A Science Agenda for the Greater Yellowstone Area

Responding to landscape impacts from climate change, land use change, and invasive species

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This paper presents a science agenda to support ecosystem management in the Greater Yellowstone area (GYA) over the next 10–20 years. The authors represent the planning committee of a November 2009 workshop at Montana State University entitled "Climate Change, Invasive Species, and Land Use Change as Drivers of Ecological Change in the Greater Yellowstone Area: A Workshop to Identify Priority Science and Implementation Strategies." The science agenda presented here reflects the input of approximately 40 invited land managers and subject area experts and approximately 50 other experts and interested-party observers at a workshop endorsed by the Greater Yellowstone Coordinating Committee.

This science agenda is intended to be a living framework that captures the state of knowledge in late 2009 with flexibility to incorporate continuing research and new information to support adaptive management. In general, a science agenda seeks to identify critical information gaps, steer the research community toward management needs, guide future science funding and permitting, and help managers understand science priorities that underpin management efforts. This science agenda focuses on three key drivers: climate change, land use change, and invasive species. We suggest that these are long-term issues for the GYA, and they also are consistent with the science framework of the National Ecological Observatory Network (NEON), a National Science Foundation project to collect data from across the United States on the impacts of climate change, land use change, and invasive species on natural resources and biodiversity. A transect from the Yellowstone northern range to Bozeman, Montana, has been identified as the core site for long-term NEON science in the Northern Rockies (NEON 2009). These drivers are acting independently and synergistically to alter North America, including the landscape of the GYA. Within the GYA we expect these changes to amplify in scope and ecological relevance over the next 20 years. If we are to manage resources effectively in the GYA, an informed understanding of how these drivers influence GYA wildlands will be critical.

Brief description of the GYA

The GYA covers roughly 18 million acres in three states (Wyoming, Montana, Idaho). The region is often described as the largest intact ecosystem in the lower 48 states, with Yellowstone and Grand Teton national parks at its core. Some 75% of this land area is in public ownership, including national parks, national forests, national wildlife refuges, and Bureau of Land Management land. One of the

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Approximately 90 land managers and experts attended the November 2009 "Climate Change, Invasive Species, and Land Use Change as Drivers of Ecological Change in the Greater Yellowstone Area: A Workshop to Identify Priority Science and Implementation Strategies" at Montana State University.

important and unique components of the GYA is long-standing land-management partnerships. For example, the Greater Yellowstone Coordinating Committee was formed in 1964 with a Memorandum of Understanding (MOU) between the National Park Service and the Forest Service. By 2002, the partnership expanded to include the US Fish and Wildlife Service. Various Greater Yellowstone Coordinating Committee subcommittees, comprised of federal, state, and non-governmental organization staff, carry out the ongoing coordination of management activities in the GYA, including subcommittees for Aquatic Invasive Species, Clean Air, Fire Management, Fisheries, Hydrology, Recreation Visitor Use, Sustainable Operations, Weeds, and Whitebark Pine. Greater Yellowstone Coordinating Committee priorities include climate change, invasive species, and landscape integrity. Another example of a long-standing partnership in the GYA is the Interagency Grizzly Bear Study Team, which has been in place since 1983 to oversee conservation of the Yellowstone grizzly bear population. The Interagency Grizzly Bear Study Team operates under the guidance of the Yellowstone Grizzly Coordinating Committee, which includes representatives from the National Park Service, Forest Service, the US Fish and Wildlife Service, the Bureau of Land Management, and the US Geological Survey; state wildlife agencies from Montana, Idaho, and Wyoming; representatives of local governments from Idaho, Wyoming, and Montana; and representatives from the Shoshone Bannock and Eastern Shoshone tribes. These partnerships have provided valuable opportunities for coordinating resource management within the GYA.

The need for an ecosystem-level science agenda

In recent years, attention on ecological stressors in the GYA has shifted from local impacts associated with recreational use and land use practices to more regional issues associated with changing land use patterns and invasive species. In addition, recent scientific information suggests that climate change may have significant effects on the GYA. These larger-scale stressors are expected to impact both ecosystem dynamics and services in ways that are hard to predict based on our current understanding (Hansen and DeFries 2007; Bartlein et al. 1997; Shafer et al. 2001). Over the coming century, these changes may significantly alter the ecosystems we see today and lead to major disruptions of habitats and species (IPCC 2007; McWethy et al., forthcoming; Ashton 2010). Such potential changes present a profound challenge for natural resource managers in the GYA (Baron et al. 2009).

