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The mission of the National Wildlife Research Center (NWRC) is to apply scientific expertise to resolve human-wildlife conflicts while maintaining the quality of the environment shared with wildlife. NWRC develops methods and information to address human-wildlife conflicts related to the following:

- agriculture (crops, livestock, aquaculture, and timber)
- human health and safety (wildlife disease, aviation)
- property damage
- invasive species
- threatened and endangered species

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Cover Photos: Advances in technology have made small, unmanned aircraft systems (sUAS or small drones) less expensive and more powerful. As a result, the devices are becoming useful tools for wildlife damage assessments and management.
Photos by USDA Dwight LeBlanc, Justin Fischer (inset, WS employee holding UAS) and Tommy King (inset, controls upclose).

Message From the Director

Since 2008, it has been a privilege to provide an annual "Message from the Director" about the NWRC's research and development activities. However, this was my last year doing so, as I retired in December 2019.

Over the last decade, our employees have witnessed a profound increase in the Center's productivity and technology transfer efforts, as well as explorations into new scientific disciplines not traditionally thought of as a part of wildlife management. Overall, the impact of these efforts has improved our ability to resolve challenging and complex wildlife damage problems.

Larry Clark, NWRC Director
Photo by Federal Laboratory Consortium

The NWRC is a transformational wildlife management and research center—in part as a natural consequence of the evolution of technology and science, but also as a result of a willingness to engage in cross disciplinary research spanning the breadth of scientific and social disciplines.

It has been my good fortune to have been at the helm of this institution. Our collective success in this effort is reflected in the numerous group and individual accolades accumulated over the past few years, including four Federal Laboratory Consortium awards for partnerships and outstanding technology development (see the Awards section for recent honors), and two Colorado Governor's awards for high impact research.

Any time there is a major change within an organization, there is some anxiety about what the future will bring. This fear can become paralyzing, as John F. Kennedy observed when he said, "Change is the law of life. And those who look only to the past or present are certain to miss the future." In my opinion, NWRC employees have always embraced the challenges present in the unknown and will continue to do so with the same energy and success they have shown in the past.

I share with you now a quote that I have shared many times with employees, as I think it epitomizes the NWRC spirit: "Vision without action is just a dream, action without vision just passes the time, and vision with action can change the world."[1]

It is with pleasure that I present to you this year's research accomplishments for the National Wildlife Research Center.

Larry Clark, Director
National Wildlife Research Center
Wildlife Services, APHIS-USDA
Fort Collins, CO

[1] *Quote by scholar Joel Barker.*

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Research Spotlights

The National Wildlife Research Center (NWRC) is part of Wildlife Services (WS), a program within the U.S. Department of Agriculture's (USDA) Animal and Plant Health Inspection Service (APHIS). NWRC's researchers are dedicated to finding biologically sound, practical, and effective solutions for resolving wildlife damage management issues. The following spotlights feature some of NWRC's expertise and its holistic approach to addressing today's wildlife-related challenges.

Spotlight: Expanding Vulture Populations and Damage

Vultures are federally protected migratory birds that play an important role in our environment by cleaning up animal carcasses. However, their increasing and expanding populations may be associated with problems including agricultural and property damage, and human health and safety concerns. In recent years, these adaptable birds have adjusted to higher levels of human activity. As a result, the birds are increasingly coming into conflict with people.

"Two different vulture species are native to North America: black vultures and turkey vultures," says Dr. Bryan Kluever, leader of the NWRC Florida field station in Gainesville. "Turkey vultures are almost exclusively scavengers, relying upon their very sensitive sense of smell to locate food. Black vultures, on the other hand, rely predominantly on visual cues to find food, including following turkey vultures to food. They can also attack and kill live animals."

Vultures often damage residential and business property. Their droppings can kill trees and create unsanitary and unsafe working conditions at power plants, refineries, and communication towers. Their aggressiveness unsettles park users and homeowners. Vultures harass and kill livestock, primarily newborns. In flight, they can be a danger to aircraft.

Vultures often damage residential and business property.
Photo by USDA, Wildlife Services

Vultures play an important role in our environment, but their increasing populations have led to more conflicts with people.

As vulture complaints multiply, pressure grows on wildlife managers to develop safe, effective ways to manage vulture populations that both maintain sustainable numbers of birds and reduce conflicts and damage. NWRC researchers are hard at work to find solutions.

Estimating Black Vulture Populations and Appropriate Take Levels

Soaring vultures are a common sight throughout the southeastern United States. In fact, black vulture populations have not only increased, but also expanded north and west over the past several decades. This has resulted in more frequent interactions and reports of conflict with people, including predation on livestock and property damage. With an increase in vulture conflicts comes an increase in requests for the U.S. Fish and Wildlife Service (USFWS) to authorize the lethal removal (also known as allowable take) of the birds in areas with documented damage and where nonlethal control methods are ineffective.

The USFWS issues permits for the lawful take, including lethal removal, of migratory birds, including turkey vultures and black vultures, under various laws and treaties. These permits help to balance human needs and the conservation of migratory birds. The USFWS is committed to science-based approaches for estimating the take of migratory birds and is currently assessing alternatives for a take-permitting program for black vultures. To assist in this effort, researchers with the NWRC Florida field station and U.S. Geological Survey (USGS) have expanded an existing analysis used to estimate allowable black vulture take in Virginia to include the entire range of black vultures in the eastern United States. They combined population demographic rates, population size estimates, and management objectives to estimate allowable take at four different levels: (1) individual States; (2) Bird Conservation Regions (as delineated by the Commission for Environmental Cooperation); (3) USFWS administrative regions; and (4) migratory bird flyways.

Results showed the overall black vulture population estimates for the Atlantic and Mississippi Flyways were 4.26 million in 2015. As illustrated in Table 1, subsequent estimates for allowable take per State ranged from a few hundred individuals per year in States at the northern end of the species range to almost 75,000 birds in Florida.

The USFWS has no legal mandate regarding the spatial scale at which allowable take should be managed, and researchers found little biological evidence of genetically unique subpopulations of black vultures in the eastern United States. Researchers suggest that allowable take for the species be at a scale that reduces conflicts, ensures some black vultures remain in local areas, and is efficient for administrative and monitoring purposes.

STATE	BLACK VULTURE POPULATION ESTIMATE	ESTIMATED ALLOWABLE TAKE
AL	223,904	14,954
AR	180,146	11,588
DE	5,291	335
FL	1,149,817	74,848
GA	707,042	47,083
IL	5,851	367
IN	17,039	1,080
KY	124,159	8,030
LA	433,436	28,908
MD	71,423	4,730
MO	6,970	450
MS	381,332	25,117
NC	126,976	8,041
NJ	29,652	1,915
OH	4,569	295
PA	13,509	877
SC	168,522	11,038
TN	234,947	15,487
VA	117,741	7,798
WV	24,484	1,530

Table 1. Estimated black vulture populations and allowable take by State.

Vulture Movement Patterns and Impacts to Aviation

Florida has one of the largest black vulture populations in the United States. Furthermore, Florida's population of turkey vultures typically swells from late fall to early spring when the birds migrate south to warmer climates. Because of their large size, low maneuverability, and flocking tendency, these large numbers of soaring birds pose a serious hazard to aircraft.

A 2018 study by researchers at NWRC's Ohio field station identified turkey vultures as a significant risk to aircraft across the United States. Of the 11,364 bird strike records and 79 bird species studied, red-tailed hawks, Canada geese, turkey vultures, pigeons, and mourning doves have the most frequent and damaging collisions with aircraft. Black vultures are also high on the list for causing damaging strikes, but because of their more limited distributions, they are not involved in as many bird-aircraft collisions as turkey vultures.

NWRC Florida field station researchers are working collaboratively with numerous airports to live-capture and tag black and turkey vultures. The effort helps to gather information on the birds' activities and movement patterns.
Photo by Department of Defense, MacDill Air Force Base

“Information on vulture activities and movement patterns can help in the development of effective management strategies to lessen risks to aircraft,” says Kluever. “Our team is working with several military airbases to live-capture and place wing tags on black and turkey vultures, and to monitor the birds’ movements and activity patterns.”

In this multi-year effort, NWRC has collectively tagged and released more than 1,000 vultures, and attached transmitters as well to a subset of them (27 black vultures and 28 turkey vultures). The transmitters record the birds’ daily movements. Observations of tagged birds and information from transmitters showed that black vultures are non-migratory and sedentary, while turkey vultures are wide-ranging seasonal migrants. In fact, some turkey vultures tagged during the winter at Key West Naval Air Station were observed as far as 1,677 miles/2,700 kilometers (km) away on breeding grounds in the northern United States and southern Canada.

At Beaufort, South Carolina, data from birds with transmitters showed that black vultures consistently spent less time flying (8.4 percent of daily activity) than did turkey vultures (18.9 percent of daily activity). Analysis of vulture flight altitudes versus time of day revealed that greater than 60 percent of vulture flight activity occurred from 4 to 9 hours after sunrise and at altitudes below 650 feet/200 meters. By comparing the telemetry locations of flying vultures with aircraft approach and departure paths, NWRC researchers identified areas at high risk for vulture collisions with aircraft. This information helps wildlife managers and airport personnel target areas for vulture harassment and dispersal.

Vulture Predation on Livestock

Both turkey and black vultures normally feed on animal carcasses. Black vultures, however, also attack and kill calves, lambs, piglets, adult livestock incapacitated while birthing, and other vulnerable animals.

Vultures harass and kill livestock. A 2017 USDA report on cattle and calf losses in the United States reported that vultures were responsible for 10 percent of all calves lost to predators. *Photo by USDA, Wildlife Services*

This predatory behavior often results in serious injury or death to livestock, as vultures target the eyes and soft tissues. In most cases, affected animals must be euthanized because of their injuries. A 2017 USDA report on cattle and calf losses in the United States reported that vultures were responsible for 10 percent of all calves lost to predators. In 2019, WS experts responded to approximately 1,790 incidents related to black vultures and livestock damage (cattle, horses, goat, sheep, and pigs), up from the 1,152 incidents reported in 2016 (WS 2016 and 2018 Program Data Report C).

NWRC first began estimating the costs of this damage in 2006. NWRC Florida field station researchers collaborated with the Florida Farm Bureau to survey 374 Florida cattle ranchers regarding their ranch and vulture conflicts. In cases where vulture attacks to livestock were reported, respondents were asked to estimate the value of their property that was lost and any preventative measures taken to reduce vulture predation. The survey revealed that 142 respondents (38 percent) had experienced vulture predation, averaging more than $2,000 in damages (total value of cattle lost was $316,570). Attacks were recorded

Vultures are dispersed from roosts by installing a vulture effigy. An effigy is either a taxidermic preparation or an artificial device designed and constructed to look like a dead vulture. *Photo by USDA, Wildlife Services*

throughout the year, with the greatest number occurring during the calving season in December and January. By gaining better knowledge of stakeholder views and opinions, as well as the extent and characteristics of their depredation problems, wildlife managers can more efficiently address the needs of livestock ranchers to reduce vulture damage. Because of the importance of such data and the rise in the number of reported vulture predation incidences, NWRC researchers plan to collaborate with partners to conduct a similar survey in 2020 in Virginia and Indiana, where vulture-livestock conflicts appear to be increasing.

Vulture Effigies and Other Management Tools

Both black and turkey vultures share communal nighttime roosts, containing dozens or even hundreds of individuals. In most roost situations, whether in trees or on a structure, birds can be dispersed quickly and efficiently by installing a vulture carcass or effigy. An effigy can be either a taxidermic preparation or an artificial device designed and constructed to look like a dead vulture.

Vulture carcasses and taxidermic vulture effigies have been effective in resolving a variety of roost problems involving property damage, communication towers, crop and livestock protection, and aircraft safety. Generally, vultures that encounter a hanging carcass or taxidermic effigy vacate their roost within 5 days and do not return as long as the stimulus is in place. In some cases, vultures do not return even when the carcass or effigy is removed. Dispersal of vulture roosts near livestock operations can help reduce the likelihood of depredations. However, the effectiveness of an effigy at livestock operations is dependent on a variety of factors, including the size of the operation and availability of alternate roosting sites.

"Sound- and light-devices, such as propane cannons, pyrotechnics, and lasers, also may be used to disperse vultures, especially at roost locations at night or as birds return to settle for the night," says Kluever. "Motion-activated sprinklers and inflatable air dancers may be useful for dispersing vultures from rooftops."

Obvious attractants, such as open garbage, dead livestock, and outdoor feeding of domestic or wild animals, can be removed or excluded, although the source of a site's attraction can be unclear. In some situations, selective, lethal removal of birds may be needed to resolve damage effectively.

NEXT STEPS—NWRC researchers are estimating cattle loss due to black vulture predation and identifying factors that influence predation. They are also investigating black vulture movements in livestock

For many years, NWRC researchers have worked to develop methods to reduce the transmission and spread of CWD among wild and captive deer and elk.

production areas and evaluating the effectiveness of existing and emerging management tools for vulture management in general, such as motion-activated sprinklers and inflatable air dancers.

SPOTLIGHT: Accomplishments in Chronic Wasting Disease Research

Chronic wasting disease (CWD) is a fatal neurological disease that affects a number of wildlife ungulates, including mule deer, white-tailed deer, elk, and moose (collectively known as cervids). CWD is caused by abnormal proteins called prions. Prions change normal proteins in the host animal's cells, resulting in concentrations of abnormal proteins. Over time, these abnormal proteins accumulate in the central nervous and lymphatic systems, causing a degenerative lack of control and a "wasting-away" death.

There is no known cure or vaccine for CWD. The origin of CWD is unknown. Initially believed to be malnutrition, CWD was first observed in a captive deer in 1967 in Colorado. In 1977, CWD was determined to be a transmissible spongiform encephalopathy, and the first infected wild animal—an elk from Rocky Mountain National Park—was diagnosed in 1981.

Since that time, CWD has been found in 25 States and has impacted numerous wild and captive populations of deer and elk. Concerns about the impacts of diseases, such as CWD, on the United States livestock industry, and captive and wild cervid populations continues to prompt research studies on preventing disease outbreaks and minimizing the transmission of diseases between wildlife and livestock.

Direct and indirect contact between wild and captive elk through fences at captive elk farms may play a role in chronic wasting disease transmission.
Photo by USDA, Wildlife Services

From 2002 to present, NWRC researchers have been active in CWD research, conducting more than 100 basic and applied studies on deer and elk to help mitigate disease transmission at the wildlife-livestock interface. Results from this research have helped inform many management and regulatory actions at the State and Federal levels. The following provides a summary of NWRC's CWD research accomplishments and recommendations for future research efforts.

Tools for Detecting and Estimating CWD

Initial methods for detecting CWD in dead deer and elk were expensive and time-consuming, limiting the number of animals tested. Live tests can also be invasive and require anesthesia.

"NWRC has worked with private, State, and Federal collaborators to develop the first rectal biopsy test for detecting CWD in both dead and live deer and elk," says NWRC supervisory research wildlife biologist Dr. Kurt VerCauteren, who has worked extensively on CWD and other ungulate diseases. "The test is easy to perform, does not require anesthesia, and can be repeated on individuals over time. This live-animal test is currently used in routine monitoring for CWD infection in private deer and elk herds."

To verify the accuracy of the test, NWRC scientists and partners collected more than 1,300 rectal biopsies from captive elk to quantify sex- and age-related variance in numbers of rectal lymphoid follicles in order to determine the influence of elk sex and age on the diagnosis of CWD. Results showed that the number of lymphoid follicles gathered from typical biopsy tissues decreased with the age of the animal. In elk over 8.5 years old, the number of lymphoid follicles found was too low for use in CWD detection tests. The sex of the animal had no effect on the number of lymphoid follicles found in each age group. Also, the test may not detect animals that have just recently contracted the disease. Based on these results, the researchers conclude that rectal biopsies are most useful for the captive cervid industry, because the biopsies can be performed on entire herds at regular intervals, whereas it would be difficult to biopsy wild cervids at regular intervals.

NWRC experts have also developed models for estimating CWD prevalence in wild elk. Infected animals shed prions into the environment through saliva, feces, urine, and antler velvet, but little is known about how long animals live and shed prions once they become infected. While immunohistochemistry (IHC) is considered the gold standard for diagnosing CWD, it may not enable detection in animals in the early stages of infection. NWRC researchers and partners compared and assessed the ability of IHC and serial protein misfolding cyclic amplification (sPMCA) to detect CWD prior to the onset of clinical signs. They analyzed brain and lymph tissue samples from 85 wild elk to estimate the IHC and sPMCA tests' sensitivity and specificity. Sensitivity estimates were higher for sPMCA than IHC. Further analysis and modeling predicted that the prevalence of prion infection in elk may be higher than previously thought—18.9 percent versus prior estimates of 13 percent. Data also revealed a previously unidentified sub-clinical, prion-positive portion of the elk population that could represent silent carriers capable of significantly impacting CWD ecology. These findings have helped determine additional research needs and are taken into consideration by managers addressing CWD in captive and wild deer.

