Surveillance of Wildlife Diseases: Lessons from the West Nile Virus Outbreak

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ABSTRACT The West Nile virus outbreak of 1999 revealed many weaknesses in this country’s ability to respond to disease threats that cross species lines. There were issues of poor communication among human, domestic animal, and wildlife health agencies that delayed diagnosis; a lack of diagnostic capacity of wildlife agencies at the state level; the exclusion of captive wildlife from any surveillance efforts; an inability to visualize the geospatial relationship between the human and avian outbreaks in a timely manner; and marked disparities of funding levels across agencies. Wildlife has played an important role in recent emerging infectious diseases, and it is clear that a One Health approach will be necessary to respond to future threats. The question is, are we any better prepared to recognize and respond to a wildlife-related emerging infectious disease than we were 14 years ago? Have the lessons of WNV been learned?

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INTRODUCTION

In 1998, before the West Nile virus (WNV), monkeypox, and severe acute respiratory syndrome outbreaks, Childs et al. (1) made the prescient observation that “multidisciplinary teams of ecologists, mammalogists, ornithologists, and entomologists, as well as physicians and epidemiologists, may be required for successful investigations of zoonoses.” This was proven to be true in 1999 when the lack of a One Health approach significantly delayed recognition of WNV. This was due to a number of factors including:

- Poor communication across the human and animal sectors
- Weak diagnostic capacity at a state department of natural resources
- Exclusion of captive wildlife from any surveillance efforts
- Lack of timely recognition of the geospatial link between the bird and human outbreaks

Given that “60.3% of emerging infectious disease (EID) events are caused by zoonotic pathogens” (2), that “the number of EID events caused by pathogens originating in wildlife has increased significantly with time” (2), and that “wild animals seem to be involved in the epidemiology of most zoonoses and serve as major reservoirs for transmission of zoonotic agents to domestic animals and humans” (2), there is a certain urgency to taking a more integrated approach to zoonotic threats, especially regarding wildlife. Wildlife EIDs not only pose a threat to human health but pose a substantial threat to the conservation of global biodiversity (3). But if another WNV-like event were to occur tomorrow, would the recognition and response time differ from that of 14 years ago? The question is, have the issues that caused us to miss early warning of WNV been addressed? Have the lessons of WNV been learned?

Certainly progress has been made. Communication across sectors has improved since 1999. There is increased awareness of “the need for closer collaboration between the veterinary profession, wildlife specialists, and public health personnel” (4). There is now recognition of the role that “veterinarians and other wildlife specialists can play in surveillance, control, and prevention of emerging zoonoses” (6) and that cooperation between human and animal health professionals is “imperative to strengthen the evidence base that will allow for rational use of animal data in public health decision-making” (7). Great strides in cooperation and collaboration were made between the Centers for Disease Control and Prevention (CDC), U.S. Department of Agriculture (USDA), and U.S. Geological Survey (USGS) once WNV was diagnosed. The USGS National Wildlife Health Center (NWHC) established strong ties with CDC’s Division of Vector-Borne Infectious Diseases (now the Division of Vector-Borne Diseases in the National Center for Emerging and Zoonotic Infectious Diseases). The CDC developed a remarkable integrated database called ArboNET that included data on people, horses, mosquitoes, and zoo species and included data from the USDA and maps provided by USGS. The CDC even funded a novel public-private partnership with the zoo community that resulted in a national surveillance program of captive wildlife.

Has similar progress been made in the free-ranging wildlife component of the equation? What is the status of wildlife disease surveillance in the United States? If wildlife can serve as sentinels for emerging zoonoses, what guarantees do we have that future sentinels will be diagnosed in a timely manner? In early June 1999, hundreds of crows died and were submitted to the New York State Department of Environmental Conservation (NYSDEC) for evaluation. This was almost 2.5 months in advance of any human morbidity or mortality associated with WNV. Why did it take so long to get a diagnosis in the wild birds? There are two reasons. First, high case fatalities are not unusual in wild populations and often do not trigger the same sense of alarm as they would in human or domestic animal populations. Wildlife personnel manage populations of animals and are not necessarily sensitive to emerging events in individual animals. Second, while “human and domestic animal health are agency mandates at most major levels of government (i.e., municipal, state, federal, provincial) and have direct budget allocations for disease program development and operations, and often are able to obtain supplemental funding when disease emergencies arise,” until recently “wildlife disease was not a mandated activity of natural resources agencies and decisions to allocate funds and develop capabilities for this type of activity are internal administrative decisions” (8). As a result, not all states have well-equipped laboratories that deal with wildlife on a regular basis, and many animal facilities that see wildlife specimens may not be prepared to effectively diagnose disease. The NYSDEC was limited in its diagnostic capabilities. The combination of these factors resulted in significant delay in recognition of a sentinel event.

