and 4,245 elk in 2000. The decline in these MNA estimates over time do not represent a decline in the elk population. There is simply a smaller sample of elk mortality

data used for population reconstruction in years closer to the present (these numbers become more accurate with each additional year of elk mortality data).

We recommend that the NPS continue to gather data on elk mortalities caused by hunting, cougars, wolves and winterkill. Both the MNA estimates and sex–age composition of the northern herd will become more robust with each additional year of population reconstruction data.

Project title: Climatic Variation in the Greater Yellowstone Ecosystem: Evaluating the Evidence for Decade–to–Centennial Variability in Climate

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Objective: Our objective is to investigate the record of climatic variability in the Greater Yellowstone Region (GYR) to enhance our understanding of regional patterns and processes. The climate record will be reconstructed by climatically sensitive tree-ring chronologies. For example, studies of the interactions between climatic variability, fire, and grazing in regulating forest stand structure and composition will be enhanced by longer and more detailed climatic histories of the region. Similarly, research on interactions of fire, climate and geomorphic processes will benefit from better information on climatic trends and variability. Finally, long-term histories of climate can inform the monitoring strategies for assessing the impact of global environmental change on mountain regions.

Recently discovered long (1,000+ years) tree-ring records from the Greater Yellowstone Region (GYR) in the Rocky Mountains are relevant to the larger effort to understand the patterns and causes of climate variability at high elevations. The GYR is one of the few places in the world where we can develop a strongly replicated, multi-species network of long tree-ring series that are sensitive to precipitation. Interannual and decadal-scale variation in winter precipitation and snow pack in the GYR exhibits patterns that are strongly coherent with variability in the Northwestern United States. The regional snowpack anomaly patterns are, in turn, associated with regional- to hemispheric-scaled atmospheric circulation patterns. As such, a strong potential exists for using the GYR data to reconstruct 1,000+ year histories of key multi-decadal atmospheric circulation patterns such as the Pacific Decadal Oscillation.

Findings: Eight tree-ring records that extend 1,000 years and longer from the GYR were obtained from species including Douglas-fir, limber pine, and whitebark pine. Sites range in elevation from 1,740 m to 3,080 m, and are characterized as low productivity sites unaffected by fire. An abundance of remnant wood exists at these sites due to the absence of fire and an ideal climate for wood preservation. The remnant wood, when cross-dated with samples from living trees, provides chronologies that extend up to 2,200 years before present. We analyzed the climate signal in the most drought sensitive tree-ring chronology (Mt. Everts Douglas-fir; MEDF) by relating the series to modern data for winter precipitation, snow-

pack and stream flow at nearby observational stations. To characterize the series in the frequency domain, we applied spectral analysis using a multi-taper method with red noise assumptions to the full length of the MEDF chronology.

The correlation between the MEDF chronology and winter precipitation and associated variables such as the Palmer Drought Severity Index and April snowpack is significant and positive. Further, during the 20th century, the MEDF chronology exhibits strong decadal-scale variability similar to that of the Pacific Decadal Oscillation (PDO), notably shifts in series value at 1947 and 1977.

The full MEDF record exhibits decadal-scale variability over the full length of the record. Spectral analysis of the record (1167–1999) reveals significant peaks (>95%) centered approximately at periods of 60, 40, 28, 6.5, 2.8, and 2.3 years.

The changes in the dominant periods of decadal-scale variance in a tree-ring series that is strongly related to PDO is consistent with other recent reports of changing amplitudes of PDO over the past several centuries. Incorporating the larger tree-ring network currently under development will facilitate a more complete investigation of the changes in precipitation regimes in the GYR.

These results, although preliminary, have two important implications for our understanding of mountain climate variability. First, characterization of PDO and other ocean-atmosphere interactions based on 20th century observations does not capture the full range of these dynamics. Second, the impacts of anthropogenic greenhouse warming in mountain regions will be modulated by the impacts of PDO and other drivers of decadal-scale climate variability on winter precipitation and snow accumulation.

**Project title: Ecology of Selected Habitats in Yellowstone National Park—A Wheaton College
Science Station Course**

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Objective: 1) Quantify vegetation species richness and density in 1988 burn and 1984 blowdown areas. 2) Evaluate the influence of thermal runoff on aquatic macroinvertebrates in streams draining geyser basins and compare to streams outside of the park lacking thermal runoff. 3) Observe adaptations of bacteria, algae, cyanobacteria, and other life to the diverse hydrothermal features of YNP.

Findings: We found densities of lodgepole pine in burned areas to be about eight times greater than those in 1984 blowdown areas that also had burned in 1988. Plant species richness was slightly greater in burn/blowdown areas than in burn-only areas. The Firehole River was substantially warmer (28°C) than a stream at a comparable elevation outside the park (Tongue River, Bighorn Mountains, 19°C), and harbored some invertebrates (e.g., amphipod crustaceans) that streams without thermal runoff did not. Both the Firehole River and Nez Perce Creek were infested with the New Zealand mud snail; infestations

seemed heavier in Nez Perce Creek. At West Thumb Geyser Basin, as has been previously published, distributions of bacteria, algae, and cyanobacteria were related to water temperature, as determined by color of the microbial mats. These results are intended for educational use only and not for publication.

Project title: Browsing Phenology of Willows, Cottonwoods and Aspen on the Northern Range, Yellowstone National Park

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Objective: The objectives of this study are to determine when the woody riparian species are browsed during the winter and to determine if it occurs as a short-term episode or as a continuous process during the course of the winter. This information will be correlated with climate to look for climate-browsing interactions. We are recording only the cumulative percent of stem tips browsed and not the percent of current annual growth taken.

Findings: Each year has followed a pattern of browsing. Early in the season there has been very light browsing, which we interpret as exploratory, followed by a short period of more intense browsing, terminated by a complete taking of at least the current year tips. This has occurred generally between late December and late January to mid February.

The timing of these events has varied geographically, between species and between years. At sites where both willows and aspen or willows and cottonwoods occur, the willows have been eaten earlier than the other two species.

Project title: Landscape Use by Elk During Winter on Yellowstone's Northern Range

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Objective: The objectives of this study were to document winter patterns of landscape use by Yellowstone northern range elk, measure elk feeding activity (as indexed by number of feeding craters), quantify snowpack characteristics, and examine how these and other landscape and habitat features influence elk foraging locations. How does snow affect the distribution of elk during winter on Yellowstone's northern range? What other factors, such as winter temperature, forage, and

predator/prey density, affect their distribution?

Findings: We measured site and snowpack characteristics, elk (*Cervus elaphus*) feeding crater densities and morphometry, and elk numbers in the Lamar River Valley and the Blacktail Plateau on the northern range. We conducted the study over three winters, 1992–1993 to 1994–1995, but the main sampling effort occurred over four monthly sample periods in year one. Snow Department, snow water equivalent (SWE), and snow resistance to horizontal movement and vertical penetration all increased steadily over the winter. The mean (SD) feeding crater diameter and Department was 118 (37) cm and 34 (11) cm, respectively, and both were positively correlated with snow Department. The mean (SD) crater volume was 385 (321) l, and the mean (SD) mass of snow excavated from a crater was 82 (72) kg. Non-woody plants (grasses, sedges and forbs) were the primary browse item in 90% of the craters. The highest aerial elk counts were observed in early- to mid-January, and counts declined substantially and steadily after January 29. At this time, mean snow Department was about 50 cm and mean SWE was about 12 cm. The mean number of new craters on a plot showed a significant, negative association with snow Department, SWE and booted-foot sinking Department. We used the sum of craters on a plot across all four sample periods as an index of winter long feeding activity. Elevation and habitat type were the best site characteristics for differentiating plots in regard to winter-long use. Summed craters were negatively associated with elevation, and the habitat type with the highest summed craters was tufted hairgrass/sedge. Only about 5% of plots that had craters had areal crater coverage in excess of 14%, with a maximum of 23% coverage, suggesting that snow disturbance associated with cratering activity may inhibit elk foraging. We are preparing manuscripts for publication and are also preparing for field work starting November 2002.

Project title: A Landscape Approach to Aspen Restoration: Understanding the Role of Biophysical Setting in Aspen Community Dynamics

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Objective: Widespread loss of aspen stands in the western United States has been well documented. Valued as a keystone species, aspen communities are critically important to maintaining biodiversity, soil quality, and nutrient cycling. Fire suppression, ungulate herbivory, and climatic change are the most widely advanced explanations for the decline of aspen. The role of biophysical factors (e.g. topography, climate, soils, competitive interactions), in governing aspen performance, however, is poorly understood. To better understand the influence of biophysical variables on aspen dynamics, this study addresses the following three hypotheses: 1) the aerial distribution of aspen is not random across the landscape and varies as a function of biophysical setting. 2) Within its distribution, growth rates and productivity of aspen stands differ relative to biotic and abiotic variables. 3) Rates of aspen loss in the landscape differ relative to bio-

physical setting.

The study area is the Greater Yellowstone Ecosystem from a southern boundary near Jackson, Wyoming. The study area includes areas of Yellowstone National Park, the Gallatin National Forest, Targhee National Forest, Bridger–Teton National Forest, and Grand Teton National Park. Analysis to date is restricted to the Gallatin National Forest and Yellowstone National Park, and addresses the first two hypotheses.

Findings: Preliminary analysis of aspen distribution involved mapping the distribution of aspen across the study area (currently Gallatin National Forest and Yellowstone National Park) and using classification and regression tree analysis (CART) to examine the relationship between environmental variables and aspen distribution. Aspen distribution was obtained from aerial photograph interpretation and GIS data from the Gallatin National Forest stand cover map and Yellowstone National Park cover-type map. Predictor data used were elevation, slope angle, aspect, and soil parent material. Hold-out data showed that the resulting CART model accurately predicted aspen occurrence 91.2% of the time; however, mapping the model across the landscape showed over-prediction of aspen occurrence. We plan to expand our study area to include the southern end of the ecosystem and include climatic predictor variables and more specific soils predictor data.

Aspen performance relative to biophysical setting is being examined through field measurement of aspen stand structure, composition and growth rates. We sampled 47 sites in the Gallatin National Forest and Yellowstone National Park (eight sites in Yellowstone were sampled) during the 2001 field season. We used a nested, circular plot design to measure tree density by species and dbh class, seedling/sapling density, herbaceous biomass, shrub density, canopy cover, and density of coarse woody debris. We also took increment cores of aspen trees of each dbh class represented on a site.

Analysis of field data is in the preliminary stages. Using BIOPAK software, we have calculated biomass estimates for shrubs and trees by species. We will be using increment cores to estimate current and past aspen biomass and obtain annual change in above-ground biomass. We will regress this measure of aspen productivity against abiotic (topographic, soils, and climatic) and biotic (herbaceous biomass, shrub biomass, and tree biomass by species) variables to examine any relationship between aspen annual net productivity and biophysical environment.

Project title: Medium-Sized Carnivore Project

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Objective: 1) Assess several methods to inventory and monitor medium-sized carnivores: weasels, otter, wolverine, marten, fisher, lynx, bobcat, mountain lion, fox, coyote, and gray wolf. 2) Examine various habitat and landscape characteristics related to their presence/absence. 3) Conduct presence/absence surveys in

Yellowstone National Park and surrounding wilderness areas. 4) Evaluate long-term changes in presence/absence detection trends.

Findings: With the notable exception of three decades of research on grizzly bears, and more recent studies on mountain lions, pine marten, and coyotes, we know very little about Yellowstone's mammalian carnivores. Members of the order Carnivora are typically secretive, nocturnal, and exist at low population densities. In many cases, we do not even have reliable methods to determine presence, let alone estimates of abundance and other important demographic parameters. During the winters of 1990 through 1997, we conducted detection surveys and evaluated three methods: hair snares, remote camera stations, and snow track transects. Their utility as estimates of presence, distribution, and abundance were evaluated, as well as their cost, maintenance, reliability, precision, and bias. Response to hair snares and camera stations were variable locally and between years. Hair snares have the exceptional advantage of providing DNA and potentially identifying individuals, but has the disadvantage of relatively high maintenance and cost and provided unreliable results from the analysis of hair characteristics. Camera stations, like hair snares, performed well in adverse weather and can identify individuals, but suffer from avoidance bias by several resident species. Camera stations were costly in terms of expense and maintenance. Snow track transects identified four species not detected by other methods and were simple, low cost, and low maintenance. They provide precise habitat information, whereas camera stations and hair snares are baited with food and scent lures which bias results concerning habitat use. Snow track transects allow researchers coverage of large areas and habitat types and can provide valuable information if scats are found and if DNA is successfully extracted. The reliability of species identification from snow track transects is a major disadvantage due to poor climatic conditions and the similarity of many species' track characteristics. Although the specifics of objectives and logistics should dictate use of these methods, we suggest a variable combination of all three methods for determining presence and distribution. All methods have significant problems, especially when inferring abundance. Determining relative habitat use from snow track transects proved reliable and matched that known from previous studies. This project resulted in the confirmation of fisher in the Yellowstone ecosystem. Efforts in 2001 focused on continuing detection surveys across the northern range. All survey routes were covered twice (once early and once late) during the winter of 2001–2002. Further analysis of data and preparation of manuscripts for publication will proceed.

Project title: The Ecology of Arbuscular Mycorrhizae in Yellowstone's Thermal Areas

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Objective: *Arbuscular mycorrhizae* (AM) are a plant–fungus symbiosis, in which the plant provides the fungus with a carbon source, while the fungus increases plant fitness via enhanced nutrient availability (especially phosphorus) and water acquisition, and protection from pathogens. Fossil evidence has shown the presence of mycorrhizal fungal structures associated with the first land plants. The early existence of

this relationship suggests that mycorrhizae are significant in the evolution of terrestrial plants. In addition, approximately 95% of extant plant species are estimated to be mycorrhizal; therefore, we cannot thoroughly understand plant response to environmental stress gradients without simultaneously examining the mycorrhizal symbiosis.

The role of AM in Yellowstone's thermal areas has not been studied and is difficult to predict, especially across the existing environmental gradients. Mycorrhizae might augment plant growth in a broad range of environments for numerous host and endosymbiont species. However, they have also been shown to decrease growth in situations where the cost of carbon allocation to the fungus exceeds the benefits of the symbiosis. In these high-stress environments where carbon fixation and biomass accumulation are limited, the mycorrhizal symbiosis might function differently than in environments that are more amenable to plant growth.

With this research we will 1) assess the distribution of AM fungi across environmental gradients at geothermal sites, 2) measure the effects of AM on plant growth in thermal-influenced soils, 3) determine whether AM fungi isolated thermal sites are better adapted to maximize mycorrhizal benefits to host plants growing in extreme conditions than fungi from non-hydrothermal sites, and 4) increase our understanding of this plant/fungal interaction in extreme environments, such as the high temperature, extreme pH, and low nutrient sites found adjacent to thermal sites in Yellowstone.

Findings: In summer 2000, we sampled plant roots from five sites including Hundred Springs Plain in the Norris Basin, Amphitheater Springs, the Firehole River near Ojo Caliente, and Rabbit Creek. Plants from these sites, growing in soils with rooting zone temperatures up to 480°C, and soil pH values down to 3.4, were mycorrhizal, with colonization levels ranging from 2 to 54%. Mycorrhizal fungal propagules were 77% less abundant in geothermal-influenced soils as compared to soils from well-vegetated areas.

In the summer and fall of 2001 we examined mycorrhizal colonization levels of *Agrostis scabra*, *Dichanthelium lanuginosum*, and *Mimulus guttatus* across thermal and soil pH gradients during June, July, August, and October. *Mimulus guttatus* was sampled in June, but had senesced by July. *Agrostis scabra* was first identified and sampled in July, and had senesced by August. *Dichanthelium lanuginosum* was sampled each month. Overall colonization of the plants did not vary significantly by month, soil chemistry, or soil temperature. However, the percentage of arbuscules present in the *Dichanthelium lanuginosum* roots decreased from June through August and then increased slightly in October (ANOVA; $F=3.114$, $p=0.036$).

