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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: NWRC scientists are exploring the use of new genetic technologies in wildlife damage management.

Photos by USDA (scientist in lab) and iStock (Norway rat). Graphics by Wikimedia Commons.

Message From the Director

Larry Clark, NWRC Director
Photo by USDA, Gail Keirn

In his book *Thinking Fast and Slow*, the Nobel Prize-winning economist and psychologist Daniel Kahneman summarizes how biases may influence our thought processes. Kahneman notes there are two systems that drive the way we think. The first system is intuitive and emotional, resulting in quick decisions. We often call these our "first impressions" or "gut reactions." The second system is slower, more deliberate and focused. It relies on reasoning to come to a conclusion.

Through a series of experiments, Kahneman found these two systems can arrive at completely different results or answers even when given the same inputs. These differing results are due to our cognitive biases. Kahneman identified at least 20 cognitive biases that affect our thinking. They include things such as confirmation bias, overconfidence, placebo effect, stereotyping, and zero-risk bias. When these and other biases affect scientific conclusions and policymaking, the consequences can be far-reaching.

Over the years, the U.S. Department of Agriculture and other Federal agencies have taken many steps to strengthen their science-based programs. Efforts to date include, among others, revising regulations and encouraging education and training on scientific integrity. In all, the goal is to prevent bias or misconduct, or any perception thereof—and maintain the trust of the public we serve.

As scientists, we pride ourselves in being deliberate, focused thinkers. We shield against bias by using the scientific method—a systematic approach involving observation, measurement, and experimentation, along with formulating, testing, and modifying hypotheses.

One example of our commitment to objective and rational approaches in the research and development process has been NWRC's decades-long involvement in pesticide development and Federal registration of wildlife damage management products. NWRC's strict adherence to protocols, documented processes, and administrative records makes us well-positioned to address public concerns. Our staff is dedicated to solving problems and offering solutions to wildlife damage management issues based on accurate, reliable, repeatable, and defensible data. As part of this year's report, we feature NWRC's efforts to promote scientific integrity through its research grade evaluation and project management systems and peer-reviewed research, data, and findings (see **Spotlight: Scientific Integrity and the Research Process**).

I am pleased to present this year's NWRC Accomplishments Report and highlight our many important research activities and findings from 2017.

Larry Clark, Director
National Wildlife Research Center
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Research Spotlights

The National Wildlife Research Center (NWRC) is the research arm 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: Synthetic Biology and Other Genetic Tools

What if we could modify an animal's genes to select for certain traits or abilities? Could mosquitos be genetically engineered to prevent disease? Or could invasive rodents be altered to produce only male offspring? What if control techniques could be species-specific to avoid hazards to nontarget species?

Once only considered tools of the future, such genetic technologies are now a reality. The field of synthetic biology combines biology and engineering to help design, manufacture, and modify genetic materials in living organisms. The CRISPR/Cas9[1] system is an example of a gene editing tool.

"Humans have been altering plant and animal genomes for thousands of years through selective breeding. Synthetic biology allows us to do this more efficiently and precisely than ever before," says NWRC geneticist Toni Piaggio. "Now the question becomes how can we safely and effectively use these tools to help address some of the most challenging wildlife management and conservation issues?"

In addition to exploring the use of these tools in wildlife damage management, NWRC scientists are actively working with federal agencies from various countries, conservation organizations, and others to discuss the technical, ethical, social, safety, and regulatory challenges posed by gene editing. Regulations surrounding the use of gene editing for wildlife and other animals are still being debated.

"These tools hold great promise for wildlife disease and invasive species management because of their species specificity, low environmental burden, scalability, and potential cost-effectiveness. As Government scientists, it's important that we engage experts and the public in discussions on if, when, and how these technologies will be used," notes NWRC Director Larry Clark.

Below are highlights of some of NWRC's work related to synthetic biology and other genetic tools.

Genetic Biocontrol of Invasive Rodents (GBIRd) Partnership

Invasive species are the leading cause of plant and animal extinctions on the world's islands. In particular, invasive rodents deplete animal and plant populations and spread disease. Many island conservation efforts involve eradicating invasive rodents with toxicants. Such methods are costly and time-consuming; they

[1] *CRISPR, or "Clustered Regularly Interspaced Short Palindromic Repeats," is a family of DNA sequences in bacteria; "Cas" are CRISPR-associated genes.*

may also cause secondary hazards to other species, which limits their use. Wildlife managers need new tools to prevent rodent-caused extinctions on islands, and genome editing holds promise as a selective tool to manage the problem.