Increasing human population growth is likely to constrain both the movements of species and organisms and the adaptation strategies of managers (Heller and Zavaleta 2009). Since 1970, the human population in the 22 counties that compose the GYA has increased an average of 55% and the number of rural homes in that area has increased 350% (Hernandez 2004). Land use around the parks and wilderness areas in the GYA affects ecological function in many ways, including (1) changing ecosystem size, with

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Gallatin County (the Gallatin Valley south of Bozeman shown here) is located within the Greater Yellowstone area and is Montana's fastest growing county. Its growth rate is in the top 3% of all counties in the United States. Since 1990, Gallatin County's population has grown by 73%; its annual growth rate has accelerated since 2000. While the populations of cities in the county grew by 98% since 1970, the population in rural areas outside of towns has grown by 239%. (Data from the Sonoran Institute; www.sonoraninstitute.org.)

Nonnative lake trout (*Salvelinus namaycush*) were first documented in Yellowstone Lake during the summer of 1994. Lake trout are efficient predators that have been associated with substantial declines of native Yellowstone cutthroat trout (*Oncorhynchus clarki bouvieri*; smaller fish in photo removed from stomachs of lake trout). The National Park Service operates a lake trout suppression program to curtail negative consequences to Yellowstone cutthroat trout and the Yellowstone Lake ecosystem.

implications for minimum dynamic area, species-area effects, and trophic structure; (2) altering flow of materials and disturbances into and out of reserves; (3) altering crucial habitats for seasonal and migration movements and population source/sink dynamics; and (4) increasing negative human impacts through poaching, exotic species invasion and spread, and disease (Hansen and DeFries 2007).

Some invasive species, including plants, aquatic species, and wildlife pathogens, are likely to thrive under the conditions brought on by climate change and land use change, and bring impacts of their own. Broadly, one of the first-order casualties of invasive species will likely be changes in native biodiversity (Gude et al. 2007; Bartlein et al. 1997). For example, introduced blister rust (and native mountain pine beetle) have killed more than half a million whitebark pine trees in the GYA (Forest Service 2008). Aquatic nuisance species such as New Zealand mudsnails are spreading into GYA waters (McMahon et al. 2009) along with introduced pathogens such as whirling disease (Koel et al. 2006). Bivalves such as zebra and quagga mussels may also spread into GYA waters (IEAB 2010). Exotic lake trout have taken over Yellowstone Lake and caused dramatic declines in Yellowstone cutthroat trout (Varley and Schullery 1995; Gresswell 2009). Terrestrial systems have also suffered from invasions of spotted knapweed, nonnative thistle, and other plants that are threatening rangelands used by domestic and wild ungulates (Olliff et al. 2001). Future projections show yellow starthistle, cheatgrass, and spotted knapweed increasing their range in the GYA (Bradley et al. 2009).

Developing the agenda

This GYA science agenda is based on discussion and debate during the November 2009 workshop that reviewed the current understanding of how climate change, land use change, and invasive species are expected to drive GYA ecology over

In August 2008, the National Park Service convened a scientific review panel to evaluate the park's lake trout suppression program and provide direction for future suppression and recovery activities. The review panel consisted of government, academic, and non-profit scientists. After an intensive, three-day review, Dr. Robert Gresswell of the US Geological Survey delivered the findings and recommendations to National Park Service personnel. Efforts such as this improve communication among stakeholders and assure that managers have the best available scientific information available to make decisions.

the next 20 years, and translated that state of knowledge into guidelines for near-term ecological research needed to manage GYA wildlands. In preparation for the workshop, we surveyed managers on their concerns regarding ecosystem management in the face of climate and land use change and invasion of nonnative species, and compiled an annotated bibliography on the three drivers and their current and potential impact on the GYA. At the workshop, plenary talks were followed by concurrent breakout sessions where three agency managers met with five to seven scientists to discuss each driver, the current issues, and the state of our knowledge, and to project consequences into the future. Interchange among breakout groups, other experts, and interested observers occurred during several combined sessions (fig. 1).