Preventing the Spread of CWD

A large focus of NWRC's CWD research has been on the ecology and behavior of wild and captive deer and elk and the development of simple management methods to prevent its spread. For instance, NWRC researchers conducted a suite of studies focused on deer and elk activity along game farm fences, the ability of deer to jump fences of various heights, and the design of effective barriers to prevent interactions between captive and free-ranging animals.

Deer can breach fences by going over, through, or under the structure. In studies with wild-caught deer, NWRC scientists determined that motivated deer cannot jump 8-foot or higher fences. The results from these studies have been critical in setting fence-height standards for security and containment of captive deer herds.

Direct and indirect contact through fences at captive elk farms may play a role in CWD transmission. NWRC researchers examined the effectiveness of a baited electric fence as an addition to an existing single woven-wire fence, for altering behavior and reducing fence-line contact between elk. Video surveillance cameras were used to monitor the test fence at a captive elk ranch. Researchers varied motivation levels between elk on either side of the test fence area. Motivation levels or animal groupings included separating bulls from cows during the mating season, separating cows from calves, and spreading sweet feed along the woven-wire fence. Prior to the installation of the electric fence, researchers documented 700 contacts between elk and the woven-wire fence. Following installation of the electric fence, contacts dropped to zero. This simple, inexpensive, baited-electric fence strategy provides a practical tool for reducing the potential for disease transmission between captive and wild elk.

In studies with wild caught captive white-tailed deer, NWRC scientists determined that deer cannot jump fences higher than 8 feet. This information has influenced fencing requirements for security and containment of captive deer herds.
Photo by USDA, Wildlife Services

Certain areas in the environment may serve as hotspots for CWD transmission. NWRC investigations into frequently used landscape features, such as mineral licks, wallows, and scrapes (i.e., a scratched out area of the ground where bucks urinate and leave glandular secretions from their hooves, eyes, and mouth), revealed these areas may contribute to the spread of prions among many free-ranging species. With the help of motion-activated cameras, NWRC scientists quantified deer and elk visits to these key sites and documented behaviors. Researchers concluded that the white-tailed deer breeding activity of establishing scrapes as signposts for communication are likely a means of disseminating and contracting CWD. Mineral licks are also likely sites for transmission of prions among deer, elk, and moose. As modes for disease transmission become better understood and decontamination methods are developed, this information will help pinpoint specific areas for management activities.

NWRC investigations of landscape features, such as mineral licks and wallows, revealed these areas may contribute to the spread of chronic wasting disease prions.
Photo by USDA, Michael Lavelle

Some spread of CWD has been attributed to the movement of captive deer and elk, but some CWD-infected areas have no captive animal facilities. NWRC researchers studied whether scavengers, such as American crows and coyotes, are able to pass CWD-positive tissue through their digestive systems and infect new areas. In laboratory studies, captive cervidized transgenic mice (i.e., mice containing the genetic material of the elk prion protein PrP) were inoculated with feces from American crows that were fed prion-positive material. All of the mice subsequently showed severe neurological dysfunction. Results suggest that prions can pass through a crow's digestive system intact. Therefore, if a crow scavenges on a CWD-positive carcass, it can potentially carry prions a long distance and deposit them, via feces, in new locations. A similar study with coyotes showed they also can pass infectious prions through their feces for at least 3 days after eating them and may play a role in the spread of prion diseases. Management efforts to remove CWD-infected carcasses and/or prevent bird and coyote scavenging may help to reduce prion dissemination by these routes.

NWRC scientists also investigated whether inhaling CWD prions found in soil and dust can cause disease. Researchers inoculated the nasal passages of captive white-tailed deer with a mixture of CWD-positive tissues and montmorillonite clay dust (a common soil in the United States). The deer were euthanized and samples were collected for analysis. Results showed that montmorillonite clay dust is an efficient carrier of CWD. NWRC scientists observed CWD in deer as early as 98 days after the last inoculation. This confirmed that animals can be exposed to CWD by simply inhaling windborne-infected dust. Understanding and quantifying the overall impacts of transmission risks from scavengers and the environment will be difficult, yet critical, next steps in the fight against CWD.

NWRC researchers studied whether scavengers, such as American crows and coyotes, are able to pass chronic wasting disease-positive tissues through their digestive systems and infect new areas. *Photo by Belwin Outdoor Science, trail camera*

Mitigating CWD Impacts

The captive cervid industry, meat processors, hunters, farmers, and others need effective methods and techniques for eliminating the spread of CWD and other transmissible spongiform encephalopathies (e.g., bovine spongiform encephalopathy, scrapie, Creudzfeldt-Jakob disease). NWRC scientists and partners conducted research on an enzymatic product that breaks down prion proteins and renders them harmless. Prions, the infectious agents of CWD, bind to a wide range of soils and minerals, potentially forming environmental reservoirs for infection. NWRC, the University of Nebraska-Lincoln, and Creighton University researchers tested the ability of the commercially available enzyme, Prionzyme, to degrade CWD prions in soil. Investigators concluded that Prionzyme which is produced by soil bacterium successfully degraded CWD prions bound to contaminated soil. Although it may be impossible to totally eliminate prions in the environment, a topical enzyme treatment could help limit indirect disease transmission to cervids in some areas. Also, this product potentially could be used to sanitize and decontaminate tools, surfaces, facilities, mineral licks, and other areas infected with transmissible spongiform encephalopathies.

NEXT STEPS—Recommendations for future CWD research include: evaluating the use of dogs to detect CWD-volatile organic compounds in the breath and feces of deer and elk, as well as in environmental samples, to aid in early detection; exploring targeted sex- and age-class removal of deer to reduce CWD's spread and prevalence; and characterizing and mapping CWD prion strains across the United States to determine if and how the disease is different or evolving in different regions.

Advances in technology have made small, unmanned aircraft systems (sUAS or drones) less expensive and more powerful. As a result, the devices are becoming useful tools for wildlife damage assessments and management.

SPOTLIGHT: Unmanned Aircraft Systems for Wildlife Damage Management

The U.S. military has long used small, unmanned aircraft systems (sUAS), also known as small drones, to protect troops, find enemies, and conduct damage assessments. With advances in technology, small drones have become less expensive, easier to use, and more powerful. As a result, these devices are increasingly more functional and practical options for a wide variety of users, including WS researchers and operations personnel.

The following section highlights recent research and training on the use of small drones for wildlife damage assessments and management.

Dispersing Birds From Crops, Fish Farms, and Airports

Upon first glance, people may think the object swooping over blackbirds in the North Dakota sunflower field is a hawk. But after taking a closer look, they will discover it is actually a small drone disguised as a bird of prey. Research wildlife biologist and leader of NWRC's North Dakota field station, Dr. Page Klug, hopes blackbirds feeding in the field are also fooled. Klug is one of several NWRC scientists investigating the use of sUAS to disperse birds from agricultural crops, airport environments, and aquaculture facilities.

"Scientists have learned that small drones cause antipredator behavior in some birds. When flown over or towards a flock, the aircraft cause the birds to disperse or seek cover," Klug says. "We want to see if the antipredator response by blackbirds varies by the type of sUAS platform and the direction of its approach. For instance, do more birds flee when the small drone is flown directly at them as opposed to overhead? And does the sUAS cause them to leave the crop field and forage somewhere else?"

With support from the National Sunflower Association, Klug and researchers from North Dakota State University (NDSU) conducted a study to evaluate the response of blackbirds to a multi-rotor sUAS flown at decreasing altitudes. Both captive and free-ranging flocks of red-winged blackbirds showed alert or escape responses to the multi-rotor sUAS when it was flown within 98 feet/30 meters above ground level and at lower altitude approaches. Results suggest that the sUAS' altitude is important to increase risk perception when used as a hazing device (i.e., at low altitude) or to minimize disturbance when monitoring populations (i.e., at high altitude).

In similar studies supported by the Federal Aviation Administration (FAA), Klug and researchers with NWRC's Ohio field station, NDSU, and Purdue University tested the effectiveness of three different sUAS designs—multi-rotor, fixed-wing, and raptor-shaped—for dispersing birds. Each sUAS design was flown towards foraging blackbird flocks in commercial sunflower fields, as well as captive birds. Results suggest that small drones designed to look like raptors (predators) are more effective at flushing individual birds than fixed-wing or multi-rotor models. However, flock size and landscape features, including the size of the sunflower field and adjacent roosting habitats, also influence the effectiveness of the small drone for hazing free-ranging blackbird flocks.

This hawk-shaped unmanned aircraft system is one of several platforms being evaluated for use in dispersing birds from agricultural crops. *Photo by Fish and Game New Zealand, Rudi Hoetjes*

"Foraging birds can cause millions of dollars in damage to crops and property," Klug concludes. "Small drones may be a nonlethal tool for dispersing blackbirds and other species from areas where they are not wanted, but context such as landscape and bird behavior likely influence their effectiveness. Our findings suggest that future research should focus on ways to enhance perceived risk posed by drones especially for larger flocks of birds."

In another study looking at the use of small drones for dispersing fish-eating birds from catfish ponds, researchers with the NWRC Mississippi field station and Mississippi State University (MSU) found no difference in effectiveness between small drones and traditional harassment methods, such as pyrotechnics, automatic exploders, effigies, lights, and human bird chasers. Although the frequency and intensity of traditional harassment methods (i.e., pyrotechnics and bird chasers) were greater than those of sUAS harassment at fish farms, their use did not result in fewer birds at the sites. Researchers believe that as an sUAS' battery life and its ability to perform in windy and wet weather continues to improve, the technology may become more adaptable and less costly than human harassment.

Building upon these findings, researchers at the NWRC Ohio field station are evaluating the usefulness of different small drone designs to disperse birds at airports, as well as ways to make existing sUAS platforms more threatening to birds. Additionally, researchers are partnering with airports that use small drones for wildlife management purposes in order to create best management practices and define logistics for flying in classified airspace.

Estimating Wildlife Damage

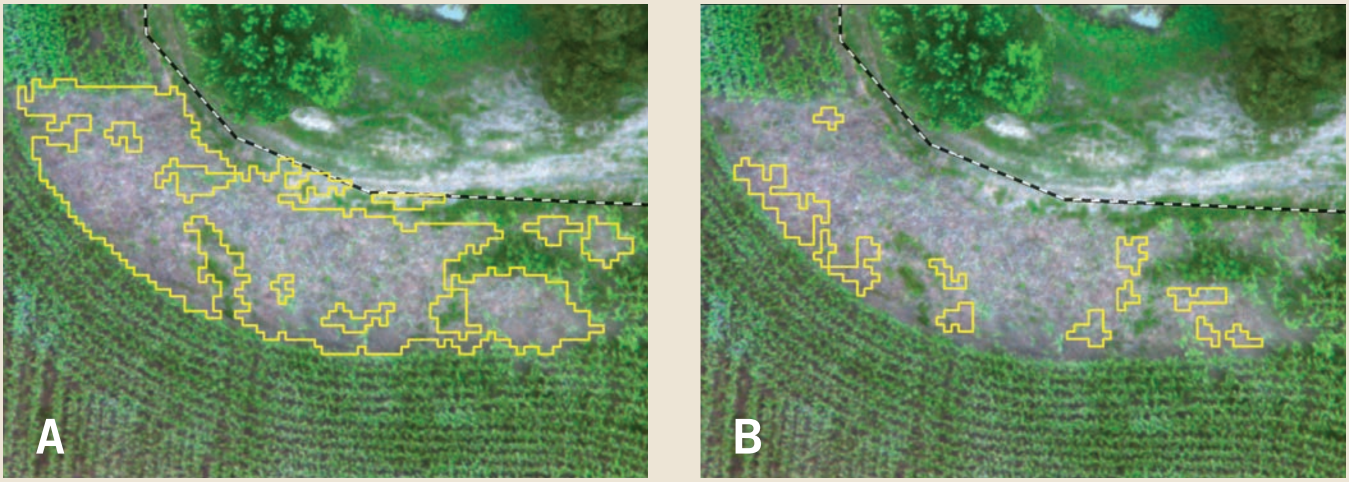
Small drones are proving to be valuable tools for estimating wildlife damage to crops and other resources. In the past, it has been difficult to locate and quantify damaged areas in commercial crop fields, especially when the damage is near the center of the fields versus their edges.

To help improve wildlife damage assessments, NWRC experts evaluated a new method that used multispectral high-resolution aerial imagery collected from sensors mounted on small drones, in conjunction with feature extraction software to detect and map damaged areas in agricultural fields.

"The sUAS provided us with a unique 'bird's-eye' view of the fields we were mapping," says NWRC wildlife biologist and GIS analyst Justin Fischer.

Combined with the multispectral imagery collected at very high spatial (2 to 4 inches/5 to 10 centimeters (cm)) and temporal resolutions (daily or hourly), and new classification software, NWRC researchers could detect, map, and estimate wildlife damage to a variety of resources. In 2019, they tested the method on cornfields damaged by feral swine in southern Missouri.

NWRC researchers conducted damage surveys of five cornfields using a 3DR Solo multirotor sUAS equipped with a RedEdge multispectral sensor. The sensor captured reflectance data—i.e., data about the light reflected from the cornfields' surface—in blue, green, red, red edge and near infrared spectral bands. Images were verified by ground surveys and



Estimates of feral swine damage to a cornfield using visible and near-infrared information *(left)* versus only visible information *(right)* collected from sensors mounted on small, unmanned aircraft systems. *Photo by USDA, Wildlife Services*

stitched together to form an orthomosaic—an aerial photo composed of multiple photographs that are scaled for accuracy and corrected for distortion. Areas damaged by feral swine generally had a unique spectral signature and textural pattern, compared to areas of undamaged corn or other areas in the fields. The accuracy of the damage estimates to cornfields ranged from 74 to 98 percent for combined visible and near-infrared information, compared to 72 to 94 percent for visible information alone.

"This approach provides a quick and efficient method for gathering quantitative information on feral swine damage to cornfields," notes Fischer. "We plan to conduct similar studies for other species and damage."

Small Drone Training for WS Employees

Since the program began in 2016, each year approximately 40 WS field specialists and biologists participate in a weeklong training course on "Basic Small Unmanned Aircraft Systems" hosted by the WS National Training Academy. The Academy, located at MSU, is the first institution in the United States dedicated to the training and instructional use of tools and techniques related to wildlife damage management. WS employees start the week learning the basics of maneuvering small, radio-controlled drones the size of their hands. By the end, they are piloting larger platforms.

"It may seem like play, but the goal of the small drone exercise is to learn the basic skills of maneuvering a sUAS before piloting larger, more expensive, camera-laden systems," says instructor and WS wildlife biologist Mark Lutman. "This course provides a mixture of classroom instruction, flight simulations, and outdoor flight training for field operations."

Like other government programs, WS sees the benefits of using small drones to help accomplish its mission. These devices are used to conduct wildlife damage assessments as well as to disperse and count wildlife.

Following the completion of the course, WS employees know how to conduct pre- and post-flight inspections, identify hazards, know the basics of aircraft, and have skills needed to use sUAS in the field. They also receive a WS Unmanned Aircraft System (UAS) Pilot Certificate that is required for sUAS field operations. The FAA also requires a written exam followed by a background check that must be renewed every 2 years.

Students of the Wildlife Services' Basic Unmanned Aircraft Systems (UAS) course talk with their instructor before trying their hand at flying the 3DR Solo *(in foreground)*. WS biologists use UASs to find and assess damage. *Photo by USDA, Gail Keirn*

In addition to gathering wildlife damage information, sUAS are also used by WS employees to estimate animal abundances, identify beaver dams, and haze wildlife from landfills, crop fields, and aquaculture ponds. Small drones have become another valuable tool in the toolbox for wildlife professionals.

NEXT STEPS—Future NWRC studies are combining sUAS with methyl anthranilate, a bird repellent, to determine if directly spraying the repellent at blackbird flocks may increase the likelihood of birds leaving crop fields. WS is also planning to provide advanced UAS training courses on night flying and UAS image processing.

SPOTLIGHT: Wildlife Hazards to Aviation

January 15, 2019, marked the 10th anniversary of the extraordinary landing of U.S. Airways Flight 1549, known as the "Miracle on the Hudson." After striking a flock of Canada geese and losing power to both engines, Captain Chesley "Sully" Sullenberger safely landed the plane on the Hudson River, saving the lives of all 155 people on board. It was a sober reminder of what can happen when wildlife and planes collide.

Many great strides have been made since the incident to improve aviation safety and reduce damaging strikes, with WS and its FAA partner leading the way. From 2009 to 2019, WS airport biologists and researchers have:

- Increased the number of airports receiving technical assistance from 755 in 2008 to 890 in 2017.
- Trained thousands of airport personnel in the identification and management of wildlife hazards to aviation. In 2017 alone, WS trained more than 5,000.
- Conducted wildlife hazard assessments and developed wildlife management plans for airports. In 2017 alone, this included 128 of the former and 189 of the latter.
- Captured and relocated more than 22,100 raptors from airports across the country.
- Maintained the National Wildlife Strike Database for the FAA.
- Conducted more than 120 research studies in support of the development of new tools and techniques for reducing wildlife hazards at airports.