We conducted a greenhouse experiment to assess the effects of mycorrhizae on *Dichanthelium lanuginosum* and *Agrostis scabra* plants growing in elevated rooting temperatures (400°C). Plants were grown in three soils: sterilized, sterilized with native microbial community, and nonsterilized (mycorrhizal). Comparisons presented are made between the latter two soil treatments because these isolate the effect of AM fungi from the rest of the soil community. *Agrostis scabra* plants were smaller when grown with mycorrhizae in both ambient and elevated rooting temperatures, suggesting that the cost of AM exceeded the benefits in these soils. *Dichanthelium lanuginosum* was smaller when growing with mycorrhizae in ambient temperatures, but equal in size when grown in elevated temperatures. However, a significant increase in shoot biomass was observed in mycorrhizal plants, that was most pronounced when grown in elevated temperatures. Plants with more above-ground biomass also have more leaf area, thereby increasing photosynthetic ability and, potentially, overall fitness. For *Dichanthelium lanuginosum*, mycorrhizae shifted from detrimental to beneficial as the environmental stress (here elevated rooting temperature) increased.

Our current greenhouse experiment addresses objectives 2 and 3 concomitantly by examining the effect of acidic and alkaline soil water on the mycorrhizal symbiosis in *Dichanthelium lanuginosum*, *Agrostis scabra*, and *Mimulus guttatus*, and the possible adaptation of AM fungi to their native environment. The

greenhouse experiment is complete factorial and includes four mycorrhizal treatments (a control with no AM fungi, and AM fungi added from an acidic thermal soil, an alkaline thermal soil, or a non-thermal soil) and three pH treatments. Plants are watered with dilute nutrient solutions of pH 3.5 (altered using H₂SO₄), 6.5 (unaltered), and 9.5 (altered using NaOH). Preliminary analysis suggests that both the mycorrhizal source and pH have significant effects on the fecundity of *Mimulus guttatus* and the height of *Agrostis scabra*, supporting our hypothesis that mycorrhizal function is dependent on environmental conditions, and that AM fungi from extreme environments function differently than AM fungi from non-thermal soils.

Project title: Specificity in Ectomycorrhizal Symbioses

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Objective: To Determine how above-ground disturbances, such as natural fire, foliar diseases and defoliation, and litter manipulations, affect structure and function of below-ground microbial communities.

Findings: Litter addition: In this study, we used molecular-genetic methods to determine effects of litter addition on the EM community of a *Pinus contorta* stand in Yellowstone regenerated after stand-replacing fire. Results indicate that 1) species richness did not change significantly following perlite addition (2.6 +/- 0.3 species/core in controls, 2.3 +/- 0.3 in perlite plots), but decreased significantly ($P < 0.05$) following litter addition (1.8 +/- 0.3), 2) EM infection was not affected by perlite addition, but increased significantly ($P < 0.001$) in response to litter addition; this increase occurred only in the upper soil layer, directly adjacent to the added litter, and 3) Individual EM fungal species reacted differently to each treatment type.

Defoliation: Molecular genetic methods were used to determine whether artificial defoliation affects ectomycorrhizal (EM) communities. All lodgepole pines in three replicate plots were defoliated 50%, while Engelmann spruce were left untreated. This was done to determine how defoliation of one conifer species would affect EM mutualisms of both treated and neighboring, untreated conifers. Results indicated no significant effect on either EM colonization (142.0 EM tips/core in control plots and 142.4 in treatment plots), or on species richness (5.0 species/core in controls and 4.5 in treatments). However, the relative abundance of EM of the two tree species shifted from a ratio of approximately 6:1 without treatment (lodgepole EM: spruce EM), to a near 1:1 ratio post-treatment. In addition, EM species composition changed significantly post-defoliation. Furthermore, species of EM fungi associating with both lodgepole pine and Engelmann spruce were affected, indicating that alteration of photosynthetic capacity of one species can affect mycorrhizal associations of neighboring non-defoliated trees.

Litter removal: Three treatment/control blocks were established comprising three treatment plots in which all litter was removed. Results of soil analyses indicate significant decreases in total nitrogen (0.22% total nitrogen in controls and 0.18% in treatments) and ammonium (6.6 ppm in controls and 4.8 ppm in treatments) following litter removal. Results of molecular analyses indicate that 1) litter removal significantly decreased EM fungal species richness, from 3.0 to 1.5 species/core; 2) as expected from previous

studies that indicate that increased nitrogen in litter can inhibit EM infection, litter removal induced a significant increase in EM infection, from a mean of 228 EM/core in controls to 326 in treatments; 3) the ratio of basidiomycetes to ascomycetes changed significantly in response to litter removal, from 12:1 ratio of basidiomycete to ascomycete EM, to a 3:1 ratio.

Project title: Multifactor Controls on Persistence of Willows: Quantitative Assessment and Analysis of Factors Contributing to Variable Herbivory Levels Pre-1995 and Post-1997

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Additional investigators: Tom Hobbs, David Cooper, Linda Zeigenfuss

Objective: To determine whether willows have been released from their browsing-induced suppressed state as a result of lower elk populations following reintroduction of wolves to Yellowstone National Park.

Findings: At this point, several northern range willow stands and tagged willows from studies conducted by F.J. Singer in the late 1980s have been relocated and measured for productivity during August 2001. These stands will be revisited in April 2002 to be examined for winter offtake levels by ungulates. Additionally, several stands that are further in the backcountry from the northern range will be located and measured as well. These stands will also be measured for a second year of productivity in August 2002.

Project title: Ectomycorrhizae of Thermal Soils

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Objective: To determine microbial community structure and function in low pH thermal soils.

Findings: Molecular methods and comparisons of fruiting patterns (i.e., presence/absence of fungal fruiting-bodies in different soil types) were used to determine ectomycorrhizal associates of *Pinus contorta* in soils associated with a thermal soil, classified as ultra- to extremely acidic (pH 2–4). Ectomycorrhizae were sampled by soil core (36 total) from six paired plots of three cores each, from both thermal soils and forest soils directly adjacent to the thermal area. Fruiting-bodies (mushrooms) were collected for molecular identifications, and to compare fruiting-body (above-ground) diversity to below-ground diversity. Results

indicate 1) significant decreases in both EM infection (130 SE 22 EM root tips/core in forest soil, 68 SE 22 in thermal soil) and EM fungal species richness (4.0 /- 0.5 species/core in forest soil, 1.2 SE 0.2 in thermal soil) in soils associated with the thermal feature, 2) that the EM mycota of thermal soils was comprised of a small set of system dominants, with very few rare species, while that of forest soils contained a few dominants, with several rare EM fungal species, 3) *Dermocybe phoenecius* and a species of *Inocybe* which was rare in forest soils, were the dominant EM fungal species in thermal soils, 4) that aside from this single *Inocybe* species, there was no overlap in the EM fungal communities of forest and thermal soils, and 5) the fungal species forming the majority of the above-ground fruiting structures in thermal soils (*Pisolithus tinctorius*, commonly used in remediation of acid soils) was not detected on a single EM root tip in either soil type. Thus, *P. tinctorius* may be fulfilling a different role in these thermal soils. This indicates that this species may not perform well in remediation of all acid soils, and indicates the relationships among factors such as pH, soil temperature, and soil chemistry in influencing EM fungal community structure. In addition, at least one new species with potential for use in remediation of hot acidic soil is indicated.

Project title: The Living Stream

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Objective: Course was not taught in 2001

Findings: None. The course will be resumed in 2002

Project title: Persistence of Willow in Yellowstone National Park: Interactive Effects of Climate, Hydrology and Herbivory

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Objective: The focus of our study is to tease apart the influences of hydrology and herbivory on the growth and reproduction of willows (*Salix* spp.) on the northern range of YNP. Willows have declined in the northern range over the last 100 years, and potential driving factors include a recent increase in elk (*Cervus elaphus*) and a decline in water tables, due to a decline in beaver (*Castor Canadensis*), and/or a dry-

ing climate. We will use an experiment, a study of willow dendrochronology, and a modeling exercise to address how these factors may influence willow survival. We will also examine historic beaver occupation in the park in order to gain insight into the role of beaver in willow establishment.

First, we are conducting a field experiment with two treatments: herbivory reduction (by enclosing large herbivores), and water table elevation (by inhibiting the velocity of small adjacent streams). The experiment is fully factorial, meaning that each site consists of four plots: an enclosed and water-elevated plot, an unenclosed and water-elevated plot, an enclosed and water-normal plot, and a control plot. We are replicating this design four times at the site level in order to obtain enough statistical power to determine the relative influences of the treatments and any potential interactions. We will measure the response of three willow species (*S. geyeriana*, *S. bebbiana*, and *S. boothii*) by measuring current annual growth, plant height and volume, seed production, water stress (by measuring C13 concentrations of leaves), and groundwater utilization (by comparing isotopic signatures of groundwater vs. xylem water).

Second, we will conduct a study of willow ages and ring widths in order to address willow establishment and to expand the temporal and spatial scope of the study. Comparison of willow ages and ring widths with elk population data, climate data, and historical records of beaver ponding will allow an analysis of the relative importance of herbivory, climate, and beaver presence to willow growth and establishment over the past 50–100 years. Aging of willows will take place in areas of documented beaver damming and will allow us to determine if the timing of willow establishment coincides more closely with damming or with periods of reduced elk. We will also examine growth patterns of willows in areas where beaver ponds have likely not been historically present (i.e. groundwater discharge zones and large streams) to differentiate the effects of climate and elk population on willows growing in other hydrologic environments.

Because beavers may be instrumental to willow survival and their historic presence in the Park prior to the 1800s is not well documented, we will conduct two studies to determine their historic presence in the park. First, we will examine stratigraphic cross-sections of stream floodplains to date beaver pond deposits. Pond deposits will be identified using sediment grain size analysis. Second, in order to extend the spatial extent of the study (since streams migrate and beaver don't always build dams in the same spot), we will conduct a dendrochronological study of floodplain conifers to look for evidence of ponding in the ring record. Calibration of the trees' sensitivity to ponding will be done by selecting a set of trees that are various distances from known historic beaver pond margins. These tree rings associated with stream flow conditions will be compared to long-term regional tree ring series to look for correlation with climatic patterns.

The final stage of our project will consist of modeling willow survivorship using an existing ecosystem model, SAVANNA. Results from the experiment and correlative studies will be used to refine parameters of the model so we can better predict willow growth and survivorship over the northern range.

Findings: 2001 was our first field season and most of the time was spent selecting sites and installing enclosures, water wells, and velocity inhibitors for our field experiment. All eight enclosures, all eight stream velocity inhibitors, and the majority of the ground water monitoring wells were installed. Water table measurements taken before and after velocity inhibitor installation indicate that we have successfully raised the water table by an average of 39 cm across the experimental plots (based on limited post-treatment measurements). We also took pre-treatment data on the willows in our study, tagged them, and precisely surveyed their locations. Because pre-treatment water table levels vary across and within plots, we conducted a preliminary analysis of our baseline data in order to determine what percentage of existing variation in willow growth can be attributed to Department to water table. Each plant's maximum water table Department was determined by interpolating water well data, and the resulting data was used in a simple

linear regression analysis. We found that water table Departmenth accounts for 28% and 17% of naturally occurring variation in plant volume and current annual growth, respectively, for *S. bebbiana*. Initial water table effects were much less explanatory for the other two species. These results indicate that it will be helpful to use our pre-treatment water table measurements as a covariate in later analyses to reduce the noise in our data caused by naturally occurring variation in willow growth and size.

We also began our work on the history of beaver occupancy in YNP. A probable pond deposit on Elk Creek, 1.7 m below current floodplain level, yielded a date of 900–1160 AD.

Project title: The Behavioural–Ecological Role of Wolf Howling

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Additional investigators: Mary Theberge

Objective: Wolf howling is one means of social coordination in wolf packs, one way that helps packs function as biological units. This study is design to test the extent to which the forgoing statement is true. To qualify, howling must: be shown to alter behavior of the pack or individuals in the pack, and that alteration must assist pack fitness by helping it accomplish a task of biological necessity such as procurement of food, raising young, defending territory.

The packs at Yellowstone offer an opportunity to compare the use of howling in packs whose unfolding history is, and will continue to be known. While many factors undoubtedly contribute to individual and group success, these packs may provide information on differences in their use of howling.

Hypothesis 1: Howling plays a role in group cohesion. Prediction: 1) There will be more howling in both the season of highest group cohesion (most pack members together or close to one another), and the pack that shows the highest cohesion.

Possible outcomes: Howling high when cohesion high, and howling low when cohesion low. (Not a definitive outcome because other factors could be responsible.) Howling high when cohesion low, or vice versa. Disproves hypothesis. 2) There will be a set of observations of cases where howling of distant pack members brings them together, versus a set of observations where howling does not bring them together. 3) Howling will be more frequent when some pack members are known to be absent versus all present, or when alphas are absent.

Hypothesis 2: Howling acts to coordinate pack movements. Prediction: There will be a set of observations of wolves bringing pack members together either when the pack is travelling, or to initiate travel, or at a kill or rendezvous site or den.

Hypothesis 3: Howling acts to identify pack members to each other versus non-pack members. Prediction: Set of observations of: wolf howling as wolf comes in to rendezvous site, den, or kill where the rest of the pack is present; ambivalent behavior of approaching wolves broken with a howl (pack members show acceptance, non-pack members show avoidance); packs near each other, or aware of each other, separate more after a howl.

Hypothesis 4: Group howling aids in social bonding/social partitioning. Prediction: Set of observa-

tions associated with play or group social display (before play or to initiate it, part of it, terminate a bout of it) or when pack members arrive or leave the rest of the pack.

Hypothesis 5: Howling aids in territorial defense. Prediction: 1) Sets of observations of packs aware of each other, howling (versus packs not howling). 2) Group howling more common (howls per minute of observation) at kills near territorial boundaries than distant.

Data: Rick McIntyre's notes will be a primary source of data. Many of them are on computer and so can be word-searched. Secondly, we will add field observations when feasible. Obtaining data of this kind can only be done opportunistically, not experimentally (no stimulus from the researchers), a drawback of the study but one that is accepted.

Sound analysis: When possible, we will record howls with the intent of conducting computer-based sound analysis to look for features that are context-specific.

Findings: We were in the field from October 23 until October 27. Our mission was to record as many context specific howls as possible, and note occasions when howling occurred or when behavior that might have elicited howling did not do so.

During this period, portions of the Druid Peak pack were almost continuously visible during daylight hours at their traditional rendezvous site. We observed howling on 10 occasions, and recorded it nine times. Three of these howls were of a single wolf. The other recordings were of group howls. Group howls from the rendezvous site took place at crepuscular times, morning and evening. All of these howls were preceded and followed by group social interactions, but none involved movement of wolves into or from the rendezvous site. One group howl, before daylight, was from part of the pack travelling between the rendezvous site and a kill located 5.2 km away.

The single howls were from a yearling or pup that howled from Soda Creek–Lamar River junction while other members of the pack howled from the rendezvous site. They could hear each other. Nonetheless, the single wolf howled repeatedly, without going towards the rendezvous site, then took off running up Soda Butte Creek valley and was recorded or heard howling repeatedly, as we advanced too, for a distance of eight kilometers. Clearly this was an agitated wolf, and subjectively it appeared to try to attract attention to itself, then when it failed, proceeded up the valley at a very fast rate with an obvious purpose. Its howls, which are of a quality suitable for sound analysis, broke downward and upward in pitch repeatedly, but between these breaks held reasonably steady notes as is characteristic of the Yellowstone wolves (in contrast to Algonquin wolves).