Engineered gene drives are a genetic technique that targets and promotes the inheritance of a particular gene to increase its prevalence in a population. During normal sexual reproduction, each of the two versions of a given gene (also known as alleles) has a 50-percent chance of being inherited by offspring. Gene drives are genetic systems that circumvent these traditional rules. They greatly increase the odds that one specific version of a gene will be passed on to offspring. Gene drives occur naturally, but the idea of engineering them for disease management first came about in the 1940s. Since then, the discovery of mechanisms, such as CRISPR, has allowed more efficient editing.

The Genetic Biocontrol of Invasive Rodents (GBIRd) program is an international partnership of diverse experts from universities, government, and not-for-profit organizations advancing gene-drive research for conservation purposes. Partners include Island Conservation, Commonwealth Scientific and Industrial Research Organisation, Landcare Research, North Carolina State University, Texas A&M University, University of Adeladie, and the NWRC.

"Together, GBIRd experts are cautiously investigating the feasibility of gene-drive modified organisms that would produce single-sex offspring and could be used to eliminate invasive rodents on islands," says NWRC

Invasive rodents are a leading cause of plant and animal extinctions on islands. The Genetic Biocontrol of Invasive Rodents (GBIRd) program is an international partnership of experts advancing gene drive research as a new tool to combat invasive species. *Photo by DoD, Scott Vogt*

geneticist Toni Piaggio. "In addition to answering whether or not we *could* create such an organism, we're also exploring the social, ethical, and biological risks and whether or not we *should* create and use such an organism."

While GBIRd's gene-drive research has been ongoing for a few years, it is still in its early stages. The team plans to develop mathematical models of how effective gene drives would be to produce a single-sex mouse population, and then, if initial efforts show promise, perform breeding tests at NWRC's facilities in Fort Collins, CO. NWRC has highly contained, biosecure simulated natural environment rooms that can mimic real-world conditions. Under captive conditions, NWRC researchers and their GBIRd partners will monitor populations of gene-drive mice modified to produce only male or only female offspring. The gene-drive mice will be compared to non-modified mice to see how well models predict breeding choices and population changes. Ultimately, the modified mice will breed themselves out of existence, allowing eradication without chemical pesticides. GBIRd experts also plan to conduct risk assessments and engage with the public, other scientists, and conservationists to further evaluate the suitability of this potential tool.

siRNA

As part of normal bodily functions, a cell's DNA sends out "messages" to other parts of the cell to create specific proteins. These proteins are the building blocks of organisms. For instance, if the body needs to build more muscle, the DNA sends out a message triggering the production of more muscle proteins. These DNA "messages" are strands of ribonucleic acid (RNA). siRNA (also known as "small interfering RNA") is a specially designed RNA molecule used to disrupt the expression of a particular gene.

Using siRNA, scientists can create specific RNA strands or "messages" to suit their needs. These RNA strands direct the cells' own machinery to attack and destroy other naturally occurring RNA strands that have complementary nucleotide sequences. Such "interfering" allows scientists to use the body's natural defenses to eliminate the production of certain proteins.