If “efficient surveillance is dependent upon a laboratory system that is capable of identifying and
characterizing the pathogens in question" (9), what is the status of diagnostic capabilities for free-ranging wildlife in the United States today? Has anything changed since the WNV outbreak of 1999? Are state wildlife labs better prepared to respond to emerging zoonotic threats? If not, where can they turn? “To increase the capability of recognizing zoonoses with a wildlife reservoir, better national surveillance systems for humans and animals are needed, as well as better national and international integration and sharing of information from such systems” (10). This implies that there must be equal diagnostic and surveillance capabilities across species, and such is not the case.

In his 2006 book Disease Emergence and Resurgence, Milton Friend, former director of the USGS NWHC in Madison, WI, comprehensively detailed the associations between wildlife and emerging diseases. Unfortunately, he also noted that although this association is evident, “the true integration of the wildlife component in approaches towards disease emergence remains elusive” and that “the broader community of disease investigators and health care professionals has largely pursued a separatist approach for human, domestic animal, and wildlife rather than embracing the periodically proposed concept of ‘one medicine’” (8).

Dr. Friend further analyzed the similarities and disparities of disease programs and found that

In general, response to disease in humans and domestic animals is guided by well-defined areas of responsibility, established regulations and protocols, existing organizational structures, pre-established communication processes, and other components that provide a reasonably cohesive infrastructure for carrying out this important activity. The situation for wildlife is quite often different. Responses are generally ad hoc and are guided by biologists within the agency managing the site with the disease event (3) and funding for disease diagnosis is usually limited. Unfortunately, this is because the collective resources allocated for wildlife disease investigations within North America by natural resources agencies are only a small percentage of the total resources allocated for the Centers for Disease Control and Prevention (CDC) of the U.S. Department of Health and Human Services (HHS) to combat human disease and those allocated to the U.S. Department of Agriculture (USDA) to combat domestic animal disease. Only a few wildlife disease programs have adequate facilities and are insufficiently staffed or integrated with other programs to provide analyses and the spectrum of expertise required to meet the demands of rapid, accurate diagnoses for guiding disease response efforts. This is especially true and important when unfamiliar diseases are encountered. (9)

If a One Health approach to zoonotic disease surveillance is to be made a reality, these inequities and coverage gaps will need to be addressed.

**WILDLIFE DISEASE SURVEILLANCE AT THE STATE LEVEL**

Responsibility for most wildlife rests with the state fish and wildlife agencies that are entrusted to conserve and manage native wildlife within their geographic boundaries. Recently, more states have taken an increasing interest in implementing programs and have integrated fish and wildlife health as part of basic management and research programs.

In 2007, recognizing the need for greater capacity within state agencies throughout the United States to better respond to wildlife disease threats, the Association of Fish and Wildlife Agencies, Fish and Wildlife Health Committee, published the National Fish and Wildlife Health Initiative Toolkit. This toolkit provides the framework upon which state and federal fish and wildlife agencies can define current capabilities for disease surveillance, monitoring, and response within their respective agencies, and further build capacity within the agency or through collaborative efforts with partner agencies. The National Fish and Wildlife Health Initiative recognized that state fish and wildlife agencies are responsible for “managing diseases in free-ranging fish and wildlife” (10). In a move toward One Health, it also recognized that there is a need to “foster collaboration, coordination, and communication among fish and wildlife health jurisdictions, as well as with animal health and public health agencies at the state and national level” (10). Several states (Wyoming, Colorado, Michigan, and California) have had long-standing management and research wildlife health programs that serve as models for succeeding state programs. But according to a recent survey (11), most states will need to hire more specialized staff and/or take novel approaches to disease surveillance if the initiative is to be a success. Funding and staffing issues continue to be major hindrances to implementing the initiative nationwide.

In 2012, Siemer et al. (11) conducted a survey that identified factors that affect agency capacity to address disease issues. The survey explored perceptions of how nine factors contribute to agency capacity, including interagency agreements related to staff sharing, interagency coordination, funding sources, regulatory authority, funding level, staffing, diagnostic facilities, funding, and response plans (program management). One terrestrial and one aquatic wildlife health representative
was contacted in each state. Response to the terrestrial wildlife survey was 94% (47 states); the only states not represented were Hawaii, Kentucky, and Delaware. Response to the aquatic wildlife survey was 84% (42 states); the states not represented were Connecticut, Hawaii, Oklahoma, Massachusetts, Nevada, Texas, Vermont, and Virginia.