On two occasions, wolves returned to the rendezvous site with no howling, although there were greeting ceremonies. On both of these occasions, the alpha animals were among the returning wolves. On one occasion, all or most of the pack left the rendezvous site, at dusk, without howling (there had been a group howl 30 minutes earlier, but after it, most of the wolves had bedded, so the howl may not have been associated with the subsequent movement).

Besides the forgoing observations and recordings, we discussed the howling project with Rick McIntyre whose field notes are important to the project, and reaffirmed the cooperative nature of the venture.

Project title: Breeding Strategies of the American Elk

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Objective: Animal behavior is often optimized as a trade-off between survival and reproduction. During the breeding season, mammals tend to maximize their effort in reproduction within the constraints of predation pressure. When predation pressure is reduced, greater effort can be allocated to reproductive behavior and less in vigilance and predator avoidance. The objective of this study was to test the hypothesis that elk in Yellowstone National Park (YNP), a predator-rich environment, would spend more time in vigilance and risk-avoidance behavior than would elk in Rocky Mountain National Park (RMNP), a predator-free environment.

Findings: Cow elk in YNP spent more time in vigilance and less in foraging during activity periods than did cows in RMNP. Also, elk in YNP retreated to forested cover during the midday inactive period whereas elk in RMNP remained in open habitat. Vigilance was not correlated with group size at either site. Cows with calves spent more time in vigilance and less in foraging than did cows without calves. Elk at Mammoth Hot Springs, a predator-free area of YNP, behaved similarly to those at RMNP. Bull elk spent more time foraging and less time in courtship at RMNP than at YNP, however these results are based on small sample sizes. Mean harem sizes were similar among the three sites, 17.0 at RMNP, 15.2 at YNP and 16.7 at Mammoth Hot Springs. The proportion of cows with calves was significantly lower at YNP (0.10) than at RMNP (0.24) or Mammoth (0.33). Elk in predator-rich areas of YNP apparently adjust their behavior to decrease predation risk

Project title: Determining Forage Availability and Use Patterns for Bison in the Hayden Valley

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Objective: 1) Determine seasonal bison habitat use patterns and factors that influence these patterns in the Hayden Valley of Yellowstone National Park, 2) identify interactions between bison and vegetation, 3) develop a monitoring strategy to track changes in vegetation due to ungulate herbivory, and 4) provide baseline data for models of ungulate-vegetation relationships in the Hayden Valley.

Findings: Data collected during 1998–2000 was analyzed. Field work was limited to tests of equipment/imagery accuracy. Estimates of forage available on a pixel basis were calculated from LANDSAT imagery

and these data were made available to modelers. Preliminary models of forage production and use were created. We are securing the set of satellite images needed for estimating biomass for three summers and have completed preliminary analysis of forage offtake from cage sites. Remaining work includes spatial rectification of all satellite images, creation of a fine-scale cover map for the Hayden Valley, and integrating bison herd locations from other studies with our time-specific biomass estimates.

Project title: How Do Disturbance-Generated Patterns Influence the Spatial Dynamics of Ecosystem Processes?

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Additional investigators: William H. Romme, Daniel B. Tinker

Objective: Our studies following the 1988 Yellowstone fires demonstrated that succession was surprisingly more variable in space and time than even current theory would have suggested, and that initial spatial patterns of disturbance may persist to produce long-lasting changes in vegetation. Our focus now is on explaining the spatial and temporal patterns of succession and understanding how these patterns influence ecosystem function. As part of extensive, long-term research on the causes and consequences of fire in the Greater Yellowstone Ecosystem, we are studying the spatial and temporal dynamics of nutrient cycling in areas of Yellowstone's subalpine plateau that have burned in 1988 and 1996, as well as a chronosequence of stands that have not burned for many years.

We are addressing several questions: 1) Do the enormous differences in postfire tree density produce differences in carbon and nitrogen availability across the landscape? Or, is nutrient availability governed largely by broad-scale (i.e., 10's of km) abiotic gradients (e.g., climate, substrate) and/or fine-scale (i.e., < 10 cm) heterogeneity in resources or the microbial community, such that nutrient variability is not sensitive to the spatial variation in plant community structure? 2) Does the disturbance-created mosaic leave a persistent functional legacy? What mechanisms in vegetation development may contribute to convergence (or divergence) in ecosystem structure and function across the landscape as succession proceeds? 3) How does the spatial pattern of coarse woody debris vary across the post-1988 landscape, and what is the importance of this variation for ecosystem function? Are patterns of coarse woody debris abundance related to both prefire stand structure and postfire sapling density? 4) Does the spatial heterogeneity of processes such as ANPP, nitrogen mineralization, and decomposition change with time since fire? How quickly do spatial patterns in processes develop following a large fire?

Findings: This particular component of our study was initiated during summer of 2001, although we continued monitoring some of our long-term plots in the 1988 fires. Most of our 2001 field data collection, however, was focused in the Grand Teton National Park, where fires burned during the summer of 2000.

Project title: Developing Effective Ecological Indicators for Watershed Analysis

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Additional investigators: Rick Lawrence, W. Andrew Marcus, G. Wayne Minshall

Objective: Natural resource extraction, other human activities, and natural perturbations such as fire have altered most watersheds throughout the Rocky Mountains. The level of alteration of these watersheds might be an important factor influencing the integrity of streams and associated riparian ecosystems that are affected by the nature of the runoff from the watershed. If stream and riparian systems are altered by watershed outputs, then characteristics of these systems might be useful as indicators of the watershed condition.

This study is designed to develop improved indicators and innovate techniques for assisting and monitoring ecological integrity at the watershed level in the western United States. Its specific objectives are to develop practical, scientifically valid indicators that 1) span multiple resource categories, 2) are relatively scale independent, 3) address different levels of biological organization, 4) can be rapidly and cost-effectively monitored by remote sensing, and 5) are sensitive to a broad range of anthropogenic and natural environmental stressors.

This study, using tributaries of the Upper Yellowstone River and their watersheds as study areas, is based, in part, on the hypothesis that streams and riparian areas often reflect the ecological integrity of the associated watersheds. Due to a funnel effect, these areas are the accumulation zones of environmental disturbances occurring in the watershed.

Identification, assessment, and validation of effective indicators will involve integration of results from research at various scales, including 1) analysis of hyperspectral and traditional multispectral imagery from both aerial and satellite platforms, 2) field surveys of stream morphology and riparian habitat, 3) analysis of remote sensing of stream and riparian attributes to assess indicators, and 4) intensive site-specific stream sampling of macroinvertebrate communities to validate the effectiveness of these indicators in assessing the watershed condition. Use and evaluation of remote sensing technologies in conjunction with ground sampling is the primary research methodology. Selection of appropriate indicators will be influenced by their ability to be monitored by remote sensing. Research on indicators first requires an understanding of the processes and components that create the system from which indicators are selected. Only after this understanding can truly functional indicators be selected. This project is guided by this principle.

Findings: 42 watershed parameters, including levels of landscape alteration, have been identified with LANDSAT Stream geomorphic measurements and have included morphological units, determination of woody debris, morphometrics. However, this relationship is not site specific, but is a system-wide state. Riparian indicators are being selected through use of several multivariate analysis techniques. Riparian community factors are closely related to watershed parameters. Aquatic ecological variables are being used to validate the relative pristine or altered nature of the watershed. Variables include water chemistry. Remote sensing hyperspectral imagery data have been made available to this project from a NASA project in YNP to allow early evaluation of its potential for identifying possible indicators. Initial analyses show that it can distinguish between several stream physical parameters, such as pools and riffles.

Future work on this project will include limited collection of field data to fill in data gaps identified during early data analysis. More comprehensive, integrated forms of multivariate analyses will be used with combined stream and riparian data. Hyperspectral imagery flights in summer 2002 will generate images to evaluate the potential of remotely sensing indicators identified through multivariate analysis. Aquatic samples collected in summer 2001 will continue to be analyzed, along with limited summer 2002 samples, to designate levels of significance of alteration of project watersheds.

Project title: Study of the Effects of the 1988 Wildfires on Yellowstone Stream Ecosystems

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Objective: This project examines the processes of stream ecosystem recovery after a large-scale disturbance (fire), while also examining the cumulative effects of a natural disturbance on an entire watershed (Cache Creek, YNP). Changes were monitored in the chemical properties of water, physical habitat conditions, and in the structure of biotic communities that included primary producers (algae) and secondary consumers (macroinvertebrates). These results also will be used in conjunction with data from the previous 13 years to determine mid-range effects of wildfire on stream ecosystem recovery. We also are examining the difference between natural and anthropogenic disturbances to stream ecosystems by comparing stream ecosystem recovery after the 1988 fires in YNP with stream ecosystem recovery after anthropogenic disturbances such as logging and livestock grazing in stream watersheds outside Yellowstone National Park's northern boundary in Montana.

Findings: Chemical: Specific conductance ranged from 60 mS/cm in the uppermost Cache Creek 2nd order location to 252 mS/cm at the lowermost Cache Creek 4th order location over the past two study years. As is expected, specific conductance increases downstream and is highest in the larger streams. Alkalinity is a measure of the carbonate content of stream water. Alkalinity like specific conductance increased from upstream to downstream. Cache Creek sites had alkalinity ranging from 34 mg CaCO₃/L to 114 mg CaCO₃/L at the furthest downstream site. Alkalinity at the Cache Creek sites and the Montana Big Creek watershed were lower than the remaining comparable streams. Hardness is a measure of calcium and magnesium ions, which are usually the principal cations in solution. Hardness values were higher overall in the 2000 sampling dates. Hardness values only slightly increased as sampling continued downstream, however all fourth order streams had higher hardness values than lower order streams. The pH for all streams ranged from 7.11 to 8.61 all within acceptable aquatic biotic limits.

Physical: Discharge did not always increase downstream as is typical. This may be indicative of sub-surface vertical and lateral flow. The year 2000 was a record low water year in YNP and presumably in the

Montana sites as well. Hydraulic slope was higher at lower order streams and tributaries in the groupings and lowest in the higher order streams.

Mean bankfull width, mean baseflow Departmenth, mean particle size, and percent embeddedness were calculated for each stream system. Bankfull width and Departmenth increased with increasing stream order. Both Cache Creek 4th order sites had smaller mean baseflow Departmenth than the 3rd order sites which would influence the smaller discharge values for those sites. Mean particle size is a first step in substrate analysis and further analyses should be done to test for differences in substrate heterogeneity.

Biological: Overall mean periphyton chlorophyll a was higher in the smaller order streams. However, the Tom Miner Creek./Horse Creek grouping and the Mill Creek/Lion Creek grouping had two to six times more chlorophyll a per mg/m² than all the other streams. Perhaps these watersheds are nutrient enriched when compared to similar watersheds in the surrounding area. However, this conclusion is not supported by the total dissolved solids content of the water as indicated by the specific conductance values. At a finer resolution there appears to be no relationship between the amount of chlorophyll a and upstream, tributary, or downstream placement. Periphyton AFDM was very similar to trends seen with chlorophyll a. The one notable difference is the Soda Butte locations had larger amounts of AFDM than was represented with the chlorophyll a measurement. High algal biomass often indicates nutrient enrichment (Mill Creek/Lion and Tom Miner/ Horse Creek) but high algal biomass also can accumulate in less productive habitats after long periods of stable flow, which may explain why Soda Butte Creek has higher algal AFDM than the Cache Creek sites. Surber samples for the August 2000 and 2001 sampling date have been processed but the aquatic macroinvertebrates remain to be identified, counted, and weighed. Supporting tables and figures for these results can be obtained by contacting the Principal Investigator.

Project title: Fire Effects in Yellowstone National Park

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Additional investigator: Eric Miller, Rebecca Seifert, Scott Weyenberg

Objective: 1) Monitor the effects of prescribed and natural fires on Yellowstone's ecosystems, 2) provide information to evaluate whether prescribed burns meet management objectives, and 3) refine our ability to predict fire behavior and fire effects through applied research.

Findings: The Yellowstone Fire Effects Monitoring crew is part of the National Park Service's overall Prescribed Fire Program. In Yellowstone our responsibilities include monitoring the long-term effects of wildland fire-use fires (prescribed natural fires), management ignited prescribed fires, and monitoring of other issues regarding wildland fire as an ecosystem process. In 2001 the Yellowstone Fire Effects Crew: 1) re-read our three Wildland Fire Use monitoring plots which burned last year: Boundary Fire and Two-Smokes Fire. We also resampled a Wildland Fire Use monitoring plot installed in 1997 by Don Despain in the 1996 Coyote Burn. 2) We installed four Wildland Fire Use FMH plots on our Sulphur, Stone, Little,

and Falcon Fires. Three of the four plots burned. 3) Pre-burn FMH plots were re-read in our proposed hazard fuel reduction burn at Grant Village. This burn was not implemented in 2001. 4) We installed our first pilot plots for our mechanical treatment for hazard fuel reduction monitoring type at Deaf Jim and Crevice Cabins. These units are slated for hazard fuel reduction using chainsaws. The Deaf Jim plot, however, was converted from the mechanical treatment monitoring type to a fifth wildland fire use plot when the Little Joe Fire consumed both the plot and the cabin. 5) The Little Joe Fire also burned one of our FPSME1T08 plots established in 1999 in a prescribed burn unit in the Electric Peak drainage. This plot and seven others were installed to monitor a prescribed burn which was not implemented. After this plot burned we also converted it to our wildland fire use monitoring type. 6) We resampled the entire set (11 plots) of post-fire vegetation monitoring plots installed by Don Despain (USGS). These plots were established in 1977, 1979, and 1988 ahead of wildfires and will provide valuable information on pre-fire condition and post-fire vegetation recovery in Yellowstone. 7) We resampled the entire set of fireline explosive (FLE) transects established around the park in 1996. This study seeks to understand the effects of FLE as a fireline construction method on vegetation recovery. 8) Our Fire History project is mostly completed. Data on fire perimeters in the archive have been researched and collated into a single database. Historical large fire perimeters dating from early in the century have been entered into a GIS. Smaller fires have also been plotted. This record is reliable back to about 1928 with sporadic records extending into the late 1800s. 9) In late May we hosted students from the University of Iowa and the University of Utah who helped us sample the bulk density of coarse woody debris in four lodgepole pine cover types in Yellowstone. This information will allow us to predict heavy fuel consumption using spatial analysis. One of the students will use the data as her senior project. 10) We plan to issue the second annual newsletter of the NPS Fire Effects Monitoring Program, *Rx Effects* in June as NPS fire effects crews in the region come on (www.nps.gov/yell/technical/fire/rxfx.htm). 11) We also maintain a website describing our activities (www.nps.gov/yell/technical/fire/effects.htm).

ENDANGERED SPECIES

Project title: Documenting the Presence and Distribution of Lynx in Yellowstone National Park

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Objective: Document the presence and distribution of lynx in Yellowstone National Park.

Findings: Research is continuing. Historically, lynx (*Lynx canadensis*) in the conterminous U.S. were reduced by persecution and habitat destruction, prompting their listing as a threatened species by the U.S. Fish and Wildlife Service during 2000. Despite evidence that lynx were and are still found in Yellowstone National Park (YNP), no rigorous effort has been made to document their presence. In 2001, we began a 3-year survey in YNP to collect baseline information necessary to assess the status of the lynx. We used a GIS-based analysis of YNP topography to identify prime lynx habitats. From 2001–2003, we are conducting intensive surveys in prime habitats using 1) ground-based and aircraft-based snow tracking during winter, and 2) hair snares to obtain DNA samples in the summer. During winter 2000–2001 and 2001–2002, we found one possible and two probable lynx tracks in YNP. During summer 2001, we installed a 32-transect hair-snare grid in east central YNP and obtained 155 hair samples (results pending laboratory analysis). We concluded that ground-based snow tracking, air-based snow tracking, and hair-snare surveys are highly complementary and provide more robust conclusions about the presence or absence of a species than if just one of these techniques were used alone.