Wildlife Services works with the Federal Aviation Administration to provide technical assistance aimed at reducing wildlife hazards at more than 850 U.S. airports. *Photo by USDA, Anson Eaglin*

WS experts strive to make skies safer for birds and people.

As aircraft become larger, faster, and quieter, and as airports grow, and air travel expands to new locations, research on ways to reduce wildlife hazards becomes more critical. Experts at NWRC's Ohio field station continue to explore and develop new tools for use at airports across the country and around the world. Some of their key accomplishments and discoveries include the following:

Habitat Modification at Airports

NWRC scientists have studied vegetation types and vegetation management practices to identify strategies for making areas on and near airports less attractive to wildlife.

The average commercial airport in the contiguous United States is approximately 2,000 acres. About 39 percent of that area is covered by grasses. However, few studies have evaluated the economics and safety of these grasses relative to other types of land cover. Managed turf grasses are expensive to maintain and can attract wildlife hazardous to aircraft, such as Canada geese, gulls, and large flocks of European starlings. Land cover that attracts fewer wildlife and generates income might provide an alternative to turf grasses on some portions of airport properties.

NWRC researchers and collaborators have studied the way birds respond to photovoltaic solar arrays—i.e., a collection of solar panels—on airports and adjacent airport grasslands in Arizona, Colorado, and Ohio, to determine whether photovoltaic solar arrays increase the risk of bird-aircraft collisions. Although researchers observed more birds in the areas with solar arrays than in the grasslands, those observed represented fewer and less hazardous species than those in the grasslands. The results suggest that even though birds were found in areas with solar arrays, the number and type of birds in those areas do not necessarily increase the risk of bird-aircraft collisions and do not conflict with safety regulations concerning wildlife at airports. Solar arrays play a major role in efforts to design and operate "greener" and safer airports.

In addition to birds, many large mammals are attracted to airports because of their surrounding habitats. NWRC, Mississippi State University (MSU), and University of Georgia researchers compared white-tailed deer and coyote use of two experimental fields: one with mixed, native warm-season grasses and one with switchgrass *(Panicum virgatum)*. Observing the fields via remote cameras, researchers found that coyotes and deer used the switchgrass field much less than the mixed, native warm-season grass field—27 percent and 51 percent less, respectively. Considering that deer and coyotes are among

Solar arrays play a major role in efforts to design and operate "greener" and safer airports.
Photo by USDA, David Bergman

the most hazardous mammal species to aircraft, fields of switchgrass may be a better alternative land cover around airports than native grasses.

NWRC scientists also identified several commercially available tall fescue grass varieties, including Titan LTD, 2nd Millennium, and Crossfire II, which grow successfully in airport environments, but are not a preferred food source for geese. These grasses and other land covers, such as switchgrass, may be planted on some portions of airport properties to discourage wildlife use.

Evaluating Avian Radar

Avian radar systems have the potential to track bird activities on and near airports during the day and night, providing real-time estimates of bird locations, altitude, and speed that could warn pilots and ground personnel of potential wildlife hazards. WS evaluations of the technology suggest they may be useful for monitoring bird flock activity at airports, but less so for monitoring single, large birds, such as raptors.

For example, experts with NWRC, WS Operations, and the University of Illinois evaluated the effectiveness of three X-band marine radar sensors for tracking birds and flocks of birds at Chicago O'Hare International Airport. Researchers used field observations to determine how often the radar sensors gave corresponding information on bird targets.

NWRC research shows avian radars may be useful for monitoring large flocks of birds at airports, but less so for monitoring single, large birds, such as hawks or eagles.
Photo by USDA, Wildlife Services

In total, there were 972 sightings of individual birds or flocks on the airfield. Of these, 143—approximately 15 percent—were tracked by at least 1 radar sensor. All confirmed tracks of individual birds or flocks were 3 miles/4.8 km or less from the radars. Larger bodied birds, birds/flocks flying at higher altitudes, and birds/flocks flying closer to the radars increased the radars' ability to detect and track them. When using avian radar to detect and track birds, wildlife managers could best apply this tool by placing the radar system within 2.5 miles/4 km of the landscape, habitat, or bird's suspected flight path.

Changing Lighting Systems on Planes

Birds frequently collide with buildings, wind turbines, and vehicles. Lights may help to alert birds and minimize the chances of collisions. But little is known about what kinds of lights work best to deter birds.

"Bird vision is different from human vision," says NWRC research wildlife biologist Dr. Brad Blackwell. "And bird species also differ in how they perceive objects."

In a recent study, Purdue University and NWRC researchers used perceptual models to find out which light emitting diode (LED) lights were most visible to brown-headed cowbirds, based on the specific wavelengths of the LEDs and the chromatic (color) and achromatic (white, grey, and black) contrast to background light conditions. The researchers then evaluated the birds' response to the lights—avoidance, attraction, or neutral—with a behavioral test.

Individual birds were released into an area where they moved in a single direction and had to choose a left or right exit. One of the exit routes included a lit LED light, the other an unlit LED light.

"Our findings suggest that brown-headed cowbirds significantly avoid exit routes with lit LED lights that have peaks at 470 nanometers (nm) (blue) and 630 nm (red), but do not avoid or prefer LED lights with peaks at 380 nm (ultraviolet) and 525 nm (green) or broad-spectrum (white) LED lights," continues Blackwell, referring to portions of the electromagnetic spectrum, including visible light. "It's important to note that these findings are limited only to steady lights under diurnal ambient light conditions, and to a single bird species."

However, the approach could be applied to a wide set of conditions and species. Identifying wavelength-specific lights for use as visual deterrents might help reduce bird collisions with stationary and moving objects, such as aircraft.

Damage and Risk Assessments

Bird collisions with aircraft cost the aviation industry more than $1 billion each year. NWRC scientists have conducted numerous studies to identify which wildlife species pose the greatest risk to aviation, which helps airport managers target management methods and strategies.

Recently, NWRC and the WS Aviation Hazards Program developed a model to estimate economic strike risks for different bird species. The model combines the relative hazard score (RHS) and bird strike frequency for common bird species found at airports. RHS is the percentage of total strikes for each species that results in damage, substantial damage, or a negative effect on the aircraft's flight (e.g., delay, emergency landing). It provides an index of severity, not frequency.

Of the 11,364 bird strike records and 79 bird species studied, red-tailed hawks, Canada geese, turkey vultures, pigeons, and mourning doves posed the greatest risk (i.e., frequent and damaging collisions) to aircraft across the United States.

Wildlife Services airport biologists help to reduce collisions between birds and aircraft by capturing and relocating hawks and owls away from airport environments. *Photo by USDA, Wildlife Services*

Researchers encourage airport wildlife biologists to adapt the model to their airport-specific strike data and use standardized bird surveys, corrected for detection bias, to prioritize management efforts at their airports.

NEXT STEPS—The NWRC Ohio field station plans to continue its research on the design of aircraft lighting to enhance detection of approaching aircraft and avoidance response by birds; developing and enhancing civil and military strike risk metrics; and evaluating movement ecology of hazardous birds near airports. Researchers also will focus on the effectiveness of live-capture and translocation programs for raptors and seabirds. New research will evaluate the effectiveness of small drones as wildlife hazing and monitoring tools at airports, as well as the use of camera-trap data to model habitat use by white-tailed deer, coyotes, and other mammals at airports and other environments.

2019 Accomplishments in Brief

NWRC employs about 150 scientists, technicians, and support staff who are devoted to 16 research projects (see Appendix 1). Below are brief summaries of select findings and accomplishments from 2019 not already mentioned in this year's report.

Devices

- **Machine Learning To Identify Animals in Camera Trap Images.** Motion-activated cameras (also known as camera traps or trail cameras) often are used to remotely observe wildlife. Wildlife studies involving camera traps result in millions of images that must be viewed in order to extract data for ecological analyses. To help reduce the amount of time required to review such images, NWRC and APHIS' Veterinary Services, as well as State, non-profit, and university partners, used more than 3 million known wildlife images to train and test a deep learning model to classify species of wildlife captured on camera traps. The trained model classified approximately 2,000 images per minute on a laptop computer with 16 gigabytes of RAM. The trained model achieved 98-percent accuracy in identifying U.S. wildlife species, the highest accuracy of such a model to date. The tool is available as an R package (Machine Learning for Wildlife Image Classification) that allows users to either 1) use the existing trained model, or 2) train their own model using images of wildlife from their studies. Such a tool will improve the efficiency of camera traps for wildlife studies.
  Contact: Kurt VerCauteren

- **Reducing Injury and Flight Response When Capturing Feral Swine.** Research on the ecology, behavior, and movements of feral swine often involves the immobilization of study animals in

Capturing and immobilizing feral swine can be challenging because the animals are easily agitated. NWRC researchers observed a reduction in feral swine stress-related behaviors when corral traps were enshrouded with a visual barrier.
Photo by USDA, Michael Lavelle

order to attach global positioning system (GPS) collars or other monitoring devices. In this process, it is important to minimize stress and injury to the animals. Immobilizing feral swine can be challenging because feral swine often are trapped in large groups and can easily become agitated. NWRC researchers evaluated two trap modifications for reducing feral swine stress and injuries. One involved the use of tightly spaced wire mesh for trap walls, and the second enshrouded traps with a visual barrier prior to handling. Results from tests involving 148 feral swine in corral traps showed that the tightly spaced wire mesh panels (10.2 by 5.1 cm) reduced animal injuries by 88 percent compared to more widely spaced mesh sizes. Researchers noted a rapid reduction in stress-related behaviors from feral swine when traps were enshrouded. Enshrouding corral traps also facilitated a 28-percent quicker delivery of chemical immobilization drugs via darting as feral swine became inactive. Researchers recommend using tightly spaced mesh panels to reduce trap-related injuries and incorporating trap shrouds to help with the delivery of chemical immobilization drugs when handling feral swine.
Contact: Michael Lavelle

Pesticides

- **Feasibility of Four Toxicants for Use with Invasive Small Indian Mongooses.** The eradication or control of invasive small Indian mongooses from islands, such as Hawaii, likely requires toxic baiting when trapping proves insufficient. The one toxic bait currently registered for mongooses in the United States has relatively low palatability and efficacy for mongooses. NWRC researchers conducted a product feasibility assessment of four toxicants, comparing the costs and requirements of U.S. Environmental Protection Agency (EPA) registration and the use potential of each in baits for mongooses. The toxicants are bromethalin, diphacinone, para-aminopropiophenone (PAPP), and sodium nitrite (SN). A diphacinone bait was estimated to be the cheapest and fastest to register with EPA and had more application methods. On the negative side, the time to death following exposure and onset of symptoms was longer for diphacinone than the other toxicants. However, this interval provides time for administering an antidote following an accidental exposure. The use of a bromethalin, PAPP, or SN bait would likely be limited to bait stations or burrow baiting due to the baits' risks to non-target species. A bromethalin bait would be the cheapest and fastest to register of the three, particularly if an existing, commercially available bait proved efficacious for mongooses. A PAPP bait would be slow and the most expensive to register. An SN bait would be challenging to formulate into a palatable bait with a reasonable shelf life. This feasibility assessment serves as a template for managers considering the development of toxicant products for vertebrate pest species.
Contact: Emily Ruell

- **DRC-1339 Residue Levels in Bird Tissues.** DRC-1339 (also known as 3-Chloro-4-methylaniline hydrochloride) is a slow-acting bird toxicant registered for controlling blackbirds, European starlings, pigeons, collared doves, gulls, magpies, crows, and ravens that damage agricultural crops and property, or prey upon federally listed threatened or endangered species. Time to death for birds that eat bait coated with DRC-1339 is 1 to 3 days. Public concerns exist regarding non-target species exposure to DRC-1339, through animals eating dead or dying birds treated with DRC-1339. To improve upon methods of detecting and measuring DRC-1339 residues in bird tissues, NWRC chemists combined a new method (gas chromatography in tandem with mass spectrometry) with improved extraction techniques. Gas chromatography uses heat to separate individual substances in a mixture while mass spectrometry identifies the substances based on their mass. To evaluate the new method, NWRC chemists randomly assigned 37 red-winged blackbirds to groups and exposed them to 1 of 3 doses of purified DRC-1339. After 3 days, the chemists humanely euthanized the birds and collected tissue samples for analysis. The limits of detection (DL) for previously reported methods for detecting DRC-1339 residues were between 12 and 25 nanograms per gram for breast, gastrointestinal tract, liver, or kidney tissues. The new method showed DL between 2.6 and 5.9 nanograms/grams for breast, gastrointestinal tract, liver and kidney tissues. The recovery of DRC-1339 residues in the tested birds averaged 101 percent in liver, 98.8 percent in GI tract, 92.9 percent in breast muscle, and 87.9 percent in kidney tissues. This increase in precision allows for greater confidence in secondary hazard studies and risk assessments associated with the use of DRC-1339. *Contact: David Goldade*

DRC-1339 is a slow-acting bird toxicant registered for use with European starlings *(shown)* and several other bird species. NWRC chemists developed a new method for detecting DRC-1339 residues in bird tissues, which will aid in secondary hazard studies and risk assessments. *Photo by USDA, Wildlife Services*

- **Biomarker Used To Estimate Potential Feral Swine Population Reduction**. Researchers with NWRC, Texas Parks and Wildlife Department, Invasive Animal Cooperative Research Center, and Animal Control Technologies Australia Pty Ltd. are developing a feral swine toxic bait containing the active ingredient SN. To gather information on how a future toxic SN bait might reduce feral swine populations, researchers conducted tests using a placebo (i.e., nontoxic) bait with the biomarker rhodamine B. This is a dye that causes fluorescent bands in growing vibrissae (i.e., whiskers) of many mammals. Following baiting in three areas of Texas with a rhodamine B-treated placebo bait, researchers collected whiskers from 400 non-collared and 28 GPS-collared, free-ranging feral swine for evidence of bait consumption. Results showed that 91 percent of the feral swine within 0.5 miles/0.75 km of the bait sites ate the simulated toxic bait, exposing them to possible lethal effects. Bait sites spaced 0.5 to 1.0 miles/0.75 to 1.5 km apart achieved optimal delivery of the bait, but feral swine ranging more than 1.8 miles/3 km away also were susceptible.

