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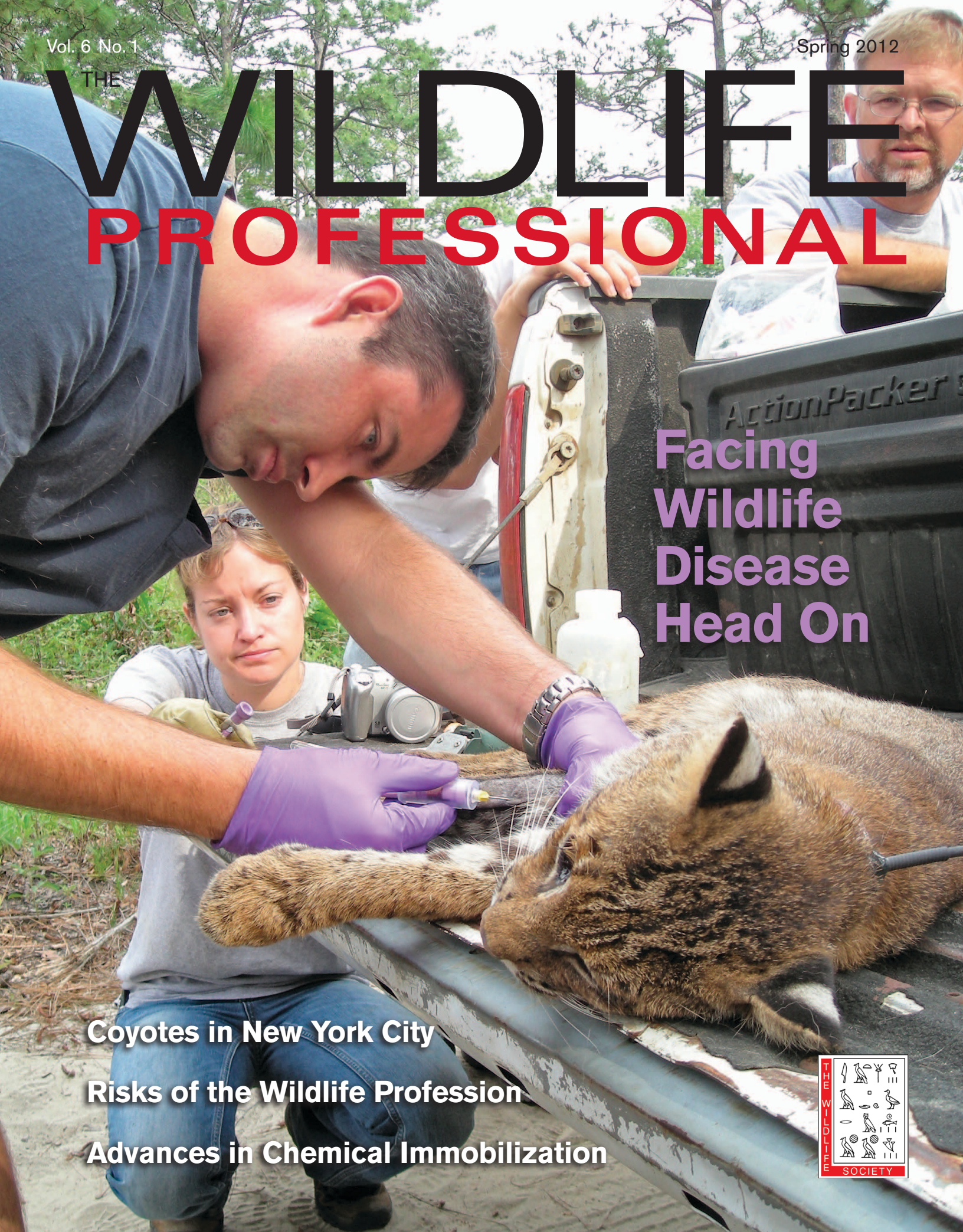
THE WILDLIFE PROFESSIONAL



Facing Wildlife Disease Head On

Coyotes in New York City

Risks of the Wildlife Profession

Advances in Chemical Immobilization

THE WILDLIFE SOCIETY

THE WILDLIFE PROFESSIONAL

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Rotating feature departments include:

- COMMENTARY
- EDUCATION
- ETHICS IN PRACTICE
- HEALTH AND DISEASE
- HUMAN-WILDLIFE CONNECTION
- LAW AND POLICY
- RESEARCH AND PRACTICE
- PROFESSIONAL DEVELOPMENT
- REVIEWS
- TOOLS AND TECHNOLOGY
- WILDLIFE IMAGING

COVER: While teaching a course on field methods and research at the University of Georgia, biologist Michael J. Yabsley draws blood from a sedated bobcat to test for several pathogens including *Cytauxzoon felis*, a parasite that can kill domestic cats, and *Trypanosoma cruzi*, a parasite common in many wildlife species that can cause Chagas disease in dogs and humans. Credit: Jennifer Yates Andrew

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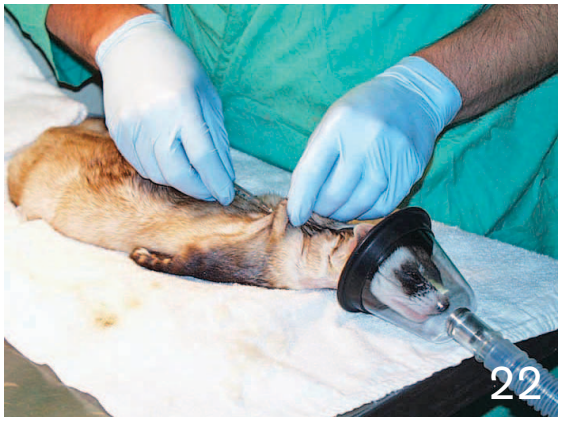
Cover Story: Wildlife Health and Disease



Credit: USGS National Wildlife Health Center

Credit: Tracy Graziano/Pennsylvania Game Commission

Credit: Idaho Fish and Game

ROTATING FEATURES

DEPARTMENTS

Online Extra:

Watch a video of volunteers and biologists with the Wyoming Game and Fish Department use a drop net to capture 35 bighorn sheep (*Ovis canadensis*) from the Whiskey Mountain, Wyoming herd and test them for a devastating strain of pneumonia.

More Online!

This publication is available online to TWS members at *wildlife.org/twplogin*. Throughout the magazine, mouse icons and text printed in **blue** indicate links to more information available online.

Facing Disease Head-On

By David A. Jessup and Colin Gillin

"The role of disease in wildlife populations has probably been radically underestimated."

– Aldo Leopold, *Game Management*, 1933

Once again, Aldo Leopold proves visionary. Nearly 80 years after his initial observation, we daily see the specter of wildlife disease exerting major influence on state, federal, provincial, tribal, and private wildlife management activities. New diseases have emerged and old ones have reemerged and/or moved around against a backdrop of increasing human and wildlife population densities and habitat loss and degradation. Humans clearly have a major hand in the problem—but also in the solution.

Hunting practices such as baiting deer, bear, and wild pigs, as well as recreational activities like feeding wild birds and small mammals, can cause animals to congregate, leading to disease transmission. Likewise, management practices such as fire suppression or winter feeding of large ungulates may also have profound effects on disease prevalence and infectivity. However, with a growing recognition of wildlife diseases and their implications for domestic animal and human health, there is also increased social, political, legal, and financial pressure to control and limit disease.

Then and Now

Historically, the fear of foreign animal diseases (like rinderpest and "foot and mouth") becoming endemic in wildlife has been a major concern in North America. More recently, wildlife as reservoirs for rabies, TB, brucellosis, plague, avian influenza (AI), West Nile, and Lyme disease have garnered great public attention. In just the last decade we have seen a strange, almost alien, life form called a prion, the cause of chronic wasting disease, spread across deer and elk populations in the United States and Canada, despite the best efforts of wildlife agencies to limit it. And the seemingly common chytrid fungus appears to be wiping out whole populations of amphibians in many parts of the world.

Perhaps the most dramatic recent example of an emerging disease is white-nose syndrome (WNS) in bats, a fungal infection that arose in the eastern U.S. and in just the last four or five years has rapidly spread, devastating bat populations in much of the eastern U.S. and into Canada. The environmental, human, and animal health consequences of losing these insectivores may be huge, dwarfing the effects of chronic wasting disease on deer and elk. Ironically, fungal diseases have been considered the weakest of pathogens, far less aggressive and deadly than parasites, bacteria, viruses, or prions.

Because healthy wildlife populations are an extremely valuable natural resource, and because wildlife diseases can be very difficult and expensive to control, disease outbreaks can have serious financial and political implications. Responding to such outbreaks therefore takes collaborative action among government wildlife conservation agencies, universities, non-profit organizations, and organizations charged with protecting livestock and human health. Such cooperative models provide some of the most successful examples of wildlife disease research and management, particularly in an era of limited financial resources.

For example, the response to the more lethal strains of avian influenza involved rapid cooperation between many governments worldwide, and between human health, agriculture, and wildlife agencies at the highest levels of government, which became nearly unprecedented cooperation and understanding of the threat at most levels of society. Many agencies and conservation NGOs (the Wildlife Conservation Society was at the forefront as AI emerged in wild geese in Mongolia), as well as university laboratories and researchers, cooperated to bring global testing and disease surveillance online.

We hope that all wildlife professionals will heed Leopold's words and consider the significance of disease to wildlife populations. For those with a passion for wildlife health and conservation medicine, we hope you'll join TWS' Wildlife Diseases Working Group, the Wildlife Disease Association, the American Association of Wildlife Veterinarians, or other organizations working to optimize the health of wildlife, people, their livestock, and the environments that support all. ■

Credit: Sharon Toy-Choutka

David A. Jessup (DVM, MPVM, CWB) is Executive Manager of the Wildlife Disease Association.

Courtesy of Colin Gillin

Colin Gillin, DVM, is President of the American Association of Wildlife Veterinarians.

In a World Dominated by Parasites

FUNDING POSES THE GREATEST CHALLENGE

By Scott E. Hygnstrom and Richard N. Brown

Credit: UNL

Scott E. Hygnstrom is Professor and Extension Wildlife Specialist in the School of Natural Resources at the University of Nebraska at Lincoln and Immediate Past Chair of TWS' Wildlife Diseases Working Group.

Courtesy of Richard N. Brown

Richard N. Brown is Assistant Professor at Humboldt State University's Department of Wildlife and Chair of TWS' Wildlife Diseases Working Group.

The issue of disease is relevant to anyone studying or managing wildlife populations. Most diseases are caused by infectious and/or parasitic agents (such as viruses, bacteria, fungi, flatworms, nematodes, and arthropods), and some cause problems severe enough to force managers to act.

Within the management community, broad recognition of the importance of diseases has paralleled the emergence or reemergence of diseases that devastate wildlife populations or that threaten livestock and/or human health. Infectious agents—including those that cause avian malaria in Hawaii, Lyme disease, brucellosis, chytridiomycosis, West Nile encephalitis, avian influenza, devil facial tumor disease, and white-nose syndrome—impact wildlife populations as well as budgets at all levels. Many of these rapidly emerging diseases have been exacerbated by globalization and the movement of wildlife, vectors, or pathogens into naïve systems. Management therefore needs to be proactive, well-funded, and flexible to meet the challenges of disease-related problems in the modern world.

The Ups and Downs of Money

Levels of funding for surveillance, monitoring, research, and management of wildlife diseases have fluctuated widely over time. In the 1960s, major outbreaks of avian cholera and duck plague attracted attention, and state and federal funds were generated to beat back these ills. Research labs were opened, seminal books written, and programs developed to aid public agencies in the detection, diagnosis, and management of wildlife diseases. But government interest waned, funding dried up, and programs died on the vine.

In the early 1980s, an outbreak of Lyme disease in the upper-Midwest renewed interest in a perplexing bacterial disease, but again funding was reduced. In 1993, an undiagnosed outbreak of hantavirus in the Southwest attracted attention nationwide. Diligent efforts by the Centers for Disease Control and state agencies helped break the case, but coffers of state and federal agencies remained thin. In 1999, an outbreak of West Nile Virus (WNV) occurred in New York, and we were not ready for the ensuing tidal wave: In four years, WNV swept across the country infecting thousands of horses and humans and leaving hundreds dead in its wake. Some states made funds available for surveillance, vaccination, and public education programs, but many ignored the warnings. Perhaps WNV did us a favor by shocking the public and decision makers into taking action.

Chronic wasting disease (CWD), which moves slowly, wasn't a concern until 2000, when it started popping up across the country. Congress directed millions of dollars to state programs through the USDA and USGS to facilitate surveillance, monitoring, and research. Unfortunately as the disease spread, the stream of federal funds for CWD dried up. About the same time, avian influenza (AI) was spreading rapidly across Asia and Europe. Again, congressional money flowed and agencies developed surveillance programs. Even Hollywood got caught up in the act with a TV movie, "Fatal Contact: Bird Flu in America." But just as fast as it came, funding for AI dried up and now, with the virus knocking at our door in the North Pacific, we no longer have a nationally coordinated surveillance program. AI was just another "disease of the day."

What will be next? Will it be another rogue, never-before-seen prion, or the reemergence of an old enemy such as foot-and-mouth disease? Either way, crises can't be met without constant and sustainable funding. To promote that goal, the Wildlife Diseases Working Group (WDWG) of TWS recently drafted a position statement that recommends funding of a sustained nationwide program of surveillance, monitoring, research, and management.

So, where do we as TWS members fit into all of this? Consider joining the WDWG. Now with 210 members, it is one of the largest and most active of all working groups. We have developed a website and newsletter (the *Vector*) to inform members about wildlife disease issues, and we have reviewed position statements, agency plans, organization guidelines, and Congressional directives to enhance the role of science in disease management. By supporting this effort, you can help tackle the growing challenge that disease poses to wildlife around the world. ■

"One Health" Drives Wildlife Vets

Wildlife veterinarian DEANA CLIFFORD tackles big-picture problems

By Jessica P. Johnson

Credit: Jaime Rudd

Deana Clifford gives a physical exam to a desert kit fox while investigating a recent cluster of canine distemper cases at the construction site of a solar energy facility near Joshua Tree National Park.

Deana Clifford can't remember a time when she didn't want to work with animals. Her interest eventually led her to the University of California at Davis (UC Davis), where she chose to study wildlife medicine rather than the more lucrative but predictable specialty of pet or livestock care. "You never know what you'll be faced with or working on every day," she says.

Now a wildlife veterinarian with the Wildlife Investigations Laboratory (WIL) at the California Department of Fish and Game (CDFG), Clifford has started the department's first program for non-game wildlife health. "We've got more species in the conservation gray zone. They are not listed as endangered, but they are nonetheless facing significant conservation threats. My goal is to see what the need is for these species and act proactively to keep populations healthy."

Clifford's approach to wildlife management is driven by the principle of One Health—an ethic that recognizes how public and animal health are dependent on the interconnectedness of humans, animals, and their shared environment. One Health was central to Clifford's training even as she pursued her master's in preventive veterinary medicine and Ph.D. in epidemiology at UC Davis.

During her master's studies, Clifford took a commercial test used to detect oil content in soil and modified it to measure the amount of oil on bird feathers from oil spills. "It was a turning point in my career," she says. "I found out that I didn't like working in a lab and wasn't great at it. I decided I wanted to conduct applied field-based research to help make recommendations to solve wildlife conservation problems." During her subsequent Ph.D. research, she used health indices such as reproductive rates, pup mortality, and survival to determine infectious disease risk in island foxes—a species almost driven to extinction by canine distemper virus. She then used her data from the wild population to evaluate a captive breeding program run by the Catalina Island Conservancy and the Institute for Wildlife Studies. "Working closely with island managers ... ensured that my research would directly contribute to pressing management needs."