Agency capacity to assist with collection of surveillance data is limited by availability of staff. About 75% of agencies reported that they had adequately sized staff to provide a short-term response to a terrestrial disease outbreak, but only 25% had adequate staff to provide a long-term response. About 80% of agencies reportedly had adequate staff for a short-term response to an aquatic disease outbreak, but only 46% had the staff capacity to provide a long-term response. Though many agencies offered limited staff training related to collecting and submitting samples as part of surveillance activities, substantial minorities of agencies reported that training on those topics was less than adequate.

The survey found that the ability to design surveillance programs or collect or interpret surveillance data may also be affected by access to specialized staff. Wildlife veterinarians and wildlife biologists normally conduct investigation, surveillance, monitoring, and research of wildlife diseases and manage the health of free-ranging wildlife primarily in agencies, but also as part of university programs and through the work of nongovernmental organizations and individuals. Wildlife veterinarians and biologists also frequently work with state and federal veterinarians on disease issues that affect livestock and with public health officials if there are zoonotic disease concerns. State emergency management planning activities increasingly include wildlife disease specialists to assist responders and emergency managers with minimizing negative impacts on wildlife populations while safeguarding domestic animal and human health. In 2011, a majority of agencies surveyed did not have veterinarians or pathologists on staff. To date, only half of states have one or more wildlife veterinarians or other staff (wildlife health specialists) dedicated to a wildlife health program for terrestrial and/or aquatic species. Access to veterinarians or pathologists was perceived as an impediment to disease detection and response in about 15% of states.

Another goal of the National Fish and Wildlife Health Initiative is to “establish an integrated surveillance and diagnostic laboratory network” (10). Access to diagnostic testing is variable across states. Using data from the 2011 agency survey, Siemer et al. (12) compared self-identified high-capacity (n = 7) and low-capacity (n = 12) agencies on multiple traits, including access to diagnostic facilities. Most representatives reported that their agency had access to diagnostic laboratories in other states, National Animal Health Laboratory Network (NAHNL)-accredited facilities to test for chronic wasting disease and highly pathogenic avian influenza (HPAI), and an in-state diagnostic laboratory operated by another agency or a university. But representatives of high-capacity agencies were more likely than those in low-capacity agencies to have access to their own diagnostic facilities (71 vs. 17%), other in-state laboratories (100 vs. 75%), and NAHNL-accredited facilities for HPAI testing (100 vs. 67%). Survey findings suggest that having one’s own facilities for routine monitoring and surveillance tasks is not essential to agencies but is more likely to be a trait of high-capacity agencies. Federal funding for WNV and HPAI surveillance within states and within federal agencies has disappeared during the last few years and is unlikely to be replaced. Both of those national surveillance programs provided relatively good national and state surveillance and good training and experience for participants. This trained national workforce will be lost without future support.

Where does the funding for state wildlife agencies come from? State wildlife agencies have a narrow range of funding mechanisms. A major source of funding for state wildlife programs, including many wildlife health programs, is generated from federal funds administered by the U.S. Fish and Wildlife Service under the Pittman-Robertson and Dingle-Johnson Acts. These bills, passed in the mid-20th century, levied federal excise taxes on all firearms and ammunition (Pittman-Robertson) or fishing equipment and boat fuel and motors (Dingle-Johnson). The funds generated are distributed to states for the restoration of wildlife. The money is distributed to the state fish and wildlife management agencies based on a formula derived from the size of the state and the number of hunting and fishing licenses sold in each state. States match 25% of the funding they receive, often through the sale of hunting and fishing licenses. Other funding sources often include the state’s general fund, other federally administered grants (U.S. Fish and Wildlife Service, Section 6 and State Wildlife Grants), local or national sportsmen’s organizations, mining and energy companies (mitigation funds), and state tax or earmark sources (vehicle license fees). Federal funds earmarked for surveillance for specific diseases of national concern (e.g., chronic wasting disease, HPAI, white-nose syndrome, viral hemorrhagic septicemia, and cold water disease of fish) are also available through competitive and noncompetitive grant sources. These...
funds are subject to congressional budget approval and are limited in their availability as long-term funding sources. Because disease surveillance levels are dependent on a narrow range of funding sources, surveillance efforts can decline markedly when those sources of funding expire, leaving us vulnerable to disease threats.

About 40% of agency representatives reported that funding for detection and response to disease threats had declined over the past 5 years (20% reported that funding had increased). Representatives in the majority of states reported that funding levels were “adequate” or “partially adequate” to conduct disease monitoring, surveillance, and response activities; about 25% said current funding levels were “not at all adequate” for response to disease outbreaks in terrestrial and aquatic wildlife. Only 24% of wildlife (and 35% of aquatic) representatives reported that the funding level in their agency in 2011 was adequate for purposes of diagnostic testing. So, although state wildlife agencies may now be interested in performing disease surveillance, they do not have sufficient funds to do so.