Project title: Application of Stable Isotopes and Trace Elements to Understanding the Potential

Effects of Long-term Changes in Food Resources to Yellowstone Grizzly Bear Productivity

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Additional investigators: Chuck Schwartz, Kerry Gunther

Objective: Estimate the nutritional importance of spawning cutthroat trout in Yellowstone Lake to Yellowstone grizzly bears. Estimate the nutritional importance of white-bark pine nuts to Yellowstone grizzly bears.

Findings: Study is currently underway, but in the very early stages. Results are not currently available.

ENTOMOLOGY

Project title: Butterflies of Yellowstone and Grand Teton National Parks (also *odonata*)

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Objective: The objectives of the research are: 1) photograph butterflies, dragonflies, and damselflies within the borders of Yellowstone National Park. 2) Produce field guides to the above mentioned insects for the use of the general public. 3) Donate book quality slides to the Museum located at Mammoth Hot Springs at the Albright Visitor Center. 4) Produce additional writings based upon scientific observations of the behaviors, abundance, and all other factors related to butterflies, dragonflies, and damselflies.

Findings: Slides were obtained for the following dragonflies: Common Whitetail, Variable Darner, Pacific Spiketail, American Emerald, Flame Skimmer, White-faced Meadowhawk, Western Pondhawk, and Dot-tailed Whiteface. Slides were obtained for the following damselflies: Tule Bluet, Common Spreadwing, and Emerald Spreadwing. We specifically want to obtain slides for the following butterflies; Lustrous Copper, Green Hairstreak, and True Skipper. Work on the text of the butterfly field guide has begun. There are many more wetland areas within the Park that we need to visit. Wetlands are to be found parkwide and therefore we need access parkwide in order to complete our research. We also need to access the park in the winter season in order to observe dragonfly and damselfly larvae in thermal waters. Our findings include: dragonflies can withstand temperatures up to almost 90°F and prefer waters within the neutral range of pH.

**Project title: Assessment of Host Races in the Ovary-Feeding Beetle,
Brachyterolus pulicarius (Coleoptera: Nitidulidae)**

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Additional investigators: Kelly Hering, Bryan FitzGerald

Objective: This continuing research is being completed as part of a Master's thesis project for Kelly Hering at Montana State University. Beetles have been collected in order to investigate the existence of host races in the species *Brachypterolus pulicarius*, a natural enemy of yellow and Dalmation toadflax. Because the beetle exists on the two separate host plant species, the question of whether *B. pulicarius* actually consists of two distinct host races is being examined. In selecting sites for collection of beetles, locations were sought where no intentional releases of *B. pulicarius* have ever been made. Rather, populations of the beetles were collected in areas where they had been introduced accidentally with their host plants. Because the beetle has never been introduced into Yellowstone National Park, and because both host plant species are present within its boundaries, the Park offers an excellent opportunity to harvest insects as they naturally occur on their host plants. Along with sites in Yellowstone, others in Canada and throughout the northeastern United States are being analyzed via molecular genetic techniques.

Findings: During the summer of 2001, populations of *B. pulicarius* at research sites throughout Montana and Wyoming supported only very low numbers of beetles. Suspected causes of this low population density are the extreme drought conditions being suffered in these areas for the past several years as well as late spring snows that fell in June. Because of these conditions, no beetles were collected in Yellowstone during the summer of 2001. DNA has been extracted from all beetles previously collected in Yellowstone. During 2001, an optimized amplified fragment length polymorphism (AFLP) protocol was developed for the beetles, and amplification reactions were completed. The number of sites for final analysis was narrowed to include only one Yellowstone site where large numbers of individuals were collected. Final analyses are currently being conducted, with an anticipated conclusion of the project by the summer of 2002.

Project title: Respiratory Physiology and Thermal Preference in Thermophilic Aquatic Insects

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Additional investigators: Lori Ybarrondo

Objective: 1) To understand the degree to which the peculiar respiratory physiology of water scavenger beetles correlates with environmental variation in thermal areas. 2) To understand the degree to which thermal preference in water scavenger beetles reflects respiratory stress and successful dispersal from thermal pools having potentially lethal temperatures. 3) To understand the degree to which thermal preference in dragonfly niads correlates with development and territorial contests.

Findings: To date, we have shown that the respiratory complex of water scavenger beetles functions essentially as an oxygen reservoir at summertime temperatures. This is not consistent with long-

standing theoretical predictions that the plastron/macroplastron complex will function as a “physical gill” deriving oxygen dissolved in ambient water into the gas phase for tracheal ventilation.

Preliminary findings show clear habitat partitioning, with respect to ambient water temperature and dissolved oxygen tension, between two species of dragonfly.

**Project title: The Mosquito of Yellowstone National Park, A Study of
Their Species and Their Biology**

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Additional investigators: Dr. Robert Garrott, Dr. Charles Schwartz

Objective: To determine mosquito species present and their biology.

Findings: No collections were made during the year 2001.

ENVIRONMENTAL MONITORING

Project title: Development of an Empirical Model for Predicting the Stream Invertebrate Fauna of the Greater Yellowstone Ecosystem: A Pilot Study

Principal investigator: Dr. Chuck Hawkins
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Additional investigators: Trey Simmons

Objective: The objectives of this study are to develop an accurate, sensitive, and ecologically meaningful method to assess the biological integrity of streams in the Greater Yellowstone Ecosystem (GYE). By collecting physical habitat data and benthic macroinvertebrate samples from a large number of relatively pristine streams, most of them located in Yellowstone National Park, we can use multivariate statistical methods to generate a mathematical model that predicts the macroinvertebrate species composition at a potentially impaired stream. Comparison of the expected species composition (based on modeling) with that actually found at such a stream allows us to draw inferences about the biological integrity of the stream. The GYE is the largest relatively intact ecosystem remaining in the lower 48, but is under considerable pressure from urbanization, as well as traditional resource based industries. The bioassessment tool we are developing will allow us to determine the degree to which these activities are negatively impacting aquatic resources in the GYE.

Findings: Thus far, we have collected data from 47 streams and rivers in Yellowstone National Park, as well as over 50 streams in the GYE outside the Park. We have used these data to build a multivariate predictive model that accurately predicts the benthic invertebrate fauna of GYE streams. We assessed the accuracy of the prediction by measuring the ratio of observed (O) to expected (E) taxa (O/E score) at relatively pristine sites. The mean value of O/E for reference sites is 1.0, as would be expected if the model performs correctly. The standard deviation (SD) of the reference site O/E scores is a measure of model error. For our model, the SD of O/E scores is 0.128, which is quite good for these kinds of models. We are in the process of using the model to assess the biological integrity of 19 “test” streams in the GYE that are potentially impacted. The results of these analyses will help us to determine which land use activities may be having the greatest impact on aquatic resources in the GYE. In addition, we will be using these data to assess whether changes in stream biodiversity are adversely affecting stream ecosystem processes in an upcoming phase of the project.

Project title: Trace Element Content of Cervid Antlers

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Objective: I am studying the strontium isotopic composition and the content of strontium and other trace elements in elk and deer antlers from selected national parks in the western U.S., including Yellowstone. The study will add to the general body of knowledge about the cycling of trace elements through the environment and increase our understanding of the biogeochemistry of strontium. The study will provide baseline data from which future changes may be gauged. (A copy of the research proposal which I submitted to the Green Educational Foundation [which has provided \$12,017.00 for this study] is on file in the Research Office, Yellowstone Center for Resources, Mammoth Hot Springs, Yellowstone National Park. Said proposal provides a detailed description, etc. of this project.)

Findings: No significant findings to date inasmuch as no analytical data are yet available. Evidence of antler-chewing/osteophagia by Yellowstone elk has been obtained from several areas of Yellowstone's Northern Range, and such activities are likely related to the major and/or trace element content of the antlers/bones and the nutritional status of the elk. Much of my field work in the park in 2001 was directed toward determining the geographic distribution and frequency of occurrence of antler-chewing/osteophagic behavior through observations of skeletal remains of dead animals and cast (shed) antlers of elk and mule deer, mostly on Yellowstone's Northern Range.

Project title: A Remote Sensing and GIS-Based Model of Habitat as a Predictor of Biodiversity

Principal investigator: Dr. Diane Debinski
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Additional investigators: Kelly Kindscher, Mark Jakubauskas

Objective: In 1992, we initiated an interdisciplinary project entitled "Modeling Spatial and Temporal Dynamics of Montane Meadows and Biodiversity in the Greater Yellowstone Ecosystem." Our research team has been developing predictive species assemblage models based upon landscape level habitat analysis (e.g., Debinski and Humphrey 1997; Debinski et al. 1999, 2000; Kindscher et al. 1998; Jakubauskas et al. 1996, 1998; Jakubauskas and Debinski 1995). The goal was to use intensive, local field sampling to extrapolate species distribution patterns within a region. The

hypothesis was that plant and animal locations could be predicted by analyzing spectral reflectance characteristics as recorded by satellite multispectral scanners. This research was originally conducted in the northwest corner of the Greater Yellowstone Ecosystem (GYE) and then expanded to the Grand Teton National Park in 1996. Grants from the U.S. Forest Service, the U.S. Park Service, the U.S. Environmental Protection Agency, and three universities have supported our work.

Findings: Our sampling sites were identified using remotely sensed classification of the montane meadow habitats. Six meadow types were identified using a GIS to stratify the study area by topography and geology. Field sampling was used to collect data on the distribution of plant, bird, and butterfly species. We sampled extensively for four summers (1997–2000) in two regions of the ecosystem: the northern region included the Gallatin National Forest and northwestern portion of Yellowstone National Park (Gallatins); the southern region included Grand Teton National Park (Tetons). These two regions are 192 km apart, but have very similar plant and animal communities. Twenty-five sample sites were located in the Tetons and thirty sample sites were located in the Gallatins during 1997. These were termed “core sites” and were sampled during each of the four years. Additional sites were added in later years (including up to 65 sites per region), but we have focused the efforts during 2001 on these core sites.

Our previous research showed that montane meadow communities can function as early indicators of environmental change because they are highly sensitive to variations in precipitation and temperature (Debinski et al. 1999, 2000; Kindscher et al. 1998; Jakubauskas et al. 1998). However, the rarity and low abundances of some of the species have limited our understanding of these patterns. Thus, additional data will allow us to expand upon our understanding of these groups as indicators. We believe that the plant, bird, and butterfly communities may be some of the best indicators of environmental change in the GYE. Continued surveys of the plant, bird, and butterfly taxa will allow us to quantify the year-to-year variation in species abundances and distribution patterns. These data are critical if we hope to differentiate between natural background fluctuations and real changes caused by climate change.

Other accomplishments: We are drafting a manuscript that summarizes the results of the work that we have been conducting on biodiversity assessment techniques using remotely sensed and on the ground data from 1997–2001 on birds, butterflies, and plants in GYE montane meadows.

We are finalizing a publication that summarizes the comparison of our biodiversity assessment techniques to that of the Wyoming and Montana GAP analysis work (Su et al.). Drs. Diane Debinski and James Pritchard finished their manuscript “A Complete Guide to Butterflies of the Greater Yellowstone Ecosystem” to be published by Roberts Rinehart Publishers. Dr. Debinski collaborated with Dr. Paul Opler, author of the Peterson’s Guide to Butterflies, to create a current list of butterflies of Grand Teton National Park. This list will be linked to the Northern Prairie Biological Resources database on biodiversity across North America: <http://www.npwrc.usgs.gov/resource/1999/insect/gteton.htm>. The Northern Prairie Wildlife Research Center, which is part of the U.S. Geological Survey located in Jamestown, North Dakota, is compiling biodiversity data nationwide for this web page, and there were previously no listings for invertebrates of any kind in the Greater Yellowstone Ecosystem. Dr. Debinski’s graduate student, Amanda Hetrick, designed a web site to describe our research in the GYE to the general public. It may be found here: <http://www.public.iastate.edu/~ahetrick/prototype/homepage.html>.

EXOTIC SPECIES

Project title: Gypsy Moth Trapping Program

Principal investigator: Mr. Paul Miller
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Objective: To trap Gypsy Moths (*lymantris dysstrinnaus*) with pheromone traps and eliminate that non-native species so they don't defoliate the trees of Yellowstone National Park.

Findings: We put out 105 pheromone traps throughout Yellowstone National Park where vehicles were left for one day or more during the spring, summer, and fall. The traps lure gypsy moths into them from a radius of one mile around the traps. We checked the traps throughout the summer and gathered them in the fall. Any Gypsy Moths are identified and destroyed and a grid of traps is set up in the near vicinity to trap any other Gypsy Moths in the area.

We set out 105 traps and the only major suspect was found in the Fishing Bridge RV Park with trap 7B.

Project title: Food Web Impacts of Exotic New Zealand Mudsnails in Rivers in Yellowstone National Park

Principal investigator: Dr. Robert Hall
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Additional investigators: Mark Dybdahl, Billie Kerans

Objective: Our objective is to measure mud snail and native invertebrate secondary production in the Firehole and Gibbon Rivers as a means of estimating the degree to which mud snails dominate invertebrate production and energy flow through food webs.

Findings: We have completed one year of sampling of the Firehole and Gibbon Rivers as of September 2001. All data are collected, and we are analyzing it and preparing a manuscript. We found very high rates of snail secondary production and biomass, and these rates are higher than that for any taxa of native invertebrates, suggesting that mud snails are dominating the invertebrate assemblage. We also found fewer mud snails in summer 2001 in the Firehole River than in sum-

mer 2000. This decrease in mud snails appears to be correlated with an increase in native snail and invertebrate densities. For this reason we would like to collect summer invertebrate samples from these sites for several years to document population changes in snails and if they cause population changes in native invertebrates.

Project title: Linking Modeled and Experimentally Measured Interaction Strength Between Exotic New Zealand Mudsnailes and Algae in Rivers

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Additional investigators: Billie Kerans, Mark Dybdahl

Objective: The objective is to estimate the impacts of exotic New Zealand mudsnails on benthic river algae using small scale experiments. We are also attempting to predict the snail impact by estimating the consumption rate of algae by snails relative to the growth rate of algae.

Findings: Mud snails have strong per biomass effects on algae production. Densities of only 13,000 adults/m² can reduce primary production of algae on rocks in half relative to snail-free controls. Consumption rates of snails were near that of primary production in these chambers, suggesting that most primary production was consumed by snails. Per biomass impact of snails on algae in the Firehole was four times higher than the Snake River, despite the fact that snails grew faster in the Snake River. We have also combined these data with similar experiments conducted in Polecat Creek in the JDR Parkway just south of Yellowstone. We found almost no impact of mud snails in Polecat Creek, despite using very high densities of snails in the experimental chambers, suggesting that algae there can compensate for high grazing rates by snails.

We have completed the field parts of this project and we are analyzing data and preparing a manuscript.

Project title: Preliminary Sampling of Exotic Weeds in The Northern Ranges of Yellowstone: to Define a Sampling Methodology Protocol

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Additional investigator: Bruce Maxwell, Tad Weaver, Don Despain, Richard Aspinall

Objective: The overall objective of the six-month pilot project was to determine the most efficient and accurate approach for creating an inventory of the non-native plant species within the northern elk winter range of Yellowstone National Park. The area is too large to look for non-native species over the entirety so we focused on identifying sampling methods that provide the highest probability of locating even the rarest non-native plant species. This overall objective would be achieved through computer simulation (Objective 1a) and field sampling (Objective 1b).

Objective 1a. Evaluate the most efficient sampling method to record species occurring at low frequency within a heterogeneous environment. This would be achieved by computer simulations of hypothetical plant population distributions and combining them with a variety of sampling strategies.