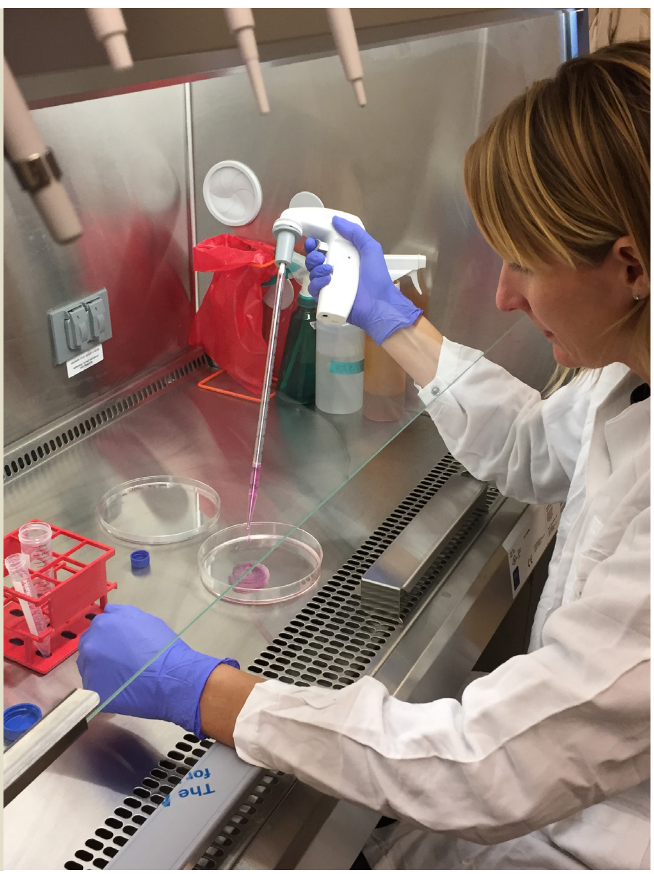
This cellular process was only discovered by scientists in the late 1990s. However, the technology and its development have quickly shown promise in treating numerous illnesses, such as Huntington's disease and some cancers and liver diseases.

Katherine Horak, a pharmacologist and toxicologist at the NWRC, hopes to harness the power of siRNA to improve the selectivity and effectiveness of wildlife damage management tools, such as contraceptives, repellents, and toxicants.

"If we could tell an animal's cells to stop producing certain proteins, we could use that to our advantage," says Horak. "We can also be very selective—targeting gene sequences that are unique to a species."

For example, suppose feral swine had a particular DNA "message" (RNA sequence) unique to them that was critical to producing energy. A scientist could theoretically stop the production of those proteins using siRNA. The animal would no longer be able to produce the energy necessary for life.

Getting siRNA into cells without activating their defense systems is a complicated task. But already, NWRC researchers have not only synthesized siRNA to gene sequences of interest, but also identified the best method for getting siRNA into the targeted cells.



Small interfering RNA (siRNA) may be used in the future to improve the selectivity and effectiveness of wildlife damage management tools, such as vaccines, repellents, and toxicants. *Photo by USDA, Gail Keirn*

Although the use of such a technology in wildlife damage management is still many years away, Horak is laying the foundation. In the lab, she is looking for unique gene sequences that could be targeted using siRNA technologies in feral swine, rodents, and other invasive and pest species.

Environmental DNA

Environmental DNA (eDNA) refers to DNA that is shed by an organism into the environment (for example, water, soil, or air). The genetic material could come from shed skin, hair, or scales; mucous; urine; or feces.

NWRC geneticists are developing new methods for using eDNA to detect invasive species, such as Burmese pythons, feral swine, and monitor lizards. For instance, NWRC experts have developed a polymerase chain reaction (PCR) method to detect python eDNA at low concentrations in water. Tests showed python eDNA was detectable for up to 96 hours in water. This method now helps monitor the presence-absence and current distribution of invasive Burmese pythons in Florida.

NWRC has also developed quantitative PCR tests to detect feral swine eDNA in turbid waters, such as wallows. WS biologists and NWRC researchers are using this technique to locate the last remaining pockets of feral swine in New Mexico after eradication efforts in the State. WS field specialists collect water samples in parts of the State where remnant feral swine populations may occur, but where water is limited. Thus, the samples are more likely to include feral swine DNA, if swine are present. If feral swine DNA is detected, WS experts increase their monitoring and trapping efforts until remaining swine are removed.

NWRC experts have also improved the usefulness and efficiency of eDNA techniques by determining eDNA detectability limits and degradation rates for different species, evaluating various extraction methods, and improving field collection and shipment procedures.

NWRC geneticists have developed new methods to detect invasive species, such as Burmese pythons, using environmental DNA. *Photo by USDA, Eric Tillman*

Gene Sequencing To Uncover Host Species

More than 1,400 species of biting midges (also known as “No-See-Ums”) are found throughout the world. Female midges feed on blood and can transmit a variety of pathogenic viruses, parasitic worms, and blood parasites to people, livestock, and wildlife. Among the most damaging pathogens are bluetongue virus, epizootic hemorrhagic disease virus, vesicular stomatitis virus, African horse sickness, and Schmallenberg virus.

To identify what species biting midges target in the United States, scientists with NWRC, Colorado State University, and California’s Lake County Vector Control District collected and ran DNA tests on 366 blood-engorged midges from three States, including one area in California where bluetongue virus is found in both livestock and wildlife.