**THE SUMMER OF 1999**

During the WNV outbreak, it was fortunate that states were able to turn to a federal wildlife diagnostic laboratory. The USGS NWHC is unique in its breadth of in-house technical disciplines and physical facilities devoted to wildlife disease investigations. These capabilities enabled the NWHC to quickly become a partner in the One Health type of response to this unique outbreak, representing the wildlife health part in collaboration with the public health and domestic animal health parts of the response triad. The NWHC was an active participant in collaborative planning and investigative efforts throughout the early WNV epidemic period and beyond. A federal working group among CDC’s Division of Vector-Borne Infectious Diseases, the USGS NWHC, and the USDA Animal and Plant Health Inspection Service (APHIS) Veterinary Services and Wildlife Services was established, and they cooperated closely, in conjunction with relevant state agencies, to conduct WNV surveillance in a One Health manner.

Since its establishment in 1975, the federal NWHC has (i) monitored wildlife diseases and assessed the impact of diseases on wildlife populations; (ii) defined ecological relationships leading to the occurrence of disease in free-ranging wildlife; (iii) provided on-site investigations and control for wildlife disease emergencies; and (iv) provided guidance, training, and technical information for reducing wildlife losses when outbreaks occur. The NWHC provides technical support, knowledgeable guidance, and timely intervention to wildlife managers who are regularly confronted with sick and dead wild animals, frequently on a large scale. The expertise and resources of the NWHC disease diagnostic laboratory are crucial in providing a rapid response to wildlife mortality events.

The USGS NWHC is a high-security biosafety level 3 (BSL3) infectious disease facility in Madison, WI, designed to meet all of the criteria set down by the National Institutes of Health and CDC for BSL3 research. It is the only federal facility devoted exclusively to the diagnosis, prevention, and control of diseases of wildlife.

Another federal program is the National Wildlife Disease Program (NWDP) of the National Wildlife Research Center, Wildlife Services, APHIS, which is located on a 43-acre master facility located on the Colorado State University campus in Fort Collins. The National Wildlife Research Center mission is consistent with lending emergency diagnostic support for specific pathogens, especially those whose reservoirs are in wildlife. Within the context of normal endemic disease emergencies, support for wildlife disease surveillance for foreign animal diseases and support for emergency laboratory testing as a result of a bioterrorism event are within the technical and infrastructure capacity for specific agents and protocols. Wildlife disease biologists conduct surveillance activities in all 50 states and act as Wildlife Services’ first responders in cases of emergency, as part of the NWDP’s Surveillance and Emergency Response System. As part of their everyday duties, wildlife disease biologists participate in avian influenza surveillance, as well as other disease monitoring and control activities that are of particular interest and concern in their designated regions. Additionally, the NWDP collaborates with nongovernmental organizations and officials from other countries to promote and assist in the development of wildlife disease monitoring programs worldwide.

The NWHC became involved in the WNV outbreak when on September 2, 1999, the Field Investigations Team received a call from the NYSDEC reporting morbidity and mortality in American crows in the Bronx and Queens boroughs in New York City. During early stages of the surveillance, the NWHC was one of only a few BSL3 facilities capable and available to test birds for WNV after it was declared a BSL3 agent. This initial involvement to help NYSDEC with the first group of dead crows was part of the routine service the NWHC provides to state wildlife agencies. It set in motion an intense investigation of these events that would culminate in the examination for WNV of 142 specimens (47
species) from New York in 1999, and 68,578 from 2000 to 2012 (357 species; 50 U.S. states and Canada).

From the investigation of crow mortality in August 1999, the NWHC isolated an unidentified virus in the first week of September that was subsequently confirmed to be WNV. The NWHC then conducted field studies and diagnostic laboratory testing in support of dead bird surveillance in a number of states in the Northeast, especially New York. WNV was isolated and identified from a migratory bird captured in the Bronx; this was the first isolate of WNV from a live, free-ranging wild bird (13) and an early indication that migratory birds could move the virus out of the epidemic focus. In 2000, WNV research was initiated at the NWHC. These studies demonstrated the lethality of the New York 1999 strain, crow reservoir competency, and direct transmission between inoculated crows and controls, likely from WNV-laden discharge (13).

As robust as the initial response was, due to the increase in specimens received, the NWHC did struggle in 2000 to keep up, and this delayed delivery of results to the states. NWHC staff during these times were challenged by the limited resources, but continued until the states were capable of managing their own testing. This occurred when funding and training became available directly from the CDC to state public health agencies.

