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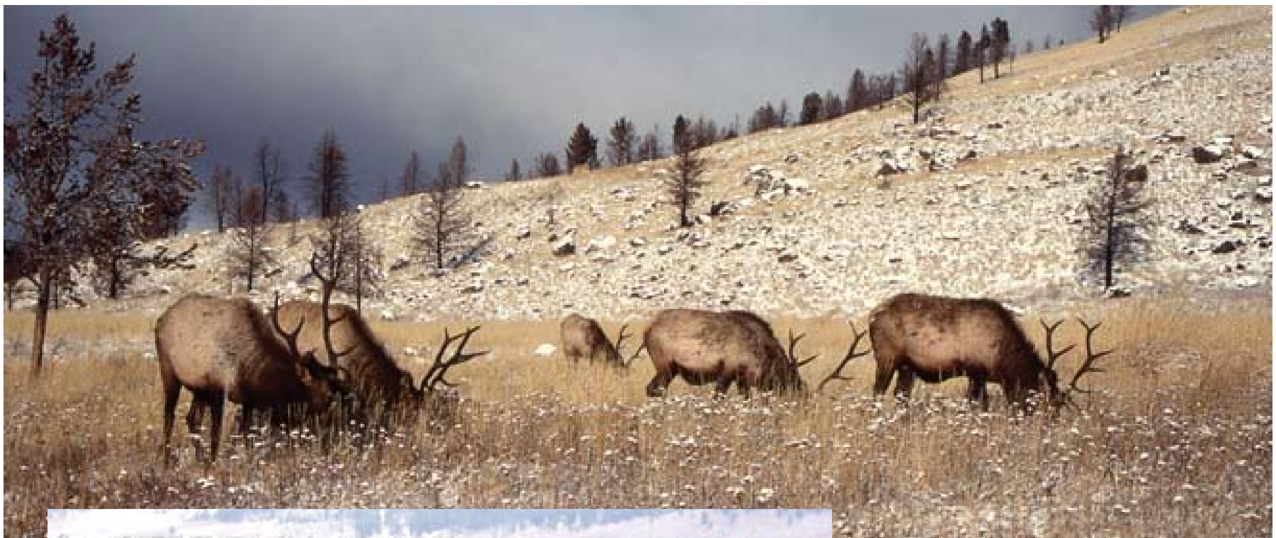

Disease Ecology and Wildlife Health

in the Greater Yellowstone Ecosystem

The Invisible Hand of Disease

HISTORICALLY, diseases were viewed as minor players in the ecosystem relative to predators, competitors, and resources. This is not surprising. In places like Yellowstone National Park, with intact predator and scavenger communities, disease impacts are often hard to detect because carcasses disappear so quickly. As a result, the observed effects of diseases have been limited to large, but sporadic mortality events. More and more studies, however, show that disease impacts may be both subtle and important. Pathogens (and the diseases they cause) may increase predation rates, decrease productivity, and alter competitive interactions. As a new member of the research community around the Yellowstone area, I am happy to serve as guest editor for this edition of *Yellowstone Science,* where we explore the role that pathogens play in the ecosystem dynamics of the Greater Yellowstone Ecosystem (GYE).

Some of these diseases, such as brucellosis in elk and bison, have a long history of research and management in the GYE. Many pathogens, however, have only recently been detected and/or studied. In this issue, we look at the current effects of brucellosis in bison, whirling disease in cutthroat trout, chytrid fungus in amphibians, distemper, parvovirus, and mange in wolves, and future potential plans to address chronic wasting disease in elk and mule deer.

The ability of managers to eliminate new invasive pathogens is often very limited, but new technologies and outlooks abound that may provide novel solutions to old problems. Research funding for ecological studies of disease has increased over the past decade due, in part, to the human health risks posed by many emerging infectious diseases in wildlife and domestic animals (e.g., hantavirus, West Nile virus, avian influenza, and severe acute respiratory syndrome [SARS]). Hopefully, we can translate this additional research into management solutions that will maintain healthy wildlife populations while minimizing human–wildlife conflicts. As part of that effort, Yellowstone National Park is in the early stages of a wildlife health initiative (described herein) that would be the first of its kind in the U.S. national park system.

I hope you enjoy the issue.

—Paul C. Cross
Disease ecologist, U.S. Geological Survey

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For back issues of *Yellowstone Science*, please see www.nps.gov/yell/planyourvisit/yellsciweb.htm.

Submissions are welcome from all investigators conducting formal research in the Yellowstone area. To submit proposals for articles, to subscribe, or to send a letter to the editor, please write to the following address: Editor, *Yellowstone Science*, P.O. Box 168, Yellowstone National Park, WY 82190. You may also email: Tami_Blackford@nps.gov.

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on the cover

Clockwise from top:
bull elk, NPS/Jim Peaco;
cutthroat trout, Paul Scullery;
bison calf nursing, NPS/Jenny Jones.

FEATURES

DEPARTMENTS

NEWS & NOTES

NPS/ABBY NELSON

Glenn Plumb Receives Natural Resources Award

NPS

Regional Director Mike Snyder (left) presents award to Glenn Plumb.

Dr. Glenn Plumb, Branch Chief of Natural Resources in the Yellowstone Center for Resources, received the Professional Excellence in Natural Resources Award at the George Wright Society meeting in St. Paul, Minnesota, on April 19, 2007. The award recognized Plumb for his leadership on the development of science and research agendas for national parks, especially in regard to wildlife health issues. Common to many of his accomplishments has been successful collaboration with domestic animal and public health organizations as well as academic institutions, with a focus on improvements in applied research and bio-medical technology to enhance wildlife health and develop fundraising partnerships to keep these initiatives moving forward.

For example, working with the U.S. Department of Agriculture Animal and Plant Health Inspection Service, Plumb organized an international symposium at the University of Wyoming in 2005 to discuss the fundamental technological gaps in the means available to manage brucellosis in greater Yellowstone. He has been appointed to a five-year term as Chair of the United States Animal Health Association Brucellosis Committee, which serves as a clearing house for brucellosis management proposals that have been submitted by state and federal agricultural officials, industry representatives, veterinarians, researchers, and wildlife interests.

Plumb, who joined the National Park Service in 1990, has been working at Yellowstone since 1998. Last year he developed the Yellowstone Wildlife Health Program, a partnership between the park and the University of California–Davis, Montana State University, and the Yellowstone Park Foundation to combine expertise from several disciplines to address existing and potential diseases in the park. Plumb was also on the team that developed the Greater Yellowstone Science Learning Center, a joint effort by Yellowstone and Grand Teton national parks, Bighorn Canyon National Recreation Area, the Greater Yellowstone Inventory and Monitoring Network, and the Rocky Mountains Cooperative Ecosystem Studies Unit at Montana State University to share information about resources and research in the parks with a variety of audiences using a web-based platform funded in large part by a grant from Canon U.S.A., Inc., through the Yellowstone Park Foundation.

U.S. Delegation Attends Disease Workshop in Kyrgyzstan

In December 2006, the U.S. State Department Bureau of International Security and Nonproliferation/Cooperative Threat Reduction (ISN/CTR) invited Dr. Glenn Plumb to join a delegation to Bishkek, Kyrgyzstan, to attend the Central Asian Disease Surveillance Workshop regarding development of a brucellosis management program for Kyrgyzstan. The ISN/CTR helps redirect former Soviet weapons experts, including scientists in the Kyrgyz Republic, toward peaceful, sustainable civilian research. This work includes engaging the ministries of health and agriculture in participating nations to develop projects that can meet nonproliferation goals and also combat global public health threats. The incidence of animal and human brucellosis in the Kyrgyz Republic and neighboring countries has increased dramatically in recent years, and the gravity of this situation led the Kyrgyz Deputy Minister of Health to request last summer that the U.S. bring over experts for consultations on how best to control it. Glenn and the delegation met with the Kyrgyz Deputy Minister of Health, Deputy Minister of Agriculture, and numerous other scientists, ministry officials, and members of the Kyrgyz National Academy of Sciences to review opportunities to help meet U.S. nonproliferation goals and for aiding the Kygryz Republic in its efforts to combat one of that country's most significant public health challenges.

Blood Test Required for Stock Entering Yellowstone

Beginning this year, owners of horses, mules, and burros must have proof that their animals have recently been tested for Equine Infectious Anemia (EIA) before bringing them into Yellowstone National Park.

The virus is spread from infected to healthy animals through large biting insects like horseflies. There is no vaccine, treatment, or cure. The disease can be fatal to members of the horse family.