“We used DNA sequencing to identify the mitochondrial DNA of 7 species of biting midges and 12 host species,” says NWRC geneticist Toni Piaggio. “This approach allows us to have a better understanding of the transmission cycles of pathogens from vectors to host species."

Analysis of the blood meals showed midges fed on both wild and domestic animals. Blood meals from black-tailed deer were the most abundant (37%), followed by cattle (16%), sheep (12%), horses (11%), white-tailed deer (7%), dogs and black-tailed jackrabbits (6%), emus (3%), donkeys (1%), and goats and house finches (0.5%). These results indicate that biting midges feed on multiple hosts and may be more opportunistic feeders than previously thought.

Although the method successfully identified transmission pathways, it was time-consuming. To increase cost-effectiveness and speed up the surveillance process, NWRC researchers are refining the approach. Instead of analyzing individual midges and their blood meals, researchers are combining all of the midges from trap catches into one large 'midge DNA soup,' which is then analyzed with DNA sequencing.

Results from a genetics study looking at the blood meal of biting midges found that the insects feed on multiple wildlife and domestic animal species. *Photo by USDA*

Next Steps

NWRC researchers will continue exploring new genetic technologies and their applications to wildlife damage management. Funding from the U.S. Department of Defense, Defense Advanced Research Projects Agency's Safe Genes program is allowing NWRC geneticists to analyze the DNA of wild-caught invasive rodents on approximately seven islands and mainland source locations to identify alleles that are unique to the island rodents. Because such alleles are geographically limited, they may be appropriate targets for gene editing.

In 2018, NWRC's siRNA efforts will focus on identifying gene sequences predicted to be lethal for the species of interest. Researchers plan to use many different biochemical techniques, including cell culture and protein assays, to confirm the gene sequences of interest are expressed in the target species.

NWRC researchers are also exploring the use of eDNA to detect invasive monitor lizards, as well as terrestrial endangered species and species of concern. Efforts are also underway to aid disease surveillance in Puerto Rico by identifying wildlife species that serve as zoonotic reservoirs for flaviviruses including the Zika virus. This work will use a method called metabarcoding to identify insect species, blood meal species, and pathogens from insects captured in a single trap.

A new droplet digital PCR technology that is less affected by inhibitors in environmental samples is being used to identify avian influenza samples for whole genome sequencing. Whole genome sequencing allows NWRC geneticists to assess relationships among low pathogenic avian influenza samples from wild birds and identify areas where wild birds are most likely to share a high diversity of viral subtypes and reassortments. These areas may be targeted for surveillance during disease outbreaks.

Fish-eating birds cause an estimated $25 million in yearly damage and damage prevention costs to America's catfish industry.

SPOTLIGHT: Protecting Aquaculture From Fish-Eating Birds

Populations of fish-eating birds, such as pelicans and cormorants, have increased dramatically over the last several decades, causing substantial economic impacts to U.S. aquaculture production. For the catfish industry alone, bird damage and prevention cost an estimated $25 million annually.

"NWRC's Mississippi field station is uniquely suited to address wildlife damage issues to aquaculture. We're located in the heart of aquaculture country in the south-eastern United States at Mississippi State University," says Fred Cunningham, field station leader. "Our facilities for aquaculture research allow us to house fish-eating birds, study their behavior and impact on aquaculture and natural systems, and determine their role in the life cycle and transmission of fish parasites and diseases."

The station develops methods to reduce the impacts of fish-eating birds, such as double-crested cormorants, pelicans, egrets, and herons, on aquaculture stocks. Its goal is to determine the economic impact of fish-eating birds on aquaculture production and natural resources and to develop methods that reduce depredation and disease impacts on southeastern catfish, baitfish, and crawfish industries. The summaries below highlight recent research on managing wildlife damage to aquaculture.

Learning About Cormorant and Pelican Behavior

The double-crested cormorant and American white pelican are large, long-lived, fish-eating waterbirds

Fish-eating birds like the double-crested cormorant (*pictured*) cause substantial damage to U.S. aquaculture production. *Photo by U.S. Fish and Wildlife Service*

whose recent population growths in some areas have led to conflicts with other wildlife and people. To address these concerns, NWRC researchers are studying their migratory and nesting behaviors. For instance, by tracking the birds' movements and distribution, researchers can better anticipate where conflicts may occur and advise natural resource managers and others on ways to target control efforts. This research also helps determine how different management actions influence the overall viability and sustainability of bird populations.