The CDC received $4 million for WNV control in the FY2001 budget, and the NWHC received about $200,000 per year for a few years. This significant contrast in funding levels suggests less support for wildlife diagnostics and research even when the country was in full crisis mode.

**CREATIVE APPROACHES TO ACHIEVING STATE WILDLIFE DIAGNOSTIC CAPABILITIES**

How do states without their own diagnostic labs do disease surveillance? States utilize a number of diagnostic sampling strategies. Carcasses may be sent to a veterinary diagnostic lab for necropsy or examined in the field by a veterinarian or a biologist trained in sample collection, preparation, and shipment. A number of states in the Southeast, East, and Midwest utilize the diagnostic and disease investigation services of the Southeastern Cooperative Wildlife Disease Study (SCWDS) located in Athens, GA, as part of a state contractual agreement. This cooperative approach was the first effort to link state wildlife agencies with a dedicated and specialized wildlife disease diagnostic center.

The SCWDS story began in 1949 when there was a major die-off of deer. Facilities were not available to investigate widespread deer mortality, and conservationists and the general public wanted action. However, it was too costly for any single state to establish and maintain an organization with the expertise to cope with future deer mortality crises.

After careful deliberation, a multistate organization was established for the Southeast, and on July 1, 1957, the Southeastern Cooperative Deer Disease Study (SCDDS) was founded at the University of Georgia’s College of Veterinary Medicine. The initial annual SCDDS budget of $18,000 was provided by the 11 southeastern state wildlife management agencies that were the original cooperative members. Membership grew to 13, then to 15, and now numbers 19, including states outside the Southeast. Current members are the wildlife resource agencies of Alabama, Arkansas, Florida, Georgia, Kansas, Kentucky, Louisiana, Maryland, Mississippi, Missouri, New Jersey, North Carolina, Ohio, Oklahoma, Pennsylvania, South Carolina, Tennessee, Virginia, and West Virginia.

In 1960, in recognition of the increasing demand for wildlife health information, the SCDDS expanded its mission to encompass all game and nongame species and changed its name to the SCWDS, as it is known today. SCWDS objectives are to (i) detect causes of morbidity and mortality in wildlife, (ii) define the impacts of diseases and parasites on wildlife populations, (iii) delineate disease relationships between wild and domestic animals, and (iv) determine the role of wildlife in the epidemiology of human diseases.

In 1963, the U.S. Congress enacted a recurring annual appropriation, administered through the U.S. Department of the Interior, to support basic wildlife disease research conducted by the SCWDS. In 1967, a vital alliance between wildlife and domestic animal interests was established when the USDA and SCWDS sponsored a 3-day Foreign and Emergency Disease Surveillance Training Program for wildlife biologists at the University of Georgia. The USDA and SCWDS continue to conduct the annual Wildlife Seminar for Emergency Animal Disease Preparedness every year.

Since its inception, the SCWDS has conducted surveillance and research on zoonotic diseases. The diseases diagnosed run the gamut from those that affect only wild animals to those with significant human or domestic animal health implications, such as rabies, tularemia, plague, WNV, eastern equine encephalitis, and others.

Since its establishment in 1957 as the first regional diagnostic and research center specifically for wildlife diseases, the SCWDS has provided untold benefits to this country’s natural resources, wildlife managers, domestic
animal and public health officials, and citizens and visitors. With its cooperative approach and pooling of resources, the SCWDS has grown and evolved by leveraging funds from individual supporters with those of the other states, federal agencies, and granting organizations to develop and distribute wildlife health information and services of value to everyone.

In 1970, states in the Northeast took a similar approach and the Northeast Research Center for Wildlife Diseases was established in the Department of Pathobiology, College of Agriculture and Natural Resources, University of Connecticut, Storrs. This cooperative center was established to conduct large-scale projects that would have been difficult to conduct on an individual state basis.

The center consisted of a multidisciplinary team of four pathologists, a microbiologist, a virologist, an immunologist, a toxicologist, an electron microscopist, a hematologist, and veterinarians and PhDs with specialties in clinical medicine and reptilian diseases. The center also engaged extramural consultants from regional affiliated states and universities, including pathologists in human medicine from both Harvard University and Yale University.

The primary functions were identified as (i) research on new and poorly understood diseases of wildlife; (ii) diagnosis of diseases of wildlife; and (iii) dissemination of information and education through teaching of undergraduate students, graduate students, and wildlife biologists about the recognition, control, and prevention of diseases of wildlife. The center was also identified as a participant in the Regional Emergency Animal Disease Eradication Organization established by the USDA. Staff members of the center were on call and assisted as wildlife disease specialists in the early diagnosis and eradication of any infectious foreign and native diseases of animals that might be introduced to the northeastern United States. The activities of the Northeast Research Center for Wildlife Diseases slowly decreased in 1995 after the retirement of its chief pathologist, Svend Nielsen. The center was officially closed in 2007. In 2011, however, another Northeast regional initiative was launched, the Northeast Wildlife Disease Cooperative (NEWDC).