The only way to know if an animal is infected with EIA is to conduct a Coggins Test, which checks for EIA antibodies in the animal's blood. While proof that a negative Coggins Test has been conducted in the past 12 months must accompany every equine that enters the park, Yellowstone National Park does not require a Certificate of Veterinary Inspection or perform brand inspections on stock animals.

Late Winter Bison Count

Yellowstone National Park completed the 2007 late winter bison population estimate. Based on a late winter aerial survey, the late winter population was estimated to be 3,600 bison. The survey takes into account the 2006 late summer population estimate of 3,900 bison, known brucellosis risk management mortalities, and scientific estimates of over-winter mortality rates.

The population estimate is used to guide adaptive management strategies under the Interagency Bison Management Plan (IBMP). Specific management actions may be modified based on expected late winter population levels as corroborated by the annual late winter estimate. This is the seventh winter the IBMP has been used to guide brucellosis risk management actions.

The IBMP is a cooperative plan designed to protect Montana's brucellosis-free status while also conserving a viable, wild bison population. Protecting Montana's brucellosis-free status requires keeping bison from mixing with cattle grazing on land adjacent to the park.

The five cooperating agencies operating under the IBMP are the National Park Service, the U.S. Forest Service, the USDA Animal and Plant Health Inspection Service, the Montana Department of Livestock, and Montana Fish, Wildlife and Parks.

9th Biennial Scientific Conference on the GYE

The Greater Yellowstone Ecosystem biennial scientific conference series, initiated in 1991, is designed to encourage awareness and application of wide-ranging scientific work on the region's natural and cultural resources. These conferences, with the active involvement of professional societies and other institutions, provide a much-needed forum for knowledge-sharing among hundreds of researchers, park managers, and the general public.

The next conference, *The '88 Fires: Yellowstone and Beyond*, will remember the events of the greater Yellowstone area fires of 1988. As such, we are skipping a year in our regular conference schedule in order to hold the 9th conference September 7–13, 2008—the 20th anniversary of the 1988 fire season's end. This conference is being sponsored by the International Association of Wildland Fire and the Association for Fire Ecology in association with the 9th Biennial Scientific Conference on the Greater Yellowstone Ecosystem. It is expected to be much larger than previous conferences in the series, and will therefore be held at the Snow King Resort in Jackson Hole, Wyoming.

This conference will be both a scientific meeting and a homecoming for many people who were involved in the 1988 fires throughout the West. These history-making fires will provide springboards for discussions and presentations about lessons learned, ecological research related to the fires, fire effects, large fire management, wildland fire planning and policy, the use of fire as a management tool, human values and perceptions of fire, and many other issues.

The Call for Papers is expected to come out this October. For more information, visit http://www.iawfonline.org/conferences.shtml.

Heasler Appointed to Advanced National Seismic System Committee

Dr. Henry Heasler, Park Geologist in Yellowstone National Park's Center for Resources, has been appointed to serve on the Regional Advisory Committee for the Intermountain West Region of the Advanced National Seismic System (ANSS), which is part of the U.S. Geological Survey (USGS). The Yellowstone Volcano Observatory (http://volcanoes.usgs.gov/yvo/), a partnership between Yellowstone National Park, the USGS, and the University of Utah, contributes to the overall ANSS mission, which is to provide accurate and timely information on seismic events. Recent efforts of the Regional Advisory Committee have focused on developing a long-term strategic plan for seismic monitoring throughout the region and obtaining the resources needed to improve earthquake reporting. The committee is concerned that the existing broadband seismograph stations in the region are inadequate to meet ANSS minimum performance standards.


NPS

As one of the four at-large members on the Regional Advisory Committee, which also includes representatives from each of the eight states in the region, Heasler will not be representing a particular constituency, but he will be in a position to speak for the interests of Yellowstone National Park. Along with geologists, the committee is made up of other users of seismic information, such as engineers, emergency managers, utility operators, and transportation officials.

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COURTESY OF PAUL CROSS

Disease ecologist Paul Cross with an African buffalo.

Wildlife Health Initiatives in Yellowstone National Park

Paul C. Cross and Glenn Plumb

Wildlife and their parasites do not recognize political or jurisdictional boundaries and, as a result, national parks are not immune to the environmental changes occurring around them. Habitat fragmentation, habitat loss, introductions of invasive species, and climate change all have direct impacts on the many wildlife species that move across park boundaries. These disturbances are also likely to affect parasite communities and wildlife health. In particular, encroachment of native landscapes by people, pets, and livestock may increase the frequency with which alien invasive parasite species are introduced. Mange, canine parvovirus, brucellosis, chronic wasting disease, whirling disease, and chytrid fungus are all examples of the pathogen pollution that is occurring in the Greater Yellowstone Ecosystem (GYE). (A pathogen is any disease-producing agent, especially a virus, bacterium, or other microorganism.)

In this issue of *Yellowstone Science,* we highlight the ongoing work in Yellowstone National Park (YNP) and the surrounding region on wildlife health issues. Some of the diseases we cover in this issue have chronically infected the GYE for many years (e.g., brucellosis). Other diseases are relatively new to the system (e.g., canine parvovirus, chytrid fungus, whirling disease); while others are still on the horizon (e.g., chronic wasting disease). All of them will require novel management solutions that draw upon the expertise of many disciplines. The work detailed here is the beginning of a wildlife health program carried out by a collaborative group of researchers and managers from academia, federal and state government, and conservation organizations (*see inset page 7, The Yellowstone Wildlife Health Program*).

Wildlife and Human Health are Linked

Much of the interest in disease ecology and wildlife health has been prompted by the emergence, or resurgence, of many parasites that move between livestock, wildlife, and/or humans. Wildlife diseases are important because of their impact on both the natural ecosystem and human health. Many human diseases arise from animal reservoirs (WHO 2002). Hantaviruses, West Nile virus, avian influenza, and severe acute respiratory syndrome (SARS) are examples of disease issues that have arisen over the last decade. Indeed, nearly 75% of all emerging human infectious diseases are zoonotic (a disease that has spread to humans from another animal species). Many of these diseases have spilled over from natural wildlife reservoirs either directly into humans or via domestic animals (WHO/FAO/OIE 2004). Unprecedented human population abundance and distribution, combined with anthropogenic environmental change, has resulted in dramatic increases in human–animal contact, thus increasing the intimate linkages between animal and human health (Figure 1).

Linkage of human and animal health is not a new phenomenon, but the scope, scale, and worldwide impacts of contemporary zoonoses have no historical precedent (OIE 2004a). Zoonotic infectious diseases can have major impacts on wild and domestic animals and human health, resulting in serious damage to the economies of developing and developed countries (WHO 2002, OIE 2004b). In wildlife and disease management there are many examples of well-intentioned ecological interventions going awry due to an incomplete understanding of all the ecological connections. In response to these realties, Conservation Medicine has arisen as a new field based at the crossroads of wildlife, human, and ecological health (Aguirre et al. 2002). Our ability to meet the disease management challenges of the twenty-first century will be greatly influenced by our ability to expand basic and applied disease research programs and communicate research results.

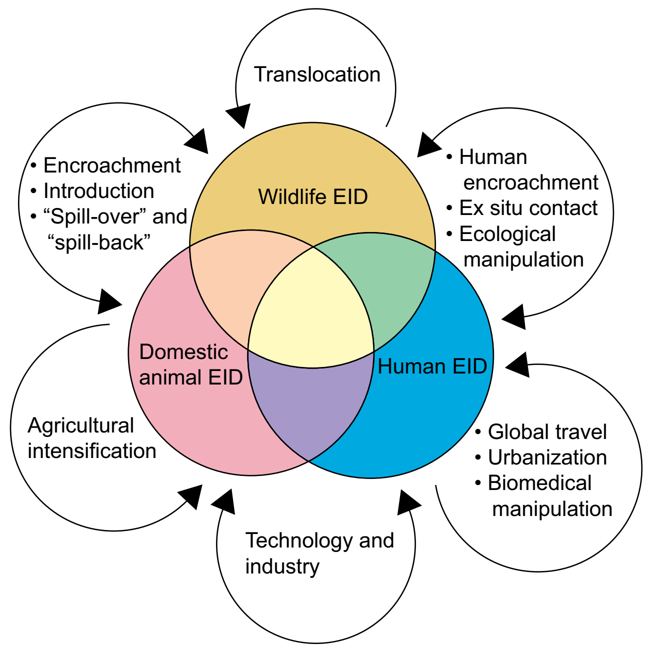

Figure 1. Many emerging infectious diseases (EIDs) are shared by wildlife, domestic animals, and/or humans. Arrows depict some of the key factors promoting disease emergence. Reprinted with permission from Dazsak et al. (2000).