Using free-roaming radio-collared feral swine and placebo bait treated with a biomarker, NWRC researchers demonstrated the potential for an oral baiting strategy to expose a large proportion of feral swine to a toxic bait.
Photo by USDA, Wildlife Services

Non-target species were not able to access the bait in bait stations that were designed specifically for feral swine. These findings demonstrate the potential for exposing a large proportion of feral swine in an area to a toxic bait.
Contact: Nathan Snow

Other Chemical and Biological Methods

- **Environmental Factors That Influence eDNA Sampling.** When using environmental DNA (eDNA) to determine whether a species is present in an area, many factors, such as environmental conditions (e.g., water temperature and pH level), DNA availability, and assay specificity and sensitivity can influence the results. In order to account for these uncertainties and improve the accuracy of eDNA sampling, NWRC researchers evaluated the eDNA collection processes and methods for detecting feral swine at 12 collection sites in Bexar County, Texas. Because feral swine use water bodies for drinking and wallowing, and are widely distributed, they are a good species for evaluating the potential application of eDNA. Images from trail cameras at collection sites helped assess whether eDNA was successfully collected from sites with documented feral swine. Results showed that eDNA sampling for feral swine is influenced by the conditions of the water body sampled, as well as by laboratory processes. Researchers recommend collecting a minimum of 10 water samples per site and processing the samples in the laboratory sequentially, stopping once a detection threshold is reached to reduce laboratory costs. Researchers note the availability of DNA varied by month and was considerably higher when water pH was near neutral. These factors must be accounted for, otherwise estimates of species presence may be biased, which could have serious implications for conservation or invasive species management.
Contact: Amy Davis

- **Microsatellite Loci for Black and Turkey Vultures.** The black vulture and turkey vulture are well adapted to human-dominated landscapes in the United States. As their populations have increased, so too have reports of property damage, livestock depredations, and aircraft safety issues associated with them. NWRC and USGS researchers used next-generation genetic sequencing to develop microsatellite loci for use in future genetic studies on black and turkey vultures. Microsatellite loci are markers that identify tracts of repetitive DNA in an organism's genome. These markers can be used to reliably assess genetic diversity, gene flow between populations, relatedness among individuals within a population, demographic parameters, and population boundaries for species. Researchers

NWRC and U.S. Geological Survey geneticists used next-generation sequencing to learn more about black vulture genetics. When combined with ecological field studies, this information helps biologists understand the ecology of black vultures across their range. *Photo by USDA, Gail Keirn*

collected tissue and blood samples from black and turkey vultures and characterized 11 microsatellite loci for black vultures and 14 loci for turkey vultures. When combined with ecological field studies, such as satellite telemetry studies, this information will help biologists and natural resource managers to better understand the ecology of black and turkey vultures across their ranges.
Contact: Toni Piaggio

- **Improving the Accuracy of Detection Dog Surveys.** Detection dogs—domestic dogs specially trained to find and/or identify specific animal scat or specimens—are valuable tools for conservation and wildlife damage management. The dogs help land managers and others determine the presence or absence of certain animals in an area through these detection techniques. Sometimes, however, non-target scat samples inadvertently are collected during detector dog surveys. NWRC, Nebraska Game and Parks Commission, and Washington University researchers and their partners at PackLeader Dog Training LLC, conducted a series of tests to determine whether non-target wildlife and target wildlife species behavior, such as urine-marking, eating, or moving scat with their mouths, contaminates scat samples and alters the accuracy of detection dog surveys. Results show target species' scat can be contaminated by non-target species' DNA, and vice versa. Because detection dogs locate scat based on odor, the collection of samples with mixed olfactory profiles (target and non-target species) is possible. Only genetic testing can uncover misidentified scat samples. Researchers note additional costs may arise from non-target scat collection. This can be reduced by: (1) training dogs on a variety of scat samples (e.g., different diet, individuals, sex and age) for both target and non-target species; (2) removing old scat from areas of non-target species overlap prior to conducting surveys; and, (3) using sample collection and storage protocols that optimize DNA quality.
  Contact: Julie Young

- **Immobilization Drugs for Use with Feral Swine.** Immobilizing feral swine is challenging. Drug combinations commonly used often result in unsatisfactory immobilization, poor recovery, and adverse side effects, leading to unsafe handling conditions for both animals and people. NWRC researchers and partners compared four chemical immobilization drug combinations to determine which might be most effective for use with feral swine. The drug combinations were medetomidine–midazolam–butorphanol (MMB), butorphanol–azaperone–medetomidine (BAM), nalbuphine–medetomidine–azaperone (NalMed-A), and tiletamine–zolazepam–xylazine (TZX). Of the four, MMB performed most optimally for immobilization and recovery of feral swine, with no post-recovery illness or injury.
  Contact: Kurt VerCauteren

- **Understanding Bird Vision: Implications for Management.** Birds perceive the world very differently from people. Understanding how birds see—their visual acuity, field of vision and color vision—provides insights into how birds interact with each other, respond to predators, and identify food resources. NWRC and university scientists studied the visual system of red-winged blackbirds, one of the most abundant and most studied birds in North America. Researchers discovered that blackbirds have a relatively wide field of vision and are, therefore, able to gather information about foraging opportunities (watching other birds finding food) and potential risks (predators) while their heads are down in a foraging posture. Researchers were also able to measure the binocular and lateral fields of vision and estimate the distances by which red-winged blackbirds can detect other blackbirds or predators based on their eye structure. For instance, red-winged blackbirds are likely able to identify a Cooper's hawk from 915 feet/279 meters away and a raccoon from 1,670 feet/509 meters based on visual stimuli, such as motion, size, coloration and contrast. Red-winged blackbirds are also sensitive to the ultraviolet (UV) portion of the spectrum. Such information on bird vision aids in the development of species-specific perceptual models and damage management tools, such as nonlethal repellents.
  Contact: Scott Werner

Understanding how birds see provides insights into how birds interact with each other, respond to predators, and identify food resources. NWRC and university scientists studied the avian vision of red-winged blackbirds, one of the most abundant birds in North America.
Photo by USDA, Kevin Keirn

Disease Diagnostics, Surveillance, Risk Assessment, and Management

- **Predicting the Spread of Influenza A Virus in Wild Waterfowl.** Wild waterfowl and shorebirds are natural reservoirs for influenza A viruses (IAV). Some IAVs are considered highly pathogenic, causing high mortality in domestic poultry, but limited mortality in wild waterfowl. Using data from hunter-harvested and live-captured banded ducks, NWRC, and USGS scientists identified hotspots for waterfowl activity in the Pacific flyway of the United States. These hotspots were then used in targeted disease surveillance to predict the occurrence and movement of a novel IAV (clade 2.3.4.4) introduced from Asia by waterfowl during a 2014 outbreak in North America. Scientists also tested whether the IAVs were detected more readily inside the hotspots versus other sampled areas. Results found that the hotspots were useful in predicting areas with higher virus prevalence. This approach demonstrates the value of using waterfowl ecological and behavioral data to help target disease surveillance activities and predict risk to agricultural operations.
  Contact: Alan Franklin

- **Maternal Antibodies to Avian Influenza Virus in Mallard Ducklings.** Wild waterfowl are hosts of most IAV subtypes and are often the subjects of IAV surveillance and disease modeling. While maternal antibodies have been detected in egg yolks and in nestlings for a variety of wild bird species and pathogens, the persistence of maternal antibodies to IAVs in mallard ducklings *(Anas platyrhynchos)* has

Avian influenza research at NWRC found that more than 70 percent of mallard ducklings had detectable maternal antibodies to influenza A virus for 4 to 17 days after hatching, thus temporarily protecting the ducklings from infection. *Photo by USDA, Susan Shriner*

not been previously investigated. This information is important for a full understanding of the spread of IAV among birds because ducklings protected by maternal antibodies may not be susceptible to infection. In this study, NWRC and Colorado State University (CSU) researchers examined the transfer of IAV-specific maternal antibodies to mallard ducklings. Blood samples were collected and analyzed for antibodies every 5 days from ducklings hatched from mallard hens previously infected with an H6 strain of IAV. Seventy-one percent of ducklings had detectable maternal antibodies from 4 to 17 days post-hatch, while a small subset of individuals (29 percent) had detectable maternal antibodies for 21 to 33 days post-hatch. Antibody concentrations in hens near the time of egg laying correlated with maternal antibody concentrations. This information aids in the interpretation of IAV surveillance results and disease modeling.
Contact: Susan Shriner

- **Viral Shedding of Avian Influenza by American Robins.** Although waterfowl are considered the primary reservoir hosts of avian IAVs, recent studies have suggested that passerines (songbirds) may play a role in IAV ecology. American robins *(Turdus migratorius)* are commonly found near farms in the United States. In 2015, IAV antibodies were documented in two American robins near a poultry production facility affected by a highly pathogenic (HP) H5 virus in Iowa. To determine if American robins can replicate and shed select HP IAVs, NWRC researchers experimentally infected 24 robins with HP H5N2 and H5N8 viruses. Twenty-two of the 24 infected birds shed the virus for up to 6 days post-infection. This study adds the American robin—an additional wildlife species commonly found near farms and other human-populated areas—to a growing list of animals that can successfully replicate and shed some IAVs.
Contact: Jeff Root

- **Role of Feral Swine in IAV Ecology.** Each year, respiratory disease due to IAV results in 290,000–650,000 human deaths worldwide. The human IAV pandemic of 2009–2010 that originated from a virus reassortment event in domestic swine highlights the role swine can play in the global dynamics of human IAVs. Transmission of IAVs between swine and people occurs in both directions, and reassortment of swine IAV strains with avian and human IAV strains is well documented. However, little is known about the role of feral swine in IAV ecology because disease surveillance in feral swine often looks at antibodies (serosurveillance) which are not necessarily indicative of current infection risk. Building upon what is known about IAV infection in people and domestic swine, and integrating it with feral swine antibody data from 15 States, NWRC researchers and partners created a framework for understanding IAV infection risk in feral swine across seasons and regions. Researchers

found a positive correlation between IAV trends in domestic swine and people, and IAV infection risk in feral swine. Similar to domestic swine, the analyses revealed that IAV infections in feral swine occurred year-round, but that infection risk was highest from January to March. Results also suggested that predicting IAV infection risk in feral swine is complicated by local ecological factors (i.e., climate) and by the potentially long-distance translocation of infection through the illegal movement of feral swine. In addition to revealing factors of IAV infection risk in feral swine, researchers note the framework can be used to determine risk factors for other diseases using opportunistic serosurveillance sampling.
Contact: Kim Pepin

- **Biomarkers for Use with Mongoose Oral Rabies Vaccine**. The small Indian mongoose *(Herpestes auropunctatus)* is a reservoir of rabies virus in Puerto Rico and comprises over 70 percent of animal rabies cases reported annually. Oral rabies vaccination (ORV) is the primary strategy used to control rabies in wildlife reservoirs, but currently no wildlife ORV program exists in Puerto Rico. Research into oral rabies vaccines and optimal bait types for mongooses has been done in Puerto Rico with promising results. To help evaluate ORV strategies targeting free-ranging mongooses in Puerto Rico, NWRC researchers tested the effectiveness of two biomarkers (ethyl-iophenoxic acid and methyl-iophenoxic acid) incorporated into placebo ORV baits to estimate bait uptake by captive mongooses. A biomarker is a measurable substance in an animal that can indicate it has at least partially eaten a bait. Researchers fed biomarker-treated baits to mongooses and collected blood samples from mongooses prior to treatment, one day post-treatment, and then weekly up to 8 weeks post-treatment. Results showed mongooses that ate greater than or equal to 25 percent of the marked baits had robust short- and long-term (4 to 8 weeks) levels of iophenoxic acid biomarker in their blood, which will be useful in evaluating future ORV programs for mongooses on Puerto Rico.
Contact: Are Berentsen

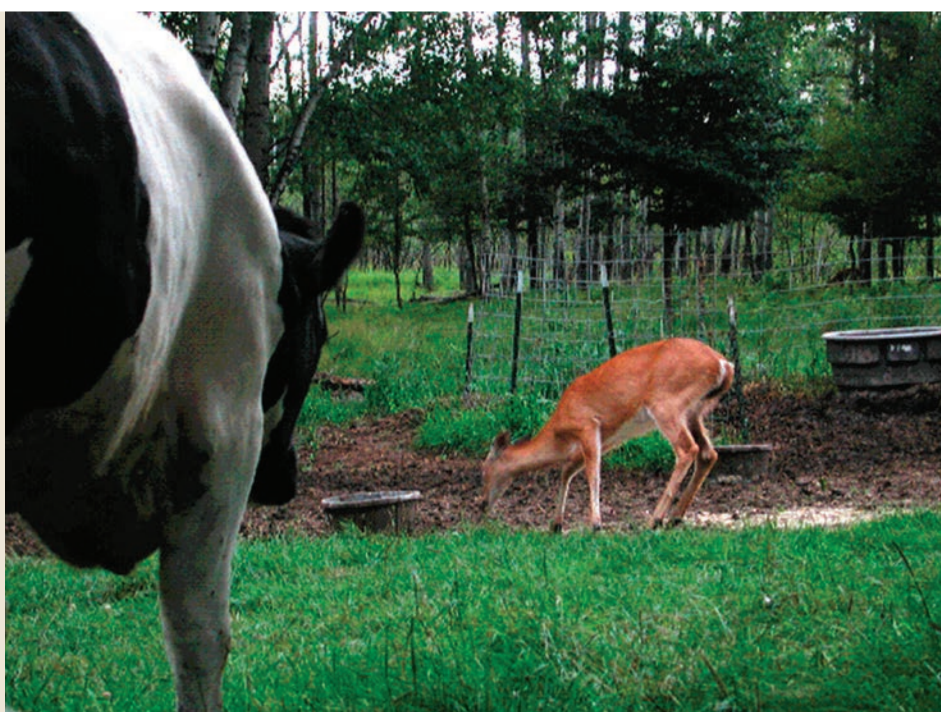
To help evaluate oral rabies vaccination (ORV) strategies targeting free-ranging mongooses in Puerto Rico, NWRC researchers tested the effectiveness of two biomarkers incorporated into placebo ORV baits to estimate bait uptake by mongooses. A biomarker is a measurable substance in an animal that indicates bait consumption.
Photo by USDA, Wildlife Services

- **Modeling Differences in Disease Hosts.** Multiple animal species often play a role in the transmission and maintenance of a pathogen. Understanding the relationships among these species and the differences in their abilities to host and transmit an infection can help identify species that are disproportionately contributing to the maintenance and persistence of the pathogen in a community.

NWRC, CSU, Michigan State University, and University of Wisconsin-Stevens Point researchers developed a network-based analysis to explore how individual- and species-level differences influence contact rates among individual animals. Contact data from proximity loggers placed on raccoons, white-tailed deer, Virginia opossums, and cattle on four farms in Michigan's Lower Peninsula were used to estimate contact structure in a community of hosts capable of transmitting *Mycobacterium bovis (M. bovis)*, the bacterium that causes bovine tuberculosis (bTB). Bovine tuberculosis (bTB) is a chronic disease that affects cattle, wild mammals, and people. It can spread via direct host-to-host contact or through indirect contact with the bacteria *M. bovis* in the environment. Researchers (1) explored how management methods, such as the installation of deer fences, to control the spread of bTB can alter animal contacts, and (2) predicted the role that different wildlife species have in maintaining bTB in the community. Importantly, the analysis showed that the full host community was important for disease persistence, while persistence was less probable if only a single host species was considered. This suggests that controls may need to target the host community, rather than single host species. Researchers also found that the installation of deer fences significantly reduce indirect contact rates between deer and cattle. This analysis illustrates the importance of differences among individual- and species-level disease hosts and the importance of using a multi-prong approach for managing bTB at the wildlife-livestock interface. *Contact: Kim Pepin*

- **Preventing Pathogen Spillover.** Pathogen spillover, or the transmission of infections among species, can occur from animals to people, from people to animals, or even from environmental reservoirs to animals and people. Environmental change—including deforestation, habitat fragmentation, or climate change—can create new opportunities for pathogens that were previously circulating

Multiple animal species often play a role in the transmission and maintenance of a disease. NWRC researchers used data from proximity loggers placed on raccoons, white-tailed deer, Virginia opossums, and cattle on farms in Michigan to estimate host-to-host and indirect contact between these species.
Photo by USDA, Wildlife Services



only in wildlife or environmental reservoirs to spill over into people or livestock. A group of national and international researchers, including NWRC scientists, has proposed the use of novel ecological interventions to reduce disease spillover. Methods, such as preventing wildlife-livestock contact, limiting the amount of time birds are at live-bird markets, and stocking mosquito predators in mosquito breeding habitats, may be used in addition to traditional medical and veterinary approaches to help reduce disease spillover with minimal environmental damage. Ecological interventions can be complementary to traditional methods, such as culling and vaccination, which are often reactive, short-lived, and target different aspects of the spillover process. Researchers conclude that the use of ecological interventions might offer new cost-effective, socially acceptable, sustainable methods to reduce spillover risk. *Contact: Kim Pepin*

- **Managing Pathogen Spillover.** Managing pathogen spillover at the wildlife–livestock interface is crucial towards improving global animal health, food security, and wildlife conservation. However, predicting the effectiveness of management actions across multiple host–pathogen systems is challenging. NWRC, Veterinary Services, USGS, Idaho Department of Fish and Game, and multiple university scientists developed a simulation model to explore the effectiveness of different management strategies based on host movement patterns and epidemic growth rates. The model suggested that fast-growing, fast-moving epidemics (e.g., avian influenza) were best managed with actions (e.g., biosecurity or containment) that limited and localized overall spillover risk. For fast-growing, slower moving diseases like foot-and-mouth disease (FMD), depopulation or preventative vaccination were effective management options. Many actions performed well when epidemics grew slowly and host movements were limited. The model provides a useful framework for disease management at the wildlife–livestock interface based on general epidemiological traits. *Contact: Kim Pepin*

- **Hunting and the Spread of Disease.** Recreational hunting has been proposed by community groups as a method to control wildlife disease. However, hunting in general and hunting with dogs in particular may affect the prevalence of disease in hunted wildlife due to chronic stress and immunosuppression. Hunting with dogs increases the stress levels of both the targeted animal and the animals pursued but not killed. NWRC and University of Florida scientists, along with WS Operations experts, compared the prevalence and exposure of two non-native pathogens—pseudorabies virus and *Brucella* spp.—in 2,000 feral swine serum samples from areas that allow hunting with dogs and areas that use trapping or shooting without pursuit. Results showed the likelihood of exposure to pseudorabies

Hunting may affect the prevalence of disease in wildlife due to chronic stress and immunosuppression. NWRC research showed that the likelihood of exposure to pseudorabies and co-exposure to pseudorabies and *Brucella* was significantly higher in feral swine that were hunted by dogs than those that were harvested by other methods. *Photo by USDA, Wildlife Services*

and co-exposure to pseudorabies and Brucella was significantly higher in feral swine that were hunted by dogs than those that were harvested by other methods. This pattern did not hold for *Brucella* alone. Researchers note the impact of hunting dogs on the emergence of pathogens has the potential to affect public health, the livestock industry, and wildlife conservation.
Contact: Kurt VerCauteren