WILDLIFE DISEASE SURVEILLANCE INITIATIVES
Regional coordination of wildlife disease diagnostics and reporting is essential to detect, respond to, and ultimately control disease outbreaks. Successful models of wildlife disease diagnostic and research laboratories exist in California, the southeastern United States, and throughout Canada, but the Northeast has no dedicated wildlife health facility to survey for, detect, or aid in the response to wildlife diseases, even those with potentially severe impacts on the human population. Unlike most western states, many states in the Northeast do not have their own wildlife health specialist. Moreover, the region consists of several small states with many shared borders, necessitating good communication among agencies. Yet there is no coordinated regional disease-reporting system, so information about wildlife health events is not rapidly or effectively disseminated to key stakeholders; as a result, the regional response to disease outbreaks is often sluggish and reactive rather than nimble and proactive. Scientists, veterinarians, and wildlife managers currently submit case material through the same channels used by companion animal veterinary clinics, or submit samples from large-scale die-offs to the USGS NWHC. This approach precludes a holistic, population-level understanding of wildlife and ecosystem health.

In 2010, staff from the Cummings School of Veterinary Medicine at Tufts University, Connecticut Veterinary Medical Diagnostic Laboratory at University of Connecticut, and New Hampshire Veterinary Diagnostic Lab met to discuss the idea of reviving a regional diagnostic program. The Animal Health Diagnostic Center at Cornell University and the University of Maine Animal Health Lab joined the effort soon thereafter. Collectively, these laboratories have considerable expertise in diseases of domestic animals and wildlife in the Northeast. And with multiple laboratories cooperating to provide diagnostics, both the diagnosticians and the “clients” benefit. This new project was named the NEWDC. The overarching goal of the NEWDC is to preserve and protect biodiversity and ecosystem health in the Northeast by offering wildlife diagnostic services, expertise, and cutting-edge research on the interplay of wildlife, domestic animal, and human health. The NEWDC will support and augment the services of the USGS NWHC and the Association of Fish and Wildlife Agencies in a collaborative but regionally focused effort that engages regional expertise and allows for timely and effective response to wildlife diseases. A key contact from each participating state wildlife agency, a regional representative from each of the USDA APHIS Wildlife Services and USDA APHIS Veterinary Services, and a public health veterinarian will be included on the advisory board to ensure a One Health approach.

The specific objectives of the NEWDC are to provide (i) timely diagnoses of wildlife disease outbreaks and
mortality events; (ii) surveillance of diseases in live and dead wildlife; (iii) health assessments of live wildlife; (iv) expertise in wildlife-domestic animal and wildlife-human disease transmission; (v) educational opportunities for veterinarians, scientists, and wildlife managers; (vi) an accessible database of regional wildlife disease for use by human and animal health professionals; and (vii) streamlined communication regarding disease outbreaks across state lines and between agencies.

**SURVEILLANCE OF WILDLIFE OUTSIDE OF FEDERAL OR STATE AGENCIES**

State and federal wildlife agencies are not the only ones handling wildlife in the United States, and there are several new initiatives in the private sector that should be recognized.

Wildlife care centers manned by wildlife rehabilitators represent an untapped source of health data on a diverse array of wild animals, providing a unique “window” into wildlife health. More than 5,000 organizations and individuals in the United States alone hold permits to provide veterinary care and rehabilitation to native wildlife. Current estimates suggest that these rehabilitation programs receive 500,000 birds, mammals, reptiles, and amphibians each year. In the United States, wildlife rehabilitation generally requires state and/or federal permits in addition to filing of annual reports documenting the inventory of species and health issues encountered. However, since the several federal agencies and 44 state agencies that require such reports do not use standardized datasets or terminology or an electronic format, it is nearly impossible to access, let alone compile and analyze, the wildlife health information collected by wildlife care facilities.

The Wildlife Center of Virginia has created a program to establish the validity of data originating from wildlife care facilities. WILD-ONE (Wildlife Incident Log/Database and Online Network) is a system designed to capture admission and health data from wild animals entering rehabilitation facilities. This database provides incentives to encourage timely, standardized data entry, making it a novel source of wildlife health information. WILD-ONE is a free online database created to assist wildlife care facilities in the collection and use of data about their patients. WILD-ONE includes (i) standardized terminology and incident descriptions; (ii) standardized admission documentation; (iii) GPS coordinates for rescue-and-release sites (Google Maps with transferable coordinates); (iv) ability to assess wildlife health trends in wildlife care facilities across states/provinces, regions, and countries; (v) state, federal, and organization report generation; (vi) incentives for the rehabilitators; (vii) scheduled prescription generation; (viii) data fields for entering patient weights, meals, medical notes, etc.; (ix) contact management tools for recording patient history and for use in fund-raising; and (x) annual report generation.