NWRC researchers study the behavior and migratory movements of American white pelicans. *Photo by USDA, Tommy King*

In South Carolina, resident double-crested cormorants are managed for conservation purposes, while migratory birds are managed to reduce damage. To help managers address these different goals, NWRC and Clemson University researchers used species distribution models (SDM) to identify nesting habitat characteristics for resident birds in Florida and migratory birds in Minnesota.

"We looked at all sorts of habitat characteristics to determine what the birds select when looking for suitable nest sites," says NWRC wildlife research biologist Brian Dorr. "Once known, we used those characteristics to predict nesting habitats in South Carolina."

Results showed that nesting habitat characteristics from resident birds in Florida more accurately predicted the presence and absence of cormorant nesting colonies in South Carolina than nesting habitat characteristics from migratory birds in Minnesota. Management strategies that focus on these characteristics (such as the amount of water bodies, forested land, standing dead cypress trees, and fish stocking) may serve a dual purpose: reducing conflicts with wintering migrant birds, while conserving less common colonies of resident cormorants and their habitats. In short, the SDM approach has potential for addressing different management goals when dealing with geographically overlapping subpopulations.

Researchers are also interested in habitat conditions that affect bird migration. Arriving at breeding grounds when climate conditions are favorable enhances a bird's nesting opportunities and reproductive success. Recent studies on short-distance migratory birds suggest that environmental queues, such as local temperatures, likely initiate spring migration.

American white pelicans found east of the North American Continental Divide are short-distance migrants, breeding in the Great Plains and wintering in the lower Mississippi River Valley. The arrival of pelicans to North Dakota in the spring has advanced over the last 30 years. To see why pelican spring migrations are occurring earlier, NWRC, Mississippi State University, and Oregon State University researchers reviewed 11 years of global positioning system (GPS) relocation data from 36 pelicans in relation to several environmental variables. Findings showed that spring migration timing for pelicans advanced substantially over the 11 years, but neither spring departures nor arrivals were related to winter daily temperatures, total winter precipitation, or vegetation green-up dates. While a bird's age and experience may affect migration timing, those factors alone do not explain the advanced migration dates of pelicans. Environmental queues, though not yet fully understood, may also influence when birds begin to migrate.

How Fish Predation Impacts Disease

Double-crested cormorants, American white pelicans, and other fish-eating birds consume an assortment of fish and parasites as they move from one foraging site to another. As a result, the birds can be problematic to stocked ponds and aquaculture facilities—the birds eat cultivated fish and may spread pathogens among the facilities and to other water bodies.

NWRC research has shown that cormorants, wood storks, great egrets, and pelicans shed the virulent strain of *Aeromonas hydrophila* (VAH) after consuming infected fish. *Aeromonas hydrophila* is a bacterium that is abundant in freshwater and brackish aquatic environments and can cause infections in fish, people, reptiles, and birds. A 2009 outbreak of VAH caused an estimated loss of more than 1,360 metric tons of catfish in western Alabama catfish farms. The shedding of VAH by these bird species after consuming infected fish could explain how VAH is transmitted from one commercial catfish pond to another without any obvious connections between the ponds or farms.

NWRC is also researching the role fish-eating birds play in the spread of trematodes. Trematodes are parasitic flatworms that can infect many different fish species, including catfish. Their complex life cycles often rely on infected birds shedding trematode eggs into ponds and other habitats. NWRC researchers have documented trematode infections in cormorants from Alabama, Minnesota, Mississippi, and Vermont. Trematode infections were present in 98 percent of the birds sampled. Sixty-six percent of the birds were infected with roundworms, 65 percent with tapeworms, and 4 percent with thorny-headed worms. Birds from wintering grounds had higher parasite species richness and diversity than did birds from breeding grounds. The researchers also saw differences in parasite richness and diversity between male and female cormorants, but not between immature and mature birds. The most common parasite found was *Drepanocephalus auritus (spathans)*, a disease agent that negatively impacts the catfish industry in the United States.