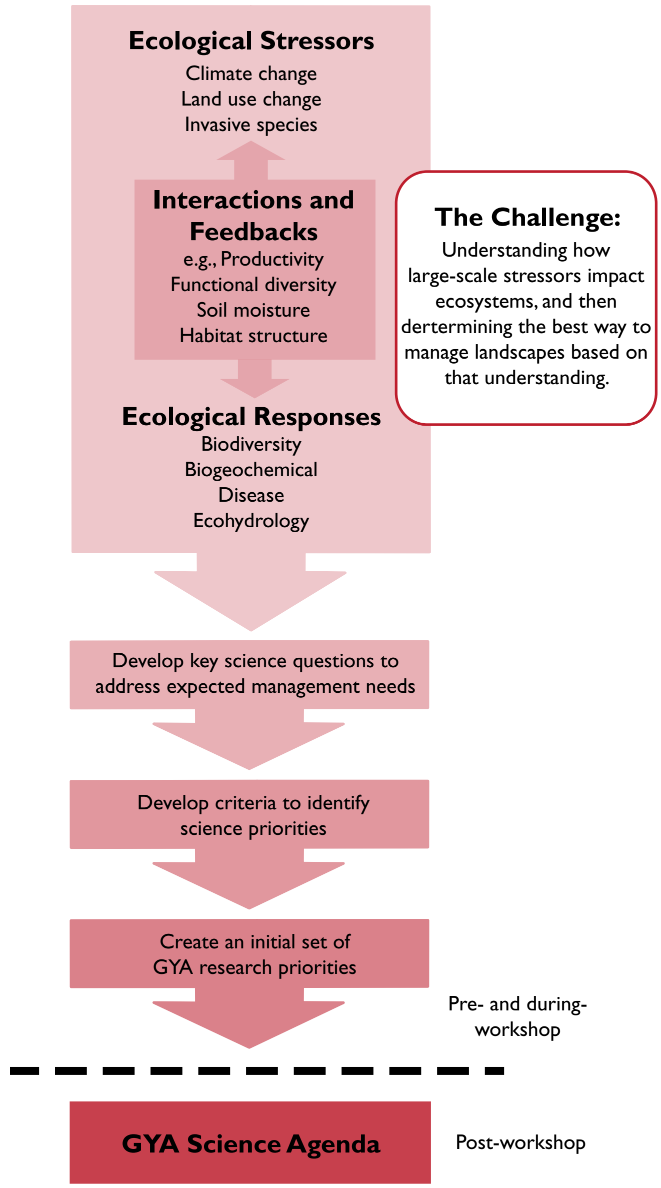

Figure 1. Conceptual model for development of the Greater Yellowstone area science agenda.

GYA science agenda: The central elements

Collaboration is the first fundamental element of the GYA science agenda. The GYA is uniquely organized for a viable, long-term, integrated approach to ecosystem management, as multiple, long-standing, collaborative partnerships exist between federal, state, tribal, and local government agencies, non-government organizations, and the general public. These existing collaborations will be cross-linked within the Great Northern Landscape Conservation Cooperative (LCC) recently mandated under Department of Interior Secretarial Order 3289 (Secretarial Order 3289). The goals of the Great Northern LCC align with this science agenda: LCCs seek to inform integrated resource management actions addressing climate change and other stressors within and across landscapes based on management-science partnerships. Thus the goal of the LCC program matches the goal of the GYA science agenda—to link science and conservation delivery. Similarly, each of the Greater Yellowstone Coordinating Committee partner agency strategic plans mandate collaborating across large landscapes and using the best available science to build a strong foundation for assessing climate change and its impacts, and continuing to improve the scientific basis for a unified approach to managing ecosystems (National Park Service, forthcoming; US Fish and Wildlife Service 2009; Forest Service 2010). By becoming integrated into the LCC program and linked to the respective agency strategic plans, the GYA science agenda will be immediately linked to the four key aspects of a successful program: mandate, funding, leadership, and communication.

Relevance is the second fundamental element of the GYA science agenda. We use the term relevance to mean the explicit linking of scientific knowledge to management action through an adaptive management framework. Adaptive management links management action to monitoring where the results from that monitoring are used to validate or potentially change the management action (Walters and Holling 1990; Glick and Stein 2010). Scientists can help managers understand the linkage between management actions and outcomes by designing monitoring efforts that measure the outcomes. Monitoring and evaluation provide cross-over points for interaction between managers and scientists. The evaluation period in particular provides a venue for managers to petition scientists for more information, and for scientists to redesign data collection schemes based on the information learned to date. The key is to continue baseline inventory and long-term monitoring programs at timescales that allow for meaningful interpretation.