Presently 80 organizations are using WILD-ONE for all patient admissions, and there are more than 25,000 patients currently in the database. It is hoped that in time WILD-ONE will be adopted by most rehabilitation organizations and result in a nationwide searchable database. While it is acknowledged that the successful rehabilitation and release of individual animals is unlikely to have significant impacts on populations or species, the data collected from these individual animals could provide unprecedented insights related to natural and anthropogenic threats to wildlife and aid in the establishment of critical baseline data.

**NEW EFFORTS TO ENGAGE THE PUBLIC IN WILDLIFE DISEASE SURVEILLANCE**

One of the reasons early recognition of WNV was missed is that there was no way to see the geospatial relationships between the avian and human outbreaks. Although the public was the first to notice the crow die-off, those reports were not captured and could not be visualized. In 2004, a study concluded that “reporting systems for wildlife professionals and the public should be created, and their use should be encouraged to document unusual disease events and die-offs” (7). One effort to do so is a project called the Wildlife Health Event Reporter (WHER). This easy-to-use Web application was created to record wildlife observations by the public concerned about dead or sick wildlife. After being recorded, these observations are connected with other wildlife event sightings and are viewable in tabular reports or in map form, enabling anyone to see where similar events are happening. To keep track of what is being reported to WHER, anyone can sign up for an e-mail alert for a certain area of interest or subscribe to one or more GeoRSS feed options that will connect them with the latest reports as they are shared.

With the help of the public, this system can collect timely and useful information about wildlife mortality events (e.g., date, location, and affected species). The data are integrated and summarized by the system to provide essential information for better understanding of wildlife disease patterns and their potential impact on wildlife, human, and domestic animal health, as well as
to provide knowledge about baseline mortality levels. This information is being used by natural resource managers, researchers, and public health officials in an effort to protect the well-being of all living things and promote a healthy ecosystem by (i) assisting in detection of common disease events and biosecurity concerns; (ii) exploring the interconnections between human, domestic animal, and wildlife diseases; and (iii) helping to design and coordinate disease control and prevention strategies.

To build a more robust set of observations, WHER can be configured to import data from external systems and translate the information to match the data and standards used in WHER. In true One Health mode, the WHER application currently ingests mortality or morbidity reports from several other efforts, including HealthMap’s mobile application for human outbreaks (“Outbreaks Near Me”). Another volunteer monitoring effort, the Seabird Ecological Assessment Network (SEANET), feeds GIS data directly to WHER about beached bird mortalities observed during periodic monitoring activities along the East Coast from Maine to Florida.

Technical development of the WHER application and framework was performed by the Wildlife Data Integration Network (WDIN) in collaboration with the University of Wisconsin-Madison’s Division of Information Technology’s Academic Technology group. WDIN is a collaborative research project currently located at the University of Wisconsin School of Veterinary Medicine, the aim of which is to tackle data and information integration, standardization, visualization, and dissemination challenges to increase decision makers’ access to information on the health of wildlife. The WDIN project and WHER online application are currently maintained by the University of Wisconsin School of Veterinary Medicine and the WDIN project team.

**ZOO SURVEILLANCE**

The WNV outbreak showed how “domestic, wild, and zoo animals can be considered ‘sentinels,’ providing an early warning device for diseases that can harm people” (11). However, “several persons involved in the outbreak commented that the zoo community is currently left out of the animal and public health paradigm” (11). Officials indicated that “because zoo animals are not considered to be wildlife or domestic animals, they do not fall within the jurisdiction of animal health agencies such as the USGS, which tracks wildlife issues, or the USDA, which tracks concerns related to domestic animals” (11). The utility of animals as sentinels for disease has long been recognized, but the power of zoological animals as sentinels for diseases of public health concern remains underrecognized. Inherent characteristics of zoological institutions and their collections make them ideal partners in sentinel surveillance programs.