The Future of Wildlife Health Research and Management in the GYE

Here we suggest a number of new research directions that we hope will yield new insights and management options in the GYE. While some of these avenues echo those suggested in a recent text on the ecology of wildlife diseases (Hudson et al. 2001), others are particularly relevant to the GYE.

Predator and hunting effects. Recent theoretical work suggests that predators may have beneficial effects for prey populations by selectively preying upon diseased individuals, thus reducing the burden of disease in prey populations (Packer et al. 2003). Similar results may also be expected if diseased prey were more easily hunted by humans. So far, there are few tests of these hypotheses in large mammals, but with the potential spread of chronic wasting disease (CWD), the GYE may become a testing ground.

The potential for wolves to improve the health of elk herds depends upon a number of factors, many of which are poorly understood for CWD infections. First of all, selective predators are likely to have a greater impact on diseased prey than non-selective predators. Thus, we would expect wolves, which chase down weaker prey, to have a more beneficial effect than mountain lions, which are primarily stealth hunters and may be less selective. Secondly, the relative timing of the onset of symptoms and when individuals are infectious is likely to be very important (Figure 2). For example, wolves may have a much smaller impact upon disease prevalence if elk become infectious long before they show symptoms than if elk become symptomatic and are targeted by wolves before becoming infectious. For CWD, we still have little information on the relative timing of when individuals are symptomatic versus infectious. We also lack data on the overall survival rates of infected versus uninfected elk or deer. Clearly, more research needs to be done before we can understand the role of predation in GYE disease dynamics.

Viral tracking of hosts. Disease ecology requires the integration of many different disciplines, including immunology, genetics, veterinary science, microbiology, mathematics, epidemiology, and ecology. As no one person can excel in all of these fields, there is a strong need for collaborative research programs incorporating experts from many different fields. One example that we think has great potential in the GYE is the use of parasite genetics to estimate the movement of a host species (the organism from which a parasite obtains its nutrition and/or shelter) among populations or the amount of transmission among different host species. Traditionally, population geneticists have looked at host genetics to investigate the amount of movement, or lack thereof, among populations. Since the generation time of large mammals is many years, however, host genetics typically inform researchers about historical connections. Parasites, and in particular viruses, have very short generation times, which may allow researchers a glimpse at contemporary movement patterns of the host. Roman Biek and Mary Poss have applied these techniques to Feline Immunodeficiency Virus to reveal the population structure of cougars across Montana (Biek et al. 2006). This approach may allow researchers to investigate the effects of recent land-use change on host connectivity. Data on the movement of hosts across the GYE will allow for the construction of detailed spatial disease models that can be used to address management issues.

Fire and land use. To date, we have found very few studies investigating the effects of fire and land use on disease processes, despite the importance of these factors to host dynamics, particularly in Rocky Mountain ecosystems. Many parasite species are either transmitted through the environment or have a free-living lifestage that may be susceptible to the effects of fire, and fires may increase in intensity or frequency due to climate change (Westerling et al. 2006). We suspect that this may be an important avenue of future research.

Farnsworth et al. (2005) found that chronic wasting disease was more prevalent among mule deer in developed areas than in rural areas. At this point, it remains unclear whether this is due to a lack of hunting or increased aggregation in suburban neighborhoods. However, the fact that some of the regions surrounding YNP are among the fastest-developing in the nation along with the slow approach of chronic wasting disease from the south and east gives us substantial cause for concern.

Spill-over and spill-back. Many parasites are shared among livestock, wildlife, and humans. In several cases, such as brucellosis and tuberculosis, spill-over infections from livestock to wildlife led to disease epidemics within the new wildlife host. Subsequently, the disease was mostly controlled within livestock, but eradication efforts remain difficult due to potential "spill-back" infections from wildlife to livestock. In some cases, these spill-over infections from livestock to wildlife result in almost complete die-offs of the new wildlife host (e.g., rinderpest and African buffalo). In other cases, however, the impact of the disease has almost undetectable effects on population growth (e.g., brucellosis and bison). However, there have been very few cases where such diseases have been subsequently eradicated from the wildlife host. Thus, these new infections are continually added to the suite of challenges wildlife species face. Although any one disease may have a minor effect, collectively they may affect the resiliency of wildlife populations to natural and anthropogenic disturbances. Despite the important role of wildlife to the emergence and dynamics of disease in livestock, there have been very few studies in the GYE that have attempted to estimate the risk or actual amount of transmission between host species and between wildlife and livestock. Estimating disease transmission is not easy, particularly in wildlife systems. However, we believe new technologies in radio-tracking and genetics may be a powerful approach. Global Positioning System (GPS) collars now facilitate the collection of fine-scale data that can be used to estimate the amount of contact among different species, while genetic analyses of the parasites may allow researchers to estimate parasite transmission among host species. Finally, transmitters that record when they are in close proximity to one another will enable researchers to start looking at the rate of contact among individuals.

Multi-host and multi-pathogen. Traditional wildlife biology began with an emphasis on the dynamics of single species. Over time, however, a more holistic research approach developed that incorporated the effects and interactions of competition, predation, and herbivory. The disease ecology field is undergoing a similar transition away from simple, single host–pathogen systems to embrace the complex interactions that occur in the more common multi-host and multi-pathogen ecosystems.

Recent immunological studies have shown that helminths (intestinal worms) and brucellosis can stimulate opposing sides of the immune system (Abbas 1996). As a result, individuals that are heavily infected with worms may be less able to control brucellosis and vice versa. Both bison and elk are likely to be infected with a diversity of helminths. Thus, there may be interactions between helminths and *B. abortus* that drive the dynamics of brucellosis in the elk and bison populations of YNP. Understanding how multiple parasites interact within a single host, and how alternative hosts affect disease dynamics in the primary host may lead to novel and effective management strategies.

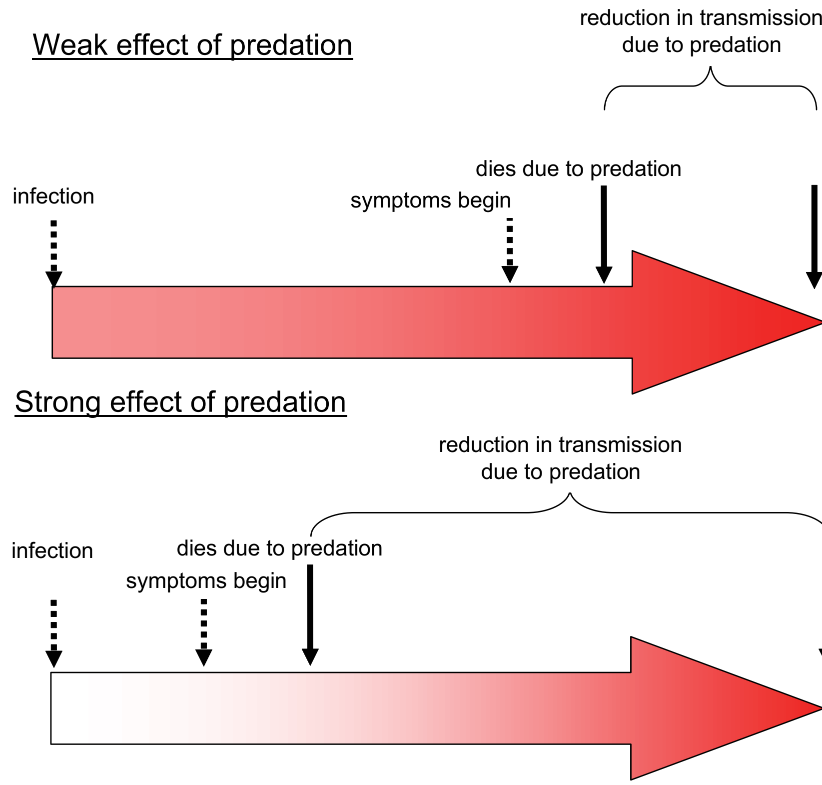

Figure 2. The effects of predation on disease. Each large arrow represents the course of disease in the prey species: the timing of infection, onset of symptoms, and when the individual would die from predation or disease (if predators were absent). The intensity of the red color indicates how infectious the individual is. Predators will have a weak effect if prey are infectious throughout the course of disease, but are only symptomatic later in life (A). Predators will have a strong effect upon disease if the prey are symptomatic earlier relative to when they become infectious (B).