Objective 1b. Use the chosen sampling methodology to inventory the occurrence of target weeds in the northern range. Nine non-native target species were selected. These species were believed to represent a range of different frequencies and possess a range of growth habits. Species included: cheatgrass (*Bromus tectorum*), smooth brome (*Bromus inermis*), timothy (*Phleum pratense*), spotted knapweed (*Centaurea maculosa*), Dalmatian toadflax (*Linaria dalmatica*), houndstongue (*Cynoglossum officinale*), yellow sweetclover (*Melilotus officinalis*), Canada thistle (*Cirsium arvense*), and ox-eye daisy (*Chrysanthemum leucanthemum*).

Findings: Computer simulations to evaluate the most efficient sampling method to record species occurring at low frequency within a heterogeneous environment were performed in ESRI ArcView GIS. This implemented several different sampling strategies including simple random sample, random walk, random transects, transects normal to specified linear features, stratified random sampling, and regular (grid) sampling. Surveying along transects was found to be the most efficient and effective methodology for sampling the target weeds. Transects allow data to be collected continuously and a large sample size to be generated. Additionally, surveying along transects allows changes in underlying environmental variables to be recorded. This is important for estimating the geographic distribution of the species from the sample data.

The fieldwork was performed at four sites in the northern range in 2001. Transect positions were randomly generated, starting on roads or trails and were 2,000 m long and 10 m wide. The locations of target weeds were recorded with GPS along with details of habitat type, topography, aspect, and disturbance. Forty-two transects were completed. Using the data collected we can calculate the proportion of the study area infested with each of the target species. When all sites were combined the percentage of the study area infested was above 0.2% for all species except ox-eye daisy and spotted knapweed. The per-

centage infestation for the 16 transects around Mammoth were relatively high: Dalmatian toadflax and timothy were present at levels of 1.4 and 1.9% respectively, the remaining species were present at densities above 0.4%, with the exception of ox-eye daisy and spotted knapweed. When considering only the other three sites (Blacktail Creek, Tower Junction, Lamar Valley) the percentage infestation of timothy was still relatively high (1.5%) but the values for all the other species were less than half those calculated for Mammoth.

The perception was that higher levels of weed infestations would be found closer to areas of human disturbance. These perceptions were borne out with respect to roads/trails. As distance from road/trails increased, the occurrence of target non-native weeds decreased. For all species combined 35% were observed within 100 m of roads/trails, after which there was a very marked decline. Fourteen percent of all observations were made within 100–200 m, 6.5% between 400 and 500 m, and only 9% between 1,100 m and 2,100 m.

The data suggests that the big sage/bluebunch wheat grass (*Artemisia tridentata/Agropyron spicatum*), big sage/Idaho fescue (*Artemisia tridentata/Festuca idahoensis*) and to a lesser extent Douglas fir/pinegrass (*Pseudotsuga menziesii/Calamagrostis rubescens*) habitats had a higher proportion of the target species.

Dalmatian toadflax, houndstongue, and yellow sweetclover were more common on an easterly aspect. Cheatgrass was more common on the easterly and southerly aspects. Timothy, Canada thistle, and smooth brome were equally prevalent on all aspects. Too few data points were collected for ox-eye daisy and spotted knapweed to determine a pattern. All the species, except timothy, occurred more frequently on sites with no aspect, i.e. level areas, but it should be considered that this information is confounded with moisture and angle of slope factors, as level areas generally also indicated increased moisture availability.

In all cases data were weighted to allow for the unequal number of observations taken in each variable class. However, it was not ensured that transects increased monotonically from 0 to 2,000 m from roads/trails; this will be addressed in subsequent data collection. Two different forms of analysis were performed—principal component analysis, and an inductive modeling procedure based on Bayes theorem within Arcview.

**Project title: Cross-Boundary Plant Invasions in Protected Areas:
The Case of West Yellowstone Area**

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Additional investigator: Anibal Pauchard

Objective: 1) Determine susceptibility of plant communities to invasion at the landscape scale in the interface between Gallatin National Forest and Yellowstone National Park. 2) Determine both forest edge effects on alien plant invasions and biodiversity patterns, contrasting natural and human disturbances. 3) Determine the invasive strategy of *Linaria vulgaris* Mill. at multiple spatial scales

in the study area and characterize its potential to invade areas in relation to disturbance types and regimes.

Findings: *Linaria vulgaris* Mill. is invading disturbed areas in Yellowstone NP and Gallatin NF over 2,000 m in elevation. We assessed and monitored *L. vulgaris* in the West Yellowstone area using a multi-scale method during the years 2000 and 2001. At the landscape scale, the species occurs over a broad range of sites, both natural and human disturbed, apparently coming from two historical sources. The large majority of patches are located in Gallatin NF. At the stand scale, patches tend to be distributed randomly or dispersed in heavily infested areas and aggregated in newly invaded areas. Radial patch growth rates are related to site characteristics such as soil disturbance and nutrient availability. Clonal patch scale analysis shows that ramet densities and effects on native plants are higher in the patch centers than the edges. Both mean ramet height and reproductive vs. vegetative ramet height ratio are higher in patches core. We conclude that *L. vulgaris* is a significant threat to native biodiversity in open and human or naturally disturbed environments in protected areas of the Rocky Mountains. During 2002, we will monitor the species in the existing plots and will complete the landscape assessment. We expect to have publishable results at the end of 2002.

**Project title: Dynamics of Climate, Fire, and Land Use Change
in the Greater Yellowstone Ecosystem**

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Additional investigators: Andrew Bunn, Jeremy Littell, Lindsey Waggoner, Sean Hill

Objective: The history and future of fire as a disturbance process in forests of the western United States represents an intersection of two of the most pressing questions in ecosystem management. At local and regional scales, it is widely recognized that fire exclusion in fire-prone ecosystems during the 20th century has caused changes in forest structure and composition. These changes, in turn, are thought to be responsible for increasing the risk of widespread wildfire and outbreaks of pests and diseases (Sampson et al. 1994; Veblen et al. in press). In order to manage forest ecosystems, we must address the following question: How significantly has fire exclusion changed the fire regime during the present century and what are the impacts of that change on forest structure and composition?

At sub-continental scales, fire exclusion during the 20th century is seen as a primary driver of carbon accumulation in terrestrial ecosystems. The net flux of carbon attributable to historical land management within the western United States is significant (Houghton et al. 1999). Quantifying current and future status of these carbon pools is a critical component of the effort to develop a firm scientific base on which to negotiate, and potentially implement, the Kyoto Protocol (ref. to USGCRP). In order to move towards an era of carbon management, we must address the following question: How have past and current fire management policies altered carbon pools and what role might western forests play in an overall carbon management strategy for the future?

The ultimate goal of my research is to contribute to a sound scientific basis for managing fire at landscape as well as global scales. Towards this end, I am developing a research program that uses dendrochronological techniques to quantify the interactions of climate, fire and land-use as they structure forest composition, structure, and productivity within the Greater Yellowstone Ecosystem (GYE) over the last 300 to 1,000 years. To relate this goal with broader issues of global climate change, I collaborate with others in developing an integrated research program to address questions of the role of mountain regions, and specifically forests, in global change (e.g., coordinating committee of International Geosphere Biosphere Projects Global Change and Mountain Regions). I have a long history of research on climate and forest dynamics at time scales of seasons to millennia. I have obtained funding to continue research on fire history because 1) in general, disturbance is a critical mediator of the interaction of climate and ecosystem processes, and 2) specifically, fire is an

important, but poorly understood, process in lower elevation forests of the GYE (Despain 1990; Meagher and Houston 1998).

Findings: The status of this project is ongoing, but preliminary results indicate the hypotheses presented in the objectives section are valid. Initial findings were presented at the Ecological Society of America's annual meeting in Madison, WI, August 4–8, 2001.

Abstract from that conference follows: Climate determinants of fire regime in the Greater Yellowstone Ecosystem (Jeremy S. Littell and Lisa J. Graumlich). Several decades of research describing pre-settlement fire regimes in western North American forests have demonstrated that fire, or its absence, is a strong determinant of ecological structure. A fundamental challenge in restoring fire in the West is to rely less on whether we have exceeded the natural range of forest structural variability and more on whether the structures we observe are compatible with fire regimes conditioned by current climate and future trends. Fire history research in the Greater Yellowstone Ecosystem has largely focused on describing fire-return intervals prior to European settlement. Very little research has attempted to link biophysical drivers and fire regimes in lower elevation (<2,500m) forests. Using dendrochronology to date fire scars and stand ages, we assembled fire histories for Douglas-fir (*Pseudotsuga menziesii*) forests and related these fire regimes to past climate. Over the last 500 years, low elevation forests had relatively high fire frequency (20–50 years) and fires tended toward lower intensity, non-stand replacing fires. Moreover, the frequency of these fires is related to regional climate anomalies. Thus, a century of fire suppression has had a far more dramatic effect on the structure of lower-elevation forests than on subalpine forests. Successful efforts to restore ecosystem structure and process must meld concepts related to natural range of variability with biophysical (i.e., climate) and social (i.e., land use) constraints.

I will be further analyzing the data sampled during the 2001 field season through the spring of 2002.

Project title: Postglacial Fire History and its Relation to Long-term Vegetational Changes in Yellowstone National Park

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Objective: The objective of this project is to study the climate, fire, and vegetation history of Yellowstone National Park. A network of pollen and plant macrofossil records from lakes and wetlands, spanning the last 14,000 years, has been examined from different environmental settings within the park. These data are used to reconstruct past changes in vegetation and climate. Information on past fire frequency is obtained from an analysis of particulate charcoal and lithologic variations in lake-sediment cores. The fire records are interpreted based on a study of modern charcoal deposition into lake sediments and a comparison of charcoal and dendrochronological

records for the last 750 years. In 2001, the primary objective was to obtain sediment cores from Crevice Lake in northern Yellowstone Park. Crevice Lake has annually laminated sediments and thus offers the opportunity to reconstruct past variations in fire, climate, vegetation, and limnology with annual precision. The Crevice Lake project involves scientists from the University of Oregon, University of Nebraska, and U.S. Geological Survey.

Findings: Sediment cores from Crevice Lake were collected from the ice surface in February. A one-week fieldwork required helicopter and logistical support from Yellowstone Center for Resources and the Fire Cache. Sediment cores, ca. 5 to 6 m in length, were taken from three locations at water Departmenths of 27.5 m. The lithology consisted of laminated gyttja, with layers of marl and coarse sand. A volcanic ash, attributed to the eruption of Mount Mazama in southwestern Oregon, was present at 2.92 cm Departmenth. The bottom sediments consisted of gravels and clays, presumably of late-glacial age. Six radiocarbon dates on plant macrofossils were submitted for age determinations, and a date of 11,426 cal yr B.P. was obtained at 4.92 m Departmenth. An age-Departmenth model based on these dates suggests that each 1-2 mm-thick lamination represents annual deposition or varves. Our next step is to develop a varve chronology for the entire record, based on counting the annual laminations and comparing it with the radiocarbon chronology. This part of the research is underway at the University of Nebraska. In summer 2002, all collaborators will meet in Nebraska to sample the cores for pollen, charcoal, diatom, lithologic, geochemical, and isotopic analyses. The fire reconstruction will be part of the dissertation of Mitch Power at University of Oregon, and Whitlock will undertake the pollen analysis.

Analysis of modern sediments in lakes with watersheds that were burned in 1988 continued in 2001. This process-based study provides information necessary to interpret the charcoal record in sediment cores by examining the deposition of charcoal into lakes following a fire event. The study is one of four process-based charcoal studies in the world, and the results have been widely used by fire researchers. The samples are being evaluated in light of previous results (Whitlock and Millspaugh, 1996; Whitlock et al., 1997) and are discussed in two manuscripts that describe charcoal depositional processes (Whitlock and Anderson, in press; Whitlock and Larsen 2002).

Other accomplishments of note are publication of a paper describing the paleoecologic record of plant invasions in Yellowstone National Park in *Western North American Naturalist* (Whitlock and Millspaugh, 2001); acceptance of two chapters on charcoal methodology (Whitlock and Larsen, 2002; Whitlock and Anderson, in press). Results of this project are also featured in books on the Yellowstone fires (Millspaugh and Whitlock, in press) and Rocky Mountain ecosystems (Whitlock et al., in press).

Project title: The Status of Whitebark Pine Regeneration in the Greater Yellowstone Area Following the 1988 Fires: Burned vs. Unburned Forests and Mesic vs. Xeric Conditions; Assessment of Blister Rust Infection in Seedlings

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Additional investigators: Anna W. Schoettle

Objective: Whitebark pine (*Pinus albicaulis*) is a subalpine conifer that is linked to the viability of the grizzly bear population in the Greater Yellowstone. The pine is threatened by white pine blister rust, an introduced disease that has decimated populations in the northern Rocky Mountains and is a growing problem in the Greater Yellowstone Area. In 1990, D. F. Tomback established 275 permanent plots in the Greater Yellowstone Area to monitor the progress of whitebark pine regeneration after the 1988 Yellowstone fires. Of these plots, 125 are in Yellowstone National Park, representing three "treatments:" stand-replacing burn, dry; stand-replacing burn, moist; and mixed severity burn, moist. In the Park, "moist" treatments had northerly exposures, and the "dry" treatment a westerly exposure. Plots were monitored for six years, with the first whitebark pine seedlings appearing in 1991 on all treatments. The study plots were revisited in 2001 to determine the 1) current regeneration densities of whitebark pine with respect to treatment, 2) cover and composition of understory plants, 3) survival of individual seedlings alive in 1995, 4) differences in water availability for soil subsurface among treatments, 5) differences in water use efficiencies of whitebark pine seedlings, 6) blister rust infection rate of seedlings in plots, and 7) prevalence of blister rust in unburned whitebark pine stands closest to each treatment. Data were gathered from the third week in June through the first week in August. Meteorological stations, including soil moisture probes and data loggers were set up in the burned treatments, and foliage was sampled from seedlings off plot for studies of photosynthetic efficiency. Plots were carefully surveyed by a team of four people, and nearby stands were surveyed for blister rust prevalence by teams of two to five people. Most work on soil moisture measurements and blister rust surveys is scheduled for summer of 2002.

Findings: The data gathered are currently being entered in several different databases for extensive statistical analysis. Final results are not anticipated for at least a year. Some general results of the study are as follows: Whitebark pine regeneration densities in all treatments inside and outside the Park are increasing over time since the 1988 fires. The greatest regeneration densities of all conifers, and particularly whitebark pine, occur on the stand-replacing burn, moist treatment in the vicinity of Dunraven Pass. In 2001, the number of newly emerged whitebark pine seedlings that occurred on this treatment was unprecedented for this study. Regeneration densities of associated conifers, subalpine fir, Engelmann spruce, lodgepole pine, Douglas fir, were also very high for this treatment. Our preliminary impression is that the dry treatment on Mt. Washburn supports comparatively low densities of whitebark pine with respect to all seven treatments in this study (three in the Park). Understory plant diversity and cover has increased through time, including the presence of several exotic grasses. Studies of soil moisture patterns and seedling water use efficiency are still in progress. No seedlings were obviously infected with white pine blister rust; and the few whitebark pine stands inspected in summer 2001 adjacent to the Park treatments on Mt. Washburn are still free of obvious blister rust symptoms. However, the stands on Henderson Mountain, just northeast of the east Park boundary, are infected with blister rust. At this time there is little to no kill or mortality in these stands, but multiple cankers and some branch flagging are apparent. For the Mt. Washburn

stands, it is only a matter of time before the blister rust infection reaches this area. To date, it appears that natural regeneration is effectively restocking the 1988 burned areas in the Park, but with pronounced differences between moist and dry sites.