Zoological institutions manage hundreds of species of animals, both North American native and nonnative species. This represents a vast array of wildlife from many continents, maintained in relatively small footprints. Populations in accredited zoos are closely managed. Unlike most free-ranging wildlife, these animals are relatively stationary and are observed daily by trained professionals. If animals are transferred to another institution, meticulous records detail these movements between zoos. Extensive medical records are kept, and serum and other biomaterials are collected and banked during physical examinations. These biological materials can serve as a historical timeline of disease exposure that is crucial for epidemiological investigation. Most importantly, all animals that die or are euthanized while in the care of an accredited zoo must undergo a complete necropsy. This step can be critical for “early warning” and was paramount in the identification of the unusual pathology that accompanied the emergence of WNV in the Bronx Zoo in 1999.

The location of accredited zoos is also significant. There are 235 Association of Zoos and Aquariums-accredited institutions, located in urban, suburban, and rural locations. Many are situated along flyways with exhibits that allow for interaction with migrating species. Zoos are therefore potential intersections of wildlife, managed animal collections, staff, and visitors.

A national-level database for zoonotic disease surveillance that includes all animal compartments including zoological data still does not exist. An early One Health diagnostic and data integration effort was the Surveillance for West Nile Virus in Zoological Institutions program, which was funded by the CDC and ran from 2001 to 2006. This program, facilitated by Lincoln Park Zoo in Chicago, was a successful effort to integrate outcomes from WNV surveillance in zoos with a national public health database for arboviral diseases (ArboNET). A more modern database has since been developed for HPAI data that is now adaptable for any disease of concern to the zoological community. The data from this pilot project showed how data from zoo cases will automatically be provided to the USDA via the NAHLN. This ensures that the data will be in the hands of animal health officials in a timely manner.
NEW APPROACHES TO WILDLIFE DISEASE SURVEILLANCE OUTSIDE THE UNITED STATES

Researchers at the University of Nottingham are leading a project aimed at developing a state-of-the-art pan-European surveillance system to monitor emerging and reemerging infections in wildlife. Novel Technologies for Surveillance of Emerging and Re-emerging Infections of Wildlife (WildTech) is a proactive attempt to predict and manage disease threats from wildlife and assess the risk to domestic animals and humans. The project has brought together a network of wildlife specialists across 24 countries and combines (i) technological development to enable high-throughput nucleic acid- and peptide-based array screening of samples from a wide variety of wild animals, (ii) surveillance of wild animal species in Europe and from countries that may act as portals of disease entry into the European Union, (iii) epidemiological analysis and risk assessment using data generated during the project and from other sources, and (iv) development and proposal of a model framework for disease surveillance in Europe. The ultimate goal of this huge effort among multiple European countries is to develop analytical tools for multiple diseases. The aim is to prevent and/or limit disease spread among animals of the same and different species as well as from animals to humans. WildTech is working closely with the World Organisation for Animal Health and government bodies to develop an effective pan-European surveillance system with a potential global impact.

CONCLUDING REMARKS

The introduction of WNV into the eastern United States and its subsequent dissemination throughout the North American continent was an unprecedented event that challenged the infrastructure of local, state, and federal public health, domestic animal health, and wildlife health agencies to monitor viral occurrence and spread, to understand the transmission dynamics and ecology, and to try to control it and protect human and animal populations. It exposed significant deficiencies in the abilities of state natural resource and public health agencies to react similarly. In subsequent years, there have been additional high-profile emerging diseases of significance to wildlife, livestock, and public health, exemplified by monkeypox, avian influenza, and whitenose syndrome in bats. While the story of WNV provided the momentum to build additional infrastructure for wildlife disease surveillance and response, it still falls far short of similar capacities for human and domestic animal populations. The contrasts are striking: there are no mandatory reportable diseases of wildlife, there is no integrated national reporting or information system for wildlife morbidity and mortality, many states have minimal or no professional staff dedicated to wildlife disease surveillance, and there is inconsistent communication between health agencies at both the state and federal level. In short, “current measures for the detection and control of human and livestock EIDs are inadequate for the identification of similar threats in wildlife” (8). “We have good earth-monitoring systems, good public health disease-monitoring systems, but we don’t have that same proactive systematic collection of data for wildlife health. Until we do that, it’s going to be very hard to get a handle on what’s driving these diseases” (14).

Many of these deficiencies are resource based, with orders-of-magnitude differences between funding for wildlife health compared with that available for public and livestock health. “There is no real economic incentive to proactively deal with wildlife disease. It gets dealt with during a crisis because of public pressure, but ultimately, there is no highly integrated infrastructure for dealing with disease, period” (14). Some issues may be related to the confusing array of species stewardship responsibilities assigned to state and federal agencies. The prospect of instituting a One Health approach gives some hope for improvement of this situation. When human and animal health agencies accept the concept that there are cross-population shared risks associated with emerging diseases, then the integration of knowledge, capacity, and response will provide a superior platform to address the health threats to all of the nation’s inhabitants.

REFERENCES