The Yellowstone Wildlife Health Program

Yellowstone National Park recently signed a Memorandum of Understanding with Montana State University and the University of California–Davis School of Veterinary Medicine Wildlife Health Center to establish the Yellowstone Wildlife Health Program, focused on understanding and addressing priority wildlife disease and ecosystem health problems at Yellowstone National Park. Initial five-year funding is being provided by the Yellowstone Park Foundation.

The Yellowstone Wildlife Health Program goal is to design and implement a long-term wildlife health assessment program to monitor and evaluate wildlife diseases and health indicators as a subcomponent of the Greater Yellowstone Network Vital Signs Monitoring Program. Specific objectives of the program include:

- Facilitation of cooperation among scientists seeking competitive grant funds to investigate wildlife health issues.
- Development of an outreach program, including educational materials for field courses on wildlife health, that provides information for the public, faculty, and federal and private funding agencies.
- Development of on-site wildlife veterinary services, including veterinary support for animal handling activities, disease surveillance, and disease outbreak investigation, including field evaluation, necropsy, and specimen sampling.
- Establishment and coordination of on-site or cooperative wildlife disease diagnostics and field and laboratory research capacity.
- Facilitation of wildlife health professional capacity development, as well as research by veterinary students, graduate students, postdoctoral fellows, and post-graduate researchers.

An Ounce of Prevention

Although there are many cutting-edge research directions to pursue, a tremendous amount of basic research remains to be done in YNP. In 1995, Aguirre et al. argued for the collection of baseline data on wildlife diseases in national parks. Over a decade later, we have yet to reach that goal. Currently, only two full-time wildlife veterinarians work for the NPS across the national park system of 390 units covering more than 84 million acres. Wildlife diseases have traditionally been very difficult to eradicate in natural settings, and although any one particular disease may have minor effects upon a host population, the cumulative effects of many new parasite species may threaten the resilience and persistence of the many wildlife species we appreciate in national parks.

The logistics and consequences of disease control or eradication efforts in NPS areas have been and will continue to be challenging. Due to the difficulties inherent in eradicating or controlling wildlife diseases in a field setting, we call attention to the need for more work on the prevention of disease. As a prerequisite for this work, active surveillance is needed on a multitude of wildlife species, which would allow for the detection of new parasites as well as changes in the intensity or prevalence of infection of pre-existing parasite species. As Yellowstone National Park is home to one of the most intact remaining wildlife ecosystems, it is fitting that the park should serve as a proving ground for the problem-oriented, basic, and applied disease research that will be necessary to conserve these wildlife resources for future generations.

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Dr. Paul Cross is a disease ecologist with the U.S. Geological Survey and a faculty affiliate with Montana State University. Previously, he worked on bovine tuberculosis in African buffalo and now works on brucellosis and chronic wasting disease. He holds a PhD in Environmental Science, Policy, and Management from the University of California–Berkeley, and a BA in Environmental Science from the University of Virginia–Charlottesville. **Dr. Glenn Plumb** is the Branch Chief of Natural Resources in the Yellowstone Center for Resources, Yellowstone National Park.

Literature Cited

Abbas, A. K., K. M. Murphy, and A. Sher. 1996. Functional diversity of helper T lymphocytes. *Nature* 383:787–793.

Aguirre, A. A., R. S. Ostfeld, G. M. Tabor, C. House, and M. C. Pearl. 2002. *Conservation Medicine: ecological health in practice.* Oxford University Press, Oxford.

Aguirre, A. A., E. E. Starkey, and D. E. Hansen. 1995. Wildlife diseases in national-park ecosystems. *Wildlife Society Bulletin* 23:415–419.

Biek, R., A. J. Drummond, and M. Poss. 2006. A virus reveals population structure and recent demographic history of its carnivore host. *Science* 311:539–541.

Daszak, P. 2000. Emerging infectious diseases of wildlife—Threats to biodiversity and human health. *Science* 287:443–449.

Farnsworth, M. L., L. L. Wolfe, N. T. Hobbs, K. P. Burnham, E. B. William, D. M. Theobald, M. M. Conner, and M. W. Miller. 2005. Human land use influences chronic wasting disease prevalence in mule deer. *Ecological Applications* 15:119–126.

Hudson, P. J., A. Rizzoli, B. T. Grenfell, H. Heesterbeek, and A. P. Dobson. 2001. *The ecology of wildlife diseases.* Oxford University Press, Oxford.

[OIE] World Organisation for Animal Health. 2004a. The importance of vaccination in the control and eradication of infectious animal diseases. OIE International Conference on the Control of Infectious Animal Diseases by Vaccination, 16 April 2004. http://www.oie.int.

———. 2004b. Emerging and re-emerging zoonoses. Editorial from the OIE Director General, Bernard Vallat. http://www.oie.int.

Packer, C., R. D. Holt, P. J. Hudson, K. D. Lafferty, and A. P. Dobson. 2003. Keeping the herds healthy and alert: implications of predator control for infectious disease. *Ecology Letters* 6:797–802.

Westerling, A. L., H. G. Hidalgo, D. R. Cayan, and T. W. Swetnam. 2006. Warming and earlier spring increase western U.S. forest wildfire activity. *Science* 313:940–943.

[WHO] World Health Organization. 2002. Future trends in veterinary public health. WHO Technical Report Series #907. 85 pp. http://www.who.int.

[WHO/FAO/OIE] WHO/Food and Agriculture Organization of the United States (FAO)/OIE. 2004. Report of the WHO/FAO/OIE joint consultation on emerging zoonotic diseases. 3–5 May 2004. 65 pp. http://www.oie.int.

Chronic Wasting Disease
Planning for an Inevitable Dilemma

P. J. White and Troy Davis

TERRY KREEGER/WYOMING GAME AND FISH DEPARTMENT

An infected elk showing exaggerated wide-legged posture, lowered head, and bony frame typical of chronic wasting disease.

The high mountains and plateaus of Yellowstone National Park (YNP) provide summer range for an estimated 20,000–30,000 deer (*Odocoileus* sp.) and elk (*Cervus elaphus*) from at least eight herds, most of which winter at lower elevations outside the park. These world-renowned herds provide significant visitor enjoyment and revenue to local economies through guiding and sport hunting. Elk are the most abundant ungulate in the park and constitute a foundation species that has strong, ramifying effects on other species and processes in the ecosystem. For example, elk comprise approximately 85% of kills made by wolves (*Canis lupus*) during winter and are an important source of protein for black and grizzly bears during spring and early summer (Smith et al. 2004; Barber et al. 2005). They also provide an important source of energy for mountain lions and at least 12 species of scavengers, including bald eagles and coyotes (Wilmers et al. 2003; Ruth 2004). In addition, elk browsing and nitrogen deposition can have significant effects on vegetative production, soil fertility, and plant diversity (Frank and McNaughton 1992). Thus, changes in elk abundance over space and time can alter species abundance, community composition, nutrient concentrations of plants, and the physical structure of vegetation in YNP.

These magnificent herds may soon be infected with chronic wasting disease (CWD), which was detected approximately 130 miles from the park in the Bighorn Basin area of Wyoming during 2003. Chronic wasting disease is a fatal neurologic disease of elk, moose (*Alces alces*), mule deer (*O. hemionus*), and white-tailed deer (*O. virginianus*) from the family of diseases known as transmissible spongiform encephalopathies or prion diseases. Other diseases in this family include scrapie in sheep, bovine spongiform encephalopathy (i.e., "mad-cow disease") in cattle, and Creutzfeldt-Jacob disease in humans. Chronic wasting disease attacks the brains of infected animals, causing them to become emaciated, display abnormal behaviors (e.g., "zoned-out" appearance, aimless wandering), lose bodily functions (i.e., excessive salivation, drinking, and urination), and eventually die (Williams et al. 2002). Infections may occur at any time of year and sexes appear to be equally susceptible.

Prevalence or susceptibility to CWD appears higher in mule deer and white-tailed deer than in elk in endemic areas of Colorado and Wyoming (Miller et al. 2000). Bighorn sheep (*Ovis canadensis canadensis*), bison (*Bison bison*), mountain goats (*Oreamnos americanus*), and pronghorn (*Antilocapra americana*) appear to be resistant or at least much less susceptible to the disease than deer and elk. There is no evidence that CWD is naturally transmissible to humans or domestic livestock (Food and Drug Administration 2001). However, a related animal disease, bovine spongiform encephalopathy (BSE), has been causally linked to the human form of that disease known as variant Creutzfeldt-Jakob disease (vCJD). While current evidence indicates that the differences between BSE/vCJD and CWD are significant, there is still ongoing research to establish whether CWD can cross the human species barrier. Thus, health experts (e.g., World Health Organization 2000) warn that no part or product of any animal with evidence of CWD should be fed to any species (human or any domestic or captive animal).