**Project title: Post-Burn Resource Selection, Physiological Condition,
and Demographic Performance of Elk**

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Additional investigators: Adam Messer

Objective: The primary objective of this research is to evaluate the consequences of the 1988 fires on elk resource selection. Selection is being quantified for populations and individuals at multiple scales ranging from selection of patches within the landscape mosaic to selection of forages and plant parts within patches. The physiological and demographic consequences of observed resource selection strategies are being assessed through noninvasive urinary and fecal assays, and telemetry. Secondary objectives include basic research on forage plant chemical compositions, plant-animal interactions and applied research to develop practical and rigorous management tools for population monitoring (aerial surveys, fecal steroid pregnancy assays, and snow-urine condition indices).

Findings: We have been successful in developing, testing, and applying a suite of research tools that is significantly enhancing our ability to address questions of animal resource selection and the physiological and demographic consequences of selection patterns. We have completed our tenth field season of data collection and maintain an instrumented population of 30–40 cow elk. Most publications to date have focused on techniques including population estimation, pregnancy assessment, and nutritional indices. This year we completed a manuscript analyzing the demographic data collected during the first seven years of research, which is currently being considered by Canadian Journal of Zoology and have a second manuscript on geochemical trophic cascades accepted in the journal *Ecosystems*. Adult survival and reproduction is near the biological maximum for the species, but recruitment is highly variable, being strongly influenced by environmental variation, primarily winter severity. Despite this variable recruitment, extensive Monte Carlo simulations indicate that the population is relatively stable and is being regulated at approximately 600–800 animals. We have generated a database of greater than 10,000 animal locations and are exploring a variety of analytical tools for the analysis of these data. We have continued to acquire and develop GIS data sets of landscape features for integration with all spatially-explicit data collected on this study. We are currently developing spatially-explicit snowpack models in collaboration with NASA scientists to enhance our analyses of elk resource selection.

Project title: Recolonization of Lichens Since the 1988 Fires

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Objective: The objectives of the study in 2001 were to examine substrates burned in 1988 for recolonization by lichens, and to measure largest colonies or thalli for estimates of growth rates. The working hypothesis was that moister spruce and Douglas fir forests would have more substrates recolonized than other sites, more species would be present and the thalli would be larger.

Findings: We visited 30 sites burned in 1988: ten lodgepole pine sites, five whitebark pine, five Douglas fir, five spruce and five grassland/meadow. A site was a discrete area within a burned stand. Some stands were in the center of extensively burned sites, and others were more mosaic with live standing trees adjacent to the burned area investigated. The latter was more common in spruce and Douglas fir sites. Distance to unburned trees was estimated. Lichens, mosses and small fungi were all present on charred logs so all these organisms were recorded. When the species was not readily identified in the field, the sample was collected for laboratory identification.

The circumference and entire length of ten burned, downed logs at each site were thoroughly examined for recolonizing species. When present, snags were also examined, as were soil and rocks. The largest colony or thallus for each lichen species was measured in order to get an estimate of maximum colonization and growth rate. Burned rock and soil substrates are more ambiguous than burned logs and snags.

Preliminary results support part of the original hypothesis. About 80% of the logs in spruce sites were being recolonized with lichens and/or mosses, while logs in other forest sites averaged closer to 40–50%. The percentage of logs with no new growth of lichens, moss or fungi was higher in lodgepole pine, whitebark pine, and Douglas fir sites (ca. 21%, 32% and 32%, respectively) than in spruce sites (ca. 5%). A slightly higher percentage of logs had more new lichen growth than moss, except in lodgepole pine sites where slightly more logs had mosses than lichens. However, on logs with new growth, the moss growth was substantially more extensive than the lichen growth. This was especially true for logs lying on the ground, where mosses appeared to grow from shaded moist soil under the log up onto the log, particularly in cracks. Most of the growth of mosses and lichens was on shaded parts of logs close to the ground. The fungi tended to be anywhere on the logs.

Dominant species identified so far on logs and snags are *Cladonia coniocraea*, *C. fimbriata*, *Letharia vulpine*, *Bryoria fuscescens*, *Usnea substerilis*, *Xanthoria fulva* and species of *Physcia*, all sorediate species common in Yellowstone forests. *Peltigera rufescens* and *P. didactyla* were common on burned soils. Primary mosses on logs were *Ceratodon purpureus* and species of *Bryum*. *Polytrichum piliferum* and *P. juniperinum* were on burned soils. Work is still in progress on identification of all moss and fungus species, and on data analysis for soils and rocks.

Project title: Fire: A Force for Change and Regeneration in a Natural Ecosystem

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Objective: To monitor growth rates and reproduction of vegetation, particularly lodgepole pine, at sites affected by various fire intensities from the fires of 1988 and to provide a long-term photographic record of vegetation change in those sites.

Findings: This year was year 12 of the study. Growth rates of lodgepole pine saplings varied from 34 cm/yr to 46 cm/yr. Lowest increases occurred at the Frying Pan Springs site. The highest increases occurred at the Norris-Canyon blowdown area and the site one mile S of Norris Junction. Reproduction (male and female cones) is now occurring at all study sites, and is especially vigorous at sites affected by severe fire intensity. The tallest post-fire saplings, south of Norris Junction, are 4.75 meters (15.58 ft) tall. The sites north of Madison Junction, near Tuff Cliff, could not be sampled in 2001 due to heavy road construction equipment operating in the area.

FISHERIES MANAGEMENT

Project title: Cutthroat Trout Egg and Sperm Collection

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Objective: To successfully manage Montana's fisheries resources, we need to maintain our broodstocks with a wide genetic diversity. These broodstocks should mirror their wild ancestors as closely as possible. The original gametes for our Yellowstone cutthroat trout broodstock came from McBride Lake in Yellowstone National Park in 1969. The last time gametes were taken from the lake to supplement the broodstock was 1987. To once again infuse our broodstock with new genetic material, we want to again collect gametes from McBride Lake for three consecutive years beginning in 2001. Each year of the three year program would require eggs and sperm be taken from 15 females and 15 males. Fish would be sacrificed for health and genetic testing. Means of collecting the fish would be electro fishing.

Findings: With help from Dan Mahony and his crew, eggs were taken from a McBride Lake tributary. On June 7, 2001, the lake was reached on horseback and foot. The water temperature was 10°C in the inlet tributary. All the fish needed were electro fished and held in holding nets in the creek. Sperm was taken from the males in groups of three. Eggs were taken from three females at a time into a sieve. Eggs were then put into a bowl where the combined sperm from three males was added along with a .75% saline solution. After several minutes, the eggs were rinsed and placed into a bucket containing 25ppm iodine for disinfection during water hardening. After water hardening, the eggs were rinsed and put into a water cooler for the trip out. A total of 27 fish were sacrificed for health and genetic testing.

Eggs were taken from 12 females, two others were spent and one was green. Sperm was used from 15 males. A total of 11,629 eggs were taken. This was an average of 969 eggs per female. There were 401 eggs per ounce with a total of 29 ozs. Percent eye-up was 41%. Hatch was 90% leaving 4,267 fry. Dry Head Creek in the Pryor Mountains was planted with 1,000 of the fish when they reached 1.7 inches long. These were put in the creek to reestablish a population of pure Yellowstone cutthroat trout. The remaining fish are being held at Yellowstone River Trout Hatchery in Big Timber, MT, to infuse broodstock on station with new genetic material.

All health tests done on the fish taken from the tributary came back negative, as did health tests done on month-old fry that resulted from the eggs taken. Genetic testing has not yet been done.

Project title: Movements and Reproductive Ecology of Genetically Pure and Hybridized Westslope Cutthroat Trout *Onchorhynchus clarki lewisi* in the Fan Creek Drainage, Yellowstone National Park

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Additional investigator: Todd Koel, Alexander V. Zale

Objective: The objectives of this study are as follows: 1) Identify spawning locations and times of pure populations of westslope cutthroat trout in the North Fork of Fan Creek and introgressed populations in the remaining reaches of Fan Creek. 2) Determine if both resident and fluvial forms of pure westslope cutthroat trout exist in the North Fork of Fan Creek.

Findings: A total of 28 fish were implanted with telemetry tags and passive integrated transponder (PIT) tags in the main stem and North Fork of Fan Creek. These fish were tagged from May 16, 2001 to June 25, 2001. A total of 22 westslope cutthroat trout were tagged in the North Fork of Fan Creek and six rainbow trout-westslope cutthroat trout hybrids were tagged in the main stem of Fan Creek. These fish were tracked on a weekly basis beginning on June 15, 2001 and finishing in mid-September when the battery life of the tags ran their course. In addition, 116 fish were implanted with PIT tags only in the main stem and North Fork of Fan Creek. A weir was installed in the North Fork of Fan Creek near the confluence with the main stem on May 15, 2001. This bi-directional weir was equipped with two PIT tag antennae able to detect fish passage both upstream and downstream in the North Fork of Fan Creek. Information was stored into two solar-powered data loggers, which were downloaded into a computer once every two weeks. This weir was removed November 28, 2001 before ice formation. A total of 127 movements were recorded as fish passed through the weir.

Fall 2001: A total of 29 fish were implanted with telemetry and PIT tags in the main stem and North Fork of Fan Creek from September 14, 2001, to October 10, 2001. Eight westslope cutthroat trout, four hybrids, and one rainbow trout were tagged in the main stem of Fan Creek. A total of 17 westslope cutthroat trout were tagged in the North Fork of Fan Creek. These fish were tracked on a weekly basis until November and on a monthly basis beginning in December.

Project title: The Spatial and Temporal Spawning Distributions of Yellowstone Cutthroat and Rainbow Trout in the Upper Yellowstone River Drainage

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Objective: To determine where and when spawning occurs for Yellowstone cutthroat trout, rainbow trout, and hybrids of the two species in the Yellowstone River below Knoll's Falls (the most upriver area accessible to fish from this study). Radio telemetry is being used to describe the spawning patterns of the three study groups of fish.

Findings: A total of 25 fish (15 cutthroat, 5 rainbow, and 5 hybrids) had radio transmitters implanted on April 5, 2001, from the Yellowstone River at Corwin Springs (approximately 16 kilometers down river from the town of Gardiner). These fish were followed on a weekly basis from the time of implantation through mid-July. Spawning was documented in tributaries for nine fish, with eight of the fish using either Cedar or Mol Heron creeks adjacent to the Corwin Springs area. One cutthroat migrated upstream to spawn in Bear Creek, approximately 3.5 kilometers upriver from Gardiner. One spawning rainbow trout and three hybrids were documented in Mol Heron Creek from mid-April until late May. Spawning cutthroat trout were observed in Mol Heron, Cedar, and Bear creeks from early June until early July. In addition, 25 fish from the Yellowstone River near Mill Creek in the Paradise Valley were also implanted with radio transmitters. These fish migrated to spawn a considerable distance down river from Yellowstone National Park and are not reported on here.

FORESTRY

Project title: Remote Sensing-Based Geostatistical Modeling for Coniferous Forest Inventory and Characterization

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Objective: In May 1999, KU's Kansas Applied Remote Sensing (KARS) Program was chosen by NASA to develop methods that use remote-sensing data and advanced geostatistical methods to create maps of forest age and successional state, or cover types, and of forest biophysical factors, including density, biomass, leaf area, basal area, and height. Geostatistical methods take advantage of the spatial dependence in forest variables and remotely sensed data. By calibrating remotely sensed multispectral data with a small number of ground measurements, characteristics of the forest measured at sample points can be extrapolated across a large geographic region. This has significant advantages for forest management, especially when forests are in remote or inaccessible locations. Benefits of the integrated remote sensing/geostatistics approach will include a reduction in the amount of time and costs required for forest inventory and mapping. The maps produced using the technique will provide information on forest characteristics that previously were very difficult or impossible to map, including the leaf area index (LAI) and aboveground biomass. By monitoring changes in forest characteristics over time, forest managers can use the geostatistical remote sensing technique to map insect defoliation, wildfire damage, and regeneration of the forest. The project will develop two demonstration projects, showing the use of remote sensing and geostatistical analysis for insect damage assessment and mapping forest cover types. A web site has been developed (www.kars.ukans.edu/forest).

Findings: 2001 Yellowstone Field Campaign: In cooperation with the Kansas NASA EPSCoR Office and the KU School of Aeronautical Engineering, the Kansas project carried out an overflight of selected study areas in Yellowstone using the new KARS Airborne Duncan Digital Multispectral Camera. The overflights were scheduled to be coincident with both ground sampling of spectral reflectance and with satellite image acquisitions by the Landsat 7 ETM and the EO-1/Hyperion sensors on July 18. Heavy cloud cover on the day of overpass—a rarity for that time of year in Yellowstone—yielded poor satellite and airborne imagery and poor field data. Airborne imagery acquired by the KU system several days later (July 19–21) were of very high quality (0.4 meter spatial resolution, three spectral bands). Over 2,000 multispectral digital images of the park were acquired during the series of overflights (samples available on request). Currently, this data is being processed for use in the KARS research, and will be made available to other Yellowstone researchers at a later date. The field sampling campaign for the Central Plateau of Yellowstone was planned and

carried out in July 2001. Data on forest density, height, basal area was collected from sample plots in an area west of the West Thumb area, south of the Craig Pass Road. Data were collected at five field sampling grid resolutions (100 m, 250 m, 355 m, 500 m and 1,000 m). Over 200 new field sampled points were collected on the nested grids during the July field season.

Over 2,000 multispectral digital images of the park were acquired during the series of overflights (samples available on request). Currently, this data is being processed for use in the project research, and will be made available to other Yellowstone researchers at a later date.

The second order image texture improves overall classification of forest age classes by over 30%, similar to results shown by other researchers. The most significant improvement is for the uneven age, uneven canopy, Engelmann spruce and subalpine fir stands (LP3), which have proven to be a difficult age class to map. This could be due to structural components of the stand (shadows) which are summarized in the pixel information level. However, with the higher resolution of the Landsat TM 7 panchromatic band, this structural component can be captured with the application of second order image texture. We have demonstrated that mapping forest stand age stages of the Central Plateau of Yellowstone National Park can be achieved when Landsat TM 7 imagery spectral and spatial components are employed.

The study also assessed how well airborne hyperspectral AVIRIS image data could discriminate differences between seedling densities in postfire regenerating sites, as compared to Landsat TM satellite data. In most forestry applications seedlings or postfire regenerating areas are usually grouped into one class. Our results show that a more detailed discrimination of the seedling class is possible, especially when hyperspectral data are available. The statistical analysis performed in this project showed the application of AVIRIS hyperspectral imagery to be an improvement in the discrimination of the seven seedlings density classes by almost 20% as compared to the Landsat TM imagery. A website has been developed for other Yellowstone researchers to download Landsat satellite imagery from our server (<http://www.kars.ukans.edu/forest/landsat7.html>). The data is free of all restrictions, and other data sets are available on request.

Project title: White Pine Blister Rust in the Greater Yellowstone Area: Local Spread and Intensification of an Introduced Pathogen

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Objective: White pine blister rust is recognized as the most damaging North American conifer disease. The disease is caused by a fungus that alternates between white pines and gooseberry and currant shrubs (*Ribes* species). Impacts from the disease have been documented in relatively pristine forests such as those of the Greater Yellowstone Area (GYA). Whitebark pine (*Pinus albicaulis*) and limber pine (*Pinus flexilis*) are the only white pines that occur within the GYA, with whitebark pine inhabiting more acreage than limber pine. White pine blister rust may be the most severe threat

that these valuable trees are facing. The overall goal of this study is to increase our understanding of the disease system and its expected impacts.

Throughout the GYA there are some sites showing high disease intensities while some sites remain at low infection levels. The study objective is to characterize sites with and without disease intensification to learn what factors may be associated with high infection levels. Specifically, the following questions are being studied: 1) Are there site characteristics related to host plant (*Ribes* and white pine) densities and distributions that correlate with whitebark pine infection levels? 2) Does the seasonal timing of *Ribes* leaf development influence *Ribes* infection levels, and what methodology is best for measuring *Ribes* infection levels? 3) What environmental conditions occur within the canopies of *Ribes* and pine hosts in whitebark pine forests?