Channel catfish showing signs of infection from *Aeromonas* bacteria. NWRC research has shown that cormorants, wood storks, great egrets, and pelicans may spread the disease between aquaculture facilities after eating infected fish. *Photo by Larry Hanson, Mississippi State University*

These findings suggest that management efforts to prevent cormorants from feeding and resting on production ponds will help keep these parasites from spreading.

Economic Impacts of Fish-Eating Birds

The U.S. catfish industry is worth more than $572 million per year in processed product sales, with over 50 percent of catfish production originating in Mississippi. Damage from fish-eating birds alone is an estimated $25 million a year. Although such damage can vary by producer and region, even small impacts can affect a producer's bottom line. Over the years, experts at the NWRC Mississippi field station have measured the economic impacts of various fish-eating birds on the catfish industry and other aquaculture interests.

For instance, NWRC researchers recently simulated different levels of double-crested cormorant predation on channel catfish in a multiple-batch cropping system. A multiple-batch cropping system contains ponds that include fish of varying sizes. This method allows faster-growing fish to be harvested selectively while replacing them with fingerlings (small fish). The process continues for years without draining the pond. Results of varying predation levels on 40, 0.05-hectare catfish ponds showed that production costs for catfish farming increase as cormorant predation increases.

"We found the maximum increase in production cost due to cormorant predation was approximately 14 cents per kilogram," says research wildlife biologist Brian Dorr. "Given the very thin profit margins in the aquaculture industry, this level of loss could easily result in making a pond unprofitable. It's important to note that this reduced profitability occurs even when losses are offset by increases in individual fish growth due to lower catfish densities in the ponds."

Another NWRC study utilized more than 10 years of data on cormorant food habits, bioenergetics, distribution, and abundance to evaluate cormorant impacts on catfish production. Results showed that cormorants use catfish ponds extensively from January through April each year, with the greatest economic damage occurring in February and March. During the study, cormorants ate between 1,347 and 1,775 metric tons of catfish in Mississippi's Delta region. This depredation translated into a loss of $5.6 to $12 million annually, or about 2–5 percent of gross farm sales in the Delta region.

It is important to note that this loss is not spread evenly across all ponds or even farms. Individual farms can have much larger predation losses that negatively affect profits. Given that, NWRC's research in this area is important to stakeholders. It helps determine the distribution of fish-eating birds and areas where human-wildlife conflicts may happen—so we can protect the aquaculture industry from damage.

Next Steps

Catfish ponds can range in size from 2 to 20 acres, with the majority being 10 acres or more. This large area makes it difficult for current harassment techniques to be effective. Future research will explore the use of unmanned aerial vehicles (UAVs) to estimate the distributions and abundance of waterbirds at aquaculture facilities and whether UAVs could effectively deter fish-eating birds from those locations. Economic studies will focus on the impacts of diving ducks, such as scaup, on the bait fish industry. NWRC is also researching how changes in the aquaculture industry, such as culture methods and the amount of land dedicated to aquaculture production, impacts the distribution, abundance, and foraging of fish-eating birds.

Trusted scientific data and analyses are crucial to successful policymaking.

SPOTLIGHT: Scientific Integrity and the Research Process

Public trust in science and the scientific process used to inform public policy decisions is crucial. Across the Federal Government, all departments and agencies have policies in place that address and uphold scientific integrity. USDA is committed to the highest level of integrity in all aspects of its scientific work.

“The USDA promotes a culture of scientific integrity,” says NWRC Director Larry Clark. “Science, and public trust in science, thrives in an environment that protects this culture.”

As part of the USDA’s Scientific Integrity Policy, employees engaged in or supervising scientific activities are responsible for the following:

- Designing, conducting, managing, evaluating, and reporting scientific research honestly and thoroughly;
- Disclosing conflicts of interest;
- Making all reasonable efforts to ensure the accuracy of their research;
- Taking all reasonable efforts to correct any identified inaccuracies in their reported research; and
- Engaging in appropriate authorship practices.

NWRC strives to make its science findings known to the public and has a formal system in place to identify, implement, and evaluate its research. Below is a summary of the Center’s many efforts to promote scientific integrity and transparency.

Evaluating the Work of NWRC Scientists

The NWRC employs about 30 “research grade” scientists. These scientists are the principal investigators for NWRC. Their job is to provide scientific expertise to conceptualize, plan, design, implement, analyze, evaluate, and document new information and technologies related to wildlife damage management.