- **Pseudorabies in Hunting Dogs.** Pigs *(Sus scrofa)* are the natural hosts of pseudorabies virus (PRV), also known as Aujeszky's disease. Infection in susceptible mammals other than pigs typically causes extreme itching, facial swelling, and excessive salivation, followed by death. When PRV was eliminated from commercial swine in the United States in 2004, it was thought that the risk to mammals decreased. However, the virus remains in feral swine populations. Infected feral swine pose a threat to the disease-free status of the commercial swine industry and to other animals, including dogs that come into direct or indirect contact with them. Pseudorabies may also impact endangered species, such as the Florida panther. NWRC researchers documented the progression of pseudorabies infection in dogs in two States after exposure to feral swine. The first case occurred in a dog in Alabama after it participated in a competitive wild hog rodeo. The second case occurred in multiple dogs in Arkansas that participated in hunting feral swine, and subsequently ate offal (e.g., entrails and internal organs) from the killed animals. Although approximately 18 percent of U.S. feral swine are likely to have had PRV at some time, county-level or local prevalence varies widely. Researchers caution dog owners that their animals are at high risk of exposure to pseudorabies if the dogs are used to hunt feral swine in the United States.
Contact: Tom Gidlewski

- **FMD Introduction into the United States.** FMD affects domestic and wild cloven-hoofed species, such as cattle, sheep, goats, and pigs. FMD is one of the costliest animal diseases in the world. Estimates indicate that FMD costs between $6.5 and $21 billion annually in endemic countries, with the main costs attributed to production losses and vaccination. As part of a risk analysis, NWRC researchers identified vulnerabilities that could lead to FMD introduction or persistence in the United States or other FMD-free regions. The legal movement of susceptible live animals, animal products, by-products, and animal feed containing animal products poses a risk of FMD virus introduction and spread. Additionally, the illegal movement of FMD-susceptible animals and their products, and an act of bioterrorism, present additional routes of FMD introduction. Therefore, robust surveillance and rapid diagnostics in the face of a possible introduction are essential for detecting and controlling FMD as quickly as possible. Researchers note wildlife species and feral swine complicate an FMD outbreak response since wildlife often are not closely monitored or managed, and there are logistical concerns related to disease surveillance and control in wildlife populations.
Contact: Sarah Bevins

- **Prevalence of Bourbon Virus Antibodies in Wild Mammals**. Since its discovery in 2014, Bourbon virus (BRBV) has been isolated from one person and ticks, but its prevalence in birds and mammals is unknown. Symptoms of people diagnosed with BRBV disease included fever, tiredness, rash, headache, body aches, nausea, and vomiting. Some infected people have died. Researchers with the Centers for Disease Control and Prevention (CDC) and CSU partnered with NWRC to screen blood samples from 301 birds and mammals for BRBV-neutralizing antibodies which indicate if an animal has been previously infected with the

virus. Forty-eight of the 156 mammal samples tested—31 percent—were positive for BRBV antibodies. Mammals with evidence of past infection included dogs, cottontail rabbits, horses, raccoons, and white-tailed deer. None of the bird samples tested positive for BRBV antibodies. These findings are useful for future public health efforts and for understanding the ecology of BRBV. Researchers note that raccoons and white-tailed deer are potential candidate wildlife sentinels for monitoring BRBV transmission risk.
Contact: Tom Gidlewski

- **NWDP Surveillance Accomplishments.** Each year, WS' National Wildlife Disease Program (NWDP) conducts and coordinates wildlife disease monitoring and surveillance throughout the United States. Below is a summary of its 2019 efforts.

ISSUE	SURVEILLANCE EFFORTS
Avian Influenza	Approximately, 1,300 samples collected from wild birds in the Pacific Flyway (Alaska and California) and tested for highly pathogenic avian influenza. Suspect samples were further evaluated at the National Veterinary Services Laboratories.
Feral Swine Diseases	More than 3,500 feral swine from 31 States, plus Guam and Puerto Rico, sampled. Serum samples were tested for antibodies to classical swine fever, swine brucellosis, and pseudorabies virus. Selected tissues from over 300 feral swine were collected for genetic research.
Plague and Tularemia	Over 1,200 samples collected, mainly from coyotes.
Ticks	Ticks and blood samples collected from over 180 wild mammals in 10 States. The information assists in estimating tick species distributions and disease prevalence in the United States, as well as identifying wild mammal host species. In the United States, reports of tick-borne diseases in people have doubled in the past 15 years.

Table 2. NWDP wildlife disease surveillance activities for 2019

Wildlife Damage Assessments

- **Bird Hazards to Military Aircraft.** Although trends pertaining to wildlife collisions with civil aviation have been recorded since the 1990s, little is known about trends in collisions between birds and military aircraft. NWRC researchers used data from approximately 37,000 bird strikes involving U.S. Navy and U.S. Air Force aircraft to calculate relative hazard scores (i.e., the likelihood of aircraft damage when a species is struck) for a variety of bird species. Results showed the most hazardous bird species to military aircraft include the snow goose *(Anser caerulescens)*, followed by the common loon *(Gavia immer)*, Canada goose *(Branta canadensis)*, and black vulture *(Coragyps atratus)*. In addition, birds damaged cargo, fighter, stealth, and rotorcraft airframes differently. Relative hazard scores were highest for stealth airframes, likely due to the airframe's specialized and sensitive equipment. Researchers recommend airport wildlife biologists prioritize management of species with high relative hazard scores, absent estimates of species strike risk, when developing airfield wildlife management plans.
Contact: Morgan Pfeiffer and Brad Blackwell

Understanding how birds react to approaching aircraft can help predict and mitigate bird strike risks, such as this collision between a red-tailed hawk and military plane. *Photo by USDA, Wildlife Services*

- **Bird Responses to Aircraft.** Understanding how different bird species react to approaching aircraft in different scenarios can help predict and mitigate bird strike risks. NWRC and Purdue University researchers, along with WS Operations experts, characterized the behavioral responses of American kestrels *(Falco sparverius)*, European starlings *(Sturnus vulgaris)*, killdeer *(Charadrius vociferous)*, mourning doves *(Zenaida macroura)*, and red-winged blackbirds *(Agelaius phoeniceus)* to aircraft (propeller-driven, jet, rotorcraft) and aircraft approach (taxi, takeoffs, landings) at Burke Lakefront Airport in Ohio. Researchers defined three categories of aircraft approach—direct (bird in line with approaching aircraft), tangential (bird within 1.5 wing spans or rotor lengths from wing or rotor tip), and infield (bird beyond 1.5 wing spans or rotor lengths). Across the five species, birds directly approached by aircraft were over 2 times more likely to initiate escape (i.e., move away) as those approached indirectly (tangential or infield). The larger mourning dove was more likely than the other species to move away from the aircraft, regardless of whether the approach was direct or indirect. As flock sizes increased, birds were more likely to move away from approaching aircraft. Birds were twice as likely to move away when approaches involved jets versus propeller-driven airframes. Researchers note that larger birds, because of the hazards they pose to aircraft, often are managed more vigorously than smaller birds. However, researchers found that smaller species were less likely to initiate escape response, so airport wildlife biologists and airport managers should manage for smaller species as well. These findings underscore the importance of developing methods to enhance bird detection of, and response to, approaching aircraft.
  Contact: Brad Blackwell

- **Economic Impacts of Feral Swine Livestock Predation and Disease Transmission.** Over the past 30 years, feral swine have expanded their range from 17 to 38 States in the United States. Their spread has inflicted substantial costs on agricultural producers. Feral swine damage to livestock production includes the spread of disease, predation on livestock, and impacts to international trade. NWRC economists collaborated with the USDA National Agricultural Statistics Service to survey more than 6,300 livestock producers in 13 States (Alabama, Arkansas, California, Florida, Georgia, Louisiana, Mississippi, Missouri, North Carolina, Oklahoma, South Carolina, Tennessee, and Texas) about feral swine damage. Findings indicate that predation and disease-related damage can be considerable in certain States and for certain types of livestock. In particular, damage to cattle operations in Texas and Arkansas was substantially higher than damage in other States and types of livestock operations. When extrapolated to livestock producers across the entire 13-State region, NWRC economists estimated that feral swine cause $40 million in

livestock predation and disease damages each year. The findings from this survey help guide feral swine control efforts and research, as well as serve as a benchmark against which the effectiveness of future control efforts are measured.
Contact: Aaron Anderson

- **Hunter Support for Restrictions on Moving Feral Swine.** One of the biggest threats to feral swine management is the transport and release of live feral swine to new areas. Only half of all States currently prohibit the practice that is done to establish new populations for hunting purposes. Preventing the spread of feral swine is key to reducing their damage. NWRC and CSU researchers explored public attitudes and the potential barriers facing policymakers when implementing new restrictions on the movement of feral swine. A total of 20,000 urban and rural residents from all 50 States were mailed a questionnaire. More than 2,200 people (11 percent) responded, which is above the minimum sample size needed for statistically significant results. Results showed that a majority of respondents have negative attitudes toward feral swine and support policies that restrict their transport and penalize transgressors. Consistent with other invasive species research, findings suggest that as knowledge and awareness of feral swine increase, so does support for policies restricting and penalizing their transport. Contrary to previous studies, this research also found that hunters are more likely to support restrictions on feral swine transport than are non-hunters. These findings suggest that legal restrictions on the transport of feral swine, even in States with large hunter populations, enjoy broad public support and may help to curb the expansion of this damaging invasive species.
Contact: Keith Carlisle

- **Economic Impacts of an FMD Outbreak in the United States.** An FMD outbreak in the United States could impose heavy losses on the economy due to billions lost in Gross Domestic Product (GDP), jobs, and trade. NWRC and Texas A&M University economists estimated the impacts of a hypothetical FMD outbreak in terms of job loss using the Regional Economic Modelling Incorporated Policy Insight + (REMI) computable general equilibrium model. Different emergency response strategies were compared, including 15 vaccination protocols and an animal depopulation strategy without vaccination. Results showed that over a 10-year period, the depopulation strategy

A foot-and-mouth disease (FMD) outbreak in the United States would impose heavy losses on the economy due to billions lost in gross domestic product, jobs, and trade. NWRC economists compared the benefits and costs of various FMD emergency response strategies.
Photo by USDA, Gail Keirn

without vaccination resulted in approximately 677,000 lost jobs and a $47 billion decrease in GDP. By comparison, a vaccinate-to-live strategy with the highest vaccination capacity and largest vaccination zone saved 509,000 of those jobs. Of all the industries affected by an outbreak, the sales industry incurred the highest job loss, followed by construction and transportation. By including detailed job losses by occupation, this study shows that job losses resulting from an FMD outbreak can go far beyond the farm sector impacts reported in earlier studies. This information provides policymakers another perspective when considering FMD vaccination strategies.
Contact: Stephanie Shwiff

- **Economic Impacts of Canine Rabies in Vietnam.** Most of the costs associated with canine rabies do not result from treatment of infected individuals, but rather the consequences of human deaths and efforts to prevent the disease in people, livestock, and companion animals. In 2015, NWRC economists estimated the total annual global cost of rabies at $1.2 billion and approximately 69,000 human deaths. Asia bears a disproportionate burden of this disease due to high human mortality and high rates of post-exposure prophylaxis (PEP)—i.e., a series of human vaccinations to prevent rabies after exposure to a known or suspect rabies-positive dog—while investing at a low rate in preventative dog vaccination. To understand the burden of rabies to society, NWRC economists incorporated the direct and indirect costs for PEP, dog vaccination efforts, livestock losses, and disability adjusted life years (DALYs)[2] into an analysis of the economic impact of canine rabies in Vietnam from 2005 to 2014. Findings indicated that over the 10-year study period, the total economic impact of canine rabies was over $719 million. The largest portion of impacts (92 percent) were from PEP-related costs. Canine rabies created between 36,560 and 45,700 DALYs, measured in years of life lost. A total of 914 human deaths were reported over the study period. For every 1 million people in Vietnam, approximately one person dies from rabies each year, which is lower than the reported level for Asian countries. The cost per dog vaccinated was $1.75. Results indicate that the impacts of canine rabies in Vietnam are consistent with other areas in Asia (i.e., large expenditures on PEP and very small investments in dog vaccination). NWRC researchers recommend a comprehensive dog vaccination program that targets rural areas combined with bite prevention programs, and management of free-roaming dogs to reduce the number of bites and potential human exposures in Vietnam.
  Contact: Stephanie Shwiff

- **Web-based Model for Canine Rabies Management.** The spread of rabies by dogs remains a threat in much of the developing world. Although human infections are preventable with pre-exposure prophylaxis (PrEP) or PEP, the management and elimination of the disease in dogs is the only definitive way to eliminate human risks and the high costs of human treatment. NWRC and international researchers created a new modeling tool to investigate different rabies management options and maximize the impact of canine rabies management resources at the local level. The model helps answer complex strategic questions surrounding vaccine application and timing, population control, and budget allocation. The model was characterized using data from a region of the Mpumalanga Province in South Africa. Findings suggested that the region could experience maximum benefits by vaccinating puppies and repeating vaccination campaigns annually. Furthermore, the model found that

[2] *According to the National Institutes of Health, DALYs represent the total number of years lost to illness, disability, or premature death within a given population.*

combining the vaccination and sterilization of female dogs was not cost effective given there was a constant influx of new dogs from other areas, and sterilization had little effect on dog abundance. Researchers note this new tool helps decision-makers maximize the benefits of their rabies programs, as well as estimate the minimum budget necessary to manage rabies in local dog populations.
Contact: Aaron Anderson

- **Measuring Bird Damage to Fruit.** Birds frequently eat and damage fruit in orchards resulting in decreased yields for growers. The true extent of damage is difficult to measure. Although producer surveys estimate damage, their accuracy is uncertain. NWRC and university researchers compared damage estimates obtained from producer surveys with those from actual damage assessments collected by Michigan State University scientists for three fruit crops: wine grapes, sweet cherries, and Honeycrisp apples. Researchers also investigated how the use of various damage management methods correlated to bird damage. Results suggest accurate estimates are dependent on crop type and growing region, with producers' damage estimates tracking more closely with actual damage assessments in crops of shorter stature and smaller fruit size. Wine grape and sweet cherry growers accurately assessed bird damage, while Honeycrisp apple growers overestimated damage. The growing region also appears to be an important damage predictor for wine grape and sweet cherry crops. The use of several bird damage management methods increased as damage estimates increased, possibly because these methods are only used when damage is severe.
Contact: Stephanie Shwiff

NWRC and university researchers compared bird damage estimates obtained from producer surveys with actual damage assessments for three fruit crops: wine grapes, sweet cherries, and Honeycrisp apples. Results suggest accurate estimates are dependent on crop type and growing region. *Photo by USDA, Patrick Tregenza*

- **Seed Removal by Invasive Black Rats.** The black rat *(Rattus rattus)* is one of the most damaging invasive rodents. To estimate the impacts of black rats on native tree populations in Luquillo Experimental Forest in Puerto Rico, NWRC and University of Puerto Rico at Mayagüez researchers conducted seed removal trials in disturbed habitats—e.g., treefall gaps, hurricane plots, stream edges)—and undisturbed habitats, e.g., continuous forest. Researchers compared seed removal of four native tree species *(Guarea guidonia, Buchenavia capitata, Tetragastris balsamifera,* and *Prestoea acuminata)* between sites that excluded rodents and other vertebrates and those that did not. Trail cameras identified animals responsible for seed contact and removal. Black rats were responsible for 65 percent of the interactions with seeds, of which 29 percent were confirmed seed removals. Two plant species—*Guarea* and *Buchenavia*—had significantly more seeds removed in disturbed habitats, especially forest gaps, than undisturbed forest. *Prestoea acuminata* had the lowest seed removal (9 percent), whereas all other species had

Research in Puerto Rico by NWRC and university scientists indicate that invasive black rats may be influencing the fate of seeds on the forest floor, and possibly forest community composition, through seed dispersal or predation.
Photo by USDA, Wildlife Services

greater than 30-percent removal. Researchers caution that black rats are likely influencing the fate of seeds on the forest floor, and possibly forest community composition, through seed dispersal or predation.
Contact: Aaron Shiels