Findings: During the summer of 2001 a total of 18 whitebark pine stands with variable infection levels were visited and quantitatively characterized. Two sites were located within Yellowstone National Park, one on Mount Washburn and one on Avalanche Peak. Both of these sites showed low whitebark pine infection levels. Additionally, weather-monitoring data-logger equipment was positioned at two sites. One weather monitoring station was located in the Gallatin National Forest on Palmer Mountain and the other within Grand Teton National Park on Rendezvous Mountain. Qualitative data was also collected on *Ribes* distributions, relative infection levels, and leaf phenology. The study is ongoing and additional field data will be collected during 2002.

Project title: Geologic Controls on Ecology of the Greater Yellowstone Ecosystem, Particularly the Grassland-Forest Contrast

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Objective: The soil moisture sensors were installed at both transect sites and recording begun at 12-hour intervals.

Findings: Post-installation checks indicated that the data loggers were recording as programmed.

GEOCHEMISTRY

Project title: *Water Chemistry and Its Relationship to Local Geology: A Yellowstone Case Study*

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Objective: This study is an ongoing component of Geology 329 taught from the Indiana University Geologic Field Station, Cardwell, MT. During the field-based class, undergraduate students involved with several environmentally oriented programs (chemistry, biology, ecology, geology, and environmental science) on campus, are involved in their first intensive field experience.

The objectives of the Yellowstone study are two-fold. First, the Yellowstone National Park field trip is a unique opportunity to look at an ecosystem that is heavily influenced by hydrothermal activity, which is in stark contrast to the riparian and mountain systems found in study areas of the Tobacco Root Mountains. During the weeks preceding the Yellowstone trip, the students engage in the collection of field measurements of various aquatic systems encountered in their study areas. This data (including oxidation-reduction potential, pH, temperature, and specific conductance) is used as a comparative set against the data collected in the thermal features of Yellowstone. The range of values encountered in the Yellowstone features gives some extreme values for real world data sets and illustrates how temperature controls many of the other chemical variables and microbial ecosystems.

Secondly, plotting the data on topographic maps gives some notion of the distribution, and the compartmentalization of the thermal features. In addition, the real time data that the students collect and plot is compared to the plots of the field data from the USGS Bulletin 1303 (Rowe et al. 1973) which was collected in the 1960s. The data illustrates the geologically ephemeral nature of the features when compared to time scales of other geologic processes observed and discussed during the course.

Findings: In June 2001, Park Geologist Paul Doss accompanied the group through the Upper Basin at Norris. The group took four sets of field measurements (oxidation-reduction potential, pH, temperature, and specific conductance) at 14 thermal features along the public boardwalk. Over lunch, the data were compiled and plotted on a copy of the figure from Rowe et al. 1973. The data was then compared to the published data from USGS Bulletin 1303 to see which features were new in the last 40 years, which had cooled or were inactive, and where the current hot spots were today.

Later in the afternoon, the group visited Octopus Spring for a look at the controlling factors in the distribution of microbial communities. Groups again took field measurements along the run-

off channel to observe how temperature controls the chemistry and the distribution of the microbial communities. Students plotted their data along their sketched map of the spring and runoff channel. Eight water samples were collected, and H₂S (HS⁻), SO₄²⁻, and Cl⁻ were trapped with Zn-acetate, BaCl₂, and AgNO₃ respectively to form precipitates. These were filtered, weighed, and the concentrations of these constituents calculated later at the Field Station. Care was exercised to leave the features as undisturbed as possible, and to avoid reactants making it into the environment.

Project title: Geochemical and Geophysical Investigations of Mine Impacts and the Soda Butte Creek Watershed, Yellowstone National Park

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Objective: The objectives of this project are to examine the geochemical systems of the Soda Butte Creek watershed, and to investigate the impact of mining activities near the Creek's headwaters on stream and sediment chemistry. This is accomplished through: 1) building a long-term database documenting seasonal and annual variations in stream chemistry and metal concentrations in stream waters and sediments, and 2) delineation of shallow subsurface features in the Soda Butte Creek floodplain.

Findings: Sediments and waters of Soda Butte Creek and selected tributaries were sampled twice in 2001. Samples collected in early June represent spring high-flow conditions, while samples collected in early August represent seasonal low-flow conditions. Results of geochemical analysis of samples collected in 2001 are consistent with the pattern established by previous years' findings. Elevated concentrations of metals persist in sediments of Soda Butte Creek immediately downstream of the McLauren tailings deposit. Concentrations of lead, zinc, copper, manganese, silver, cadmium, and iron are elevated in sediments collected in the vicinity of the tailings, and also in sediments near the Republic Creek confluence. However, concentrations decrease rapidly to "background levels" and remain relatively constant within Yellowstone National Park boundaries. Sediment concentrations of silver and cadmium are below analytical detection limits at all sample sites within the Park. By contrast, nickel, manganese, and strontium are depleted in sediments near the tailings relative to downstream sediments. Republic Creek appears to contribute these metals to Soda Butte Creek sediments. Concentrations of nickel in stream sediment diminish steadily downstream, while concentrations of manganese and strontium remain relatively constant downstream of Republic Creek.

Mineralogical analysis of sediment collected in October 2001 was accomplished through x-ray diffraction (XRD). Quartz, plagioclase, calcite, dolomite, smectite, magnetite were indicated in all sediment

samples. Kaolinite and mica were detected in samples representing the upper reach of Soda Butte Creek. Pyrite and hematite were present at irregular intervals in stream sediments. The presence of these iron-bearing minerals was not correlated to the McLauren tailings deposit.

Project title: Dissipation of Thermal and Chemical Disequilibrium in Hot Springs

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Objective: The objective of this study is to determine the kinetics (rates and mechanism) of thermal equilibration and chemical equilibration of hot spring waters as they discharge and interact with the atmosphere. The emphasis is on determining the cooling rate and the rate of gas-water exchange as a function of flow regime. It is hypothesized that the rate of cooling and gas exchange are coupled as both are dependent on the flow regime. If this hypothesis holds then we can develop a model for the rate of gas exchange based on cooling rates, which are far easier to determine than gas exchange rates.

Findings: We focused our study on Ojo Caliente in the River Group. Ojo Caliente is a boiling spring with a very constant chemical composition and a well-developed drainage. At eleven points along the drainage the flow velocities and travel times were determined. In addition we successfully implemented a method to characterize the flow regime (turbulence). This method is based on the rate of dissolution of a gypsum plate. Addressing a concern raised in the review of the permit, it is shown that the water composition in the drainage is not affected by the deployment of the gypsum plates. Water chemistry was also determined along the 11 points. The water cools evaporatively. This is supported by the predictable increase in conservative constituents, such as Na and Cl. The volatile constituents (CO₂, CH₄, H₂S) decrease more or less exponentially with distance from the orifice. This is consistent with degassing models. Interestingly, midway in the drainage we see a sharp increase in cooling and volatile loss. At this point there is more turbulence in the water. This indicates that there might indeed be a correlation between cooling and gas exchange. More work is underway to resolve this.

Project title: Geochemistry, Biochemistry, and Stable Isotope Systematics of Sublacustrine

Hydrothermal Vents in Yellowstone Lake: A Modern Hot Spring Gold-depositing Environment?

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Objective: The objectives of this study are to understand hydrothermal processes in sublacustrine hydrothermal vents in the context of the Yellowstone ecosystem and subaerial hydrothermal systems in and around Yellowstone National Park. In particular, we are using chemical composition, especially minor and trace elements and stable isotopes (H, C, N, O, and S), to understand processes of hydrothermal mineralization and to track potentially toxic and nutrient elements from hydrothermal vents into the micro- and macro-fauna of Yellowstone Lake and the Greater Yellowstone ecosystem. To this end we have sampled lake waters, streams flowing into and out of Yellowstone Lake, sublacustrine sinter deposits and altered sediments, lake and cutthroat trout, bacterial mats and small crustaceans from vent localities, and similar materials from selected subaerial hydrothermal systems Parkwide. In addition, geochemical studies will be carried out on subaerial hydrothermal areas with Ann-Louise Reysenbach and Tina Takacs as part of the NSF-NPS funded microbiological inventory of the Park.

Findings: The geochemistry of Yellowstone Lake is strongly influenced by sublacustrine hydrothermal vent activity. The geothermal source fluid feeding the lake and other subaerial hydrothermal systems can be identified using Cl and hydrogen isotope data on vent samples from Yellowstone Lake and thermal waters at subaerial sites. The chemical composition of sublacustrine hydrothermal vent fluids and the geothermal source fluid indicates strong enrichment of As, B, Cl, CO₂, Ge, Hg, H₂S, K, Li, Mo, Na, Rb, Sb, Si, and W. The Cl concentrations indicate that Yellowstone Lake is about 1% geothermal source fluid and 99% inflowing stream water and that the flux is about 10% of the total geothermal water flux in Yellowstone National Park. With recent swath-sonar mapping studies that show numerous new hydrothermal features, Yellowstone Lake should now be considered one of the most significant geothermal basins in the Park. Hg enrichments in hydrothermal vents and associated fauna contribute to elevated Hg concentrations in lake and cutthroat trout. Enriched Hg in cutthroat has potentially serious implications for grizzly bear, otter, eagle, and osprey populations that feed on cutthroat trout who spawn in the rivers. Hydrothermal deposits occur on the lake bottom near active and presently inactive hydrothermal vents. Centimeter- to decimeter-sized siliceous deposits are cemented and recrystallized diatoms and represent pathways for hydrothermal fluid migration. A second major type of hydrothermal deposit comprises hard, porous siliceous spires that were discovered near Bridge Bay in 1997. At least 8–10 spires up to 7 m tall consist of diatom-rich areas and fibrous masses and globules of amorphous silica that could be microbial in origin. Preliminary U-series dating gives an age of 11 ka for the silica spires. Bridge Bay spires formed in place by growth of chimney-like features from vigorous or long-lived lake-bottom hydrothermal vents. Chemical analyses indicate that siliceous vent deposits are almost always

strongly enriched in As, Ba, Cs, Hg, Pb, and Sr, and are often enriched in Fe, Mo, Mn, Nb, Rb, Ta, Th, Tl, and W relative to normal Yellowstone Lake sediments. Oxygen isotope analyses of silica deposits indicate formation at temperature between 80°C and 160°C. Chemical reaction modeling indicates that amorphous silica saturated fluid that vents into bottom waters at temperatures above 145°C can precipitate amorphous silica by mixing with cold, dilute lake waters.

Project title: Arsenic Biogeochemistry in Yellowstone National Park

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Objective: 1) Determine microbially mediated rates of As(III) oxidation in acid-sulfate-chloride springs in YNP, with special focus on Norris Basin, Lower Geyser Basin and Amphitheater Springs. 2) Evaluate the diversity and nature of chemolithoautotrophic microorganisms inhabiting acid-sulfate-chloride springs of YNP. 3) Characterize relationships among As, S and Fe aqueous geochemistry, solid phase formation and the microbial populations that inhabit the geothermal environments. 4) Evaluate whether microbial populations present in acid-sulfate-chloride thermal springs possess As detoxification strategies that allow survival in these extreme environments.

Findings: Geothermal springs within Yellowstone National Park (YNP) often contain arsenic (As) at concentrations of 10 to 100 μM , levels which are considered toxic to many organisms. Arsenite (As[III]) is often the predominant valence state at the point of discharge, but is rapidly oxidized to arsenate (As[V]) during transport in shallow surface water. The thermal spring selected for this study (44°43'54.8"N 110°42'39.9"W, Spring No. NHSP106, thermal inventory of YNP) is typical of many springs found in the Hundred Springs Plain of Norris Geyser Basin. The spring was selected after preliminary analyses in October 1999 that showed rapid oxidation of As(III) upon discharge. This spring discharges water between 58°C and 63°C (observed over a one-year period), and exhibits a distinctive sequence of well-separated microbial mats covering the spring floor in both longitudinal and lateral directions. The current study was designed to establish rates and possible mechanisms of As(III) oxidation, and to characterize the geochemical environment associated with predominant microbial populations in a representative acid-sulfate-chloride (pH = 3.1) thermal (58–62°C) spring in Norris Basin, YNP. At the spring origin, total soluble As was predominantly As(III) at concentrations of 33 μM . No oxidation of As(III) was detected over the first 2.7 m downstream from the spring source, corresponding to an area dominated by a yellow filamentous elemental S-rich microbial mat. However, rapid oxidation of As(III) to As(V) was observed between 2.7 and 5.6 m, corresponding to termination of the S-rich mats, decreases in dissolved sulfide, and commencement of a brown Fe/As-rich mat. Rates of As(III) oxidation were estimated

yielding an apparent first-order rate constant of 1.2 min^{-1} (half-life = 0.58 min). The oxidation of As(III) was shown to require live organisms present just prior to and within the Fe/As-rich mat. Complimentary analytical tools used to characterize the solid phase associated with the brown mat revealed an As:Fe molar ratio of 0.7 and suggested that this filamentous microbial mat contains Fe(III)-oxyhydroxide coprecipitated with As(V). Results from the current work are the first to provide a comprehensive characterization of microbially-mediated As(III) oxidation and the geochemical environments associated with microbial mats in acid-sulfate-chloride springs of YNP.

Detailed molecular characterization of 16S rDNA sequences was also performed on the predominant geochemical zones of the representative acid-sulfate-chloride spring. Analysis of amplified 16S rDNA fragments with denaturing gradient gel electrophoreses (DGGE) confirmed the presence of different bacterial and archaeal populations in each of the primary geochemical zones. Phylogenetic analyses of 1,400 base pair 16S rDNA sequences of clone libraries obtained from the yellow and brown mats suggested that Hydrogenobacter-like and Desulfurella-like populations dominate the yellow and brown mat communities but that Meiothermus-like and Acidimicrobium-like populations may also be important as well as numerous archaeal populations present in the brown mat. The appearance of archaeal sequences coincided with the onset of As(III) oxidation and the sequences obtained were affiliated with both Crenarchaeota and Euryarchaeota. The majority of archaeal sequences were most similar to sequences obtained from marine hydrothermal vents and other acidic hot springs, although the level of similarity was generally less than 90%. The role of specific bacterial and archaeal populations regarding oxidation of S, Fe and As is the subject of our continuing effort to understand linkages among microbial populations and geochemical processes in acid-sulfate-chloride geothermal springs. Specifically, we are currently addressing isolation of Hydrogenobacter-like populations and Fe(II)-oxidizing populations that may also play a role in As cycling, and that may possess unique As detoxification strategies.

Project title: Sulfur Speciation and Redox Processes in Mineral Springs and Their Drainages

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Objective: The prime objective is to determine the fate of geothermal H₂S from hot springs and geysers. The hypothesis is that H₂S can undergo both oxidation and volatilization. The amount oxidized and remaining in solution will be determined by analyzing the waters for thiosulfate, polythionates, sulfite, and sulfate. The remainder would have been volatilized. Sulfoxyanions will be determined using ion chromatography in a mobile chemical laboratory that can be located on or near site. The origin of thiosulfate and its importance to mineral deposit formation will be studied and the rate of thiosulfate formation from H₂S oxidation will be measured in hot spring overflows where possible.

Findings: During 2001 we made 27 new measurements on thiosulfate in hot springs for a total of

more than 120 determinations along with determinations of H₂S, polythionates, sulfite, and sulfate. We have shown that thiosulfate is formed very rapidly from the oxidation of H₂S and that the oxidation usually happens on exposure to the air but it does happen in a few locations in the shallow subsurface. The oxidation rates are 1–2 orders of magnitude faster than found in the lab at 25°C and there is no evidence that thiosulfate is important in complexing metals or mineral deposit formation at Yellowstone.