NWRC strives to make its science findings known to the public. In addition to posting publications online, its researchers, biologists, and technicians often present at scientific meetings, as well as host trainings and workshops. *Photo by USDA, John Steuber*

All U.S. Government research grade scientists are evaluated under a process defined by the U.S. Office of Personnel Management. The Research Grade Evaluation Process examines a scientist's: (1) research nature and scope, (2) supervisory controls, (3) originality, and (4) contributions and impact. A peer-review panel, including subject matter experts and a human resources representative, conducts the evaluations on a 3- to 5-year cycle, depending on the scientist's seniority.

"The research grade evaluation system encourages our scientists to be productive, innovative, and responsible research collaborators," says Clark. "It also serves as an independent evaluation that ensures the credibility and integrity of our research and researchers."

Project Management System

The primary mission of the NWRC is to develop new methods to resolve conflicts between people and wildlife. Direction for the NWRC's research and development efforts comes from Administrative and Congressional directives, as well as from stakeholder input.

Every 5 years, the NWRC conducts a Research Needs Assessment (RNA) that solicits input from stakeholders such as commodity groups, State and Federal agriculture and natural resource agencies, the USDA's national citizen advisory panel to Wildlife Services, and the Wildlife Services operational program. The areas of focus for future research and development fall under four overarching categories: (1) human health and safety, (2) zoonotic and animal health diseases, (3) commodity and property damage, and (4) natural resources protection.

Using the RNA as a guide, NWRC research scientists develop 5-year business plans that identify product delivery goals and the underlying research and development activities that must occur to achieve those goals. Activity and progress toward the identified goals are reviewed annually, as well as the need for and progress made toward regulatory approvals, prototyping, scalability, technology transfer, and operational use.

At the end of 5 years, a major ad hoc review is conducted to assess the business plan's overall progress and success and to identify future research and development endeavors. This final review involves both internal and external subject matter experts.

Research Publications and Data

NWRC strives to produce products that help resolve human-wildlife conflicts. These products may be direct management tools, such as repellents, toxicants, vaccines, and devices, or they may be less tangible products, such as analytical methods or best management practices. Underlying all of these products is the scientific research. Publishing this research is critical to Government transparency and the peer-review process. Other outreach efforts, such as technical notes, factsheets, workshops, and presentations at scientific or stakeholder meetings, are also vital for disseminating information and engaging the public.

NWRC publishes about 120 peer-reviewed publications each year. In 2017, NWRC scientists produced 118 publications in 73 journals, as well as 7 book chapters. These were made available through the Center's website and the Digital Commons Network. The NWRC Digital Collections website also gives digital access to all NWRC publications from 1925 to present.

Today's emphasis on the reproducibility of research findings has led some research journals to require—as a condition of publishing—that data be publically available.

"Finding new ways to make our research data and findings available to other scientists and the public

NWRC publishes approximately 120 peer-reviewed publications each year. Copies can be downloaded from the NWRC website.

is important," says NWRC's Information Service Unit Leader Jennifer Edwards. "Open access supports research repeatability and continued public confidence in our research findings."

The Information Services Unit works with the Center's scientists and other Federal agencies to consolidate and make its data available. For example, NWRC is improving access to its research data by using tracking mechanisms such as DOIs (digital object identifiers) and exploring partnerships with other Federal agencies to host research data in publicly accessible repositories such as Data.gov.

Next Steps

NWRC will continue following best practices to preserve data for long-term access. This includes migrating data from obsolete formats, streamlining data-naming conventions, and maintaining servers that can process data sets.

2017 Accomplishments in Brief

NWRC employs about 150 scientists, technicians, and support staff who are devoted to 17 research projects (see Appendix 1). Below are brief summaries of select findings and accomplishments from 2017 not already mentioned in this year's report.

Devices

- **Trapping Invasive Lizards.** Growing up to 4.5 feet in length, the invasive Argentine black-and-white tegu is the largest species of tegu lizard. It eats a variety of both plants and animals and has become a threat to many native species in Florida, including the gopher tortoise and Florida burrowing owl. Tegus were introduced through the pet trade and now populate south and west-central Florida from accidental and intentional releases.