Going Farther Afield

After Clifford finished her Ph.D., she and her graduate advisor, Jonna Mazet, formed the Health for Animals and Livelihood Improvement Project (HALI), a partnership of American and Tanzanian universities and agricultural institutions that train Tanzanian traditional livestock keepers to prevent zoonotic disease transmission. Water scarcity was forcing humans, livestock, and wildlife to congregate near shrinking water sources. As a result, livestock keepers saw a surge in bovine tuberculosis, brucellosis, and water-borne pathogens, all of which potentially threatened human populations. Clifford and her HALI colleagues tested wildlife and livestock for disease and trained locals to monitor disease and improve water quality.

"I view wildlife as sentinels for how healthy the whole ecosystem is," Clifford says. Carnivores are one such sentinel, and Clifford now works with toxicologists and ecologists from the Integral Ecol-

ogy Research Center, UC Davis, and CDFG to track carnivore exposure to rodenticides. The researchers discovered widespread exposure to anticoagulant rodenticides in fishers (*Martes pennanti*)—a candidate for listing at the federal level. Their data suggest that anticoagulants are present and likely widespread within carnivore ecosystems, a fact that could ultimately affect human health. "This finding can directly drive policy," says Clifford, who hopes to persuade the Department of Pesticide Administration to change regulations on how these rodenticides are used.

In addition to her role with WIL, Clifford continues to work with HALI and trains graduate students at UC Davis. She is also director of the Envirovet Summer Institute's Developing Country Session, an intensive three-week summer course that trains professionals in developing countries to create locally-appropriate solutions to improve the health of both animal and human populations. "To affect positive change for wildlife conservation and health," she says, "wildlife professionals have to cross boundaries and work together." ■

Jessica P. Johnson is Science Writer for *The Wildlife Professional*.

To find a mentor or mentee, go to http://mentor.wildlife.org/about

MENTOR Jonna Mazet

Professor of Epidemiology and Disease Ecology
University of California at Davis, School of Veterinary Medicine

When Jonna Mazet started vet school at UC Davis in 1988, she felt that her options for a specialty were very limited. There were programs for zoo medicine and animal care, but nothing involving wildlife. But during her second year, the Pew Charitable Trusts granted funding to begin the country's first wildlife veterinary specialty within her program. A short time later, Mazet gave her first conference talk at The Wildlife Society's Western Section meeting. There, she discovered the urgent need for wildlife vets. "I wanted to help save the world …. I wanted to work where animals and people were in conflict; where making changes in human habits would help alleviate that conflict."

Mazet completed her doctorate in veterinary medicine and continued at Davis, obtaining a master's in preventative veterinary medicine (MPVM) and then a Ph.D. in epidemiology. Now a professor of epidemiology and disease ecology, Mazet also serves as Executive Director of UC Davis' One Health Institute and its Wildlife Health Center. In addition, she is Global Director of PREDICT, a team of researchers (funded by the U.S. Agency for International Development's Bureau for Global Health) that has been tapped to identify and help prevent emerging zoonotic disease epidemics around the world.

As a new professor at UC Davis, Mazet met Deana Clifford and mentored her through her MPVM and Ph.D. "We sort of grew up as professionals together," Mazet says. Clifford then joined Mazet as a postdoctoral scholar on the Wildlife Health Center's first international One Health effort in Tanzania in 2006. "In wildlife medicine, there are often more roadblocks than paths," says Mazet. "Deana was great at finding her way around those obstacles. She is incredibly passionate, so there was no chance for her to fail."

Credit: Hannah Mazet

Jonna Mazet meets with Maasai pastoralists and international health trainees to discuss zoonotic diseases.

Through the PREDICT program, Mazet and her colleagues have identified about 100 novel viruses in 20 developing countries that could potentially pass from wildlife to humans. "When we look at health problems, it's easy to ignore the wildlife component," Mazet says. "I'm very proud to bring wildlife health professionals to the forefront of that emphasis."

While juggling teaching, research, and other duties, Mazet often travels around the globe to teach about wildlife conservation and zoonotic disease prevention. She was recently in Indonesia to train national park staff, government veterinarians, and university faculty in the safe handling of rodents and primates for zoonotic disease surveillance. But Mazet says she's most proud of her work with mentees like Clifford. "I've been so lucky to work on something that I'm so passionate about," she says. "And I've been able to meet and learn from so many amazing people along the way."

Why Focus on Disease?

EXPERTISE IN WILDLIFE DISEASE HELPS CONSERVATION

By David A. Jessup

DISEASE, whether in humans or animals, is broadly defined as "any disturbance in physiologic function that compromises health." If revised to say "any disturbance in demographic function that compromises ecologic health," the definition could also apply to wildlife populations and ecosystems. We are used to thinking about diseased wild animals, or the health of a wildlife population, but today, many disease ecologists and wildlife health professionals are beginning to recognize that even ecosystems—whole complexes of biotic and abiotic entities—can become unhealthy and degraded, losing resiliency and sustainability. Given proper treatment and time, sick wild animals, unhealthy wildlife populations, and degraded ecosystems may be able to recover, but therein lies the challenge for wildlife professionals.

The following package of articles reflects a growing recognition that disease presents a critical challenge to conservation. Indeed, the field of disease ecology has grown significantly within the biological sciences. More states now have wildlife veterinarians, and more federal agencies and conservation NGOs have wildlife health and disease programs. Within The Wildlife Society (TWS) itself, a vibrant Wildlife Diseases Working Group has emerged to explore health and disease issues, and TWS has memoranda of understanding with both the Wildlife Disease Association and the American Association of Wildlife Veterinarians.

Though many wildlife diseases have been around for a long time and show no sign of abating—including rabies, brucellosis, and TB—several devastating new wildlife diseases have emerged in just the last decade or two, such as chronic wasting disease (CWD), chytrid fungus, West Nile virus, high pathogenicity avian influenza, and white-nose syndrome.

◀ In early 2011, fungal infections took a grim toll near Pierre, South Dakota, where more than 7,000 mallards died in a small pond after eating moldy grain from a nearby cattle lot. State and federal wildlife officials bagged and hauled away the dead, fearful that the illness could spread to eagles and other scavengers.

Whether old or new, such diseases arrive and spread in several key ways. These include translocation of exotic species into new ecosystems, human incursion into previously undisturbed habitats, the illegal wildlife trade (i.e., the bush meat trade increases the threat of deadly Ebola and Marburg viruses), rapid human transportation across the continents (consider SARS and avian influenza), and wildlife farming or ranching (which may allow CWD to pass from captive to wild cervids).

Social, political, legal, and financial pressures require wildlife managers to deal with these and other disease issues, whether or not they directly affect wildlife harvest. But common ground can be found, as shown by the One Health movement, which recognizes that optimal health of people and domestic animals depends on optimal health of ecosystems and wildlife.

Technology may also hold some exciting solutions. Though it seemed impossible three or four decades ago, we now have several vaccines to help prevent or control disease in free-ranging wildlife, as well as the ability to capture and sample almost any wildlife species. But a word of caution: About 50 years ago, with the rise of vaccine technology and widespread use of antibiotics, many physicians believed that the age of infectious diseases was drawing to a close. It hasn't. Wildlife professionals need to recognize that dealing with wildlife disease and optimizing wildlife health is something that requires our commitment for the long haul.

Credit: Sharon Toy-Choutka

David A. Jessup (DVM, MPVM, CWB) is Executive Manager of the Wildlife Disease Association.

Transformation through Time

HOW WILDLIFE DISEASE BECAME A FOCUS OF CONSERVATION

By Milton Friend

Credit: Daniel H. Rich

Milton Friend, Ph.D., is Emeritus Scientist of the USGS National Wildlife Health Center.

When I began my career as an assistant waterfowl biologist in 1956, wildlife disease was not a major concern for conservation agencies. Some states—such as California, Michigan, New York, Wyoming, and Colorado—had small internal wildlife disease programs to investigate wildlife mortality events, and the U.S. Fish and Wildlife Service (FWS) had a program focused on migratory birds.

A significant change came in 1957, when the Southeastern Association of Fish and Wildlife Agencies formed what is now known as the Southeastern Cooperative Wildlife Disease Study (SCWDS). Its initial focus was to combat "Disease X," a mysterious illness (now known as hemorrhagic disease) that was causing mass mortality of white-tailed deer.

Since those early days, research on wildlife disease has increasingly become a focus of federal, state, private, and university programs. Indeed, some researchers note that "wildlife diseases are in fashion" (Gortazar *et al.* 2007), largely due to the major role that wildlife play in the current era of emerging and recurring infectious diseases that affect both animals and humans (Friend 2006). What follows is a brief exploration of how—and why—the approach to wildlife disease in North America has changed over time, and has in turn changed the dynamics of wildlife conservation itself.

In the Beginning: Pre-History

Wildlife disease predates wildlife conservation by many millennia. Lesions in the skeletal remains of prehistoric animals (Verano and Ubelaker 1992) suggest that disease has long been a factor in wildlife mortality. Some researchers hypothesize that infectious diseases—perhaps caused by hypervirulent pathogens—were a major factor in mass extinctions over the last 100,000 years (MacPhee and Marx 1997).

Devastating die-offs also occurred as human colonization, the domestication of animals, and domestic animal movements introduced new pathogens to immunologically naïve hosts. Today, such outbreaks are known as "virgin soil" epizootics (Crosby 1975).

The First Frontier: 1620-1890

The colonization and European settlement of North America is marked by great environmental degradation and overexploitation of the continent's abundant wildlife and other natural resources. Awareness of disease was minimal, and epizootic outbreaks were mainly seen as natural events that had little consequence for abundant wildlife. People saw no connection between human actions and wildlife disease outbreaks, so there was little incentive for intervention. Indeed, the seeds for addressing disease germinated not because of concerns for wildlife, but only because some major die-offs had direct negative impacts on human values and needs such as food, clothing, and recreation.

1656: A mass die-off of pelicans occurred in the West Indies. According to accounts made at that time, "so mortal was the disease, that their dead bodies covered many islands...." (Fleming 1871).

Courtesy of USGS

1891: Early members of what would become the Bureau of Biological Survey (BBS)—including C. Hart Merriam, second from left—work in Owens Valley, California.

Courtesy of Smithsonian Institution

1910: A botulism outbreak in Utah's Bear River marshes and elsewhere across the West killed millions of waterfowl and led to the creation of a field lab at the Bear River Migratory Bird Refuge.

1886: C. Hart Merriam was appointed to head the new USDA Division of Economic Ornithology and Mammology. Under his leadership, researchers began to study wildlife food habits, migration, and species distribution. In addition, farmers received education about how birds and other wildlife could benefit agriculture through actions such as insect and rodent control.

The Second Frontier: 1890-1990

The 100 years from roughly 1890 to 1990 was a period of mass agricultural development and subsequent urbanization. During this era, the percentage of the U.S. population classified as farm residents dropped from 40 percent in 1900 to 1.9 percent by 1990 (Louv 2005). This period also marked the birth of a strong wildlife conservation movement that shifted from protectionism to restoration, conservation, and wise-use stewardship of wildlife resources. Similarly, the concept of wildlife disease shifted from being an abstraction to a conservation concern. Reports of epizootic mortality events began to rise along with changing conditions, such as greater interfaces between wildlife and domestic animals.

1905: The USDA created the Bureau of Biological Survey (BBS), which began decades of inquiry, research, and technical assistance regarding wildlife conservation, animal damage control, wildlife disease investigations, and regulation. In 1939 the BBS moved from the USDA to the Department of the Interior's U.S. Fish and Wildlife Service (Friend 1995).

1908: Plague in wild rodents appeared in North America, and the western U.S. became the enzootic foci (McCoy 1911, Eskey and Haas 1940).

1913: The California Department of Fish and Game (CDFG), working with the University of California, began investigating the cause of mass die-offs of waterfowl that had been occurring in the West (Clarke 1913). Estimated bird losses during 1910 in Utah and Oregon alone reached into the millions (Kalmbach 1968, Rocke and Friend 1999). The emerging field of wildlife conservation suddenly had a "poster child," later identified as type C avian botulism (Kalmbach and Gunderson 1934). California waterfowl epizootics led the state to develop a Wildlife Investigations Laboratory, and Utah epizootics led the BBS to establish a field investigations lab at the Bear River Migratory Bird Refuge (Wetmore 1918).

1930s: During the '30s, wildlife became recognized as an integral part of the conservation whole, viewed as a public trust and managed through science (Leopold 1933). Disease investigations were sparked by a North American focus on cyclical population fluctuations in game and fur animals.

1933: In his book *Game Management*, Aldo Leopold was ahead of his time in making the radical statement that "the real determinants of disease mortality are the environment and the population, both of which are being 'doctored' daily, for better or for worse, by gun and axe, and by fire and plow." He further noted that "organized effort to understand and control game diseases is still in its infancy." Such observations made Leopold one of the first champions of the concept that wildlife disease is an ecological issue influenced by human activities.

1936: Franklin D. Roosevelt established the first North American Wildlife Conference, which featured a session on Wildlife Disease and Population Cycles. Roosevelt also established the Patuxent Research Refuge in Maryland, charged with expanding BBS' focus to investigating diseases that affect free-ranging wildlife (and not just farm or game animals), providing a scientific basis for evaluating disease between wildlife and livestock on grazing lands, and researching disease transmission between wildlife and humans.

Credit: Milton Friend

1960s: Ibis eggs show shell thinning caused by DDE, a breakdown product of the pesticide DDT. Awareness of pesticides' toxic effects rose in the 1960s after *Silent Spring* was published.

Credit: Milton Friend

1973: Thousands of mallards died of duck virus enteritis at the Lake Andes National Wildlife Refuge in South Dakota, prompting development of the National Wildlife Health Center.

1944: The first North American documentation of avian cholera in wild waterfowl took place simultaneously in Texas and California.

1951: Following the 14th North American Wildlife Conference, a committee was formed to determine interest in an organization focused on wildlife disease. As a result, the Wildlife Disease Association was formed.

1952: The Sybille Wildlife Research Station was established by the Wyoming Fish and Game Department as a research facility for the development of wildlife management techniques and wildlife disease investigations.

1960s: The Department of Veterinary Science at the University of Wisconsin at Madison initiated a graduate training program focused on wildlife disease—the first such program in the nation.

1960s: Researchers developed the first field techniques to remotely administer rabies vaccinations to foxes in the wild, work that eventually led to the successful use of vaccine-laden baits to combat rabies in foxes and other species (Rupprecht *et al.* 2004, Winkler and Bogel 1992). The approach was fueled by growing public opposition to the destruction of wildlife as the main method of rabies control.

1962: Rachel Carson published *Silent Spring*, which focused public attention on chemical contaminants that were found to be causing disease in wildlife and humans. The growing environmental concerns of the 1960s pushed wildlife conservation towards ecosystem health approaches.

1962: Tadpole edema virus (a ranavirus) was identified in bullfrogs as the first significant amphibian disease (Wolfe *et al.* 1968).

1965: The WDA began to publish *The Journal of Wildlife Disease*, the first journal devoted exclusively to sharing research and information about wildlife disease.