Synthesizing existing and new data into concise formats and actionable reports, including utilizing new information technologies, is needed to make information available to all user groups, but particularly managers making decisions. Concise information products need to be specifically tailored to meet managers' needs and integrate across topics of climate change, land use change, and invasive species. Additionally, it is critical to expand education and outreach efforts with the interested public through informal and formal education and interpretation programs.

Recognizing that an endless array of academically interesting science questions is possible, we developed criteria for deriving science priorities. These criteria helped us evaluate science relevancy to management decision making intended to protect the public trust. Our criteria for evaluating key science questions were:

(1) Does the research meet an immediate need of managers?
(2) Does the research provide forecasts that help managers deal with uncertainties and surprises?
(3) Does the research improve understanding of basic principles of interactions between human and natural systems?
(4) Does the research improve basic understanding of impacts of key drivers on key natural processes?

Using these criteria to qualitatively filter these issues, we developed a suite of GYA science priorities that were identified for each driver and then a set of questions that integrated multiple drivers (see sidebar).

Rapid climate and associated ecosystem transitions in the Rocky Mountains have occurred in the past and will likely occur in the future. Projections include a higher frequency of large fires, longer fire seasons, and an increased area of the western US burned by fire.

Sarcoptic mange (or "scabies") is an infectious skin disease caused by a mite. It was intentionally introduced in the western United States in the early 1900s as a biological control of wolf and coyote populations, and has been present in Greater Yellowstone coyotes ever since. It appeared in wolves outside of Yellowstone National Park in the early 2000s and now affects wolves inside the park.

The final step is to identify the highest priority science questions by key drivers. We anticipate working closely with members of the Great Northern LCC and other conservation partners to develop a framework for conservation action in the near future. This framework will help us prioritize the most important questions and allow for key research to be initiated. We anticipate that we will customize the framework for the GYA to take advantage of local opportunities for funding and research collaboration.

Linking science with management

There have been several other attempts to link scientific analysis with adaptive management related to climate change. These efforts have identified steps to prioritize resource values (e.g., species, habitats, ecosystems); assess resources for their vulnerability to climate change and other landscape stressors, determine which are likely to be most at risk and which are more likely to persist; identify and evaluate an array of management options based on technical, financial, and legal considerations; select management strategies to implement; and monitor the activities and outcomes in order to feed into a regular cycle of evaluation, correction, and revision (Glick and Stein 2010) and others (Cross et al., forthcoming; Chapin et al. 2010).

A model for linking science to management that builds from these frameworks will be presented in a follow-up

Key Questions of the Science Agenda

Synergistic questions

1. What has been the variability in climate (temperature, precipitation, and snow dynamics) and land use (rural home and agricultural water use) in the past and what are the projected trajectories for future decades?
2. How will projected interactions among climate change, land use change, and/or invasive species impact ecosystem function and connectivity at different spatial and temporal scales?
3. What changes in disturbance regimes can be expected under projected changes in climate, land use, and invasive species prevalence?
4. What are the cascading impacts to ecosystems, communities, and species across different trophic levels resulting from projected climate change and land use change?
5. How will climate change, land use change, and invasive species affect sensitive cultural resources, including cultural landscapes, ethnographic resources, national historic landmarks, national historic districts, and important archeological sites?
6. How are land-use and climate change altering the spatial and temporal distribution of primary productivity and what are the consequences for herbivore populations?
7. How do humans act as vectors of invasive species spread and does exurban development promote expansion of invasive species into wildlands?
8. What types of invasive organisms, diseases, and disturbance synergies are most likely under different scenarios of changing climate and land use?
9. What is the role of social science in informing management decisions and communication about climate change, land use change, and invasive species?

Climate change questions

10. How will climate change (drought, temperature, snowpack, soil moisture, flow degree and timing, and invasive species) impact cold water ecosystems?
11. How are surface water, ground water, and the timing and volume of runoff influenced by climate variability and change and what are the likely patterns of these under future climate scenarios?
12. What species, habitat, and ecosystem types are especially sensitive to climate change?
13. How will the species in fragile alpine communities (e.g., whitebark pine and pika) be impacted by expected climate-related changes in fire, insects, temperature, and moisture regimes?
14. How resilient are Greater Yellowstone area ecosystems to climate change and are there thresholds in climate change leading to new states in ecological systems?
15. What improvements are needed in the current climate station network of the Greater Yellowstone area to fill gaps in station coverage, improve quality control, and enhance suitability for describing variability and trends in climate?