Chronic wasting disease is contagious and transmissible by direct animal–animal contact or indirectly through the environment (Miller et al. 2004; Johnson et al. 2006). Human activities have exacerbated the distribution and prevalence of the disease by translocation of infected deer and elk between game farms, research facilities, and zoological parks and also by concentration of wildlife through artificial feeding, loss of habitat, and changes in movement patterns due to fragmented landscapes. Chronic wasting disease and associated control actions have substantially decreased deer and elk populations in some areas where outbreaks occurred (Williams et al. 2002). Similar population reductions in YNP could indirectly alter the structure and function of this ecosystem, adversely affect species of predators and scavengers (including the federally listed bald eagle [*Haliaeetus leucocephalus*], grizzly bear [*Ursus arctos*], lynx [*Lynx canadensis*], and wolf), and have serious economic effects on the recreation-based economies of the area (Duffield and Neher 1996). Thus, the early detection and management of CWD is recommended to stabilize or reduce the proportion of infectious individuals and avoid a precipitous decrease in the population growth rate (Gross and Miller 2001).

In 2004, we began collaborating with Montana Fish, Wildlife and Parks to test for CWD in northern Yellowstone elk. We focused on these elk because they migrate throughout park and surrounding lands during summer, coming into contact with deer and elk from other herds. Thus, they are likely to be exposed to CWD soon after it arrives at the park. Also, the highest densities of deer and elk in the park occur on the northern range, making these animals at relatively higher risk for CWD infection. State biologists collected brain stem and lymph node tissue samples from animals harvested during the Gardiner Late Elk Hunt. These samples were sent to Colorado State University Veterinary Diagnostic Laboratory in Fort Collins for testing with an enzyme-linked immunosorbent assay (ELISA) developed by Bio-Rad Laboratories, Inc. Tissue samples from 703 elk harvested adjacent to YNP's northwest boundary from the 2004 and 2005 late hunts were tested and found negative for CWD (Anderson and Aune 2004; Anderson and Southers 2005).

During winter 2006–07, we also collected and tested tissue samples from deer or elk killed by vehicle collisions in or near YNP. Data from Colorado indicate that CWD-infected mule deer were more vulnerable to vehicle collisions than otherwise healthy deer (Krumm et al. 2005). Thus, testing tissue samples from vehicle-killed deer and elk could enhance our ability to detect CWD. We will also attempt to collect samples from wolf-killed deer and elk as part of ongoing ungulate and wolf programs. If wolves detect and select deer and elk infected by CWD, then testing tissue samples from these animals could enhance our ability to detect CWD.

Even if this surveillance is successful at detecting CWD in or near YNP when prevalence is low (~1%), however, there would already be approximately 100–150 infected animals in the population. At this point, it would be extremely difficult, if not impossible, to eliminate CWD from the population because the best available evidence suggests eradication of CWD in free-ranging deer and elk is unrealistic and culling efforts to reduce prevalence have been relatively unsuccessful (Williams et al. 2002; Conner et al. 2007). Thus, we developed a management plan for CWD that was approved by YNP's superintendent during 2006. Under this plan, we will take actions to stabilize the prevalence and reduce the spread of CWD if it is detected in or near the park, while ensuring management actions (or inaction) do not harm the integrity of park resources or values. We will implement regular surveillance of deer and elk in the infected population(s) using ground and aerial surveys and remove any animals with clinical signs of CWD by shooting.

We will also respond to reports of "sick" deer, elk, and moose to evaluate them for clinical signs of CWD, remove clinical animals by shooting, and test tissue samples for CWD. If necessary, we will randomly cull animals from certain populations to assess the prevalence and spread of the disease. However, we hope to avoid large-scale culling operations or population reductions because they would remove many more healthy animals than infected animals and substantially reduce the prey base for predators and scavengers. Likewise, we will not use culling to assess the prevalence and distribution of CWD in small populations (e.g., the Madison–Firehole elk herd) because even the removal of 50 animals would constitute a 20% reduction in an already decreasing population.

In addition, we will evaluate if selective predation by wolves and other predators on CWD-infected elk reduces transmission rates and numbers of infected animals. Unlike other areas where CWD outbreaks have occurred, YNP supports an intact large-predator complex including black bears (*Ursus americanus*), coyotes (*Canis latrans*), grizzly bears, humans, mountain lions (*Puma concolor*), and wolves. Wolves are highly selective for elk throughout the year and bears are highly selective of neonatal elk during summer (Smith et al. 2004; Barber et al. 2005). If predators can detect CWD-infected animals, then

NPS PHOTO/ROCKY MOUNTAIN NATIONAL PARK

This elk, photographed in Rocky Mountain National Park, displays clinical signs of CWD, such as lowered head and ears and emaciated body.

selective predation and quick removal of carcasses by scavengers could reduce CWD transmission rates and, in turn, the prevalence and spread of the disease. Wolves could also reduce the risk of transmission by dispersing deer and elk. Model simulations based on conditions at Rocky Mountain National Park (i.e., high elk density) suggest wolves could have "potent effects" on the prevalence of CWD (Wild and Miller 2005). Also, compensatory and density-related effects could result in less net mortality than rates of infection and death from CWD would suggest. Thus, the net effect of CWD on the abundance, reproduction, and survival of deer and elk could be less than predicted based on data collected in areas with few large predators.

We are confident the selective culling of infected animals by park staff, in conjunction with selective predation on CWD-infected animals, will slow disease transmission while removing relatively few healthy animals and not substantially reduce population growth rates. However, the success of this approach depends, in part, on the vigilance of park staff and visitors at identifying and reporting animals that display repetitive behavior (e.g., moving in a set pattern) or abnormal behavior such as staggering, standing with an exaggerated wide-legged posture, or carrying their heads and ears lowered. Infected animals become emaciated and sometimes stand near and consume large amounts of water. Drooling or excessive salivation may also be apparent. Please accurately document the location of any animal that shows CWD symptoms and immediately contact P. J. White (307-344-2442 or pj_white@nps.gov) or Troy Davis (307-344-2218 or troy_davis@nps.gov). Do not attempt to touch, disturb, kill, or remove the animal. Your assistance will help preserve the diverse and intact predator–prey complex of YNP for the enjoyment of future generations.

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Literature Cited

Anderson, N., and K. Aune. 2004. CWD surveillance 1998–2003. Montana Fish, Wildlife and Parks, Bozeman, Montana.

Anderson, N., and J. Southers. 2005. CWD surveillance 1998–2004. Montana Fish, Wildlife and Parks, Bozeman, Montana.

Barber, S. M., L. D. Mech, and P. J. White. 2005. Yellowstone elk calf mortality following wolf restoration: bears remain top summer predators. *Yellowstone Science* 13:37–44.

Conner, M. M., M. W. Miller, M. R. Ebinger, and K. P. Burnham. 2006. A spatial, meta-BACI approach for evaluating focal management intervention on chronic wasting disease in free-ranging mule deer. *Ecological Applications* 17:140–153.

Duffield, J. W., and C. J. Neher. 1996. Economics of wolf recovery in Yellowstone National Park. Transactions 61st North American Wildlife and Natural Resource Conference 61:285–292.

Food and Drug Administration. 2001. Transcripts of an open meeting of the Transmissible Spongiform Encephalopathy Advisory Committee on January 18, 2001, Bethesda, Maryland, USA.

Frank, D. A., and S. J. McNaughton. 1992. The ecology of plants, large mammalian herbivores, and drought in Yellowstone National Park. *Ecology* 73:2043–2058.

Gross, J. E., and M. W. Miller. 2001. Chronic wasting disease in mule deer: disease dynamics and control. *Journal of Wildlife Management* 65:205–215.

Johnson, C. J., K. E. Phillips, P. T. Schramm, D. McKenzie, J. M. Aiken, and J. A. Pedersen. 2006. Prions adhere to soil minerals and remain infectious. PLoS Pathogens 2:1–7.

Krumm, C. E., M. M. Conner, and M. W. Miller. 2005. Relative vulnerability of chronic wasting disease infected mule deer to vehicle collisions. *Journal of Wildlife Diseases* 41:503–511.

Miller, M. W., E. S. Williams, N. T. Hobbs, and L. L. Wolfe. 2004. Environmental sources of prion transmission in mule deer. *Emerging Infectious Diseases* 10:4–10.

Miller, M. W., E. S. Williams, C. W. McCarty, T. R. Spraker, T. J. Kreeger, C. T. Larsen, and E. T. Thorne. 2000. Epizootiology of chronic wasting disease in free-ranging cervids in Colorado and Wyoming. *Journal of Wildlife Diseases* 36:676–690.