1973: Duck plague, or duck virus enteritis (DVE), caused large-scale loss of waterfowl wintering at the Lake Andes National Wildlife Refuge (Friend 1999). This "duck plague crisis" helped advance infrastructure for addressing wildlife disease, in this case contributing to the development of the FWS National Wildlife Health Center (NWHC) in 1975.

1975: Lyme disease began to emerge and became a significant and increasingly common zoonotic disease in the U.S.

1975: Nebraska had its first documented outbreak of avian cholera in waterfowl, making the state a new hotspot for the disease beyond Texas and California.

1977: Raccoon rabies emerged in the Mid-Atlantic states as a result of translocating raccoons for hunting purposes.

1978: Parvovirus emerged globally in both domestic dogs and wild canids.

1978: Chronic wasting disease (CWD) was identified in captive cervids, and was first diagnosed in wild cervids in 1981 (Williams *et al.* 2001).

1979: During a meeting of the American Veterinary Medical Association in Seattle, Washington, the American Association of Wildlife Veterinarians (AAWV) was founded.

1980s: Early this decade, previously rare tumors in green sea turtles erupted simultaneously into a panzootic, with infections exceeding 90 percent in some populations (Quackenbush *et al.* 1998, Friend 2006).

1986: At the first Conservation Biology Conference, researchers restated Aldo Leopold's perspective that

Credit: Milton Friend

1978: Staff members with the Wisconsin Department of Natural Resources remove deer tissue to test for chronic wasting disease, discovered in captive cervids in 1978.

Credit: P. Bennett and U. Keuper-Bennett/Turtle Trax

1980s: Fibropapilloma tumors—caused by an unidentified herpesvirus—erupted in Florida in the 1980s. This green sea turtle swims at a Hawaiian reef where the disease flourished in the 1990s.

"pathogens and parasites are one of the most important though frequently unconsidered aspects of conservation biology" (May 1988). Sadly, little had changed in the 50 years since Leopold wrote those words.

The Third Frontier: Current Time

According to the United Nations, more people worldwide now live in cities than in rural areas (UN 2003). Likewise, wildlife is increasingly colonizing urban environments, a somewhat paradoxical shift from early human settlement of the wilderness. In parallel, infectious disease emergence and resurgence continues as a growing public health and wildlife conservation issue. Many of these diseases have wildlife origins and some can be thought of as "crowd diseases" because they require high density populations to spread. In addition, complex habitat ownership and jurisdictional issues complicate our ability to manage and respond to urban disease crises. All of these factors create a perfect storm relative to disease emergence.

In our current era of global mass extinctions (Wilson 2002), urban wildlife habitat has become vitally important for sustaining global biodiversity (Bradley and Altizer 2006). Yet urbanization has intensified the human perception of wildlife as villains because of their role in zoonotic disease. Thus wildlife disease may be seen as a social issue as much as a biological one. Dealing with this requires collective action, not just for the sake of wildlife, but because of diseases' ramifications for agriculture, livestock, economies, and human and ecosystem health. The question we must ask is: To what extent beyond "crisis response" will the conservation community address this increasing challenge?

1990s to Now: Events in the last two decades prove how critical this question has become. During the 1990s, emerging and recurring disease outbreaks, including zoonoses, took a large toll on wildlife. Newcastle disease emerged and began to devastate cormorants in rookeries through Canada, the Great Lakes region, and at California's Salton Sea. Coral reef diseases intensified. The chytrid fungus became associated with mass deaths of amphibians in the U.S., and researchers found evidence of earlier events (Dascak *et al.* 1999, Green *et al.* 2002). Tuberculosis became established in Michigan's wild deer population, and researchers documented mycoplasmosis in finches as it began a slow spread across the country.

The highly pathogenic H5N1 influenza virus emerged in southern China in 1995, triggering multi-year mass sampling of birds in North America and elsewhere. In 1999, West Nile virus emerged in crows in the northeastern U.S. and began its spread across North America. And a decadal study from 1992 to 2002 found infectious disease to be an emerging major cause of southern sea otter mortality (Thomas 2001, Friend 2006).

Even more recently, the U.S. saw its first monkeypox cases in 2003, spawned by the exotic pet trade. SARS emerged in Canada, transmitted by human travelers from Asia, where civet cats had passed the disease to humans. And in 2006, researchers diagnosed the first cases of white-nose syndrome (WNS) in bats, a disease that has since killed millions of these valuable insectivores throughout North America (Blehert *et al.* 2009).

Such sweeping events have commanded a collaborative response from the wildlife conservation community. In 1992, the Canadian Cooperative Wildlife Health Center formed, working with Canadian schools of veterinary medicine. And in 1995, the Centers for Disease Control and Prevention began to publish the journal *Emerging Infectious Diseases* to focus specifically on emerging health crises. This action was an ironic contrast to proclamations of the late 1960s and early 1970s that infectious disease had been contained within the developed world. Clearly it has not. Disease eruptions and die-offs continue, and some (like CWD and WNS) represent new or unfamiliar diseases that challenge wildlife conservation and will occupy disease researchers for decades to come.

Find a related, fuller-length essay by Milton Friend online at *wildlife.org/twplogin*

Credit: Milton Friend

1990s: Cormorant chicks lie dead on their nest, victims of Newcastle disease, which emerged in the 1990s and devastated cormorant rookeries across the continent.

Credit: USGS National Wildlife Health Center

2006: USGS researchers examine a bat that died of white-nose syndrome, first identified in 2006 and responsible for millions of bat deaths across North America.

Ills in the Pipeline

EMERGING INFECTIOUS DISEASES AND WILDLIFE

By Jonathan Sleeman and Colin Gillin

Courtesy of Jonathan Sleeman

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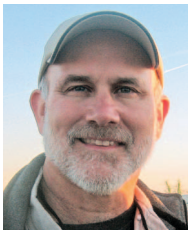


Courtesy of Colin Gillin

Colin Gillin, DVM, is President of the American Association of Wildlife Veterinarians and the State Wildlife Veterinarian for the Oregon Department of Fish and Wildlife.

In the recent film *Contagion*, a medical thriller released in fall 2011, the fictitious MEV-1 virus—passed from bat to pig to humans—spreads across the globe as easily as the common cold, killing millions of humans and causing mass hysteria as medical researchers race to find a cure. Though it's Hollywood hyperbole, the film holds a kernel of truth: Researchers believe that the close proximity of Malaysian hog farms to forested areas—the natural habitat for fruit bats—allowed the previously unknown Nipah virus to spill from bats into pigs and subsequently into people, resulting in more than 100 human deaths (Epstein *et al.* 2006).

There is no doubt that in recent times we have seen an unprecedented number of emerging infectious diseases, defined by the Institute for Medicine as new, reemerging, or drug-resistant infections whose incidence has increased or whose incidence threatens to increase in the near future. Many of these have a wildlife origin (Taylor *et al.* 2001). While this jump may be due, in part, to increased vigilance and reporting, there is a general consensus that current global conditions are creating a situation that is very favorable to the transmission of microbes that cause diseases. (For reviews, see Daszak *et al.* 2001 and Keesing *et al.* 2010). Likewise, it's increasingly important that wildlife professionals become aware of how and why new infectious diseases spread and what, if anything, can be done to minimize impacts on wildlife.

Disease Pathways

Global trade and movement of wildlife and animal products are opening up new pathways for pathogens to jump to new continents and new species. For example, we have witnessed how quickly monkeypox—a sometimes lethal viral infection carried by rodents and normally restrained to sub-Saharan Africa—found new hosts in prairie dogs and rapidly spread to humans after it was introduced into the United States as a result of the importation of Gambian giant pouched rats for the pet trade (Reed *et al.* 2004). A recent study of bush meat illegally imported into the United States detected several potential zoonotic viruses using modern molecular technologies, also demonstrating the illegal wildlife trade as a potential conduit for pathogen spread (Smith *et al.* 2012).

Changing land-use patterns are bringing people and wildlife into closer contact, which also facilitates the exchange of pathogens and disease vectors. The propensity of humans in North America to live in fragmented forested areas—otherwise known as suburbia—brings them into closer contact with the

Courtesy of Kimberli Miller/USGS National Wildlife Health Center

Credit: Kimberli Miller/USGS National Wildlife Health Center

USGS disease specialist Kimberli Miller examines little brown bats in a Vermont cave known to harbor white-nose syndrome. Caused by the invasive *Geomyces destructans* fungus, the disease can damage wing membranes (far right) and has led to the deaths of millions of bats of several species.

increasingly abundant black-legged tick, the vector for the bacteria (*Borrelia burgdorferi*) that causes Lyme disease (LoGiudice *et al.* 2003).

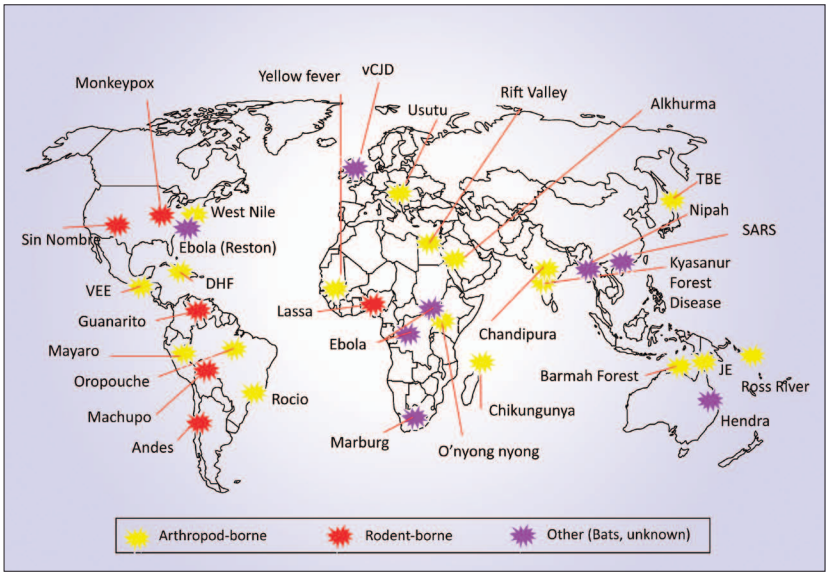
There is also convincing evidence that climate change plays a role in disease issues by affecting the phenology of plants and animals, the geographic range and distribution of disease and disease vectors, community and ecosystem composition and member interaction, pathogen virulence, and patterns of disease. (For a review, see the USGS publication *Climate Change and Wildlife Health: Direct and Indirect Effects*.) Higher summer temperatures, for example, can result in increased abundance of disease vectors such as arthropod midges, and higher viral load in infected vectors (Purse *et al.* 2008). Midges in turn can transmit orbiviruses that cause hemorrhagic disease and bluetongue, which are severe illnesses in ruminants such as deer. (For a review see, Howerth *et al.* 2001). This is just one illustration of how climate may contribute to changes in the incidence and geographic distribution of important diseases (Purse *et al.* 2008, Sleeman *et al.* 2009). These complex factors, plus the ability of microbes to change and adapt to new environments and hosts—and our nascent understanding of and capacity to address these issues—is creating a "perfect storm" for disease emergence and resurgence.

A Global Toll

The impacts of emerging diseases are global and profound, and result in an increased burden on the public health system, economic losses, human deaths, declines in wildlife populations, and subsequent ecological disturbances. Human immunodeficiency virus (HIV) provides the classic case in point. HIV is now known to be a zoonotic disease (one transmissible between animals and humans) that originated from similar simian immunodeficiency virus strains found in African primates (Gao *et al.* 1999). Today, some 35 million people are living with HIV, placing a huge burden on the global public health system.

Rampant disease in livestock and poultry takes a toll on global food supplies. To curb the spread of the highly pathogenic avian influenza virus known as H5N1, for example, more than 200 million poultry have been culled in Asia since 2003, a loss that has had negative impacts on food security for the region (FAO). Beyond affecting livestock, emerging diseases such as the well-publicized white-nose syndrome (WNS) in bats and the chytrid fungus in amphibians also have severe impacts on fish and wildlife populations. Chytrid fungus, for example, has spread to approximately 37 countries on six continents, infected 287 amphibian species, and resulted in extinction of several species (Weldon *et al.* 2004, Kriger and Hero 2009). Such unprecedented mortality events raise questions about the potential ecological and indirect human health repercussions of wildlife diseases.

Outbreaks around the Globe



Credit: One Health Initiative

This map gives a sampling of some 30 diseases that have emerged just since 1985. About 75 percent of all emerging diseases are zoonoses–animal infections transmissible to humans.

Although the occurrence of disease in wildlife can be a natural phenomenon, there is an increasing trend of anthropogenically driven novel or introduced diseases occurring worldwide, with severe consequences to wildlife populations. Not all of these diseases are infectious. For example, the widespread use of the anti-inflammatory agent diclofenac acid in livestock on the Indian subcontinent resulted in near extirpation of vultures that scavenged on carcasses containing this drug. Subsequent research revealed that this compound is highly toxic to certain species of vulture, causing renal failure (Oaks *et al.* 2004).

Disease in wildlife populations is not considered a natural process when novel infectious agents such as *Geomyces destructans*, the cause of WNS, are transported and introduced into native ecosystems. When combined with other stressors on habitats and populations—including those described above as well as others such as pollutants and contaminants—disease in wildlife can have serious conservation and management consequences and raise concerns for wildlife managers and scientists.

Credit: USGS National Wildlife Health Center

At USGS' National Wildlife Health Center (NWHC), microbiology technician Doug Berndt studies a bacterial assay to determine the cause of a wildlife mortality event. Established in 1975, the NWHC identifies and tracks pathogens that lead to wildlife disease.

To help address wildlife disease concerns, the U.S. Geological Survey's National Wildlife Health Center (NWHC) in Madison, Wisconsin was founded in 1975. The Center provides technical assistance to identify, control, and prevent wildlife losses from diseases. It also conducts research to understand the impact of diseases on wildlife populations and to devise methods to more effectively manage these disease threats. Beginning with studies of duck plague (or duck viral enteritis) and avian botulism, which can cause large-scale losses of waterfowl, the NWHC has expanded its investigations to study a wide range of diseases including avian influenza, sylvatic plague, chronic wasting disease, and amphibian and coral diseases, among others. Of particular concern is the fact that since the 1990s the number of new diseases and their severity has increased exponentially. Furthermore, the diseases we are encountering are increasingly of concern for multiple sectors of society including, but not limited to, conservationists and wildlife managers, farmers and agricultural officials, public health officials, and all concerned citizens.

Some Disease-Driven Wildlife Population Declines

Species	Pathogen/Disease	Geographic Area
Amphibians (multiple)	Chytrid fungus	Worldwide
California condor	Lead poisoning	Western U.S.
Bighorn sheep	Pneumonia complex	Western U.S.
Harbor seal	Phocine distemper	United Kingdom
Tasmanian devil	Transmissible cancer	Australia
European red squirrel	Pox virus	United Kingdom
Asian vultures	Diclofenac acid	Indian subcontinent
Black-footed ferret	Sylvatic plague	Western U.S.
Desert tortoise	Respiratory disease	Western U.S.
Ethiopian wolf	Rabies	Central Ethiopia

Credit: USGS National Wildlife Health Center

The White-Nose Challenge

One focus of work at the NWHC, white-nose syndrome (WNS) offers a vivid case study of the consequences of an emerging disease on wildlife populations. (For a review, see Blehert *et al.* 2011). Biologists in New York first recognized WNS as a concern during the winter of 2007 when they identified several hibernacula with bats exhibiting unusual behavior such as flying during daytime, roosting in large numbers near entrances, and delayed or lack of response to human disturbance. Furthermore, bats exhibited visible white growth on their muzzles, ears, and wings, which gave the disease its name. Most disturbing were the large number of bat carcasses seen littering the floors of some surveyed caves.