Wildlife Management Methods and Evaluations

- **Automated Aerial Bait Delivery To Control Brown Treesnakes.** Previous work by WS Operations and the NWRC has shown that invasive brown treesnake populations on Guam can be reduced by aerially delivering baits treated with 80 milligrams of acetaminophen to snake-infested areas. However, preparing the baits manually and applying them over large landscapes is labor- and time-intensive. Thus, WS, NWRC, and the U.S. Department of the Interior (DOI) collaborated with Applied Design Corporation to engineer an automated bait manufacturing and delivery system. The core technology is an aerially delivered biodegradable bait cartridge designed to tangle in the tree canopy, making the acetaminophen bait available to treesnakes and out of reach of terrestrial non-target species. Bait cartridges are assembled with an automated bait manufacturing system (ABMS). When mounted on a rotary- or fixed-wing aircraft, the automated dispensing module (ADM) can broadcast 3,600 bait cartridges at a rate of four-per-second and treat 30 hectares of forest at a density of 120 baits-per-hectare in 15 minutes. The ABMS and ADM together comprise the aerial delivery system (ADS) for landscape-scale brown treesnake control. NWRC researchers and WS Operations experts conducted the first evaluation of the ADM on Guam in July 2016. The ADM successfully reduced brown treesnake abundance after a single treatment. The WS Guam State Office now uses the ADM as a new operational control tool. Experimental snake eradication efforts have begun within 55 hectares of forest surrounded by a snake-proof barrier on Guam. The goal is to evaluate the possibility of using ADM to eradicate snakes within the enclosure and provide a snake-free habitat for conservation purposes. From October 2018 to June 2019, WS Operations and NWRC conducted multiple bait applications at this site, resulting in a greater than 80-percent decrease in snake activity. Further applications will continue to drive brown treesnake numbers within the enclosure toward zero. For the first time, land managers have a tool that can drastically reduce snake numbers throughout large areas, improving biosecurity and encouraging hopes for the eventual recovery of Guam's native species.
Contact: Shane Siers

A new automatic aerial delivery system for landscape-scale brown treesnake control on Guam has resulted in a greater than 80 percent reduction in snake activity at test sites. *Photo by USDA, Shane Siers*

- **Persistence of Rodenticide Residues Following a Rodent Eradication.** Rats *(Rattus spp.)* have invaded most of the world's oceanic islands, causing lasting or irreversible damage to ecosystems and biodiversity. To counter this threat, rat eradication techniques have been developed and applied across the globe. Successful eradications of invasive rats from large or complex island ecosystems often involve the use of rodenticide bait. While effective at eradicating rats from islands, rodenticides can persist in the ecosystem and potentially harm non-target species. Brodifacoum, a relatively persistent second-generation anticoagulant, was used to eradicate rats from Palmyra Atoll in the Pacific Ocean. To understand the impacts of brodifacoum use on islands, researchers with NWRC, USFWS, and Island Conservation evaluated the persistence of brodifacoum residues in terrestrial and marine species at Palmyra Atoll 3 years after the rat eradication. Researchers collected 121 samples of the following species: mullet *(Moolgarda engeli)*, cockroaches *(Periplaneta sp.)*, geckos *(Lepidodactylus lugubris)*, hermit crabs *(Coenobita perlatus)*, and fiddler crabs *(Uca tetragonon)*. Despite detecting brodifacoum residue in all five of these species 60 days after the initial application of bait, brodifacoum residue was not found in any of the samples collected 3 years after the bait application. The study demonstrates how brodifacoum residues are unlikely to persist in the marine and terrestrial food web, in a wet tropical environment, 3 years after a rat eradication. *Contact: Aaron Shiels*

- **Using Trail Cameras To Monitor Bait Uptake by Non-Target Species.** Efforts to remove invasive rats and mice from islands often use toxicant-laced baits. To quantify bait uptake by target and non-target species, NWRC researchers and their partners used trail cameras (e.g., Reconyx, motion-activated infrared cameras) to monitor individual brodifacoum-25D bait pellets distributed aerially on Desecheo Island, Puerto Rico. Trail cameras revealed 30 incidences of non-target animals contacting bait pellets 6 to 20 days after bait application. Of the 30 incidences, 47 percent were hermit crabs, 37 percent *Ameiva* lizards, 13 percent insects, and 3 percent black crabs. Despite viewing approximately 69,000 images from trail cameras, lizards were never observed eating bait on Desecheo Island; therefore, any brodifacoum exposure to Desecheo lizards likely occurred via secondary pathways (e.g., eating contaminated insects). Researchers estimate that rats ate less than 25 percent of the total bait distributed on Desecheo Island. It is common

to distribute an overabundance of bait during eradication efforts, and this baiting operation successfully eradicated the black rat from Desecheo Island. Researchers conclude that trail cameras are less expensive than residue analysis and may be a valuable tool for documenting primary exposure of target and non-target species during rodenticide campaigns.
Contact: Aaron Shiels

- **Managing Vole Populations in Perennial Crop Fields.** Voles cause extensive damage to crops throughout much of the Northern Hemisphere. Farmers often use rodenticides (i.e., aluminum phosphide) to manage vole damage, but this is a short-term solution. An integrated pest management (IPM) approach that focuses on multiple tools generally provides better long-term success. Researchers from the NWRC; University of California, Davis; and the Kearney Agricultural Research and Extension Center tested the impact of combining management tools on the abundance and activity of California voles *(Microtus californicus)* in globe artichoke fields in Monterey County, CA. Researchers used both chewing indices (vole chewing on wax monitoring blocks) and mortality estimates derived from radio-collared voles to evaluate the effectiveness of mowing, plowing, and aluminum phosphide applications. Results showed aboveground vegetation removal via mowing reduced vole activity by approximately 80 percent. Further reduction in vole activity occurred following the application of aluminum phosphide. Together, both methods resulted in an 88-percent reduction in vole activity. Plowing further reduced vole activity by completely removing vegetation and destroying vole burrows. Although highly effective at reducing vole activity, plowing is not a tool that farmers can use regularly in a perennial crop, such as globe artichokes. However, it can be a useful tool for eliminating voles from fields before periodic replantings. Combining these tools with management practices designed to slow reinvasion by neighboring vole populations (e.g., barriers, repellents, traps) can reduce the need for rodenticides for vole management. Such an IPM approach benefits both farmers and agro-ecosystems.
Contact: Gary Witmer

Combining aluminum phosphide applications with the removal of vegetation and other management practices designed to slow reinvasion by neighboring vole populations (e.g., barriers, repellents, traps) can reduce the need for rodenticides for vole management.
Photo by U.S. Geological Survey, Andrew Hope

- **Reduction in Feral Swine Expansion.** APHIS created the National Feral Swine Damage Management Program (NFSDMP) in 2014 with the goal of protecting agricultural and natural resources, property, animal health, and human health and safety from feral swine damage. To be successful, the program must show a reduction in the amount of feral swine damage as well as a decrease in the spread of feral swine and their subsequent damage. NWRC and Veterinary Services researchers analyzed data from the National Feral Swine Mapping System and the WS Management Information System using occupancy analysis and regression models to estimate changes in management and feral swine population distributions since the start of the NFSDMP.

Findings showed that after 4 years of NFSDMP activities, the probability of feral swine invading a new county decreased by 8 percent overall and by 15 percent in States with low-density feral swine populations. If feral swine had continued to expand their range at pre-program levels, the models predicted they would have invaded 122 more counties. Researchers note that extending this analysis to include feral swine damage estimates and crop distributions can help to predict the economic benefits of feral swine damage management.
Contact: Kim Pepin

- **Cost Effectiveness of Aerial Operations for Feral Swine Removal.** Aerial operations using gunning are a common method for managing feral swine populations and their damage. NWRC researchers investigated the cost effectiveness of aerial operations by estimating the impacts of multiple aerial operations on the same feral swine management site and determining how pilot/gunner experience and vegetation influence removal efforts. WS Operations personnel in Texas conducted repeated aerial operations over 3 days at three different study sites using different pilot/gunner teams. NWRC researchers estimated feral swine abundances before and after each aerial operation (pass), as well as information on the vegetation at each site and the pilot/gunner team. Researchers estimated the proportion of feral swine removed from the population and the time it would take for the population to recover. Then, three possible damage-density relationships were used to determine the overall cost effectiveness of the operational activities. Results showed that flying the same property multiple times can be cost effective in areas with moderate to high levels of damage. As expected, more feral swine are removed in areas with low amounts of vegetation cover and hourly removal rates varied substantially by pilot/gunner teams. Researchers note that managers can identify optimal removal strategies (e.g., aerial operations versus trapping) by measuring the relationship between feral swine damage and density. The most cost-effective management strategy depends on this relationship. For instance, in agricultural settings, high feral swine damage may occur even at low population densities and, therefore, repeated aerial gunning efforts may be more cost effective at reducing damage than single aerial gunning events spaced out over several months or years.
Contact: Amy Davis

- **Achieving Consistent Feral Swine Visitation to Bait Sites.** Controlling feral swine is challenging, especially since their behavior can vary among individuals and sounders (groups). For instance, some feral swine visit bait sites more consistently than others. To help optimize WS' baiting efforts, NWRC researchers examined feral swine movements relative to bait sites before, during, and after baiting. Achieving consistent visitation by feral swine to bait sites improves trapping success (i.e., whole sounder removal), and helps with potential toxicant baiting efforts in the future. NWRC researchers attached GPS collars to 68 adult feral swine throughout 2 study areas in north-central and south-central Texas. The researchers established 60 bait sites with bait stations comprised of back-to-back troughs with lids secured with approximately 30 pounds/13 kilograms of magnetic pressure. Whole-kernel corn was used initially as bait and slowly replaced with placebo HOGGONE bait. Collared feral swine movements were monitored for 2 weeks prior to baiting, 2 weeks during baiting, and 2 weeks after baiting. Data was gathered on the feral swines' daily visitation to the bait sites and changes in their home ranges, movement distances, and foraging patterns. Findings concluded that bait sites need to be within 0.6 miles/1 km of where female feral swine live and within 0.8 miles/1.25 km of male

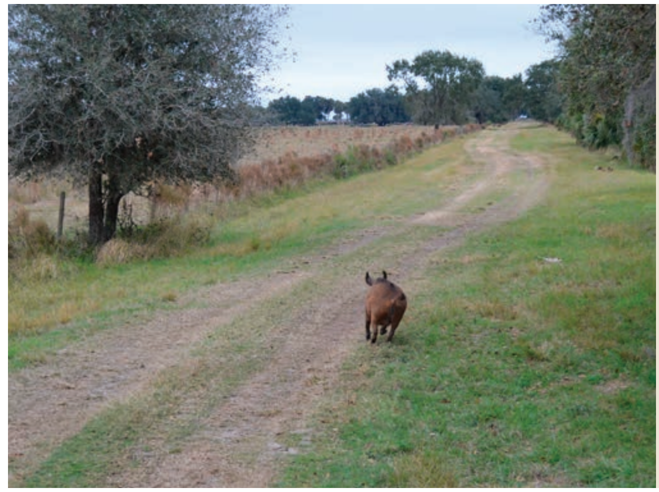
NWRC scientists are exploring feral swine baiting strategies to minimize risks to non-target species. One option involves the use of feral swine-specific bait stations.
Photo by USDA, Michael Lavelle

feral swine in order to achieve a greater than 50 percent daily visitation rate. Baiting also increased the movement distances and erratic movements of both sexes. Home range sizes increased and shifted toward the bait sites, especially for feral swine on the periphery of the baiting area. Researchers note that uncoordinated baiting for recreational hunting and trapping likely exacerbates the negative consequences of baiting, such as expanded space-use and spread of feral swine.
Contact: Nathan Snow

- **Training Feral Swine To Improve Baiting Efficiency.** NWRC scientists are exploring feral swine baiting strategies to minimize risks to non-target species. One option involves the use of feral swine-specific bait stations. To be considered a viable option for managers, the level of effort required to train feral swine to feed from novel bait stations, as well as the cost and overall efficacy of their use, must be comparable to other methods. NWRC researchers used trail cameras at 41 bait sites in Texas and fitted feral swine with GPS collars to evaluate the efficiency and efficacy of different baiting strategies for training feral swine to eat from bait stations. Researchers compared three baiting strategies that involved a bait station (incremental, pig-informed, and flash[3]) to a strategy that involved placing bait on the ground without a bait station. GPS locations of 32 feral swine were used to determine how far the feral swine traveled from their core-use areas to access bait. Results showed baiting strategies that allowed 15 or more days for training feral swine to use bait stations—i.e., incremental and pig-informed—were the most effective and resulted in the most feral swine accessing bait from the bait stations. Bait sites should be spaced 0.3 miles/0.5 km to 0.6 miles/1 km apart to maximize opportunities for feral swine to find and utilize the bait sites. If a female feral swine found a bait site during the first 5 days of pre-baiting, she was likely to continue visiting the site. Finally, bait stations excluded all non-target animals, except one instance with a raccoon. These results will aid in future feral swine baiting strategies for both toxicant baits and live trapping.
Contact: Michael Lavelle

[3] *The incremental baiting strategy started with the bait station lids propped open, then slowly progressed through six training stages, each 5 days in length, whereby the bait station lids ended in a closed position. The pig-informed strategy was more dynamic and based on observed pig behaviors at each training stage. If pigs were accessing the bait at a particular stage, the baiting strategy would automatically advance to the next stage. The flash strategy omitted the first few training stages and started with closed bait stations.*

- **Path of Least Resistance: Feral Swine and Roads.** Many wildlife species take advantage of dirt roads or tracks for easier travel. This behavior of using the "path of least resistance" comes in handy for researchers who want to determine animal abundances and record animal activity using road-based observation methods, such as camera traps and tracking plots. NWRC and university scientists placed GPS tracking collars on feral swine to investigate the frequency and timing of feral swine movements across roads in Florida pasturelands. Compared to natural Florida habitats, pasturelands offer little resistance for travel by feral swine. Results showed 17 of the 18 radio-collared swine (94 percent) were located on roads over half of the days they were monitored. Moreover, on days when collared swine were located on roads, they averaged 5.3 road crossings per day with a combined 76 road locations expected each day. Researchers conclude that although pasturelands are considered easy-to-traverse terrain, feral swine still frequently use roads, making road-based observation systems an efficient way to collect feral swine population monitoring data in a wide variety of habitats.
  Contact: Eric Tillman



NWRC research with free-roaming radio-collared feral swine showed the animals frequently use roads, making road-based observation systems an efficient way to collect feral swine population monitoring data.
Photo by USDA, Michael Milleson

- **Comparing Livestock Protection Dog Breeds.** Livestock protection dogs (LPDs) have been used for centuries to protect livestock, primarily domestic sheep, from large predators. LPDs are considered the most effective when they remain in close proximity to the livestock they are protecting. Livestock producers note LPDs that are well bonded with their livestock are less likely to roam and more likely to stay among the livestock. Between 2012 and 2016, NWRC and Utah State University (USU) researchers radio-collared

Livestock protection dogs (LPD) are used to protect sheep from predators. NWRC research explored the differences in movement patterns and proximity to sheep among LPD breeds.
Photo by USDA, Michael Marlow

64 LPDs from 3 different breeds (Kangals, Karakachans, Transmontanos) and mixed breeds often referred to as whitedogs (such as Great Pyrenees, Anatolian shepherd, and Akbash), as well as 112 sheep, to determine their movement patterns on open-range grazing allotments in the Rocky Mountains of the Northwest United States. Researchers compared data on the dogs' movements and proximity to sheep. Results showed no differences in proximity to sheep on open range among LPDs based on the dogs' breed, sex or age. All of the LPDs studied were closer to sheep in the early morning hours when sheep moved the shortest distances and predators were most likely to be active. These results suggest any of the breeds tested will remain close to sheep when properly bonded and during the time of day when sheep are likely to be most vulnerable to predation.
Contact: Julie Young

- **Does Trapping Affect Wolf Behavior?** For several decades, wolves have been live-trapped for research and population monitoring purposes. However, trapping in most areas is limited to the spring, summer, and autumn because cold winter temperatures can lead to injuries in trapped animals. In addition to physical injuries, animals may show behavioral changes to capture, such as reduced activity levels, changes in home-range size, and avoidance of the habitat in which they were trapped. Two common live capture methods include foothold traps and cable restraint devices (modified neck snares). NWRC researchers, WS Operations staff, and their partners evaluated the injuries, movement patterns, and space use of gray wolves in north-central Minnesota—23 captured using foothold traps and 24 captured using cable restraint devices. Injury scores did not differ between capture techniques, but differences were observed in movement patterns and space use. Researchers found that wolves restricted their activity and movement patterns during the first 8 to 10 days following capture by either trap type, but wolves captured in foothold traps traveled farther away from the capture site. Additionally, wolves captured with cable restraints reached normal levels of movement and home-range use more quickly. Researchers conclude that wolves captured in cable restraints recover more quickly from the capture and resume space use and activity patterns more rapidly than wolves captured with foothold traps.
Contact: Eric Gese

- **Cross-Fostering as a Conservation Tool.** The red wolf *(Canis rufus)* was declared extinct in the wild in 1980 and is currently listed as endangered under the Endangered Species Act. A captive breeding program was established in 1973 to aid in red wolf recovery efforts. Experts with NWRC, Point Defiance Zoo and Aquarium, USFWS, USU, and the Maine Department of Inland Fisheries and Wildlife investigated whether red wolf pups born in captivity and raised by non-biologically related wild wolves (i.e., cross-fostered) have a higher survival rate than those raised by captive wolves that are non-biologically related to them. Between 1987 and 2016, captive-born pups were fostered