Ruth, T. K. 2004. "Ghost of the Rockies": the Yellowstone cougar project. *Yellowstone Science* 12:13–24.

Smith, D. W., T. D. Drummer, K. M. Murphy, D. S. Guernsey, and S. B. Evans. 2004. Winter prey selection and estimation of wolf kill rates in Yellowstone National Park, 1995–2000. *Journal of Wildlife Management* 68:153–166.

Wild, M., and M. Miller. 2005. Comments cited in a *Denver Post* article dated August 9, 2005, entitled "Throw disease to the wolves?"

Williams, E. S., M. W. Miller, T. J. Kreeger, R. H. Kahn, and E. T. Thorne. 2002. Chronic wasting disease of deer and elk: a review with recommendations for management. *Journal of Wildlife Management* 66:551–563.

Wilmers, C. C., R. L. Crabtree, D. W. Smith, K. M. Murphy, and W. M. Getz. 2003. Trophic facilitation by introduced top predators: grey wolf subsidies to scavengers in Yellowstone National Park. *Journal of Animal Ecology* 72:909–916.

World Health Organization. 2000. Consultation on public health and animal transmissible spongiform encephalopathies: epidemiology, risk and research requirements. WHO/CDS/CSR/APH/2000.2, Section 4: CWD, December 1–3, 1999, Geneva, Switzerland.

Boreal toad (*Bufo boreas*) at High Lake.

Amphibians and Disease
Implications for Conservation in the Greater Yellowstone Ecosystem

Paul Stephen Corn

THE DECLINE OF AMPHIBIAN populations is a worldwide phenomenon that has received increasing attention since about 1990. In 2004, the World Conservation Union's global amphibian assessment concluded that 48% of the world's 5,743 described amphibian species were in decline, with 32% considered threatened (Stuart et al. 2004). Amphibian declines are a significant issue in the western United States, where all native species of frogs in the genus *Rana* and many toads in the genus *Bufo* are at risk, particularly those that inhabit mountainous areas (Corn 2003a,b; Bradford 2005).

As is true for most of the cold and dry Rocky Mountains, relatively few amphibian species are native to the Greater Yellowstone Ecosystem (GYE; Table 1). One of the five native species, the northern leopard frog (*Rana pipiens*), may have been extirpated. Except for a photograph of leopard frogs taken near Flagg Ranch in 1995 and an occasional unsubstantiated report, this species has not been observed during recent surveys. The remaining four species are distributed throughout the GYE, and their ranges do not appear to have retreated from historical coverage of the landscape. However, some or all of these species are declining or have declined in some portions of the GYE. Although we lack the historical data to judge whether the current percentages of potential breeding sites occupied represent declines for most species, it is likely that boreal toads have declined to some extent in the GYE. This species has declined severely in the southern Rocky Mountains (Colorado, northern New Mexico, and southeast Wyoming), and occupancy of 5% of potential breeding sites (based on sampling at selected water catchments) in the GYE is lower than the 7–15% occupancy observed in similar surveys in Glacier National Park.

Habitat degradation or loss, predation by alien species, over-exploitation, climate change, pollution, emerging infectious diseases, and complex interactions among two or more factors are demonstrated or hypothesized causes of amphibian declines. Here, I review the role disease may play in amphibian declines in the GYE, but note that other causes have been identified (Table 1) and may be as important as or more important than disease.

A variety of pathogens and their relationships to amphibian declines have been studied in recent years (reviewed by Daszak et al. 2003). These include viruses, fungi, protists (single-celled or multi-cellular organisms that are neither plants nor animals, but which may show characteristics of both), and more complex parasites such as trematodes (*Ribeiroia* sp.). Trematodes are now known to be the primary cause of the occurrences of frogs with extra limbs and other deformities that received considerable public and scientific attention in the late 1990s (Souder 2000). Water molds are oomycete protists that may infect and kill the embryos in amphibian egg masses. Although water molds can kill large numbers of embryos at some locations and populations afflicted with deformities may have high mortality of young frogs after metamorphosis, neither water molds nor trematode parasites have been shown to affect the persistence of populations and they are unlikely to have caused widespread declines.

Ranaviruses

Viruses are another group of virulent pathogens that so far have had primarily local effects (Daszak et al. 2003). Ranaviruses are a large complex of related viruses in the Family Iridoviridae that infect reptiles, amphibians, and fish. Ranaviruses are not novel pathogens for amphibians. Different strains have coevolved with their amphibian host populations and typically attack stressed individuals. Ranavirus infections are more likely to occur when hosts are in dense aggregations that sometimes occur as temporary ponds dry before metamorphosis can be completed. Tiger salamander larvae may suffer catastrophic mortality from ranavirus infection, and such episodes can recur year after year in the same population. Ranaviruses do not survive outside their hosts and are transmitted via direct contact. Some individuals survive the infection and may carry the virus back to the breeding pond in subsequent years or serve as a means of transmitting the pathogen to new sites (Brunner et al. 2004).

Although ranaviruses are part of the natural life history of amphibians, human activities may be disrupting this system and creating situations where ranavirus should be considered as the agent of emerging infectious disease. Specifically, the transportation of tiger salamander larvae (Figure 1) around western North America for use as fishing bait appears to have exposed

Table 1. Distribution and status of amphibians in the GYE.

Species	Distribution	Status	Causes of decline	References
Tiger Salamander (*Ambystoma tigrinum*)	Occurs throughout the GYE	Present at 18–24% of potential breeding sites; genetic evidence for historic and recent declines in the northern range	Fish stocking (historic) and disease (recent)	Corn et al. 2005; Spear et al. 2006
Boreal Toad (*Bufo boreas*)	Occurs throughout the GYE?	Present at 2–5% of potential breeding sites	Disease?	Corn et al. 2005
Boreal Chorus Frog (*Pseudacris maculata*)	Occurs throughout the GYE	Present at 32–43% of potential breeding sites		Corn et al. 2005
Northern Leopard Frog (*Rana pipiens*)	A few sites south of Jackson Lake	Extirpated?	Unknown	Koch and Peterson 1995; Patla and Peterson 2004
Columbia Spotted Frog (*R. luteiventris*)	Occurs throughout the GYE	Present at 14–26% of potential breeding sites; declines of Lodge Creek populations	Development (road building, employee housing, spring diversion)	Patla 1997; Patla and Peterson 2004; Corn et al. 2005

Figure 1. Tiger salamander (*Ambystoma tigrinum*) larvae (waterdogs) have been transported around the West as live bait. This practice may expose populations to novel pathogens.

salamander populations to novel virus strains (Jancovich et al. 2006). Live salamanders are used as bait mainly in warm-water fisheries and transmission of ranavirus via live bait is unlikely to be a problem in the GYE, but managers should be aware of the issue. Ranaviruses have been detected in tiger salamanders in the GYE, and may have been the cause of a mortality event in Columbia spotted frogs downstream of a sewage treatment plant near Fishing Bridge in 2002 (Patla and Peterson 2004).

Bd and Chytridiomycosis

The chytrids (Chytridiomycota) are an ancient group of saprophytic fungi, likely the sister group to all other true fungi. They cause a variety of important plant diseases and blights. Longcore et al. (1999) described *Batrachochytrium dendrobatidis* (Bd) as the chytrid responsible for chytridiomycosis in amphibians. There are two stages in the life cycle of Bd: a zoosporangium that invades the keratinized outer layers (epidermis) of frog skin, causing chytridiomycosis; and a flagellated zoospore, produced asexually in the zoosporangia and released through a characteristic discharge tube, which is the means of infecting other amphibians (Berger et al. 2005). The zoospore typically requires an aquatic environment, meaning that transmission of Bd is thought to occur mainly among tadpoles or adults in breeding aggregations. However, zoospores have survived up to three months in moist, sterile river sand and remained viable on feathers after one to three hours of drying (Johnson and Speare 2005). This suggests that a site may remain infective for a time in the absence of amphibians and, more importantly, that Bd could be transported among sites by birds or in sediments (e.g., mud on ungulate feet or fishermen's boots).

The mechanism by which chytridiomycosis kills its amphibian host is not yet known. Hypotheses include toxins released by the zoosporangia or disruption of the animal's ability to regulate body fluids and ion concentrations. Adult and metamorphic amphibians infected by Bd may show inflammation of the skin, particularly on the legs and pelvic region, frequent shedding, sometimes with a buildup of dead skin, and behavioral changes such as lethargy and loss of righting ability. Tadpoles lack keratin in their skin, and Bd infections are mainly found on their mouth parts (external tooth rows and jaw sheaths). Presence of Bd is associated with abnormalities of the oral disk and loss of keratinized parts in tadpoles of some species. Tadpoles infected with Bd do not appear to develop chytridiomycosis and usually metamorphose normally.