The NWHC and partner organizations conducted detailed diagnostic investigations and identified the white growth as *Geomyces destructans*, a cold-loving fungus new to science. What was particularly unusual is that when researchers microscopically examined the skin of these infected bats, they discovered that this was not an infection like athlete's foot (i.e., a superficial, irritating, but rarely lethal condition). Instead, it was an invasive, destructive infection causing marked disruption to the wing membrane. Subsequent experimental work has confirmed that *G. destructans* is the sole causative agent for WNS (Lorch *et al.* 2011), and work is ongoing to determine the mechanism by which the fungus kills its host. In the meantime, in the four to five years since its detection, this disease has spread to 16 states and four Canadian provinces and caused the deaths of at least one million hibernating bats.

Epidemiologically, the disease is demonstrating the classic epidemic pattern of spread when a new infectious agent is introduced into an immunologically naïve population. The pathogen is able to exploit a new host, which is unable to fight the infection due to lack of previous exposure and immunity. In this case, bats may be uniquely susceptible to infection with *G. destructans* during hibernation, as studies with other hibernating mammals have shown that immunosuppression

is a natural function of hibernation. Additionally, underground environments in which bats hibernate are ideal for the growth of this cold-loving fungus.

The explosive spread of a disease has been seen many times before throughout history, from the decimation of Native American peoples after European explorers brought measles and smallpox to the New World, to the more recent emergence of West Nile virus in North America. So where did *G. destructans* come from? As it turns out, it might be modern European explorers who have brought this pathogen to North America. Recent studies have shown that *G. destructans* is commonly found on European bats, but without the associated clinical illness and mortality. Thus, the prevailing hypothesis is that European bats have co-existed with this fungus for many years, and that it was somehow accidentally transported to a cave in New York, possibly on the boots or equipment of a person who previously visited a European cave.

However it got here, its consequences extend far beyond the bats themselves. Because bats prey on numerous insect species, they provide important ecosystem services with implications for forests, agriculture, and human health. By some conservative estimates, bats contribute at least $3.7 billion dollars to the U.S. agricultural economy in insect control, and this estimate does not include the economic and environmental costs of increased use of pesticides that will be needed to suppress insect populations if the bats vanish (Boyles *et al.* 2011).

Prevention is the Cure

White-nose syndrome will not be the last emerging disease to affect wildlife. We therefore must do what we can to prevent subsequent diseases and mitigate their impacts. Disease outbreaks start locally, and wildlife managers are all too familiar with the need for rapid diagnosis and response. State and federal wildlife management agencies are responsible for managing the wildlife species within their geopolitical boundaries, and many are using expensive management and surveillance activities to detect and prevent the spread of diseases such as chronic wasting disease and bovine tuberculosis.

Disease prevention is obviously the best method to protect the health of wildlife populations, as once a disease has been introduced into a population it can be very difficult, if not impossible, to control or eradicate. The challenge is that although there are some wildlife disease management tools that can be effective, most are expensive, lack any assurance of success, and can be unpalatable to the general public. These include population reduction through culling, trapping, or other lethal means; use of vaccines or other biologics; and environmental modification such as habitat improvements, draining wetland impoundments, fencing, or changes in farming practices.

The Bigger Picture

How do we achieve the Herculean (or possibly Sisyphean) task of addressing or preventing emerging wildlife diseases? One approach involves the One Health concept. Recently revised, the idea originally came from the "One Medicine" concept, which was further developed in the 1980s by Calvin Schwabe of the University of California at Davis School of Veterinary Medicine. It was defined as the study of health and disease regardless of species differences between human and animals, outlining the common connections between veterinarians and physicians. Today this concept has taken on a greater relevance given the 21st-century threats to human, animal, and ecosystem health. The One Health movement recognizes that human, domestic animal, and wildlife health are all interconnected within the context of ecosystem or environmental health. It requires the collaborative effort of multiple disciplines—working locally, nationally, and globally—to attain optimal health for people, animals, and our environment, and it provides a theoretical model that can be used to develop solutions.

Credit: Fred Allendorf

Swabbing the skin of a boreal toad, USGS researcher Blake Hossack demonstrates how to detect the presence of amphibian chytrid fungus, a relatively recent disease that has spread to countries on six continents and led to several species extinctions.

In the field, a researcher with the USGS National Wildlife Health Center examines a duck for potential pathogens. At the NWHC, another researcher tests a crow for West Nile virus. Such efforts advance the center's mission to identify and prevent wildlife diseases.

Credit: USGS

Credit: USGS National Wildlife Health Center

With the One Health initiative as a guide, we endorse the creation of a collaborative North American Wildlife Health Strategy that would establish a framework to address the continent's most pressing wildlife health issues. This strategy should emphasize the importance of a collaborative approach to mitigate the impact of wildlife diseases and other stressors on wildlife, domestic animal, and human health, and could provide an operational framework by which institutions with a stake in wildlife health will cooperate and collaborate to achieve optimal outcomes for human, animal, and ecosystem health.

In addition, a new paradigm in disease surveillance and research is needed. The advent of new analytical models and bench assays will provide us with the mathematical and molecular tools to identify and anticipate threats to wildlife, understand the distribution, dynamics, and impacts of disease, and ultimately provide better information for guiding management decisions. Diagnosing and understanding disease agents and other factors that threaten the health of wildlife are critical first steps for maintaining healthy populations. Furthermore, developing tools to prioritize these threats is important for the development of effective management plans and allocation of precious resources, and would serve as the foundation for future research.

Future surveillance efforts should be based on risk analysis, investigation of potential exposure pathways, and improved knowledge of reservoirs of potential emerging pathogens. Among the more promising advances toward predicting and preventing emerging diseases:

- New molecular genetic sequencing techniques have opened up avenues for pathogen discovery not previously available.
- The application of spatially referenced databases such as GIS allows for risk assessments that can assist in targeting surveillance to high-risk populations and geographic locations.
- Integration and analysis of real-time data from a variety of sources—including human and animal health data with climatic, ecological, hydrological, geological, and socioeconomic data, among other sources—can help researchers better understand drivers of disease emergence and generate predictive models that help direct resources to geographic areas and populations (so-called hotspots) with the greatest need (Jones *et al.* 2008).

Understanding the effectiveness of current management tools and developing novel disease management schemes will be critical for protecting the health of wildlife populations as well as domestic animals and humans. Finally, increased global capacity to detect, diagnose, and provide robust and rapid responses to wildlife disease outbreaks and emerging diseases will also be essential. Clearly the fish and wildlife community bears a great responsibility to be ever watchful for the next emerging disease outbreak and work collaboratively to stop it in its tracks. This is a shared responsibility we all must willingly accept. There is no room for hesitation or for us to make mistakes. Too much is at stake. ■

This article has been reviewed by subject-matter experts.

For a full bibliography and additional resources, including a list of major wildlife health and disease centers and programs, go to *wildlife.org/twplogin*.

The Art of Chemical Capture

ADVANCES IN WILDLIFE CAPTURE PHARMACOLOGY

By Michael D. Kock, William R. Lance, and David A. Jessup

Credit: Satya Gautam Bhalla

Michael D. Kock (BVetMed, MRCVS, MPVM) is Senior Field Veterinarian for the Wildlife Conservation Society, based in the Western Cape, South Africa.

In the early 1960s, when Kariba Dam rose between Zambia and Zimbabwe backing up the Zambezi River to form Lake Kariba, thousands of wild animals—including antelope, black rhinoceros, carnivores, and reptiles—became stranded in a rapidly changing landscape. Conservationists soon began a wildlife salvage effort dubbed "Operation Noah," which included some of the first efforts to chemically immobilize wildlife using dart guns.

Those early efforts were well meaning, but many animals died, were injured, or just couldn't be caught—a situation that was dangerous for both the wildlife and their would-be captors. Author A. E. Harthoon described the early days of chemical capture in his 1976 book *Flying Syringe*, in which he stated: *"The successful handling of animals with drugs, capture in the wild, and restraint for various purposes can ultimately be performed successfully only by those who ... put the animal first; by those who are guided by a code, as medical doctors and veterinarians are subjected to a code; by those who have an awareness of the value of animal life; and by those who set their sights on the welfare of all animals with which they work ...."*

Credit: Mark Gocke, Wyoming Game and Fish Department

Darted from a helicopter in Wyoming, this female moose has been anesthetized with a combination of thiafentanil, azaperone, and medetomidine (TAM) so she can be assessed and radio-collared. The anesthesia has left this animal sternally recumbent, semi-conscious (with eyes open but unfocused), breathing well, and calm enough to resist struggling—signs that TAM is well-suited for use in wildlife.

Those words still ring true today for wildlife professionals who practice "capture and immobilization," which simply means rendering a wild animal unable to flee. This can be accomplished by physical methods (nets, traps, and ropes) or with chemicals—drugs that tranquilize, cause deep sedation, provide anesthesia, or yield a combination of the three (see chart on page 36).

Practitioners of chemical immobilization often refer to it as "knock down," and call the time from chemical darting to recumbancy "knock down time." However, multiple variables affect the safety and effectiveness of the procedure, including drug type, dosage, dart weight and placement, length of time for the dose to take effect, length of time the animal is incapacitated, and ability to reverse the effects of the drug so the animal can recover safely. These variables must be carefully assessed or animals may suffer serious injury during capture such as "capture myopathy"—severe muscle damage and often death due to the combined effects of exertion, acidosis, hyperthermia, electrolyte imbalance, and fear during capture and handling.

This and other problems came into play during "Operation Noah" at Lake Kariba, conducted at a time when the drugs used for chemical capture were very limited. Nicotine and succinylcholine, for example, were primitive and often highly toxic. Etorphine and acepromazine were better, but for some species and at some doses, injected animals would become excited and run to the point of exhaustion or death. Others suffered severe respiratory depression when the drugs' effects peaked. In North America at that time, similar problems were occurring with deer, moose, bears, mountain lions, and other species.

Today, half a century later, the drugs and delivery devices used for chemical immobilization have advanced tremendously. We have new pharmaceutical drugs, more-effective combinations, and

delivery tools designed to perform a host of specialized tasks on virtually all species and sizes of animals. Among the most powerful pharmaceuticals ever developed, the new-generation drugs are critical tools for professionals involved in wildlife health, disease, and management.

The Challenges of the Past

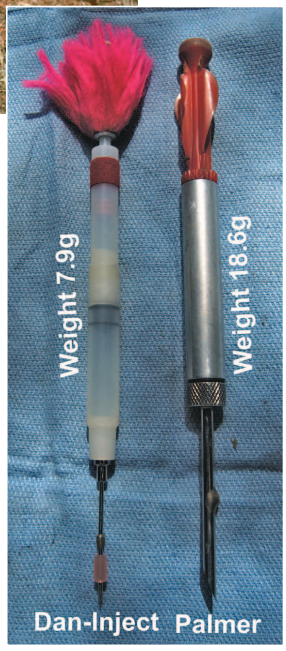
The development of new drugs and drug combinations were spurred by the problems experienced in the field. Paralytic drugs like succinylcholine, for example, provided animals no relief from fear, pain, or stress of capture. In addition, they were not reversible and the safety margin was low: A 10 to 15 percent dosage miscalculation on the low side could fail to immobilize, and on the high side could cause suffocation due to paralysis of respiratory muscles. Drugs that could provide anesthesia, deep sleep, and maybe even short-term amnesia were needed.

Some improvement came with development of the narcotic etorphine in the late 1960s. When combined with the tranquilizer acepromazine, it could provide anesthesia and pain relief. It was also readily reversible. Etorphine became the workhorse for capture of large African species like elephants and rhinos, but it had its drawbacks. It was very expensive, and the form available in North America was so dilute that very large, heavy darts had to be used. It was also only available to those with a special high-level federal government license.

Other next-generation drugs also had pros and cons. The dissociative anesthetic phencyclidine, for example, could be combined with a tranquilizer and used on most big carnivores and primates, yet it could take half a day or more to wear off and it had high abuse potential as a street drug (sold as PCP or "angel dust"). Likewise, the alpha adrenergic sedative xylazine could make some domestic stock or zoo hoofstock sleepy and even immobile, but it was ineffective on truly wild animals and it could depress breathing, keep animals down for hours, and lead to serious side effects such as bloat and regurgitation. Finally ketamine with a tranquilizer or sedative would work effectively on many species, but required darts proportionally the size of harpoons.

Wildlife managers needed drugs that were concentrated enough that they could be delivered in a 1-, 2-, or at most 3-cc dart. Larger darts were just too heavy (which could cause injury to the animal), too erratic in flight, and too limited in accuracy at distance. Managers also needed drugs that would act as quickly as five minutes or less so that darted animals wouldn't have time to outdistance humans, take cover, or disappear. Quick down times would also reduce muscular exertion, capture myopathy, high body temperature, and potential entanglement or injury.

Credit: Michael D. Kock



Credit: Michael D. Kock

A black rhino in Namibia falls on its back, immobilized by a high dose of the narcotic etorphine and tranquilizer azaperone mixed with hyaluronidase (a spreading factor) delivered in a robust Cap-Chur dart (see Palmer version at far right). Heavy steel and aluminum darts like the Cap-Chur can pierce thick skin and deliver drugs with an explosive charge. Newer, lighter darts (like the Dan-Inject, at left) can hold the same liquid volume but weigh half as much and have smaller needles, thus they strike more gently and prevent injury to thinner-skinned species.

Rapid induction of anesthesia would be of little value, however, if heart rate, blood pressure, and respiration rate and volume were compromised. If an immobilization drug or combination lasted for many hours and could not be easily reversed, free-ranging prey species like deer and antelope would be vulnerable to predators or scavengers. These problems have been solved by modern drugs such as the narcotic thiafentanil and/or the sedative medetomidine. When either of these is combined with the right tranquilizer or dissociative anesthetic, the combination can provide the almost magical properties of quick induction, balanced effects, and quicker and clean reversal.

Gifts of Modern Alchemy

A major advancement came in the 1980s with development of the first non-narcotic reversible wildlife immobilization combination. It was a mixture of

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Pharmacology 101

A glossary of basic chemical immobilization drugs

The drugs used for chemical immobilization of wildlife are from five general classes: dissociative anesthetics, sedatives (and sedative reversals), narcotics (and narcotic reversals), tranquilizers, and paralytics. Each class of drugs acts at different nerve synapses, blocking or potentiating natural neurotransmitter chemicals. What follows is a brief rundown of a few common drugs in each class, with notes on the decade they became available for wildlife use, potency, and duration of action. Potency numbers of 5x or 10x, for example, indicate a potency of five or ten times that of the least potent drug in the class.

Dissociative Anesthetics

Dissociative anesthetics override several neurotransmitters that communicate between the brain and body, rendering animals unconscious and relatively insensitive to pain or stress. They are also called psychotomimetic (psychosis mimicking) drugs, or cyclohexamines because of their common chemical structure.