NWRC and its partners found that endangered red wolf pups who are raised by non-biologically related wild wolves have a higher rate of survival than those who are raised by captive wolves. *Photo by Valerie CC BY-NC-ND 2.0*

into 8 captive red wolf litters and 15 wild red wolf litters. Approximately 92 percent of captive-born pups fostered into captive litters lived to be at least 3 months old. Over 94 percent of pups fostered into wild litters lived to be at least 5 months old. For animals of known fate—i.e., researchers know if they lived or died—the survival of captive-born red wolf pups fostered into captive and wild litters was high. Fostered red wolf pups who survived lived to an average age of 5.6 years, and some produced or sired litters in the wild as adults. The fostered pups growing to adulthood, successfully mating, and producing wild red wolf litters support the use of cross-fostering as a conservation tool.
Contact: Eric Gese

- **Post-Release Activity of Rehabilitated Black Bears.** Wildlife rehabilitation is a global practice that involves the capture and care of displaced, injured, and orphaned animals, often with the objective of returning those animals to the wild. Rehabilitated carnivores warrant specific attention, given that they are wide-ranging and may behave in ways that threaten human safety or interests. Since 2012, the NWRC Utah field station has partnered with USU and the Utah Division of Wildlife Resources to rehabilitate orphaned black bear cubs using minimal human contact. Using data from GPS radio-collared bears and various statistical approaches, researchers were able to describe the post-release activity and ecology of six rehabilitated black bear cubs (released at 9 to 11 months of age). Data showed the rehabilitated bear cubs denned shortly after release, exhibited late-summer dispersals, preferred aspen and oak habitats in the spring and summer, and displayed no use of human resources, such as roads or human-inhabited areas. The survival and behavior of the orphaned bears suggest that rehabilitation can be a safe and effective practice without habituation to people or harmful effects on the bears' overall fitness and survival. Although the sample size is small, results from this study have key implications for wildlife ecology and management, as it is the first to implement GPS-monitoring and spatial analysis for rehabilitated black bears. Bears can be observed via a webcam during rehabilitation at http://qcnr.usu.edu/bear_cam.
Contact: Julie Young

Since 2012, the NWRC Utah field station has partnered with Utah State University and the Utah Division of Wildlife Resources to rehabilitate orphaned black bear cubs using minimal human contact. Using data from radio-collared bears, researchers were able to describe the post-release activity and ecology of the rehabilitated cubs.
Photo by USDA, Wildlife Services

- **Improving Fladry for Use With Coyotes.** Fladry is a nonlethal tool designed to protect livestock from wolf and coyote predation by creating a visual barrier. It consists of a string of flags attached to a rope. The rope is mounted along the top of a fence to allow the flags to flutter in the breeze. Originally designed for use with wolves, the large spacing between the flags may reduce the effectiveness of fladry for preventing predation by coyotes, a smaller predator. To address this issue, NWRC Utah field station researchers performed experiments on captive coyotes using modified fladry. Researchers first tested two styles (top-knot and shower-curtain) for attaching flags to the rope-line that reduce gaps by preventing coiling of individual flags. Researchers also tested whether narrowing the gaps between top-knot flags, from 18 inches/45.7 cm to 11 inches/27.9 cm, helped to prevent coyote crossings. Findings showed no differences in the time it took coyotes to cross fladry with top-knot or shower-curtain attachment designs, suggesting both could be used for coyotes. Fladry with smaller gaps between flags did a better job of preventing coyote crossings than did fladry with larger gaps. Results also indicated that for each additional minute coyotes spent interacting with the fladry, the barrier's effectiveness decreased. These results suggest that persistent coyotes may stop avoiding the flags more rapidly than coyotes that do not exhibit persistent behaviors, but the use of top-knot fladry and shorter spacing between flags will increase protection of livestock from coyotes. *Contact: Julie Young*

NWRC research shows narrowing the gaps between flags on fladry helps to prevent coyote crossings.
Photo by USDA, Julie Young

- **Not So Shy: Urban Coyotes Are Bolder Than Rural Coyotes.** Some wildlife species readily adapt to changing landscapes and urban environments. The coyote is one of them. To help understand how coyotes have adapted to living in cities, NWRC and USU researchers compared two ecologically and evolutionarily important behavioral traits: (1) bold versus shy, and (2) exploration versus avoidance behavior. Boldness relates to an animal's reaction to a risky situation. Exploration relates to an animal's willingness to explore novel objects or situations. Results showed that urban coyotes are bolder and more exploratory than rural coyotes, and that within urban and rural coyote populations, there are individuals that vary across both spectrums. The results are based on a series of tests that looked at individual coyote flight initiation distances (FID)—i.e., the distance at which an animal begins to flee from an approaching predator or threat—and its willingness to take risks and approach a novel object in its environment. Forty-six percent of coyotes in urban areas showed a relatively low-level flight response when approached by people. They moved slowly away, stopped, and looked back as they retreated. In contrast, 80 percent of rural coyotes had a strong flight response—fleeing rapidly without looking back. Results from the novel object test complemented the FID results. When presented with a novel object, urban coyotes spent more time than rural coyotes in close proximity to the object and more time demonstrating investigative, vigilant, and comfort behaviors. Researchers note that bolder behavior in urban coyotes emerged over several decades and speculate that the primary factor influencing this change is the nature of the interactions between humans and coyotes in these environments. In rural areas, coyotes are hunted and trapped. In urban areas, coyotes are rarely hunted or trapped and may even be rewarded with food when near people. This adaptation has led to coyotes that are bold enough to prey on pets or

In a series of studies with captive coyotes, NWRC researchers found that urban coyotes are bolder and more exploratory than rural coyotes. Understanding bold, exploratory, and aggressive behaviors in coyotes, and the role that people play, helps wildlife managers and communities learn to coexist with these and other carnivore species.

Photo by USDA, Anson Eaglin

attack people. Understanding bold, exploratory, and aggressive behaviors in coyotes, and the role that people play, helps wildlife managers and communities develop more effective approaches to damage management involving predators in urban environments.
Contact: Stewart Breck

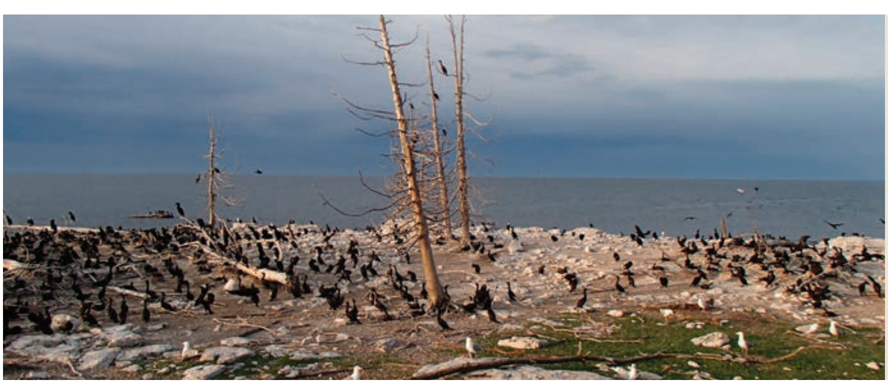
- **Coyote Habituation to People and Reduced Fear in Coyote Pups.** Previous animal behavior studies suggest that wildlife perceive people as predators, and as such, display fear responses similar to those shown to natural predators. To better understand how people influence coyote behavior and fear response, NWRC and University of Chicago researchers and their partners observed the behavior of captive coyote parents and their pups from two successive litters. Researchers quantified coyote risk-taking behavior using feeding trials. Food was placed at the front of the coyotes' pens versus scattered throughout their pens, and a human observer was stationed at the pen entrance to serve as a proxy for human disturbance. Hair samples were collected from pups at 5, 10, and 15 weeks of age to estimate hormone levels (i.e., cortisol and testosterone). Results showed that coyote parents were riskier with their second versus first litters, foraging more frequently with people present, supporting the prediction that parents become increasingly habituated to people over time. Second-litter pups were also less risk-averse than their first-litter siblings and had higher average cortisol concentrations. Results suggest that coyote habituation to people may serve as a cue for their offspring to reduce their avoidance response via behavioral and hormonal mechanisms. Given that coyote encounters with people in urban environments have become more frequent in recent decades, these findings may have implications for urban coyote management.
Contact: Julie Young

- **Using DNA To Trace Back the Source of Invasion.** The small Indian mongoose *(Herpestes auropunctatus)* is an invasive predator on Hawaii. While native to Central Asia, this species was introduced to the Hawaiian Islands to control rodent populations in sugarcane fields. However, mongooses were ineffective for rodent control and quickly became an established threat to Hawaii's native animals and invertebrates. In 2012, two small Indian mongooses were live-captured on the Hawaiian island of Kauai, which had been considered mongoose-free. By comparing their genes to those of mongooses on the Big Island and nearby islands of Oahu, Maui, and Molokai, NWRC researchers were able to determine the animals came from Oahu. This information will help to increase public awareness and improve biosecurity measures between the Hawaiian Islands.
Contact: Toni Piaggio

Wildlife Population Monitoring Methods and Evaluations

- **Using Feather Colors To Age Cormorants.** Feathers (plumage) are often used to determine the age of birds, yet little attention has been given to the molting patterns of known-age, double-crested cormorants to verify the accuracy of aging birds using feathers. In general, subadult cormorants (i.e., less than 2 years old) are identified by tan, buffy, or mottled chest and neck plumage, and adults (i.e., 2 years old or older) are identified by black plumage on their chest and neck. While studying double-crested cormorant populations in Canada with known-age birds, NWRC researchers noted that the plumage of more than 75 percent of breeding adults changed from black to heavily mottled during the course of the breeding season. Plumage changed in equal proportions for all ages from 2-year-olds to 7-year-olds. Researchers observed a similar, but reverse pattern with double-crested cormorants roosting at sites in the southeastern United States during fall migration. The majority of the roost had subadult plumage in September but shifted to 75-percent adult plumage (i.e., black plumage) by mid-January. The mechanism behind the plumage change is unknown, but researchers advise caution when using plumage to age cormorants, especially during the winter months. These observations document an important, but often overlooked part of seasonal double-crested cormorant plumage variation which may change the way cormorant management and research is conducted during the late- and non-breeding seasons. For example, previous research has shown that focusing cormorant management activities on breeding adult birds versus younger birds has a greater effect on population growth. This research shows that incorrectly aging cormorants in the field can confound management goals.
  Contact: Tommy King

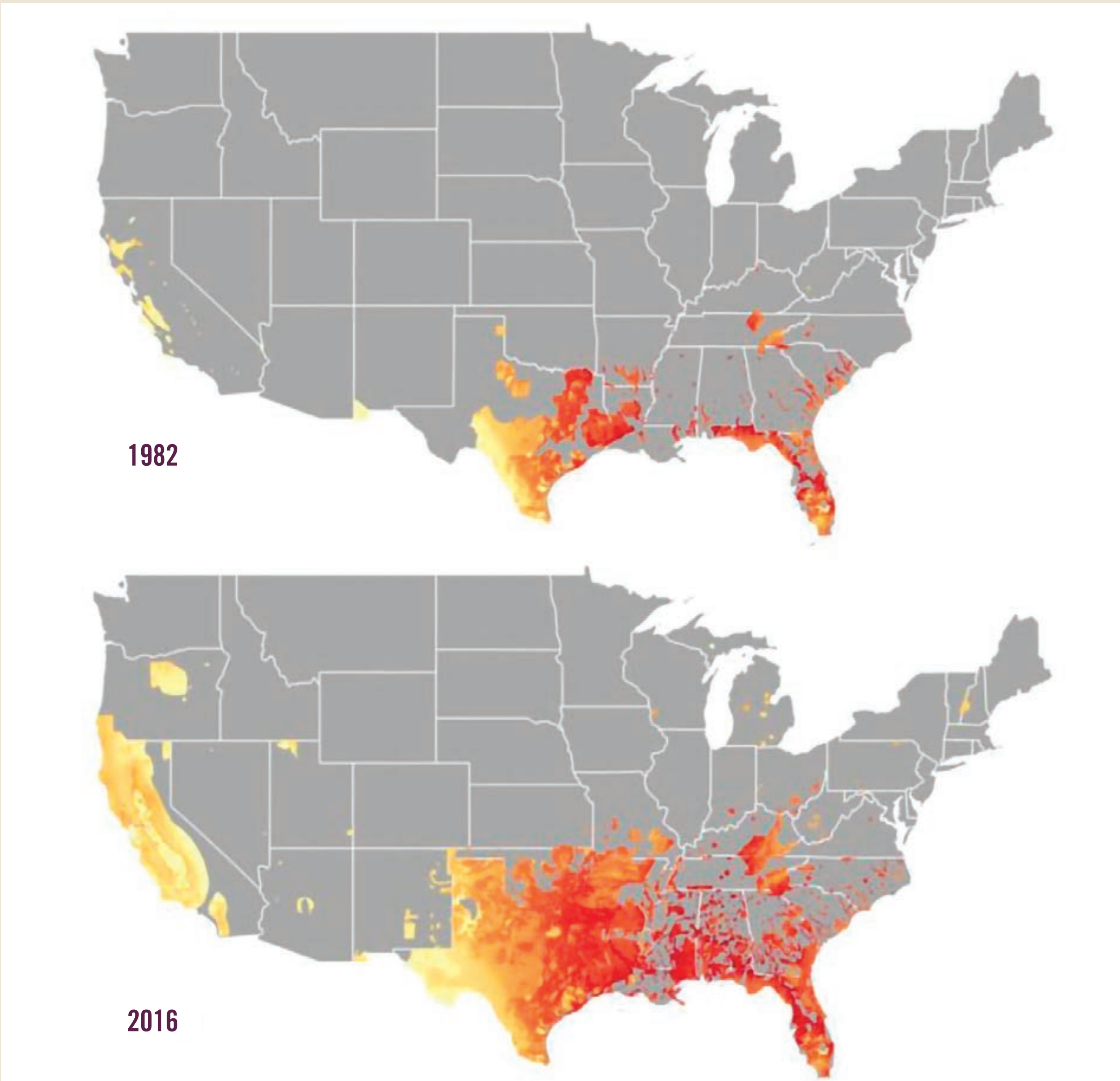
- **Survival, Site Fidelity, and Dispersal of Cormorants.** In recent decades, double-crested cormorants have rebounded from the effects of environmental contaminants and indiscriminate removal, and now nest in large numbers throughout much of their historical range. This rapid recolonization suggests a willingness of individual birds to disperse and take advantage of new breeding opportunities versus remaining loyal to previous nesting sites. NWRC and other Federal researchers, along with State and university researchers, explored the survival and movement of cormorants between two nesting colonies in Lake Michigan to better understand the impacts of cormorant population management efforts. Data from live resightings and the recovery of dead birds were analyzed in a suite of models to estimate survival rates, immigration (incoming), and emigration (dispersal). The best fitting model showed that cormorant survival rates are lowest during their first year but more than double after their second year, from 37 to 89 percent. Annual colony fidelity averaged between 48 and 62 percent, with adult birds exhibiting slightly greater fidelity than juvenile birds to nesting



High rates of double-crested cormorant dispersal from established breeding colonies may be an important driver of recent cormorant range and population expansion.
Photo by USDA, Katie Hanson-Dorr

sites. Temporary and permanent emigration tended to be greater among juvenile birds. Researchers note that high rates of cormorant dispersal from established colonies may be an important driver of recent cormorant range and population expansion. Such patterns suggest enormous potential for cormorants to repopulate, recolonize, and establish new colonies in North America.
Contact: Brian Dorr

- **Historical, Current, and Potential Population Estimates of Feral Swine in the United States.** To estimate the abundance of feral swine in the United States through time, NWRC, Veterinary Services, private, and university researchers combined information from two national data sets. One data set tracks the distribution of feral swine in the United States since 1982. The other data set predicts the potential population density of feral



NWRC, university, and private partners predicted potential feral swine population densities from 1982 to 2016. Densities ranged from low (yellow: 0-2 animals/km^2) to medium (orange: 3-5 animals/km^2) to high (red: 6-8 animals/km^2). *Maps by Arizona State University, Jesse Lewis*

swine across the United States by evaluating broad-scale landscape characteristics. Researchers used these two data sets to estimate the population size of feral swine in 1982, 1988, 2004, 2010, 2013, and 2016. Results show that feral swine have expanded and increased across the United States from approximately 2.4 million animals in 1982 to 6.9 million animals in 2016. Regions in the western, northern, and northeastern United States contain no or few feral swine populations, but could potentially support large numbers of these animals if their populations become established. This information is useful in identifying regions at greatest risk if feral swine become established, which can assist in prioritizing management actions aimed at controlling or eliminating this invasive species.
Contact: Kurt VerCauteren