Bd is often highly virulent. In the laboratory, healthy individuals may die within a few days after being infected. However, in wild populations there may be a variety of outcomes from the presence of Bd. Depending on the biology of Bd, the biology of the host amphibian, and potential external factors, there may be no effect from the presence of Bd; infection and mortality of some individuals but no effect on persistence of the population; significant mortality with population crashes but development of resistance to Bd and subsequent recovery; or lasting declines and extinction (Daszak et al. 2003; DEH 2006b). Because of several examples of the latter scenario, chytridiomycosis is currently receiving the most attention among diseases as a cause of amphibian decline.

Chytridiomycosis is the likely cause of the extinction of at least one Australian frog, the sharp-snouted torrent frog (*Taudactylus acutirostris*), and possibly other Australian species now considered extinct, including the two gastric brooding frogs (*Rheobatrachus* sp.). Several other Australian frogs have been extirpated from significant portions of their ranges by chytridiomycosis but have not yet been driven to extinction (DEH 2006b). In Central and South America, up to 30 species of harlequin frogs (*Atelopus* sp.) are feared to be extinct, an additional 12 species have undergone declines of at least 50%, and only 10 of 113 species surveyed are thought to have stable populations (La Marca et al. 2005).

Boreal chorus frog (*Pseudacris maculata*) in a wetland area near High Lake.

Closer to the GYE, the Wyoming toad (*Bufo baxteri*), a glacial relict species endemic to the Laramie Basin in southeast Wyoming, began declining around 1970 due to chytridiomycosis, and would certainly now be extinct without a captive breeding program begun in 1988 (Odum and Corn 2005). Boreal toad populations in southeast Wyoming, northern New Mexico, and throughout the mountains in Colorado have also been in severe decline for the last four decades. Chytridiomycosis is the likely cause and was associated with the collapse of one the few remaining robust populations in the mid-1990s in Rocky Mountain National Park (Muths et al. 2003).

The origin of chytridiomycosis is an interesting question that has implications for managing the consequences for amphibian populations. Bd may be a novel pathogen, recently evolved and spread around the world by human actions, or it may be an endemic pathogen that has been present but has undergone a recent increase in pathogenicity (Rachowicz et al. 2005). Genetic evidence and the apparent sudden outbreaks of chytridiomycosis on five continents within the last 30 years argue for the novel pathogen hypothesis (Daszak et al. 2003; Rachowicz et al. 2005; Lips et al. 2006). However, the presence of Bd over large areas and in species that have not declined (Daszak et al. 2005; Ouellet et al. 2005; Longcore et al. 2007) is more suggestive of an endemic pathogen. Pounds et al. (2006) hypothesized that climate warming was creating a more favorable environment for growth of Bd at middle elevations in the mountains of Central and South America and was responsible for the recent crash of harlequin frog species. Climate warming is a mechanism for the emergence of an endemic pathogen, but it could also be a synergistic factor in the spread of a novel pathogen. If Bd is a novel pathogen, efforts at control should emphasize limiting transmission into uncontaminated areas, but if Bd is endemic, then control requires dealing with the environmental factors affecting pathogenicity (Rachowicz et al. 2005). Either alternative is a huge challenge.

Chytridiomycosis in the GYE. Both Bd and chytridiomycosis have been recorded at several locations in the GYE. Columbia spotted frogs that died in 2002 near Fishing Bridge were diagnosed with chytridiomycosis in addition to the presence of ranavirus (Patla and Peterson 2004). Chytridiomycosis has also been detected in the spotted frogs studied by Debra Patla at Lodge Creek (David E. Green, USGS National Wildlife Health Center, Madison WI, unpublished data). PCR tests found Bd present on 12 of 17 live Columbia spotted frogs from Schwabacher Landing in Grand Teton National Park in 2004 (Spear et al. 2004), but necropsies of eight dead frogs from Schwabacher Landing failed to detect evidence of chytridiomycosis (D. E. Green, unpublished). Chytridiomycosis was detected in 2001 in a boreal toad from Nowlin Creek on the National Elk Refuge and from 6 of 13 toad carcasses from an oxbow of the Buffalo Fork (Figure 2) near the Black Rock Ranger Station, east of Moran Junction (Patla and Peterson 2004; D. E. Green, unpublished). Erin Muths (USGS Fort Collins Science Center, CO), David Pilliod (USGS Forest and Rangeland Ecosystem Science Center, Boise, ID), and I have been studying the boreal toads at Black Rock (Figure 3). This is a robust population, with at least 250 adult toads marked during each breeding season annually since 2003. The presence of Bd is robust in this population also. PCR testing each year of sub-samples of marked toads consistently yields high rates (up to 50%) of samples with Bd present. However, we have not seen any indications of mortality caused by chytridiomycosis since 2001.

Bd was studied in greater detail in Grand Teton National Park and the Rockefeller Parkway in 2004 by Spear et al.


USGS/P. S. CORN

Figure 2. Oxbow pond near the Black Rock Ranger Station, Bridger Teton National Forest, Wyoming. Four species of amphibians breed at this site, and it is one of the most productive amphibian breeding ponds known in the GYE.


USGS/P. S. CORN

Figure 3. Two male and one female boreal toad (*Bufo boreas*) in a mating ball at the Black Rock breeding site. Male toads in dense populations, such as the one at Black Rock, often encounter intense competition during breeding. Dense populations may provide greater opportunities for transmitting pathogens among hosts.

(2004). Boreal toads from breeding aggregations in beaver ponds at Schwabacher Landing and a gravel pit near Flagg Ranch had high incidence of Bd in late May (15 of 18 and 6 of 20, respectively). However, when radios were attached to 12 toads from Schwabacher Landing in mid July, Bd was present on only four (33%), and no Bd was detected when radios were removed in September. The seasonal variation in Bd infection and the apparent ability of individual animals to clear Bd infection have also been observed in Stony Creek frogs (*Litoria wilcoxii*) in Australia (Kriger and Hero 2006).

At least two hypotheses can be generated to explain the current coexistence of Bd and non-declining populations of boreal toads in the GYE. The strain of Bd present in the GYE might be less pathogenic than other strains of the chytrid. Alternatively, the relative scarcity of boreal toads and the effects of chytridiomycosis on toads farther south in the Rocky Mountains suggest the possibility that boreal toads in the GYE have already undergone a cycle of decline and recovery. We currently lack the data to distinguish between these hypotheses, but research is continuing. I am collaborating with Idaho State University faculty Sophie St.-Hilaire, Peter Murphy, and Chuck Peterson, and graduate student Sarah Bruer on a study in 2006 and 2007 (Figure 4) which is gathering further information on the distribution of Bd in Grand Teton National Park. It includes laboratory experiments to compare the pathogenicities of Bd cultured from the Black Rock site and a strain of Bd from Colorado known to be highly virulent. The results of this study should provide considerable insight into the magnitude of the threat from chytridiomycosis to amphibians in the GYE.

CHARLES R. PETERSON

Figure 4. Sophie St.-Hilaire (left) and Debra Patla, Idaho State University, collect amphibians at the National Elk Refuge to test for the presence of the chytrid fungus *Batrachochytrium dendrobatidis*.

NPS/JEFF ARNOLD

Columbia spotted frog (*R. luteiventris*).

Managing chytridiomycosis. The Australian government has prepared a threat abatement plan for dealing with chytridiomycosis (DEH 2006a) which recognizes that eradication of the disease is not currently possible. Instead, the plan focuses on control, based on the assumption that Bd is a novel pathogen. It emphasizes the need to limit the spread of Bd into uninfected areas and the need for additional research and monitoring. Unfortunately, beyond prohibiting transport of frogs known to be infected with Bd and mandating strict biosecurity measures for laboratories conducting research on Bd, it is not clear that methods to control the spread of Bd are effective. Field studies of amphibians are now conducted using methods intended to prevent the transport of pathogens among study sites (DEH 2006b). However, these procedures, which mainly involve washing and disinfection of equipment (waders, nets, etc.), are not used for other human activities, such as recreational boating or fishing, that are as likely as researchers to transport Bd among sites. If Bd is routinely transported by animals, then biosecurity measures imposed on humans are unlikely to have a significant effect on the spread of Bd.