Drug	Decade	Relative Potency	Duration of Average Dose
ketamine	1970s-80s	1	45 minutes to 1 hour
tiletamine	1980s-90s	5x	1.5 to 3 hours
phencyclidine	1970s	10x	2 to 12 hours

Sedatives

Sedatives render animals sleepy and uncoordinated, but usually not immobile or anesthetized if used alone. The three sedatives listed below work primarily on the alpha-2 adrenergic receptors in the brain and body and therefore are also called alpha-2 agonists. These drugs can have negative respiratory, cardiovascular, digestive, and other side effects. The newer and more potent drugs have fewer side effects and can be more readily reversed.

Drug	Decade	Relative Potency	Duration of Average Dose
xylazine	1970s-80s	1	The duration of effect of these drugs
detomidine	1990s	2x	is highly dependent on dosage
medetomidine	1990s	10x	and species sensitivity.

Sedative Reversals

Alpha-2 antagonist drugs displace alpha-2 agonist sedatives from receptor sites in the brain, thereby reversing the effects of sedation. As sedative reversal drugs have evolved, both potency and receptor site specificity have increased, and less species variation is seen.

Drug	Decade	Relative Potency	Duration of Average Dose
yohimbine	1980s	1	These reversal drugs act within minutes
tolazoline	1990s	3-5x	if given intravenously; they last longer but are
atipamezole	1990s	10x	less predictable if given intramuscularly.

Narcotics

These are traditionally drugs that produce sleep. They bind to various types of opiate receptors in the brain and body, rendering an animal immobile and unconscious if dosed correctly. However, narcotics alone do not usually produce balanced anesthesia. They can be reversed by narcotic antagonist drugs that occupy opiate receptor sites but produce less or no narcotic effect.

Drug	Decade	Relative Potency	Duration of Average Dose
butorphanol	1990s-2000s	1	30-45 minutes
etorphine	1960s	10x	1.5 to 2 hours
thiafentanil	2000s	30-40x	30 to 45 minutes
carfentanil	1980s	40-50x	several hours to half a day

Narcotic Reversals

Of the three narcotic reversal drugs listed below, the first two are pure antagonists while the third is a weak agonist with antagonist properties. Given intravenously these drugs all act within 30 seconds to a few minutes—a bit slower if given intramuscularly—but have variable durations of action (half-life) in an animal's body. Diprenorphine is not recommended for reversal of any narcotic except etorphine.

Drug	Decade	Relative Potency	Duration of Average Dose
naloxone	1980s	1	an hour or two
naltrexone	1980s	1	many hours to a day
diprenorphine	1970s	10x	a few hours

Tranquilizers

These drugs produce calmness, may cause a lack of coordination, and reduce fear or sensitivity to stress. They are not able to immobilize animals if used alone but may balance undesirable side effects of anesthetic, narcotic, or sedative drugs, and they facilitate transport and holding of wild animals. There are several different families of tranquilizers.

Butyrophenones: azaperone, haloperidol
Benzodiazepines: diazepam, zolazepam, midazolam
Phenothiazines: promazine, propionyl promazine, acepromazine
Long-acting: zuclopenthixol (lasts 3-4 days) and perphenazine (a week to 10 days)

Paralytics

Once commonly used in the 1960s and '70s, paralytics—such as succinylcholine and gallemine triethiodide—block the action of acetylcholine, which transmits messages between nerves and muscles, leaving muscles flaccid or somewhat tonic. Some are depolarizing, meaning they cannot be reversed and must be metabolized for effects to wear off. Others are non-depolarizing. Because paralytics have a low safety margin and produce no anesthesia or loss of sensitivity to pain, stress, or fear, they are now considered inhumane for general use.

the anesthetic ketamine and the sedative xylazine (KX), both concentrated to higher strengths than commercially available. As the ketamine wore off, wildlife managers could then administer yohimbine to reverse the xylazine, and the animal would get up and walk off. Soon there was a KX combination for most North American species.

A further improvement arrived in the 1990s when Telazol®—a commercial combination of tiletamine and zolazepam—became available, a much better alternative for a wide variety of species than any KX combination. Soon thereafter, even Telazol was vastly improved upon by combining ketamine or Telazol with medetomidine (which is at least 10 times more potent than xylazine), then reversing with much more effective alpha adrenergic antagonist drugs like tolazoline or atipamezole. The medetomidine-based combinations were more applicable to hooved animals and allowed most medium-sized species to be immobilized with a 2- or 3-cc dart.

Those non-narcotic combinations didn't work well for many larger African species, however. To effectively immobilize species such as black rhino, researchers developed simple yet significant advances. They increased the etorphine dose and augmented the combination with hyaluronidase to increase the drugs' absorption rates for a more rapid knock down, thereby reducing running, temperature increase, and oxygen debt. The higher doses, however, required more careful monitoring of the animal and a greater knowledge of the intricacies of the procedure, requirements best filled by veterinarians.

During the 1990s, etorphine became somewhat scarce due to lack of the raw material or finished product in some parts of the world. A newer narcotic, carfentanil, then in research in Belgium, proved to be a bit more potent and soon replaced many of etorphine's uses in wildlife in North America. But, carfentanil was very long acting, outlasting the available reversals naloxone and diprenorphine. Animals could therefore renarcotize and sometimes die or be killed a day after immobilization. The solution: Naltrexone, a pure narcotic antagonist, proved to have active metabolites in most species that could provide reliable reversal for more than 24 hours.

The narcotic thiafentanil oxalate came to light as a result of the need for a very rapid, safe drug to anesthetize people, particularly children. It was shown to be effective in elk, and a consortium of veterinarians from the U.S. and South Africa confirmed that it could also revolutionize field procedures in more difficult-to-capture African species like impala, waterbuck, kudu, Cape buffalo, giraffe, and elephant. Later, in the right combinations, thiafentanil also proved effective in eland, nyala, gemsbok, and other elusive species. Its primary advantages are very

Credit: Lonnie Pace and UC Davis Wildlife Health Center

Biologist Mark Ehlbroch prepares to blow-dart a dose of Telazol (a mix of tiletamine and zolazepam) into a mountain lion captured for genetic and disease testing during a study of the cats in southern California. Blow pipes work well for small darts at short distances.

Credit: Colorado Division of Wildlife

Lisa Wolfe (at left) and other biologists with the Colorado Division of Wildlife work on bighorn sheep immobilized with BAM (butorphanol, azaperone, and medetomidine). Safe and reversible with minimal side effects, this anesthetic combination has become widely used on cervids and bovids in North America.

rapid induction (two to four minutes commonly), greatly reduced potential for capture myopathy, improved respiratory and cardiac function, and complete reversal with naltrexone. And because of its potency it can be administered in darts as small as 1 to 2 cc.

By 2000, wildlife researchers began to experiment with combinations of up to three drugs from various families including narcotics, alpha-adrenergic sedatives, dissociative anesthetics, and tranquilizers. Combination of varying ratios of medetomidine or xylazine with carfentanil, for example, reduced the initial excitation, running, and muscular rigidity commonly seen in large hoofstock. And azaperone appeared to result in smoother inductions and improved baseline heart and respiratory rates.

One such combination called BAM (a mix of butorphanol, azaperone and medetomidine), was initially developed in the search for a safer, reversible, small-volume injectable anesthetic combination that didn't require the use of the more dangerous and restricted potent narcotics like etorphine and carfentanil. BAM is now becoming the combination of choice for field use in North American cervids and bovids. In fact, its advantages and uses have been so remarkable that it was the first anesthetic combination for wildlife granted a U.S. patent.

Credit: Michael D. Kock

Darted with the BAM combination, a hippo rests sedately as veterinarians approach with blindfold and jaw strap to safely secure the animal. This drug combination allows hippos to remain in water and retain the dive reflex–a key to their survival during sedation–reflecting one of the great recent achievements in safe capture.

Historically, mortality due to the stresses and injuries of capture, transport, and holding of certain species, especially antelope in Africa, were unacceptably high, sometimes hitting 50 percent or higher. The development of long-acting tranquilizers (LATs) for calming wildlife was actually pioneered by the use of tranquilizers in the human psychiatric medical field and the need to sedate or tranquilize for longer periods patients who wouldn't cooperate. On the animal health side, the ability to tranquilize a hyper-excited antelope or a rhino in confinement or a holding corral for three to four days was revolutionary.

Special Cases: Africa's Giants

Certain species can present special challenges, and chief among them are the large mammals of Africa. For example, some narcotics (such as etorphine, carfentanil, or thiafentanil) affect white rhinos totally differently than black rhinos. In white rhinos, muscle rigidity, tremors, respiratory depression, and hypoxia occur and can quickly become life threatening. Use of pulse oximetery in the late 1990s revealed just how hypoxic white rhinos were under combinations of etorphine and detomidine and azaperone. Researchers turned to the use of partial or low-dose narcotic antagonists given soon after immobilization to counteract the respiratory depressive effects, improve oxygenation, and produce more balanced anesthesia without waking the animal up. In the last ten years, the use of butorphanol, an opioid agonist/antagonist, has become the "wonder" drug for rhinos. Besides reversing some of the more severe respiratory depression caused by the potent narcotics, butorphanol can be combined with a variety of other drugs and used in a variety of different African species.

Few African species have provided greater challenges to professionals involved in the capture and care of wild animals than the hippopotamus. They are bad tempered and aggressive, massive in size with teeth to match, and live in water much of the time, an added challenge for would-be captors. Hippos once needed to be darted and immobilized on dry land so they couldn't reach the water, where they would likely drown as the drug took effect. Even if the hippo could be kept away

from water, there was a high risk of mortality because they have a "dive reflex" and can hold their breath until they die. The reason: their baroreceptors are not sensitive to increasing carbon dioxide in their blood—a physiologic adaptation in most land species that forces them to breath as they approach unconsciousness. Because narcotics and the onset of anesthesia can trigger this dive reflex, the standard advice to veterinarians was, "Do not anesthetize a hippo or it will die." About 90 percent of the time that was true.

If there ever was need for clever alchemy it was in regards to the hippo. Fortunately, in the early 2000s, along came BAM, the magical mix of butorphanol, azaperone, and medetomidine noted earlier. In South Africa, we also add the tranquilizer midazolam (M) to create a four-part combination called BAMM, which allows darted hippos to become sedated and immobilized and still continue to breath, despite retaining the dive reflex. Once the drug combination has taken effect, the capture team can secure the beast in the water and haul it to the shore. If the animal begins to get too light under that combination, a fifth drug, ketamine, may be used for a quick "top up." Hippo anesthesia is not perfect yet, but both BAM and BAMM are a significant improvement over past options. Midazolam even has an amnesic effect, at least in humans, so the bad memories of capture may not persist. Bravo to the brave alchemists! (To read a recent *Africa Geographic* article on hippo capture, go to *wildlife.org/twplogin*).

Progress, But Room to Grow

Alternatives to darting for physical capture, particularly net gunning, have been developed and refined but are not without their own limitations. Major advances have also been made in dart gun design, manufacture, and use. The weights and impact energies of darts have been roughly cut in half, greatly reducing potential for injury to wildlife. As noted, the volume of drugs needed has also been greatly reduced. Professional training in the use of wildlife anesthetic and immobilization drugs, dart guns, and other capture equipment has become widely available and is required in many states and countries. In addition, a number of excellent books and field manuals are now available.

In the early days of wildlife capture it was common, and even considered acceptable, if as much as 10 percent of the animals darted died or were seriously injured by darts or capture problems. As capture methods, drugs, and anesthesia have advanced over the years, the welfare of wildlife has been improved and injury and losses have dropped to less than 1 percent in most circumstances. That's a remarkable achievement in technology that saves animal lives, facilitates research, and improves the science of wildlife management and conservation. Those of us involved in wildlife capture can only look forward to the new advancements that lie ahead. ■

Credit: Michael D. Kock

After sedation, a bull elephant rests peacefully enough to allow a veterinarian to attach pulse oximetry leads (which monitor blood oxygen levels) to the third eyelid. Modern combinations of anesthetics, sedatives, narcotics, and reversal agents can act quickly and last long enough for wildlife professionals to do their work then oversee a safe, complete recovery–the ultimate goal of capture pharmacology.

For a full bibliography, a list of recent books about wildlife immobilization, and tips on training in chemical immobilization, go to *wildlife.org/twplogin*.

The Lethal Jump from Wildlife to Humans

WHY ZOONOTIC DISEASES ARE ON THE RISE

By Michael J. Yabsley, John R. Fischer, and Sonia M. Hernandez

Credit: Jessica Gonynor

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In March 2011, a resident of Deschutes County, Oregon, died of hantavirus, a disease primarily carried by rodents. County health officials said it was the 16th confirmed case of hantavirus in Oregon since 1993 (*The Columbian*). This is one small example of a growing global problem involving the rise of zoonoses—diseases for which a pathogen can be naturally transmitted from domestic animals or wildlife to humans.

Currently, 75 percent of all emerging human diseases are of animal origin, mostly from wildlife (Taylor *et al.* 2001). Transmission of diseases from animals to humans is not new, but anthropogenic changes in recent decades have dramatically increased the number of emerging zoonoses. These changes include habitat modification and human encroachment, privatization of wildlife, climate changes, and global travel and transportation. These in turn can affect biodiversity, species composition, and human population demographics, which can then alter animal ecology or interactions with people or other animals.

Often combinations of several such changes are needed to facilitate the emergence of a novel zoonotic disease. The recent emergence of a coronavirus associated with severe acute respiratory syndrome (SARS), for example, has been linked to the capture and co-housing of civet cats and other wildlife species in live-animal markets in China, many of which were amplifying hosts for SARS-coronavirus (Cheng *et al.* 2007). Its rapid spread to North America and around the world resulted from high-speed airline transportation.

Zoonoses respect no political or economic barriers. The United States, for example, is the world's largest importer of wildlife products, yet has minimal pathogen surveillance at points of entry. A new study reveals that wildlife products confiscated at several international airports in the U.S. included parts of rodents and several primate species such as baboon, chimpanzee, and green monkey. Pathogen screening identified retroviruses and herpes viruses in the samples—demonstrating that illegal bush meat brought into the U.S. could aid the spread of potentially zoonotic pathogens (Smith *et al.* 2012). A major concern is that emerging zoonoses can evolve into strictly human-to-human transmitted pathogens, as occurred with human immunodeficiency virus (HIV) and human T-lymphotropic virus (HTLV)—both of which were initially transmitted to people from primates (Smith *et al.* 2012).

Transmission of zoonoses occurs through numerous routes including direct transmission by ingestion, inhalation, or contact with the pathogen through the bite or scratch of an infected animal. Indirect routes include ingestion of contaminated food or water,

Credit: Graham Hickling

The tiny nymph of the *Ixodes scapularis* tick is the primary vector for the bacterium *Borrelia burgdorferi*. Typically passed from mice to ticks to humans, this bacterium is the causative agent of Lyme disease. If left untreated, the disease can lead to chronic neurological problems.

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contact with an infected vector, or contact with infected equipment such as traps or cages. With so many potential causes, consequences, and routes of transmission, zoonotic diseases epitomize the concept of One Health, which recognizes that wildlife, domestic animal, human, and environmental health are all interconnected. A few brief examples show just how tightly woven that connection can be.

Shifts in Community Composition

The epidemiology of several zoonoses can be tied directly to changes in habitat and/or changes in community composition. Lyme disease in the Northeastern U.S., for example, offers one of the best illustrations of how community vertebrate diversity and habitat change alter zoonotic disease epidemiology.