- **Estimating Bobcat Density in Urban Areas Using Camera Traps.** Some of the most human-populated places in the world are also home to thriving carnivore populations. Researchers with NWRC, USU, the Texas Parks and Wildlife Department, and the Welder Wildlife Foundation conducted a study on bobcats in the Dallas-Fort Worth Metro Area of Texas. They identified individual bobcats from their spot patterns using approximately 1,000 photographs from camera traps. These images, along with spatially explicit capture-recapture models were used to estimate bobcat density. Estimating density provides insights into bobcat populations, helping natural resource managers take appropriate management actions based on their goals. Camera trap data also allows managers to identify specific individuals who may be causing conflict or damage. Results showed the overall density was at least 1 bobcat per square kilometer, which calculated to approximately 43 bobcats across the entire study site. This estimate is higher than other documented bobcat densities in both rural and semi-urban studies in Texas. Researchers note this counters the assumption that these small predators require large areas of connected habitat.
Contact: Julie Young

Registration Updates

- **Sodium Nitrite Toxicant for Feral Swine Management.** Sodium nitrite (SN) is under development as a new active ingredient pesticide for the control of feral swine. Because feral swine are harvested for consumption, both recreationally and commercially, the U.S. Environmental Protection Agency (EPA) will evaluate an SN-based toxicant as a food-use pesticide under Federal regulation. To meet the requirements of a food-use pesticide, APHIS is contracting with several commercial laboratories to complete additional studies that evaluate food safety in relation to potential SN residues in feral swine tissues. This increased level of review addresses possible human health and safety concerns related to the use of SN for feral swine control.
Contact: Jeanette O'Hare

- **DRC-1339 Manufacturing.** The NWRC Registration Unit identified new chemical companies as potential sources of the bird toxicant DRC-1339 for use in APHIS' DRC-1339 pesticide products. During 2019, APHIS received EPA approval for one new source of DRC-1339. An application for a second new source was submitted to EPA and is currently under review. The EPA approval of a new source of DRC-1339 allows for the continued EPA registration of DRC-1339 and its use by WS for bird damage management.
Contact: Jeanette O'Hare

- **Sodium Cyanide Label Use Restrictions.** EPA currently registers sodium cyanide for use in predation damage management. The toxicant is delivered to targeted species via a device called an M-44. In 2019, the NWRC Registration Unit coordinated APHIS' response to the Sodium Cyanide Proposed Interim Decision (PID) published for public comment under EPA's Registration and Review process. Together, EPA and APHIS developed label language based in part on the WS M-44 Implementation Guidelines that contained enhanced safety instructions to WS sodium cyanide applicators. The resulting pesticide label language increases safety precautions for employees, the public, and pets and allows WS to continue using this tool for predation damage management. *Contact: Jeanette O'Hare*

Technology Transfer

- **Patents, Licenses, and New Inventions.** In 2019, the U.S. Patent and Trademark Office (USPTO) allowed one NWRC patent (USPTO #10,434,171) for the use of microfluidized *Mycobacterium avium* fragments as an adjuvant and carrier for mucosal vaccine delivery. Inventors on this patent include three NWRC scientists: Mr. Richard Mauldin, Dr. Douglas Eckery, and Dr. Lowell Miller (retired). This patent is currently available for licensing. NWRC scientists also prepared six invention disclosures on novel ideas including two novel biopesticide technologies, a conventional pesticide active ingredient, and a method for reducing deer-vehicle collisions. NWRC filed two invention disclosures as provisional patent applications with USPTO, one on a novel application of an avian repellent and another on an artificial intelligence system for species recognition. NWRC also filed two other provisional patent applications in 2019—one on a novel feral swine feeder, the other on a novel formulation of an immunocontraceptive vaccine. *Contact: John Eisemann*

- **Technology Transfer Agreements.** WS forms research and product development partnerships to promote the development of tools and techniques for use in wildlife damage management. Collaborations often are formalized through confidentiality, material transfer, and other intellectual property agreements. In fiscal year 2019, NWRC entered into 8 Confidentiality Agreements, 9 Material Transfer Agreements, 13 Material Transfer Research Agreements, 1 Memorandum of Understanding, 3 Cooperative Research and Development Agreements, 6 Invention Disclosures, 4 provisional patent applications, and 1 non-provisional patent application. One patent was issued. *Contact: John Eisemann*

Awards

- **2019 Excellence in Technology Transfer Award**. In February 2019, NWRC and its private industry partner Arkion Life Sciences, LLC, received the Federal Laboratory Consortium (FLC) Excellence in Technology Transfer Award for their role in developing, testing, registering, manufacturing, and distributing a suite of anthraquinone (AQ)-based repellents for reducing bird and mammal damage to crops. NWRC's Dr. Scott Werner led the research effort conducting numerous laboratory and field studies with the goal of fine-tuning AQ formulations for maximum repellency at the lowest cost. The partnership has resulted in five co-owned patented technologies and associated repellent products that are cost effective, practical, environmentally safe, socially responsible, and are currently marketed and sold nationally and internationally. Recent advances have also led to the development of a new repellent application strategy that takes advantage of both visual cues and post-ingestive consequences (e.g., an unpleasant taste or sickness in the birds that eat it). The results of the

NWRC-Arkion partnership not only impact wildlife conservation and crop and disease protection in the United States but also food production in lesser developed countries.

- **Federal Laboratory Director of the Year Award.** On April 24, 2019, NWRC Director Dr. Larry Clark received the 2019 FLC Laboratory Director of the Year Award for his outstanding contributions in support of technology transfer. Under Dr. Clark's leadership, the NWRC has successfully transferred technologies to private businesses through cooperative research and development agreements (CRADA), as well as through patenting and licensing opportunities. Although NWRC employs about 30 PhD research scientists, it collaborates on average with 140 unique entities each year. These collaborations have led to nearly 400 intellectual property agreements, including 27 CRADAs, since 2013. Examples of recently patented and licensed NWRC technologies include a wildlife contraceptive, an automated bait delivery system, and bird repellents.

NWRC Director Dr. Larry Clark received the 2019 Federal Laboratory Consortium Laboratory Director of the Year Award for his outstanding contributions in support of technology transfer. *Photo by Federal Laboratory Consortium*

- **2019 NWRC Publication Award.** Each year, the NWRC Publication Awards Committee, composed of NWRC scientists, reviews over 125 publications generated by their NWRC colleagues. The resulting peer-recognized award honors outstanding contributions to science and wildlife damage management. In 2019, the Committee presented the award to the authors of two publications.

  Amy J. Davis, Bruce Leland, Michael Bodenchuk, Kurt C. VerCauteren, and Kim M. Pepin received the award for their 2018 article, "Costs and effectiveness of damage management of an overabundant species *(Sus scrofa)* using aerial gunning" (*Wildlife Research* 45:696-705. doi: 10.1071/WR17170). This work was selected because of its quantitative rigor, collaboration between WS research and operations staff, and its applicability to many aspects of the WS program. The paper evaluates aerial operations to reduce feral swine damage (e.g., single pass in an area versus multiple passes over a short duration) and found that consecutive aerial operations in an area result in a 60-percent reduction in feral swine damage, compared to a 2-percent reduction with a single aerial operation. The research highlights the importance of monitoring and evaluating operational activities in order to improve their effectiveness.

Kurt C. VerCauteren, Michael J. Lavelle, and Henry Campa III received the award for their 2018 article, "Persistent Spillback of Bovine Tuberculosis From White-Tailed Deer to Cattle in Michigan, USA: Status, Strategies, and Needs" *(Frontiers in Veterinary Science* 5:301. doi: 10.3389/fvets.2018.00301). NWRC and WS Operations have been working on the issue of bTB in deer and cattle in Michigan for nearly 20 years. Many methods have been developed to reduce deer contact with cattle, including strategies related to fencing, use of dogs, and feeding and watering cattle. Basic research has also led to a better understanding of disease transmission and prevention that points the way toward ridding deer and cattle of the disease. This paper synthesizes and highlights how WS' collective work helps with disease mitigation at the farm level and influences State and Federal management and policy.

The Committee awarded special recognition to William C. Pitt, James C. Beasley, and Gary W. Witmer for their book, **Ecology and Management of Terrestrial Vertebrate Invasive Species in the United States**, published by CRC Press. This book offers an excellent review on the topic of invasive species management in the United States and highlights important work completed by NWRC researchers.

- **NWRC Employee of the Year Awards.** The winners of this award are nominated by their peers as employees who have clearly exceeded expectations in their contributions toward the NWRC mission. The winners this year are:
  - **Stewart Breck, Research Grade Scientist;** Developing Control Methods, Evaluating Impacts, and Applying Ecology To Manage Carnivores Project; Fort Collins, CO
  - **Jeanette O'Hare, Support Scientist;** Registration Unit; Fort Collins, CO
  - **Lanna Durst, Technician;** Defining Economic Impacts and Developing Strategies for Reducing Avian Predation in Aquaculture Project; Starkville, MS
  - **Ryan Foster, Administration Unit;** Fort Collins, CO

2019 Publications

The transfer of scientific information is an important part of the research process. NWRC scientists publish in a variety of peer-reviewed journals that cover a wide range of disciplines, including wildlife management, genetics, analytical chemistry, ornithology, and ecology. (Note: 2018 publications that were not included in the 2018 NWRC accomplishments report are listed here.)

Anderson, A.M., C. Slootmaker, E.E. Harper, S.A. Shwiff, and R.S. Miller. 2019. Predation and disease-related economic impacts of wild pigs on livestock producers in 13 States. Crop Protection 121:121-126. doi: 10.1016/j.cropro.2019.03.007

Anderson, A.M., J. Kotze, S.A. Shwiff, B. Hatch, C. Slootmaker, A. Conan, D. Knobel, and L.H. Nel. 2019. A bioeconomic model for the optimization of local canine rabies control. PLoS Neglected Tropical Diseases 13(5):e0007377. doi: 10.1371/journal.pntd.0007377

Askren, R.J., B.E. Dorak, H.M. Hagy, M.W. Eichholz, B.E. Washburn, and M.P. Ward. 2019. Tracking Canada geese near airports: using spatial data to better inform management. Human-Wildlife Interactions 13(2):344-355.

Aslan, C.E., B. Petersen, A.B. Shiels, W. Haines, and C.T. Liang. 2018. Operationalizing resilience for conservation objectives: the 4S's. Restoration Ecology 26(6):1032-1038. doi: 10.1111/rec.12867

Aslan, C.E., C.T. Liang, A.B. Shiels, and W. Haines. 2018. Absence of native flower visitors for the endangered Hawaiian mint Stenogyne angustifolia: impending ecological extinction? Global Ecology and Conservation 16:e00468. doi: 10.1016/j.gecco.2018.e00468

Aslan, C.E., A.B. Shiels, W. Haines, and C.T. Liang. 2019. Non-native insects dominate daytime pollination in a high-elevation Hawaiian dryland ecosystem. American Journal of Botany 106(2):313-324. doi: 10.1002/ajb2.1233

Ayers, C.R., K.C. Hanson-Dorr, K. Stromborg, T.W. Arnold, J.S. Ivan, and B.S. Dorr. 2019. Survival, fidelity, and dispersal of double-crested cormorants on two Lake Michigan islands. The Auk 136(3):ukz040. doi: 10.1093/auk/ukz040

Baldwin, R.A., B.G. Abbo, and D.A. Goldade. 2018. Comparison of mixing methods and associated residual levels of zinc phosphide on cabbage bait for rodent management. Crop Protection 105:59-61. doi: 10.1016/j.cropro.2017.11.006

Baldwin, R.A., D.I. Stetson, M.G. Lopez, and R.M. Engeman. 2019. *Typha* (cattail) invasion in North American wetlands: biology, regional problems, impacts, ecosystem services, and management. Environmental Science and Pollution Research 26(18):18434-18439. doi: 10.1007/s11356-019-05235-6

Bansal, S., S.C. Lishawa, S. Newman, B.A. Tangen, D. Wilcox, D. Albert, M.J. Anteau, M.J. Chimney, R.L. Cressey, E. DeKeyser, K.J. Elgersma, S.A. Finkelstein, J. Freeland, R. Grosshans, P.E. Klug, D.J. Larkin, B.A. Lawrence, G. Linz, J. Marburger, G. Noe, C. Otto, N. Reo, J. Richards, C. Richardson, A.J. Schrank, D. Svedarsky, S. Travis, N. Tuchman, and L. Windham-Myers. 2019. *Typha* (cattail) invasion in North American wetlands: biology, regional problems, impacts, ecosystem services, and management. Wetlands 39(4):645-684. doi: 10.1007/s13157-019-01174-7

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Appendix 1

More information about these projects is available on the NWRC web page at:
www.aphis.usda.gov/wildlifedamage/nwrc

List of 2019 NWRC Research Projects

Methods Development and Population Management of Vultures and Invasive Wildlife
Project Leader: Bryan Kluever

Defining Economic Impacts and Developing Strategies for Reducing Avian Predation in Aquaculture
Project Leader: Fred Cunningham

Improving Methods To Manage Healthy Forests, Wetlands, and Rangelands
Project Leader: Jimmy Taylor

Developing Control Methods, Evaluating Impacts, and Applying Ecology To Manage Carnivores
Project Leader: Julie Young

Development of Injectable and Mucosal Reproductive Technologies and Their Assessment for Wildlife Population and Disease Management
Project Leader: Douglas Eckery

Understanding, Preventing, and Mitigating the Negative Effects of Wildlife Collisions With Aircraft, Other Vehicles, and Structures
Project Leader: Travis DeVault

Methods and Strategies To Manage Rodent Impacts to Agriculture, Natural Resources, and Human Health and Safety
Project Leader: Gary Witmer

Wildlife-Borne Pathogens Affecting Food Safety and Security: Developing Methods To Mitigate Effects
Project Leader: Alan Franklin

Economics, Operations Research, and Social Dimensions of Wildlife Management
Project Leader: Stephanie Shwiff

Developing Methods To Manage Damage and Disease of Feral Swine and Other Ungulates
Project Leader: Kurt VerCauteren

Methods and Strategies for Controlling Rabies
Project Leader: Amy Gilbert

Methods and Strategies To Manage Invasive Species Impacts to Agriculture, Natural Resources, and Human Health and Safety
Project Leader: Shane Siers

Methods Development To Reduce Bird Damage to Agriculture: Evaluating Methods at Multiple Biological Levels and Landscape Scales
Project Leader: Page Klug

Chemosensory Tools for Wildlife Damage Management
Project Leader: Bruce Kimball

Genetic Methods To Manage Livestock-Wildlife Interactions
Project Leader: Antoinette Piaggio

Development of Repellent Applications for the Protection of Plant and Animal Agriculture
Project Leader: Scott Werner

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Bevins, Sarah	(970) 266-6211 sarah.n.bevins@usda.gov	NWDP: wildlife disease
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Ruell, Emily	(970) 266-6161 emily.w.ruell@usda.gov	Product registration
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Siers, Shane	(671) 635-4445 shane.r.siers@usda.gov	Project Leader: island invasives
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Sugihara, Robert	(808) 961-4482 robert.t.sugihara@usda.gov	Invasive species
Szakaly, Sara	(970) 266-6021 sara.j.szakaly@usda.gov	Archives
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VerCauteren, Kurt	(970) 266-6093 kurt.c.vercauteren@usda.gov	Project Leader: cervids, CWD, bTB, barriers, feral swine
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Appendix 3

Acronyms and Abbreviations

ABMS	automated bait manufacturing system
ADM	automated dispensing module
APHIS	Animal and Plant Health Inspection Service
BAM	butorphanol-azaperone-medetomidine
BRBV	Bourbon virus
bTB	bovine tuberculosis
CRADA	cooperative research and development agreement
CWD	chronic wasting disease
DALY	disability adjusted life years
DL	limits of detection
DNA	deoxyribonucleic acid
eDNA	environmental DNA
EPA	U.S. Environmental Protection Agency
FAA	Federal Aviation Administration
FID	flight initiation distance
FLC	Federal Laboratory Consortium
FMD	foot-and-mouth disease
GDP	gross domestic product
GMS	global system for mobile communications
GPS	global positioning system
IAV	influenza A viruses
IHC	immunohistochemistry
IPM	integrated pest management
km	kilometer
LED	light emitting diode
LPD	livestock protection dog
LPE	Lincoln-Peterson estimator
ml	milliliter
MMB	medetomidine-midazolam-butophanol
MSU	Mississippi State University
NalMed-A	nalbuphine-medetomidine-azaperone
NDSU	North Dakota State University
NFSDMP	National Feral Swine Damage Management Program
nm	nanometer
NWDP	National Wildlife Disease Program
NWRC	National Wildlife Research Center
ORV	oral rabies vaccine
PAPP	para-aminopropiophenone
PEP	post-exposure prophylaxis
RAM	random access memory
REMI	Regional Economic Modelling Incorporated Policy Insight +
RHS	relative hazard score
SN	sodium nitrite
sPMCA	serial protein misfolding cyclic amplification
sUAS	small unmanned aircraft system
TZX	tiletamine-zolazepam-xylazine
UAS	unmanned aircraft system
USDA	U.S. Department of Agriculture
USFWS	U.S. Fish and Wildlife Service
USGS	U.S. Geological Survey
USU	Utah State University
USPTO	U.S. Patent and Trademark Office
UV	ultraviolet
WS	Wildlife Services

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