If a species is declining toward extinction, captive breeding may be the only means of preservation in the short term (Mendelson et al. 2006). This solution is being pursued for boreal toads in Colorado and for the Wyoming toad. If the cause of the decline is chytridiomycosis and there is no potential site free of Bd for reintroducing the species, then it is difficult to be optimistic about the ultimate success of the effort. Surveys for the presence of Bd in the Rocky Mountains (E. Muths and D. Pilliod, unpublished data) have found it to be largely endemic. If captive breeding were to become necessary for any of the amphibians in the GYE, finding sites free of Bd for reintroduction may prove difficult. The current best alternatives for managing chytridiomycosis in the GYE are to continue to monitor the status and health of amphibian populations, refine our knowledge of the distribution of Bd, and continue research into the biology of Bd and its effects on amphibians.

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Literature Cited

Berger, L., A. D. Hyatt, R. Speare, and J. E. Longcore. 2005. Life cycle stages of the amphibian chytrid *Batrachochytrium dendrobatidis*. *Diseases of Aquatic Organisms* 68:51–63.

Bradford, D. F. 2005. Factors implicated in amphibian population declines in the United States. Pages 915–925 in M. Lannoo, ed, *Amphibian declines: the conservation status of United States species.* Berkeley: University of California Press.

Brunner, J. L., D. M. Schock, E. W. Davidson, and J. P. Collins. 2004. Intraspecific reservoirs: complex life history and the persistence of a lethal ranavirus. *Ecology* 85:560–566.

Corn, P. S. 2003a. Deteriorating status of western amphibians: can we generalize about causes? Pages 249–255 in G. Linder, S. K. Krest, and D. W. Sparling, eds, *Amphibian decline: an integrated analysis of multiple stressor effects*. Pensacola, FL: Society of Environmental Toxicology and Chemistry.

Corn, P. S. 2003b. Endangered toads in the Rockies. Pages 43–51, in L. Taylor, K. Martin, D. Hik, and A. Ryall, eds, *Ecological and earth sciences in mountain areas*. Banff, AB: The Banff Centre.

Corn, P. S., B. R. Hossack, E. Muths, D. A. Patla, C. R. Peterson, and A. L. Gallant. 2005. Status of amphibians on the Continental Divide: surveys on a transect from Montana to Colorado, USA. *Alytes* 22:85–94.

Daszak, P., A. A. Cunningham, and A. D. Hyatt. 2003. Infectious disease and amphibian population declines. *Diversity and Distributions* 9:141–150.

Daszak, P., D. E. Scott, A. M. Kilpatrick, C. Faggioni, J. W. Gibbons, and D. Porter. 2005. Amphibian population declines at Savannah River Site are linked to climate, not chytridiomycosis. *Ecology* 86:3232–3237.

[DEH] Department of the Environment and Heritage. 2006a. *Infection of amphibians with chytrid fungus resulting in chytridiomycosis: threat abatement plan*. Canberra: Commonwealth of Australia.

[DEH] Department of the Environment and Heritage. 2006b. *Infection of amphibians with chytrid fungus resulting in chytridiomycosis: threat abatement plan background document*. Canberra: Commonwealth of Australia.

Jancovich, J. K., E. W. Davidson, N. Parameswaran, J. Mao, V. G. Chinchar, J. P. Collins, B. L. Jacobs, and A. Storfer. 2006. Evidence for emergence of an amphibian iridoviral disease because of human-enhanced spread. *Molecular Ecology* 14:213–224.

Johnson, M. L., and R. Speare. 2005. Possible modes of dissemination of the amphibian chytrid *Batrachochytrium dendrobatidis* in the environment. *Diseases of Aquatic Organisms* 65:181–186.

Koch, E. D., and C. R. Peterson. 1995. *Amphibians and reptiles of Yellowstone and Grand Teton national parks*. Salt Lake City: University of Utah Press.

Kriger, K. M., and J.-M. Hero. 2006. Survivorship in wild frogs infected with chytridiomycosis. *EcoHealth* 3:171–177.

La Marca, E., K. R. Lips, S. Lötters, R. Puschendorf, R. Ibáñez, J. V. Rueda-Almonacid, R. Schulte, C. Marty, F. Castro, J. Manzanilla-Puppo, J. E. García-Pérez, F. Bolaños, F. Chaves, J. A. Pounds, E. Toral, and B. E. Young. 2005. Catastrophic population declines and extinctions in Neotropical harlequin frogs (Bufonidae: *Atelopus*). *Biotropica* 37:190–201.

Lips, K. R., F. Brem, R. Brenes, J. D. Reeve, R. A. Alford, J. Voyles, C. Carey, L. Livo, A. P. Pessier, and J. P. Collins. 2006. Emerging infectious disease and the loss of biodiversity in a Neotropical amphibian community. *Proceedings of the National Academy of Sciences (USA)* 103:3165–3170.

Longcore, J. E., A. P. Pessier, and D. K. Nichols. 1999. *Batrachochytrium dendrobatidis* gen. et sp. nov., a chytrid pathogenic to amphibians. *Mycologia* 91:219–227.

Longcore, J. R., J. E. Longcore, A. P. Pessier, and W. A. Halteman. 2007. Chytridiomycosis widespread in anurans of northeastern United States. *Journal of Wildlife Management* 71: in press.

Mendelson, J. R. III, K. R. Lips, R. W. Gagliardo, G. B. Rabb, J. P. Collins, J. E. Diffendorfer, P. Daszak, R. Ibáñez D., K. C. Zippel, D. P. Lawson, K. M. Wright, S. N. Stuart, C. Gascon, H. R. da Silva, P. A. Burrowes, R. L. Joglar, E. La Marca, S. Lötters, L. H. du Preez, C. Weldon, A. Hyatt, J. V. Rodriguez-Mahecha, S. Hunt, H. Robertson, B. Lock, C. J. Raxworthy, D. R. Frost, R. C. Lacy, R. A. Alford, J. A. Campbell, G. Parra-Olea, F. Bolaños, J. J. C. Domingo, T. Halliday, J. B. Murphy, M. H. Wake, L. A. Coloma, S. L. Kuzmin, M. S. Price, K. M. Howell, M. Lau, R. Pethiyagoda, M. Boone, M. J. Lannoo, A. R. Blaustein, A. Dobson, R. A. Griffiths, M. L. Crump, D. B. Wake, and E. D. Brodie Jr. 2006. Confronting amphibian declines and extinctions. *Science* 313:48.

Muths, E., P. S. Corn, A. P. Pessier, and D. E. Green. 2003. Evidence for disease-related amphibian decline in Colorado. *Biological Conservation* 110:357–365.

Odum, R. A., and P. S. Corn. 2005. *Bufo baxteri* Porter, 1968. Wyoming toad. Pages 390–392, in M. Lannoo, ed, *Amphibian declines: the conservation status of United States species*. Berkeley: University of California Press.

Ouellet, M., I. Mikaelian, B. D. Pauli, J. Rodrigue, and D. M. Green. 2005. Historical evidence of widespread chytrid infection in North American amphibian populations. *Conservation Biology* 19:1431–1440.

Patla, D. A. 1997. *Changes in a population of spotted frogs in Yellowstone National Park between 1953 and 1995: the effects of habitat modification.* M.S. thesis. Idaho State University, Pocatello.

Patla, D. A., and C. R. Peterson. 2004. *Amphibian and reptile inventory and monitoring Grand Teton and Yellowstone national parks, 2000–2003: final report*. Pocatello: Idaho State University.

Rachowicz, L. J., J.-M. Hero, R. A. Alford, J. W. Taylor, J. A. T. Morgan, V. T. Vredenburg, J. P. Collins, and C. J. Briggs. 2005. The novel and endemic pathogen hypotheses: competing explanations for the origin of emerging infectious diseases of wildlife. *Conservation Biology* 19:1441–1448.

Souder, W. 2000. *A plague of frogs: the horrifying true story.* New York: Hyperion.

Spear, S., N. Maxon, S. Wolff, and S. Corn. 2004. *Final report: incidence and effects of chytrid fungus on boreal toads (*Bufo boreas*) in Grand Teton National Park*. Missoula, MT: U.S. Geological Survey.

Spear, S. F., C. R. Peterson, M. D. Matocq, and A. Storfer. 2006. Molecular evidence for historical and recent population size reductions of tiger salamanders (*Ambystoma tigrinum*) in Yellowstone National Park. *Conservation Genetics* 7:605–611.

Stuart, S. N., J. S. Chanson, N. A. Cox, B. E. Young, A. S. L. Rodrigues, D. L. Fischman, and R. W. Waller. 2004. Status and trends of amphibian declines and extinctions worldwide. *Science* 306:1783–1786.

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