The causative agent of Lyme disease is the bacterium *Borrelia burgdorferi*, which is maintained in rodent reservoirs and transmitted by *Ixodid* ticks. Nymphs of this tick species can use a wide range of mammals, birds, and reptiles as blood sources. The white-footed deer mouse is the most competent and common small-mammal host for *B. burgdorferi* in old, recovering Northeastern farms and forest communities. The highest rates of exposure to Lyme disease occur in communities with greater populations of deer mice and lower populations of other mammals and bird hosts.

Clearly, the greater the diversity of small mammals and birds (the blood-source species for tick nymphs), the less the ticks need to rely on potentially infected rodents. In keeping with this "dilution hypothesis," the prevalence of *B. burgdorferi* in ticks decreases dramatically in areas that have a relatively intact ecosystem with a high diversity of hosts. However, habitat changes that favor an increase in highly-competent rodent reservoir numbers can lead to increased infection rates in ticks and increased risk of human infection (LoGiudice *et al.* 2003).

Shifts in Climate

Changes in temperature, precipitation, and other climate-related phenomena are also important factors that can influence the transmission of pathogens. Because many zoonotic pathogens are insect vector-borne, their ecology will be altered when changes in climate impact the range, number, and habitat of vectors. Each vector and host species will be impacted differently, such that some geographic regions may experience an increased risk of vector-borne zoonotic diseases while other regions may see a decrease in risk.

Studies on the impacts of climate change are difficult to conduct and interpret due to the possible multiple-level impacts climate change would have on habitats, vertebrate and invertebrate hosts within those habitats, and the pathogens they harbor. Still, researchers increasingly suggest links between climate patterns and zoonotic emergence.

In Sweden, for example, the incidence of tick-borne encephalitis (TBE) has risen dramatically since the 1980s, a period corresponding with generally milder climate. One study found that milder winters led to earlier springs and extended falls, conditions

Credit: Brian W.J. Mahy/CDC

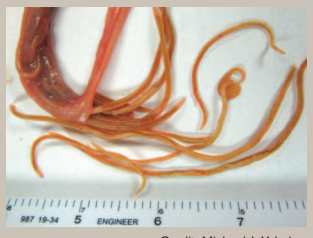
In the Democratic Republic of the Congo (DRC), researchers test a primate to see if it is infected with monkeypox, a zoonotic disease passed from primate and rodent species. The first human cases of monkeypox were identified in the DRC in 1970; a second outbreak took place there in 1996 and 1997. Monkeypox can cause a maculopapular rash on the body, as shown on the palms of a patient (below) from Lodja in the DRC. In Africa, this viral disease has killed between 1 and 10 percent of those who have contracted it.

Credit: Brian W.J. Mahy/CDC

A Zoonotic Sampler

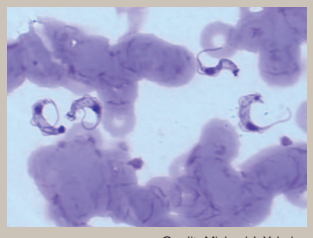
Worldwide, roughly 75 percent of human pathogens are zoonotic and can pass from animals to humans, with new diseases emerging at an increasingly rapid pace. Below is a sampling of some of these diseases and their causative agents, hosts, and routes of transmission, followed by tips on preventing contraction or spread of zoonotic disease.

Disease	Causative agent	Transmission route
Hantavirus pulmonary syndrome	Hantaviruses	Inhalation of virus shed in the waste of *Peromyscus* species and other rodents
West Nile virus	*Flavivirus - West Nile virus*	Bites from mosquitoes that have fed on infected birds
Rabies	*Lyssavirus - Rabies virus*	A bite from an infected mammal
Bartonellosis	Bacteria of the genus *Bartonella*	Bites and scratches from various mammals; transmission by ectoparasites (skin parasites) suspected
Typhus plague	*Rickettsia typhi* and *R. felis* bacteria *Yersinia pestis* bacteria	Fleas feeding on infected rodents (both) and opossums (typhus)
Undulant fever	Bacteria of the genus *Brucella*	Contact with tissues, blood, urine, vaginal discharges, or fetuses of infected animals such as deer and swine
Tularemia	*Francisella tularensis* bacteria	Inhalation or ingestion of bacteria from infected rodents and lagomorphs; also, bites from infected flies or ticks
Leptospirosis	Bacteria of the genus *Leptospira*	Invasion of skin by bacteria passed in the urine of various mammals; contact with contaminated water, food, or soil
Salmonellosis	Bacteria of the genus *Salmonella*	Ingestion of food or water contaminated with mammal and bird feces
Visceral and ocular larval migrans	Roundworms of the genus *Baylisascaris*	Ingestion of larvated eggs present in raccoon, skunk, and bear feces
Giardiasis	Parasites of the genus *Giardia*	Ingestion of food or water contaminated with bird and mammal feces containing oocysts of certain protists; ingestion of undercooked infected meat
Cryptosporidiosis Toxoplasmosis	Parasites of the genus *Cryptosporidium* *Toxoplasma gondii* parasite	Ingestion of food or water contaminated with bird and mammal feces containing oocysts of certain protists; ingestion of undercooked infected meat
Trichinosis/Trichinellosis	Parasites of the genus *Trichinella*	Ingestion of the undercooked infected meat of mammals
Echinococcosis or Hydatid disease	*Echinococcus multilocularis* and *E. granulosus* tapeworms	Ingestion of food or water contaminated with eggs from canid and felid feces; canids and felids can contract the parasite by eating infected rodents or cervids
Histoplasmosis	*Histoplasma capsulatum* fungus	Inhalation of infective spores found in bird and bat feces
Tick-borne illnesses Powassan virus Lyme disease Relapsing fever borreliosis Ehrlichiosis Rickettsiosis (American boutonneuse fever) Rickettsiosis (Rocky Mountain spotted fever)	 *Flavivirus - Powassan virus* *Borrelia burgdorferi* bacterium *Borrelia hermsii* and rarely other *Borrelia* bacteria *Ehrlichia chaffeensis*, *E. ewingii* bacteria *R. parkeri* bacteria *Rickettsia rickettsi*	All from bites from ticks that have fed on infected reservoirs (such as white-tailed deer, rodents, or other small mammals); tick species include *Ixodes scapularis*, *I. pacificus*, *Ornithodoros* species, *Amblyomma americanum*, *A. maculatum*, and *Dermacentor variabilis*



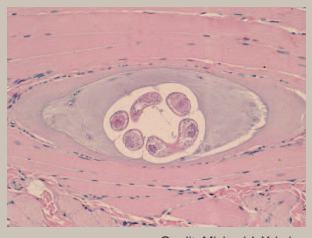
Credit: Michael J. Yabsley

Baylisascaris procyonis, causes larval migrans



Credit: Michael J. Yabsley

Trypomastigotes of *Trypanosoma cruzi*, causes Chagas disease



Credit: Michael J. Yabsley

Trichinella spiralis in muscle, causes trichinosis

Credit: J.P. Bond

Amblyomma americanum tick, can transmit *Ehrlichia* and other pathogens

An Ounce of Prevention

Wildlife professionals and others can take basic precautions to minimize their risk of contracting a zoonotic disease. These include wearing basic protective gear such as gloves when handling potentially infected wildlife, blood, or feces. Masks can help prevent inhalation of particulates from dried feces, blood, or urine, which may contain parasites, viral agents, or bacteria. Using appropriate equipment to restrain wildlife can help prevent scratches and bites. Likewise, repellents and protective clothing can prevent bites from mosquitoes, fleas, lice, and ticks. To prevent ingestion of disease-causing agents, wildlife professionals should avoid potentially contaminated food and water, cook harvested meat properly, and never feed potentially infected wildlife carcasses to other animals.

that favor greater tick abundance (Lindgren and Gustafson 2001). In addition, droughts and floods related to shifts in climate have been linked to outbreaks of malaria in South America, Asia, and Africa (Githeko *et al.* 2000). Such weather anomalies are only expected to increase.

Artificial Crowding

Zoonoses have also been associated with factors that lead to increased wildlife interactions with other animals and people, such as artificial feeding and baiting or privatization of wildlife for personal or consumptive use. In cases where hunters establish bait stations to attract white-tailed deer, for example, deer congregate and feed nose to nose, easily passing any infection from one to another.

Extensive artificial feeding in Michigan, for example, has led to the establishment of bovine tuberculosis in free-ranging white-tailed deer, making the disease nearly impossible to limit or eradicate. Its resurgence in Michigan has subsequently led to spill-back to domestic cattle and even transmission to a hunter who field-dressed an infected deer (Wilkins *et al.* 2008). Other examples of zoonotic risks associated with the intentional or unintentional feeding of wildlife include rabies from raccoons and salmonellosis from birds.

When Wildlife Become Pets

Zoonotic diseases—such as toxoplasmosis contracted from cats, salmonellosis from reptiles, or lymphocytic choriomeningitis virus from rodents—have always been a risk for individuals who keep pets. However, the taste for more-exotic pets has increased the risk of zoonotic infection. In 2003, for example, the U.S. saw its first outbreak of monkeypox virus in humans, who contracted the illness from prairie dogs obtained through a wholesale pet store (Guarner *et al.* 2004). These prairie dogs had been in contact with infected Gambian pouched rats imported from West Africa for the exotic pet trade. Likewise, in Texas in 2002, prairie dogs captured for the pet trade tested positive for tularemia, a zoonotic disease caused by the bacterium *Francisella tularensis*. Several people were exposed to the pathogen and at least one person became infected, the first known case of prairie dog-to-human tularemia transmission (Avashia *et al.* 2004).

Although it is illegal in many states to keep native wildlife as pets, raccoons have also earned a spot as exotic pets in the U.S., as well as in parts of Europe and Japan. Unfortunately, raccoons are commonly infected with an intestinal roundworm (*Baylisascaris procyonis*) that can cause fatal larva migrans in a wide range of animals and people (Murray and Kazacos 2004). Because *B. procyonis* does not produce clinical signs in raccoons, the risk is not readily apparent to owners. Kinkajous—a species related to raccoons and also kept as pets—likewise have been found to harbor this potentially lethal zoonotic parasite (Kazacos *et al.* 2011). All such examples further highlight the risks associated with private ownership of wildlife.

Credit: Michael J. Yabsley

University of Georgia Ph.D. student Mark Ruder conducts a staged field necropsy to demonstrate the appropriate protective gear—including gloves, goggles, mask, and outerwear—to prevent contact with or inhalation of potentially dangerous infectious agents.

A Call for Caution

For many known zoonoses, simple precautions can prevent infections or minimize risk of disease (see chart). Wildlife biologists, hunters, trappers, hikers, birders, or anyone who may come into contact with wildlife should familiarize themselves with precautions to avoid infection. These can be as simple as wearing protective gear such as masks or gloves, avoiding contact with animals' bodily fluids, wearing repellent to prevent tick or mosquito bites, or disinfecting equipment that animals have touched.

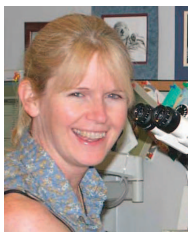
Everyone who comes into contact with wildlife must be vigilent regarding safety, as highlighted by the recent reports of fatal infections of hantavirus, sylvatic plague, and other ills. It is a privilege to encounter or work with wildlife in nature, but we must be aware of and prepare for the risks, or we ourselves may contribute to the spread of disease. ■

For a full bibliography and additional resources—including access to USAID's PREDICT project that tracks emerging zoonotic diseases—go to *wildlife.org/twplogin*.

When Marine Ecosystems Fall Ill

HARMFUL ALGAL BLOOMS AND MARINE BIOTOXINS

By Melissa Miller, Raphael Kudela, and David A. Jessup

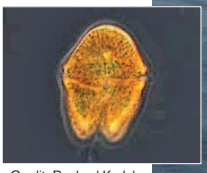


Credit: CDFG

Melissa Miller (DVM, Ph.D.) is a senior wildlife veterinarian with the California Department of Fish and Game's Office of Spill Protection and Response.

In November 2007, an unexplained crisis began to unfold in California's Monterey Bay. There, hundreds of dead and dying seabirds began to wash ashore with a slimy greenish-yellow crust on their feathers. All live birds showed signs of severe hypothermia. The strandings occurred during a "red tide"—a relatively common event in which colored algae bloom, sometimes in massive quantities, and can produce dangerous toxins that sicken or kill marine life. Yet the strandings in Monterey Bay were like nothing any of us had previously seen.

Teams from the Monterey SPCA, Native Animal Rescue, and the California Department of Fish and Game (CDFG) Office of Spill Prevention and Response gathered the stranded birds, which comprised about 14 different species including grebes (*Aechmophorus* spp.), surf scoters (*Melanitta perspicillata*), northern fulmars (*Fulmarus glacialis*), and loons (*Gavia* spp.). They were brought to CDFG's Marine Wildlife Veterinary Care and Research Center in Santa Cruz, where each was examined, blood sampled, weighed, and banded. They were given supportive care—warmth, tube feeding to provide fluids and calories, light detergent washing to remove the crust, rinsing and drying to restore waterproofing. Eventually all the birds were reintroduced to seawater, where they could begin to feed on fish and krill. Through these efforts, about 60 percent of treated birds were saved and released back into the wild.



Credit: Raphael Kudela

Credit: Melissa Miller

Credit: Mike Harris/CDFG

A distinctive line demarks the dark waters of a red tide (at left of image) moving ashore in Monterey Bay in 2007. Caused by a bloom of *Akashiwo sanguinea* (see inset), the event stranded more than 500 seabirds, coating their feathers with a yellowish crust (as seen on the dead loon above). Scientists scrambled to learn why this harmful algal bloom (or HAB) led many birds to die of hypothermia.

While giving priority to caring for live birds, we also began to examine those that had died. Postmortem examinations revealed no signs of infection or toxicity—which one would expect if the "red tide" was due to a toxic harmful algal bloom (HAB). Many of the birds were thin, which is common after completing the fall migration, but all affected birds had a surface slime or dried, crusty material on their feathers, often with a distinct "bathtub ring" distribution. During investigations of the stranding event at nearby Natural Bridges State Beach, we gleaned our first clues about the origins of this slimy material: The ocean just offshore was the color of strong tea due to a large "red tide," and copious yellow foam lined area beaches, especially in areas with strong wave action. From the cliffs above, we could see that many seabirds were resting and feeding in the areas where foam coated the water's surface. Could it be that the red tide, the foam, and the slime on the birds had the same origin and was a previously unknown type of HAB?

Examination of seawater revealed that the reddish brown discoloration was caused by massive numbers of the dinoflagellate *Akashiwo sanguinea* and contained small proteins with soap-like qualities called microsporine-like amino acids (MAAs).

MAAs are normally produced by *A. sanguinea* and other algae as protection from harmful solar radiation. Only once before, during a coral bleaching event, had there been any implication that MAAs and *A. sanguinea* could be harmful. We now know, however, that when these soapy MAA compounds escape from ruptured *A. sanguinea* cells they may act as powerful wetting agents. Tests of the slimy material coating the feathers of stranded birds revealed high MAA concentrations, while feathers of unaffected birds had no MAAs (Jessup *et al.* 2009). The MAAs proved to be the critical piece of the puzzle that linked the *A. sanguinea* red tide, the surface foam, and the slimed seabirds, all evidence of previously unrecognized impacts to wildlife.

To continue the investigation, we dipped normal bird feathers in clean seawater and compared the degree of feather wetting to feathers dipped in discolored foamy seawater. This simple experiment demonstrated that feather contact with the surface foam caused feathers to lose water repellency and likely thermal insulating properties (Jessup *et al.* 2009). Subsequent tests using cultures of *A. sanguinea* grown in artificial sea water in the lab confirmed these findings.