Land use change questions

16. In what ways and to what extent are human activities outside protected areas (e.g., national parks or designated wilderness areas) altering ecological processes and biodiversity inside protected areas?
17. What specific linkage areas are necessary to improve connectivity for wide-ranging species such as wolverine, lynx, wolves, and grizzly bears?
18. How do changes in the structure and function of protected ecosystems and the surrounding landscape feedback to change human attitudes and trajectories of development?
19. How can development (e.g., exurban, energy, recreational) be managed to minimize impacts on natural process (e.g., wildlife ecology, fire)?

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How will fragile alpine communities be impacted by expected climate-related changes?

20. What processes (e.g., economics, perceptions of crowding) will limit growth in amenity communities?
21. How do changes in land use and land cover associated with consumption of natural resources (grazing, mining, logging, energy development) impact natural processes within and outside protected areas? What are the ecological ramifications of shifting from extractive land uses to residential uses?
22. How do social/political processes operate to change biological processes through management decisions? How do changes in human demographics and values shape the operation of these decision-making processes?
23. How do changes in landscape hydrology in areas surrounding Yellowstone National Park influence thermal features within the park?

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What will Greater Yellowstone area rangelands look like in future climate scenarios?

Invasive species questions

24. What will be the rate of spread of priority invasive species (plant, animal, and pathogen) already present in the Greater Yellowstone area over space and time?
25. How quickly will invasive species (plant, animal, and pathogen) that are not currently present in the Greater Yellowstone area spread to this area?
26. What are the drivers (ecological processes and species traits) of spread of invasive species?
27. What terrestrial landscapes and waters are most vulnerable to new invasions of exotic species?
28. What are the ecological impacts of invasive species in the Greater Yellowstone area?
29. What is the current understanding of the role of invasive species in the systems where they occur and what methods best prevent and control them?

These science questions prompt the following resource management issues:

- How will managers develop capacities required to utilize the state of knowledge of changing climate, land use, and invasive species to mitigate their impacts via targeted or integrated management policies?
- What, if any, resource management approaches can build resilient ecosystems or mitigate the likelihood of extreme stressor-caused disturbance events?
- How can managers use improved understanding of human dimensions (e.g., values, expectations, behavior, and economics) to engage and influence human behavior to positive effect?
- How can managers utilize current knowledge to assess risks via tools such as scenario planning and vulnerability analyses?
- How can managers work with scientists to develop and use reliable forecasting models that provide the best possible representation of expected future conditions while recognizing uncertainty?
- How can managers develop integrated and standardized baselines of ecological data obtained from active monitoring programs so that it usefully informs management?
- What steps are needed to institutionalize monitoring programs, standardized field protocols, and data analysis activities, and what strategies are needed to provide the sustained workforce and infrastructure necessary for long-term repetitive monitoring, inventory, and analyses?
- How can managers maintain necessary funding and resources to ensure that long-term, repetitive programs such as invasive species containment are adequately carried out?
- How can managers institutionalize science infrastructure, collaboration, and delivery through a formal long-term consortium of scientists, managers, and public dedicated to high priority topics?


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How will alpine vegetation communities shift as climate changes?

article in *Yellowstone Science*, including guidelines to link scientific tools such as research studies, scenario planning, vulnerability assessments, and long-term monitoring with management approaches and adaptive management into an integrated resource management program.

Recent reports useful to managers

Since the November 2009 workshop, several synthesis reports have been initiated or completed, including syntheses of observed and projected changes in climate variables and ecological response to climate change covering most of the Great Northern LCC, including the GYA (McWethy et al., forthcoming; Ashton 2010) and a similar synthesis specific to the Shoshone National Forest (Rice et al., forthcoming). Other scientific reports that will be useful to managers include a broad scale vulnerability assessment of potential effects associated with climate change on native trout (Haak et al., forthcoming) and the report from a scenario planning workshop on climate change impacts on wolverines and grizzly bears in the northern US Rockies (Cross and Serhveen 2010).

Summary

The GYA science agenda presented herein was developed to assist scientific and management communities in addressing issues associated with three large-landscape stressors—climate change, land use change, and invasive species—that are expected to impact the region over the next 20 years and beyond. The agenda is presented as a living document, to be informed as the state of knowledge grows. An exciting opportunity for review and growth will occur at the 10th Biennial Scientific Conference on the Greater Yellowstone Ecosystem, "Questioning Greater Yellowstone's Future: Climate, Land Use, and Invasive Species" in October 2010 at Yellowstone National Park (http://www.greateryellowstonescience.org/gyesciconf2010).

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