**Project title: Geochemistry and Geochronology of Eocene Potassic Volcanism
in the Absaroka Volcanic Field**

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Additional investigator: Charles Lindsay

Objective: The objectives of this study are to investigate the origin of magmatic rocks in the Eocene Absaroka Volcanic Province and to use this information to better understand the significance of across strike increases in K₂O contents of rocks in the field and possible tectonic settings of the rocks.

Findings: No additional field work was performed in the Park this year and thus there are no additional findings. This project is now completed.

Project title: Geochemical Baselines in the Greater Yellowstone Area, ID, MT, and WY

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Objective: 1) Provide objective, unbiased geochemical baseline data for about 50 chemical elements determined in samples of rock, active stream sediment, water, plants, and animal scat collected from scattered localities throughout Yellowstone National Park and the adjacent U.S. Forest Service lands. 2) Identify the sources, such as hydrothermal features, past mining, and recreation, of anom-

alous concentrations of selected elements. 3) Determine the chemistry of selected elements in the food chain and how these elements may impact the health of wildlife in the Park. 4) Publish raw data and interpretive reports on results.

Findings: About 600 samples of stream sediment, rock, water, and/or animal scat have been collected from widely scattered sites in and around YNP. These samples have been analyzed for as many as 50 elements. In the northeastern part of the Park, weakly anomalous levels of elements related to mineralized rock or to past mining in the Cooke City area have been detected in samples from the Soda Butte Creek drainage basin. These weak anomalies extend to the confluence of Soda Butte Creek with the Lamar River, where sediments from that stream with only background levels of most elements dilute the anomalous concentrations from Soda Butte Creek to background levels. In the fossil (dead) and active hydrothermal areas of the Park studied to date (mainly areas of geysers and hot springs), a common suite of elements is generally present in water and sediment downstream from each area. Concentrations of some elements that are potentially toxic to animals, such as arsenic and fluorine, are significantly elevated in downstream water and sediment. Such elements can be taken up by plants that are consumed by animals. Concentrations of other potentially toxic elements, such as lead and selenium, are very low in the Park and thus are not considered to be a significant health issue. Cesium seems to be the best unique indicator of hydrothermal activity. Analyses of over 100 samples of bison and elk scat show anomalous concentrations of elements associated with hydrothermal features for those animals foraging near such features, indicating that animals foraging in such areas are ingesting significant amounts of elements such as arsenic and fluorine. The toxic effects of fluorine on elk have been documented by others. The effects on animals of ingesting large quantities of many of the elements determined for this study are not known. Data are lacking on the amounts of elements, such as arsenic and molybdenum, that are being retained and accumulated in animal tissue.

Project title: Quantitative Geochemical Modeling of Calcite Precipitation Kinetics at Narrow Gauge Springs, Yellowstone National Park

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Additional investigators: Alan Glennon, Weldon Hawkins, Chris Groves

Objective: Yellowstone National Park's Mammoth Hot Springs consists of nearly 100 hot springs scattered throughout step-like travertine terraces. The rapid mineral precipitation rates and known evolution history of the travertine deposits make Mammoth Hot Springs an appropriate site to quantitatively compare theoretical models to real-world measurements of calcite deposition.

Although these concepts were applicable to both travertine and sinter deposits, this study focused on calcite deposition. The water chemistry data obtained at Narrow Gauge Springs were geochemically analyzed and compared with theoretical models. Educational objectives of the study were met within the context of Western Kentucky University Geography Course 440G: Geomorphology. While we have studied carbonate mineral geochemistry in a variety of settings, including investigations into karst landscape and aquifer evolution and the deterioration of historic limestone structures in Europe, a key component of this pilot study was to begin to expand our experience to thermal systems.

Findings: Magma-heated bicarbonate-rich water rises to the surface and rapidly deposits calcium carbonate on the Mammoth terraces. Carbon dioxide is released, with partial pressures found to be approximately 1,000 times above the atmospheric background level. The 60-degree Celsius water obtained at the Western Extension of Narrow Gauge Terrace was geochemically analyzed. The water was found to be supersaturated with calcite, indicating a tendency for calcite deposition. Using an empirical calcite precipitation kinetics rate law, the rate of calcite precipitation was estimated to be 31 mm/year for a water sample obtained in August 2001. A yearlong series of photographs indicated that the spring's actual deposition rate was about an order of magnitude higher. The disparity between laboratory models and observed rates can likely be attributed to several factors, including differences in calcite porosity, growth due to biological activity, carbon dioxide out-gassing, and evolutions in the spring's water and depositional patterns.

Project title: Field Trip to Yellowstone National Park, Water Sampling

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Objective: The use of chemical and physical measurements taken in the field and in the laboratory are used to identify and classify geo-thermal features.

Findings: Measurements of simple chemical indicators including pH and total dissolved solids were successfully used in the identification of: Alkaline, Acid Sulfate, and Neutral Chloride geothermal features.

Project title: Student Project to Measure Geochemistry of Thermal Springs

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Objective: To instruct students about the geochemistry of thermal springs in YNP

Findings: On July 27, 2001, students from the University of Georgia conducted *in situ* measurements of temperature, pH, and total dissolved solids (estimated from specific conductivity) for a number of thermal springs at different localities. Below is a listing of the data we obtained, where temperature (T) is reported in degrees Centigrade and total dissolved solids (TDS) is reported in gm/L.

Norris Geyser Basin: Perpetual Hot Spring: T=90; pH=4.7; TDS=1.48. Firecracker Hot Spring: T=53; pH=3.5; TDS=1.09. Pearl Geyser: T=86; pH=8.3; DS=1.3.

Black Pit Spring: T=80; pH=8; TDS=0.31.

White Creek Area: Spindle Geyser: T=96; pH=8.4; TDS=0.85. White Creek: T=50-58; pH=8.12; TDS=0.27. Octopus Spring: T=85; TDS=0.81.

Mammoth Hot Springs: Narrow Gauge Spring: T=63; pH=9.5; TDS=1.32.

**Project title: Arsenic Geochemistry in Yellowstone National Park:
Occurrence, Speciation, and Transformations**

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Objective: The prime objective is to determine the processes that control the concentrations and redox speciation of arsenic in geothermal springs and geysers and their overflows. As(III) and As(V) will be determined routinely and as facilities become available, methylated forms of arsenic, thioarsenites, and arsine gas will be determined. Processes that mobilize arsenic, precipitate arsenic, and oxidize arsenic will be examined. Oxidation rates will be determined where possible and compared to lab rates.

Findings: We have completed 84 As(III/V) determinations during 2001 for a total of 171 determinations since the first measurements. We have found that arsenic is most commonly in the reduced As(III) state at the discharge point of a hot spring but rapidly oxidizes to As(V) within a very short distance of overflow. The fast oxidation rate is catalyzed by microbes and happens over a wide range

of pH, temperature, and composition. Arsenic concentrations reflect both non-reactive behavior (correlate with Cl) and reactive behavior (no correlation with Cl) and the controls are being investigated.

Project title: Dartmouth College Earth Sciences Field Methods

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Objective: This is one segment of the three-month course of Field Methods in Geology and Environmental Studies taught by the faculty of Earth Sciences Department of Dartmouth College. The objective for the Yellowstone segment was to teach students a number of field methods used in glacial geology, fluvial hydrology, and stream geochemistry.

Findings: The part in stream geochemistry involved sampling stream and hot spring waters for analysis of alkalinity, calcium and chloride concentrations. The sampling was designed to examine the effects of bedrock lithology and hot spring input on stream chemistry. We found, as expected that stream water near hot springs was high in alkalinity and chloride. Stream water running over limestone bedrock was high in alkalinity and calcium. Students were able to use simple mixing models to calculate the contribution of hot spring water to various streams inside Yellowstone.

Project title: Geochemistry of Thermal Springs

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Additional investigators: William Cooper, Cindy Wilson, Matt Vitale, William Woessner

Objective: The overall objective of research in Dr. Hinman's group is to identify controls on the chemistry of springs, runoff channels, and groundwater in thermal areas. Specifically, Dr. Hinman's group studies dissolved, particulate and mineral-precipitate composition to understand the chemical, physical, and biological processes that control the chemistry of thermal spring environments.

Work in 2001 focused on two areas: short-term photochemical processes and longer-term ground-water-surface water interactions.

Findings: Photochemical processes: Studies were conducted at four thermal springs—Black Sand Pool, Chocolate Pots, and the Roadside Springs to test the hypothesis that photochemical processes influence and in some cases control the chemistry of biologically important elements. The relationship between reactive oxygen species and iron was examined. Experiments consisted of several distinct parts.

The first part involved monitoring concentrations of several analytes (dissolved oxygen, hydrogen peroxide, sulfide, ferrous and total dissolved iron) as well as pH and temperature in the springs throughout the day (7–8 p.m.). Concurrent with studies in the spring, concentrations of hydrogen peroxide, ferrous and total dissolved iron were monitored in spring water isolated in whirl-pak bags. Sodium fluoride was added to half the bags to bind iron thus preventing iron cycling and possible hydrogen peroxide formation. These studies demonstrated that iron is important for the production of hydrogen peroxide.

The second part involved monitoring hydrogen peroxide decay in spring water. Water samples were collected from the springs and hydrogen peroxide was added. Hydrogen peroxide, sulfide, ferrous and total dissolved iron concentrations were monitored for two hours. Decay rates varied between the springs, probably as a consequence of differences in initial water chemistry.

For the last part of the study, water was collected from each pool. The bag experiments were repeated under controlled conditions. The purpose of these studies was to determine the role of iron and/or sulfide cycling in hydrogen peroxide formation and decay. The Roadside iron spring has the highest iron concentration of the three springs for which the data has been analyzed. There were significant differences in hydrogen peroxide concentrations in the differently pre-treated waters (i.e. unfiltered water, filtered water without fluoride, and filtered water with fluoride). In the filtered water with fluoride, there was no significant hydrogen peroxide formation demonstrating that when iron is in an unreactive form, hydrogen peroxide is not produced. The Roadside sulfur spring and Black Sand Pool both have lower iron concentrations and behaved similarly. There were significant differences in hydrogen peroxide concentrations in the differently pre-treated waters. In the filtered water with fluoride, there was significant hydrogen peroxide formation. However, hydrogen peroxide formation was lower than in the filtered water without fluoride suggesting that more than one pathway results in hydrogen peroxide production.

Hydrogeological and hydrochemical Investigations: Rabbit Creek is lined with a hard mineral deposit along most of its reach. Previous studies on this type of material suggest it forms in losing sections of thermally influenced streams. Rabbit Creek was examined to determine whether this relationship holds and to identify possible biological factors that contribute to the mineral formation. The study of the hydrogeology and hydrochemistry of these mineral deposits involves measurement of discharge, groundwater flow, and water chemistry, as well as characterization of the deposits themselves and the associated biota.

Since August 2001, stream discharge has been constant. Water table has risen less than inch. Stream temperature has dropped 8°C and groundwater temperature has dropped 5°C to 20°C between October and January. The pH of groundwater (7–8), surface water (8–9.5), and hot springs is relatively constant. Anion concentrations (Cl- 200–300mg/L; F- 20–25mg/L; SO₄²⁻ 15–

20mg/L) increased in the winter compared to the summer. Cation concentrations are dominated by Na (>300mg/L), K (10–15mg/L), B (1–3mg/L), and Si is currently precipitating from solution. Alkalinity is in the range of 200–300mg/L CaCO₃. Preliminary interpretation suggests that thermal water becomes more important as a source of recharge to the shallow aquifer during winter months.

Project title: Carbon Dioxide Emissions Related to the Yellowstone Volcanic/Geothermal System

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Additional investigators: Cindy A. Werner

Objective: 1) To determine the magnitude of CO₂ emissions due to the Yellowstone volcanic/hydrothermal system in the context of other globally important volcanic systems. 2) To monitor background temporal variability of CO₂ emissions due to environmental conditions as a baseline to be compared to changes in emissions due to changes in hydrothermal or seismic activity. 3) To study the spatial distribution of CO₂ emissions and investigate controls on spatial heterogeneity of gas emissions. 4) To monitor gas chemistry including carbon and helium isotopes to gain a broader understanding of the sources of gas emissions and interactions with the hydrothermal system. 5) To test eddy covariance as a new method for measuring emissions in volcanic and hydrothermal terrain.

Findings: Three papers have been published on our work on CO₂ degassing in Yellowstone, and one is in being submitted.

Werner, C. Brantley, S., and Boomer, K., 2000, CO₂ Emissions related to the Yellowstone Volcanic System: 2: Statistical Sampling, Total Degassing, and Transport Mechanisms, *Journal of Geophysical Research*, Vol.105, B5, 10,831–10,846.

Abstract: A stratified adaptive sampling plan was designed to estimate CO₂ degassing in Yellowstone National Park and was applied in the Mud Volcano thermal area. The stratified component of the sampling design focused effort in thermal areas and the adaptive component in high-flux regions, yet neither sampling technique biased the estimate of total degassing. Both diffuse soil fluxes (up to ~30,000 g m⁻² d⁻¹) and emission rates from thermal vents (up to 1.7 x 10⁸ mol yr⁻¹) were measured in thermal areas. Soil fluxes observed in most nonthermal regions were similar to values reported for conifer forests (15 g m⁻² d⁻¹). However, through adaptive sampling, high-flux vegetated sites were identified in Mud Volcano that likely would not have been found if sampling was focused in obvious thermal or altered regions. A simple model applied to flux measurements suggests that ~40% of the analyzed measurements were dominated by possible advective transport and ~30% by diffusive transport. Isotopic signatures of soil CO₂ generally suggest a deep origin

($\delta^{13}\text{C} = -2.3$ to 0.0) in thermal areas and biogenic origin ($\delta^{13}\text{C} = -20.5$) in nonthermal, low-flux areas. Vent emissions accounted for ~32–63% of the total degassing observed at Mud Volcano (2.4 to 4.0×10^9 mol yr $^{-1}$). The largest source of error in the estimation of total degassing (factor of ~2) resulted because the population distribution of thermal feature emissions was indeterminate. Total CO $_2$ emissions at Mud Volcano are comparable to other hydrothermal regions worldwide, suggesting that the Yellowstone volcanic system is likely a large contributor to global volcanic/metamorphic/hydrothermal (VMH) emissions.

Boomer, K., Werner C., and Brantley, S.L., 2000, CO $_2$ Emissions related to the Yellowstone Volcanic System: 1: Development of a Stratified Adaptive Cluster Sampling Plan, *Journal of Geophysical Research*, 105, B5, 10,817–10,830. (no abstract)

Werner, C. Wyngaard, J., Brantley, S., 2000, Eddy-Correlation Measurement of Hydrothermal Gases, *Geophysical Research Letters*, Vol. 27, No. 18, 2,925–2,929.

Abstract: In the first application of eddy correlation in a hydrothermal region, we measured turbulent fluxes ranging between -17 and $13,500$ g CO $_2$ m $^{-2}$ d $^{-1}$ in Yellowstone National Park (YNP). These turbulent fluxes are similar in magnitude to chamber measurements of diffuse fluxes in the region. Negative turbulent fluxes due to vegetative uptake were measured in non-thermal regions. The flux footprint was used to compare turbulent with surface fluxes within the source area of EC measurements, and turbulent fluxes were consistent within error to the spatial extrapolation of chamber measurements. EC is more representative than chamber techniques, providing a viable alternative to measuring gas emissions in volcanic and hydrothermal terrain.

Work in progress: An investigation of the CO $_2$ fluxes in Upper Geyser Basin, Mammoth Springs, Roaring Mountain, Washburn Springs, Crater Hills, and the Lamar River Valley suggest that diffuse degassing is highest in acid-sulfate and travertine precipitating regions, and lowest in regions of silica precipitation and sulfur flows.