In the end, more than 500 seabirds became stranded due to this HAB event, and more than 200 died, demonstrating—for the first time—that widespread wildlife deaths due to coastal bloom events can occur in the absence of toxin production (Jessup *et al.* 2009). The seabird strandings and deaths were caused by the wetting agent properties of *A. sanguinea* on feathers, leading to a profound loss of thermal insulation and buoyancy, similar to the effects of oil spills on feathers—the first documented case of its kind.

A short time later, in 2009, a very large *A. sanguinea* bloom occurred along the coasts of Washington and Oregon. Huge masses of foam piled up on area beaches and up to 10,000 seabirds were affected or died. Similar to the 2007 event in Monterey Bay, MAAs were found on the feathers of stranded birds, but no toxin was identified. Possible environmental contributors to this massive bloom were elevated ocean temperatures and ocean conditions that directed nutrient plumes from the Columbia River along the coast, thereby allowing them to "feed" the red tide and keeping it trapped along the shoreline, where high wave action produced abundant foam.

Credit: P. CHILTON/Coastal Observation and Seabird Survey Team

Draped in thick sea foam, a loon lies dying, one of some 10,000 marine birds stranded along the coasts of Washington and Oregon in 2009 after an *Akashiwo sanguinea* bloom. The dinoflagellates released proteins with detergent properties that created the foam and destroyed waterproofing in the birds' feathers, leading to hypothermia.

Systems Out of Balance

Think of the near shore ocean as a giant living soup, full of organisms. These range in size from large (fish, birds, marine mammals, and kelp), to small (crustaceans, bivalves, and sea weed), to tiny (krill, bacteria, viruses, and single-celled algae such as diatoms and dinoflagellates). All these organisms are part of the food chain and tend to remain in fairly balanced proportions to one another. Sometimes, however, the balance is disturbed: The levels of nutrients, currents, and/or sunlight can change such that one organism greatly increases in mass while many of the others die or become scarce. The increasing frequency and severity of coastal HABs may indicate periodic regional disturbance in ecological processes.

In the case of Monterey Bay, weather phenomena (warm autumn conditions), lack of upwelling from the deep ocean, nutrient inputs from land, and slow counterclockwise recirculation of nutrient-laden water favored an explosion of *A. sanguinea,* which soon dominated the surface ocean, crowding out the other members of the living soup, and resulting in "red tide" conditions. This produced hundreds of individual bird "patients." At the population level, as much as 10 percent of the wintering Northern fulmar population was affected along with significant numbers of grebes, a declining species. Beyond the impacts on wildlife, Monterey Bay itself could be viewed as a patient showing signs of being a "sick ecosystem" (Rapport 1988).

Co-author Affiliations

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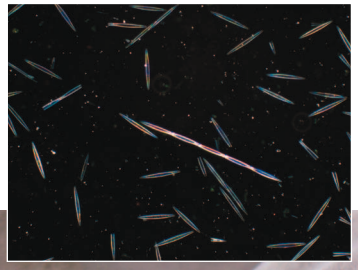
Across the nation and around the world, investigations of prior HAB events has generated a long list of toxins—including ciguatoxin, saxitoxins, brevetoxins, domoic acid, okadaic acid, and microcystins—that have significantly impacted many marine and estuarian species. The following exploration of two of these—domoic acid and microcystins—conveys just how potent, complex, and devastating these HAB-related killers can be.

Domoic Acid Attacks the Nerves

Pseudo-nitzschia is a genus of diatoms that produce the neurotoxin domoic acid (DA). Though a normal part of planktonic flora, *Pseudo-nitzschia* species are frequently implicated in HABs, especially along the Pacific coast of North America (Work *et al.* 1993). During blooms in California, DA has caused illness and death in brown pelicans (*Pelecanus occidentalis*), cormorants (*Phalacrocorax* spp.), sea lions (*Zalophus californianus*) and many other marine species (Work *et al.* 1993, Scholin *et al.* 2000).

Common signs of DA intoxication include depression, tremors, seizures, and uncontrolled scratching movements. It has been detected in the prey of affected species as well, confirming that toxicity is amplified through food chains and poses threats to both marine animal and human health (Scholin *et al.* 2000).

Credit: Peter Miller



Credit: Peter Wallerstein/Marine Animal Rescue

A sea lion suffers from ingesting domoic acid, a neurotoxin from the diatom *Pseudo-nitzschia australis* (inset). This toxin affects the hippocampus and causes seizures, somnolence, and uncontrolled scratching at the throat and head.

For example, DA has caused "amnesic shellfish poisoning" in humans in Canada and the U.S. (Trainer *et al.* 2012). The first cases were in New Brunswick in 1987, where three people died and many others suffered long-term neurological disease as a result of consuming mussels containing domoic acid from *Pseudo-nitzchia* diatoms.

Prey items consumed by sea otters (*Enhydra lutris nereis*) in California include clams, mussels, and worms, all of which are potent domoic acid accumulators (Goldberg 2003). In 2003, sea otter illnesses and deaths associated with ingestion of DA-contaminated prey was of sufficient magnitude that federal agencies declared a "marine mammal unusual mortality event," a first for Southern sea otters.

Pseudo-nitzschia ssp. and DA-related HABs often quickly cause stranding or death in species such as sea lions that eat prey like anchovies that feed directly on the harmful diatoms at the ocean surface. DA mortality in sea otters, however, often takes longer to occur—after toxin-laden algal cells and detritus settle deeper in the water column, where they are taken up by invertebrates such as clams and worms that sea otters prefer to eat.

In addition to acute poisoning, DA can also cause more chronic effects. Our research has revealed strong links between the development of cardiac disease in sea otters and prior DA exposure (Kreuder *et al.* 2005), suggesting that this toxin may injure the heart and other organs. Sea otters that survive acute exposure may later die as a result of heart disease, brain damage, or other complications. Therefore, when viewed as a whole, the acute and more chronic effects of HABs may jeopardize long-term recovery of depleted sea otter populations (Kreuder *et al.* 2003, 2005).

Human actions on land can enhance the frequency and intensity of DA poisoning and other HAB events. For example, urea is a nitrogen waste product of mammals and also a popular fertilizer applied to lawns and fields. When urea runs off into seawater, it can enhance both the growth of *Pseudo-nitzschia* diatoms and their DA production. In Monterey Bay, scientists have documented temporal and spatial associations between urea nitrogen plumes in coastal marine waters (presumably originating from terrestrial sources) and HAB events (Kudela *et al.* 2008). In addition, DA

concentrations increase dramatically in the vicinity of river plumes during "first flush" (first rainfall in the autumn) events in Monterey. There is a striking correlation between measured urea concentrations, domoic acid, otter mortalities associated with DA, and riverine inputs in Monterey. Nutrient loading of the coastal ocean may originate from both human activity and from seasonal upwelling events when cold, nutrient-enriched water from the deep ocean replaces warm, nutrient-poor water at the ocean's surface (Anderson *et al.* 2008, Kudela *et al.* 2008, Lane *et al.* 2009). So *Pseudo-nitzschia* diatoms and the DA they produce—as well as the severity, frequency, and toxicity of bloom events—may be strongly influenced by nutrients originating from both terrestrial sources and natural sources.

The Menace of Microcystin

Cyanobacteria are ancient and primitive organisms (initially misidentified as algae or so-called blue-green algae) that have a worldwide distribution. The more frequent occurrence of such blooms has become an emerging global health issue (Guo 2007), particularly because, for humans, these freshwater bloom events are an important and possibly under-recognized cause of human illness (Falconer 1996, Paerl 2008, O'Neil *et al.* 2012). They can be equally threatening to wildlife. In 2003, for example, hundreds of thousands of salmon died in the Klamath River, at least partially from cyanobacterial toxins.

Large-scale cyanobacterial blooms—which commonly occur in fresh and estuarine water—produce potent and environmentally persistent cyanotoxins that can be a thousand times more potent than DA. One of these lethal toxins, microcystin, is highly toxic to almost all living organisms and can cause death from acute liver failure in mammals as soon as two days post-exposure. Its most common source is *Microcystis aeruginosa*, a cyanobacterium that thrives in warm, nutrient-enriched, stagnant water (Zehnder and Gorham 1960, Davis *et al.* 2009, Jacoby *et al.* 2000, Welker and Steinberg 2000).

Many human activities—including damming rivers, removing water for agriculture, and discharging nutrient-rich runoff—can create ideal conditions for explosive *M. aeruginosa* blooms, which are increasing in frequency. Over the last decade, for example, massive blooms have been occurring almost yearly in the Great Lakes (Vanderploeg *et al.* 2001).

Credit: Stori Oates/CDFG

A dead American coot floats in California's Pinto Lake, where a bloom of cyanobacteria (sometimes also called blue-green algae) generated lethal loads of microcystin. Highly toxic to wildlife, microcystin can lead to acute liver failure in mammals just two days after exposure.

In 2009, our research team had its own run-in with microcystins. Suspecting that they might be a cause of liver failure in sea otters found dead near the mouth of California's Pajaro River, we sent a colleague to take water samples from a small lake that feeds into the river. She described the lake as "gnarly green." Laboratory analysis later showed that the surface lake water had more than a million times the safe drinking water limits for microcystin toxins. Decreasing levels of microcystin were traced to just above where the Pajaro River empties into Monterey Bay, the site where the otters with liver failure were found.

To further confirm the source of intoxication, we added surface water from the polluted lake to tanks of sea water containing shellfish. Both *Microcystis* and its toxins were readily taken up by crabs, clams, and mussels in the tanks, and the toxins remained at significant levels in the shellfish for weeks. This and other work confirming the deaths of Southern sea otters due to microcystin extends the negative impacts of cyanobacteria and their toxins to include nearshore marine ecosystems and federally threatened marine mammal species (Miller *et al.* 2010).

Battling the Blooms

Across many lines of investigation into the causes of Southern sea otter illness and death, we have consistently found a strong and statistically robust link between the deaths and exposure to high freshwater

Credit: Robert Ketley

Skimming thick green gunk from the surface of a California lake, researcher Stori Oates takes a water sample that will be tested for microcystin toxins. Usually occurring in fresh or estuarine waters, large cyanobacteria blooms like this are becoming more common, fueled by warming temperatures and nutrient-rich runoff, and posing potential health risks to humans–as a sign at a Kansas lake suggests (below).

Credit: Jennifer L. Graham/USGS

runoff and/or more urbanized coastlines (Miller *et al.* 2006, Conrad *et al.* 2006, Miller *et al.* 2009, Jessup and Miller 2012). Due to the otters' critical role in maintaining the kelp forest ecosystem through consumption of kelp-grazing invertebrates, the disappearance of sea otters from this complex and highly productive ecosystem would result in a cascade of secondary effects in addition to the loss of one of our nation's most visible and admired marine mammals. Potential negative impacts include reduced biodiversity of kelp forest ecosystems, reduced coastal storm surge protection, and reduced carbon sequestration by kelp forest ecosystems. Sea otters also play an important role as sentinels for potential human health risks, as both sea otters and humans depend on the health of coastal ecosystems and the safety of marine foods for their survival (Jessup *et al.* 2007).

Freshwater and marine harmful algal blooms are an escalating problem worldwide. According to one report, "In the United States, only a few regions were previously affected by HABs, but now virtually every coastal state has reported major blooms, frequently involving multiple species. Similar trends are reported for freshwater HABs in inland states" (Anderson *et al.* 2008). Between 1970 and 1995, HABs increased tenfold in China while urea loading increased fivefold (Anderson *et al.* 2008). The increasing frequency and global distribution of HABs worldwide may be due in part to large-scale ecological disturbances and global climate change. A recent analysis suggests that a 2° C change in average ocean temperatures would more than double the number of days when we might expect toxic *Alexandrium* dinoflagellate species—which cause paralytic shellfish poisoning—to bloom in the Pacific Northwest (Moore *et al.* 2008).

Understanding the underlying causes of marine wildlife mortality can stimulate mitigation of coastal pollution by nutrients and other possible drivers of HAB events. We as a society must actively address pollution that impairs the recovery of charismatic species like marine mammals and birds, not only because of their beauty, but also to retain their ecosystem services. Although HAB events have the potential to jeopardize our own future and the future of marine ecosystems, marine wildlife managers, veterinarians, and health professionals have the opportunity to diagnose and prescribe treatment for sick wildlife, wildlife populations, and the ecosystems upon which we all depend. ■

For a full bibliography and additional information about harmful algal blooms and their impacts on wildlife, go to *wildlife.org/twplogin*.

Sylvatic Plague Vaccine

COMBATING PLAGUE IN PRAIRIE DOGS AND BLACK-FOOTED FERRETS

By Tonie E. Rocke and Rachel C. Abbott

Credit: Susan Smith/NWHC

Tonie E. Rocke, Ph.D. is an epizootiologist with the USGS National Wildlife Health Center in Madison, Wisconsin.

Credit: Judy Williamson/NWHC

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After achieving promising results in laboratory trials, researchers at the USGS National Wildlife Health Center (NWHC) and University of Wisconsin at Madison will soon begin field testing a new oral vaccine for sylvatic plague, a devastating disease affecting prairie dogs and other mammals, particularly the endangered black-footed ferret. Our team has developed and is currently registering a sylvatic plague vaccine (SPV) that uses raccoon poxvirus (RCN) to express two key antigens of the *Yersinia pestis* bacterium, the causative agent of plague.

The vaccine will be distributed in prairie grasslands in the form of peanut butter flavored baits. Consumption of even a single vaccine-laden bait can protect prairie dogs from plague infection for as long as nine months, the longest time period tested so far. If all goes as well as expected, wildlife managers will have a powerful new tool to combat the unpredictable and devastating plague outbreaks that threaten western wildlife and habitats.

An Old Scourge

Though this breakthrough is new, the plague itself has been a long-time thorn in the life of western landscapes. The plague-causing *Y. pestis* bacterium was inadvertently introduced into North America in the early 1900s (Gage and Kosoy 2005). Ships arriving in San Francisco from plague-affected areas in Asia probably carried infected rats and fleas, the vectors for the disease. It quickly spread to native rodents, thereby establishing a sylvatic cycle and making plague endemic throughout the western states.

Because *Y. pestis* is foreign to the evolutionary history of North American mammals, many species have little or no immunity and succumb quickly to the disease. Infection of an animal by *Y. pestis* can range from subclinical bacteremia to clinical disease with lymphadenitis and internal abscess formation to sudden death from overwhelming sepsis. Prairie dogs are particularly susceptible to outbreaks of plague, possibly due to the close contact that occurs within their colonies. They suffer mortality rates of 90

Credit: USGS National Wildlife Health Center

Credit: U.S. Fish and Wildlife Service

All species of prairie dogs—including the threatened Utah prairie dog (above left)—are susceptible to sylvatic plague, which is causing widespread population losses. These losses threaten the survival of endangered black-footed ferrets (above right), which prey upon prairie dogs and use their burrows for shelter. A new sylvatic plague vaccine may be able to reduce infections in the wild.

percent or more during outbreaks, often resulting in local or even regional extinctions (Cully and Williams 2001). Infected prairie dogs can die within three to four days, and colonies can become eerily quiet within weeks. Along with habitat loss, poisoning, and recreational shooting, plague has contributed to significant population declines in prairie dogs. By some estimates, prairie dogs now occupy only 1 to 2 percent of their former range (Proctor *et al.* 2006).

Black-footed ferrets are also highly susceptible to plague, contracting the disease by ingestion of infected prey or via bites from infected fleas (Williams *et al.* 1994, Rocke *et al.* 2004, 2006, Godbey *et al.* 2006). Even if they manage to avoid plague exposure, ferret populations can suffer if plague destroys prairie dog populations because ferrets rely almost exclusively on prairie dogs for prey and use their burrows for shelter. Conservation of prairie dogs and black-footed ferrets therefore largely depends on our ability to control plague's impact on these species.

Currently, plague occurs throughout the ranges of white-tailed, Gunnison's, and Utah prairie dogs and in the western two-thirds of the range of black-tailed prairie dogs. Thus, potential plague-free sites for reintroduction of captive-bred black-footed ferrets are limited. In addition, plague appears to exist in an enzootic state in some prairie dog colonies, decreasing the survival rates of both prairie dogs and black-footed ferrets even in the absence of plague epizootics (Matchett *et al.* 2010, Biggins *et al.* 2010). Although flea-control insecticides such as deltamethrin are useful in stopping plague outbreaks in prairie dog colonies, dusting of burrows is labor intensive and time consuming, and has detrimental effects on other insects and arthropods such as ants, spiders, ticks, and beetles (Cully *et al.* 2006).

Efforts to Develop a Vaccine

Seeking an alternative to pesticides as protection against plague, researchers at NWHC began testing an injectable vaccine in black-footed ferrets that was based on proteins of *Y. pestis* virulence factors F1 and V (an F1-V fusion protein), originally developed for human use (Powell *et al.* 2005). In our initial studies with older animals, 69 to 85 percent of vaccinated ferrets survived infection with virulent *Y. pestis* injected subcutaneously to mimic flea bites (Rocke *et al.* 2004, 2006). Subsequently, vaccination of ferret kits at 60 and 120 days of age fully protected all of them against infection after they had ingested *Y. pestis*-infected mice (Rocke *et al.* 2008a). The vaccinated kits developed significant antibody titers to F1 and V antigens that persisted for at least three years, indicating the potential for long-lasting immunity (Rocke *et al.* 2008a).

A field study conducted in Montana also demonstrated that the injectable F1-V fusion protein vaccine provided significant plague protection for ferrets in the wild, even when the disease was occurring at enzootic levels (Matchett *et al.* 2010). Since 2008, all captive-born ferrets have been vaccinated using this F1-V vaccine before being released into the wild. However, vaccination of wild ferrets in the field is difficult and time consuming and does nothing to protect their prey base from the disease. Protection of prairie dogs is therefore vital for effective and long-term prevention of plague in ferrets.

Credit: Randall L. Griebel/USFS

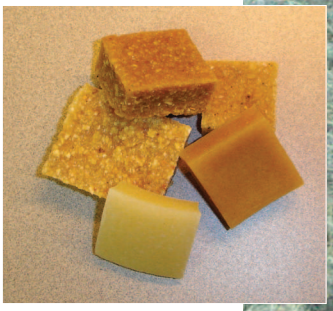
A prairie dog lies dead from plague, caused by the *Yersinia pestis* bacterium, which is usually transmitted by infected fleas. Plague can be spread as infected fleas leave the carcass in search of new hosts or are transported to other areas by scavengers, such as coyotes and foxes. Plague can kill within four days and has led to local and even regional extinctions of prairie dogs.

For prevention of plague in prairie dogs, we focused on oral vaccine using a poxvirus as a vector for *Y. pestis* antigens (Osorio *et al.* 2003, Mencher *et al.* 2004, Rocke *et al.* 2008b, 2010a). Because poxviruses (such as vaccinia virus and raccoon poxvirus) have a predilection for mucosal tissues and are highly resistant to environmental degradation, they are ideal vectors for oral vaccines for animals. Once an animal eats the vaccine-laden bait, the virus replicates in the animal's mouth and activates the immune system. Antibodies against the vaccine antigens are then produced and act to protect the animal against infection by the disease agent.

Since the early 1990s, for example, carnivore rabies in the U.S. and Europe has been controlled using an oral rabies vaccine (ORV), which utilizes vaccinia virus (a poxvirus) genetically altered to express rabies glycoprotein (Brochier *et al.* 1996). The vaccine is distributed in oral baits with an attractant for carnivores.

Using the ORV program as a model, we developed the similar SPV vaccine in collaboration with scientists at the University of Wisconsin-Madison. The first vaccine we tested in prairie dogs used raccoon poxvirus (RCN) to express F1 antigen of *Y. pestis*. The RCN-F1 vaccine was incorporated into sweet potato baits that prairie dogs willingly ate (Mencher *et al.* 2004, Rocke *et al.* 2008b). Approximately 50 percent of prairie dogs that ate two of these baits survived experimental infection with *Y. pestis* injected subcutaneously. The vaccinated prairie dogs developed significant anti-F1 antibody titers after vaccination, with higher titers in surviving prairie dogs.

In an effort to increase the effectiveness of the vaccine, we also incorporated the V gene into the viral vector. We used a truncated version of the gene, designated V307, to avoid the immune impairment associated with the full V protein (Rocke *et al.* 2010a, b). Both RCN-F1 and RCN-V307 vaccines were incorporated into sweet potato baits. We then compared survival rates of prairie dogs orally vaccinated with the RCN-F1/RCN-V307 combination to rates in prairie dogs inoculated by injection with the F1-V vaccine used in ferrets (Rocke *et al.* 2010a). Although antibody titers against F1 and V were higher in the animals vaccinated by injection with the F1-V vaccine than in the animals that ingested the RCN-F1/RCN-V307 vaccine, 94 percent of the animals vaccinated with the RCN-F1/RCN-V307 vaccine survived compared to the 58 percent of animals vaccinated with the F1-V protein vaccine (Rocke *et al.* 2010a). Thus, the oral RCN-F1/RCN-V307 vaccine provided nearly full protection against injections of virulent *Y. pestis*. The current vaccine that will be registered for field use consists of a single raccoon poxvirus containing both genes (RCN-F1-V307). With that, 60 to 85 percent of prairie dogs survived challenge by *Y. pestis* even after consuming baits containing this vaccine only one time (Rocke, unpublished data).



Credit: USGS National Wildlife Health Center

Small baits (below) flavored with peanut butter contain the oral sylvatic plague vaccine, made from a raccoon poxvirus that serves as a vector for *Y. pestis* antigens. Once ingested, the virus triggers protective antibodies that fight disease. Biomarkers, giving baits a red color (right), are used to help determine how many prairie dogs have eaten baits.

Credit: Dan Tripp/Colorado Parks and Wildlife

Distribution in the Field

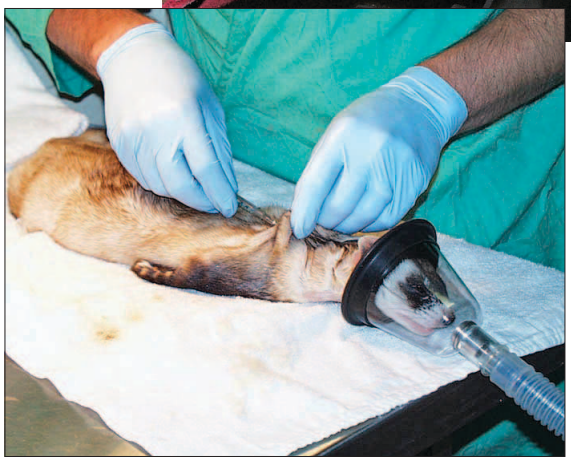
For field delivery, we have selected an effective bait matrix flavored with peanut butter that is highly palatable to prairie dogs and stable for the vaccine. Preliminary field studies in Utah using baits without vaccine have shown rates of uptake by wild prairie dogs greater than 90 percent within three to four days of application (Rocke, unpublished data). The biomarker Rhodamine B is incorporated into the baits to easily determine bait uptake by both target and non-target animals upon examination of a plucked whisker under ultraviolet light (Fernandez and Rocke 2011). Ultimately, we'll form the bait into a size and shape that facilitates distribution by plane or vehicle. Ongoing field work will help establish the optimal time for baiting different prairie dog species and determine which methods and density of bait distribution will maximize bait uptake.

The SPV vaccine is currently being registered with the USDA Center for Veterinary Biologics. Experimental field trials to confirm its safety and efficacy in free-ranging animals will begin this summer and follow a three-tiered approach. In the first phase, we'll test the biosafety and dynamics of bait uptake in the field through a series of short-term field trials in collaboration with Colorado Parks and Wildlife. The specific objectives are to measure bait uptake by prairie dogs and non-target animals under field conditions, to assess safety—for example, to test for any vaccine-associated pathology such as pox lesions, primarily in non-target animals—and to evaluate the immunological response of prairie dogs.

The second phase will entail a coordinated collection of complex and biologically relevant data from paired vaccine and placebo-treated field sites within the

ranges of all prairie dog species to assess vaccine efficacy on a wide geographic scale. Prairie dog survival at study sites will be monitored for several years, and survival rates at vaccine and placebo treated sites will be compared to assess vaccine performance, presumably in the face of both enzootic and epizootic plague. This phase will be a success if plague occurrence is reduced or overall prairie dog (and ferret) survival or population performance is higher at sites with vaccine application compared to paired control sites.

Assuming successful completion of Phase I and Phase II, Phase III will be designed to facilitate implementation of SPV as a tool to manage plague in prairie dogs. Initially, vaccine-laden baits will be distributed in prairie dog colonies where black-footed ferrets reside in order to preserve their prey and decrease the source of plague infection. If SPV is successful in eliminating or curtailing plague epizootics in prairie dog colonies, establishment and maintenance of ferret recovery sites should be enhanced.



Credit: USGS National Wildlife Health Center

At the USGS National Wildlife Health Center in Madison, Wisconsin, a biologist takes a blood sample from a prairie dog (above) to measure levels of antibodies generated in response to vaccine antigens. Another NWHC biologist injects a black-footed ferret (left) with an anti-plague vaccine containing the F1-V fusion protein. In prairie dogs, the injectable F1-V vaccine is less effective than oral vaccines containing raccoon poxvirus, which protect up to 85 percent of prairie dogs exposed to plague.

Broader Benefits to Ecosystems

In addition to benefitting ferrets, conservation of prairie dogs has important consequences for many other species of animals in the grassland ecosystem. Beyond black-footed ferrets, species such as swift fox and raptors rely heavily upon prairie dogs for prey. Burrowing owls and other animals use prairie dog burrows for shelter and protection from predators. And animals such as mountain plover and mice benefit from the effects of prairie dog grazing, which generates nutritious young grasses and nesting sites (Kotliar *et al.* 1999). Thus, plague control in prairie dogs would help preserve myriad dependent species.

Use of SPV might also ensure survival of sufficient numbers of threatened Utah prairie dogs, enabling managers to balance land-use needs with prairie dog conservation in targeted areas. By reducing the risk of plague, delisting of the species may become possible, and restrictions on development and agricultural usage of land could be lifted. Management of plague through SPV use in other prairie dog species could also prevent serious population declines that could lead to future listing as threatened.

Use of SPV to control plague in prairie dogs may also have public health benefits or help ease public fear of plague exposure. Although most human cases in the U.S. are associated with ground squirrels, people have become infected by contact with infected prairie dogs or their fleas (Craven *et al.* 1993). SPV could be used as an alternative management tool in areas where people encounter prairie dogs, such as cities, recreational areas, military property, or tribal lands.

Clearly, controlling plague outbreaks is a vital concern for ongoing ferret recovery programs and conservation efforts for both ferrets and prairie dogs. If SPV lives up to its potential to alter plague dynamics in the grassland ecosystem, ferret recovery, prairie dog conservation, and public health will all reap the benefits. ■

For a full bibliography and additional photos related to this article, go to *wildlife.org/twplogin*.

The Role of Policy in Fighting Disease

By Charlotte Weaver

Credit: TWS

Charlotte Weaver was Policy Intern at The Wildlife Society from July to December 2011.

In February of 2011, Senator Frank Lautenberg (D-NJ) introduced Senate bill 357, the Wildlife Disease Emergency Act of 2011. Prompted by the emergence of white-nose syndrome (WNS) in bats in New Jersey in 2009, the act—which is still in committee—would authorize the Secretary of the Interior to identify and declare wildlife disease emergencies, establish a fund to coordinate rapid responses to those emergencies, and address harmful wildlife diseases with actions coordinated among federal, state, tribal, and local agencies and non-governmental organizations. The power to declare an emergency would help clear the way for appropriate funding and rapid action.

Lautenberg's bill is just one of many signs that policymakers are beginning to take the issue of wildlife diseases—and the threats they pose to wildlife, livestock, ecosystems, and human health—very seriously. "We must ensure that the Fish and Wildlife Service and environmental scientists have every tool available to them as they fight devastating wildlife diseases like white-nose syndrome," Lautenberg said.

Even in this down economy, lawmakers have put some money toward the cause. The conference report for the most recent appropriations bill passed by Congress in late 2011 directs the U.S. Fish and Wildlife Service (FWS) to "fund white-nose syndrome research and response activities at no less than $4,000,000." The report also directs the Bureau of Land Management and U.S. Forest Service to prioritize research related to WNS in bats and the inventory and monitoring of bat resources on bureau- and service-administered lands, respectively.

In another effort to address concerns about the nation's ability to combat wildlife diseases, Representative Alcee Hastings (D-FL) introduced the Wildlife Veterinarians Employment and Training Act (Wildlife VET Act, H.R. 3886). The bill, supported by The Wildlife Society, aims to expand the workforce of veterinarians specialized in the care and conservation of wild animals and their ecosystems by addressing challenges such as the high cost of education, low pay, and limited job opportunities that create a shortage of wildlife veterinarians. That shortage is acute, as many state and federal agencies are unable to address routine veterinary functions and pandemics simultaneously. The Government Accountability Office (GAO) found that the FWS, for example, has only four veterinarians on its staff, far too few to effectively monitor diseases in wildlife.

Agencies Take Action

Many wildlife disease surveillance and monitoring centers —such as those at the U.S. Geological Survey (USGS) and the U.S. Department of Agriculture (USDA)—have been formed to link and track wildlife disease outbreaks across the nation and the world. The USGS National Wildlife Health Center, for example, provides a database of wildlife disease occurrences for many diseases, including WNS, avian influenza, and sylvatic plague. Monitoring combines disease data in one location to identify spreading trends and areas in need of precautionary measures. One way to leverage such efforts is to foster collaboration and communication between USGS and USDA so that information and ideas are not stove-piped but shared among all relevant organizations. Networks to share information regarding disease outbreaks and data help unite the effort to observe and respond proactively to emergent diseases.

The Wildlife Society is also actively involved in the issue of wildlife disease. Its Wildlife Diseases Working Group, for example, serves to increase awareness and understanding of wildlife diseases and works to improve and pass wildlife disease legislation. The Society itself is also drafting a formal position on wildlife diseases, which should be formalized later this year.

Currently there is no national policy or office dedicated to effectively coordinating wildlife disease response throughout local, state, tribal, and federal governments. There should be: Emerging wildlife disease is an increasing threat to maintaining sustainable fish and wildlife populations and healthy ecosystem functions that support us—providing clean water, pollination, seed dispersal, healthy game, and a valuable sanctuary to escape the stress of everyday life. ■