NWRC research with captive tegus showed the lizards are willing to enter traps of various shapes and sizes. These invasive species have become established in Florida and threaten native plants and animals. *Photo by USDA, Michael Avery*

To help State wildlife officials in their tegu control efforts, researchers at the NWRC Florida field station evaluated the responses of 12 wild-caught captive tegus to several alternative live-trap and bait combinations. Trap types included commercial live-traps and 40-inch polyvinyl chloride (PVC) pipe traps. Bait options included chicken eggs, melon-oil scent, a commercial trapper lure (My-T Mouse Blackie's Blend), and no bait. The researchers videotaped and reviewed each trial to document how long it took the lizards to enter the traps and any other important behaviors.

Results showed no significant difference between the alternative trap/bait combinations and their effectiveness. Tegus are willing to enter traps of various shapes and sizes baited with lures other than eggs. However, PVC traps are less expensive than commercial traps and could be deployed in greater numbers to maximize capture rates. *Contact: Doug Eckery*

- **Adjusting M-44 Height Reduces Risk to the Swift Fox**. WS field specialists strive to reduce the accidental take of wildlife when addressing damage issues. This is especially true when working in areas where endangered or threatened wildlife may exist. Weighing about 6 pounds, the swift fox is the smallest canid species in North America. It lives mainly in the deserts and short-grass prairies of the Great Plains. In Nebraska, the swift fox is an endangered species and occupies prairies where coyote management is essential for livestock producers. In Nebraska and many other States, M-44 ejector devices are used to deliver a lethal dose of cyanide powder to coyotes, feral dogs, and foxes that are suspected of preying on livestock. Although it is uncommon for a swift fox to trigger an M-44 device placed for coyotes, some have done so. Recent modifications to the device are making it even less likely.

NWRC and Cochrane Ecological Institute researched whether changing the height of an M-44 device could further limit the chance of a swift fox triggering it. Initial tests with captive coyotes and swift foxes suggest that increasing the set height to about 6 inches from the ground to the top of the M-44 reduces the ability of a swift fox, but not a coyote, to trigger an M-44. In field trials in North Dakota, researchers monitored 31 matched pairs of M-44s (one set at the standard height and one set at a modified/raised height) for wildlife activity. Despite equal visitation rates, only one modified M-44 was activated by a coyote, whereas 19 M-44s set at the standard height were activated by coyotes. No swift foxes were observed at the sets, but red foxes were observed at two sets and did not activate the M-44s.

Although modifying M-44 height appeared to reduce activation risk for nontarget animals, it also reduced the rate of activation by coyotes. As a result, these height changes may not be practical or efficient in areas with little or no risk to nontarget species, but could be considered for coyote management in areas where M-44s are not used because of swift foxes or other small, nontarget canids. Such changes help keep swift foxes safe, while allowing WS to continue using M-44s as a management tool in certain areas.
Contact: Julie Young

- **Preventing Nontarget Access to Feral Swine Bait Stations.** Toxic baits may be a cost-effective management tool for feral swine. However, the baits may also attract nontarget wildlife species, such as raccoons, white-tailed deer, coyotes, and black bears. NWRC researchers are evaluating swine-specific bait stations designed to keep other wildlife from accessing toxic bait for feral swine. Raccoons, in particular, are a challenge because of their

Toxic baits may be a cost-effective management tool for feral swine. However, nontarget wildlife species, such as raccoons, may be attracted to the bait. NWRC researchers are evaluating swine-specific delivery systems designed to keep other wildlife from accessing toxic bait for feral swine. *Photo by USDA* dexterity and problem-solving skills. Researchers evaluated the abilities of captive raccoons and feral swine to open the lids of magnetically sealed, hinged-lid bait stations. Although the majority of feral swine could open the bait station lids, no raccoons could open bait station lids with magnets that had 30 to 40 pounds of resistance. Results suggest that a threshold-weight-of-resistance of 30 to 40 pounds excludes raccoons while still allowing access by feral swine.

Field evaluations are ongoing to document how the bait stations perform with nontarget species, such as white-tailed deer and coyotes. A study specifically designed to assess modified bait stations' abilities to exclude black bears is also underway.
Contact: Michael Lavelle

- **Flushing Invasive Snakes From Cargo Using Heat.** The brown treesnake is an invasive species on Guam, and its accidental export to other Pacific Islands in outbound cargo is a concern. Current attempts to avoid such exports rely mainly on snake detector dogs to inspect outbound cargo and vehicles. In past work, NWRC researchers showed that thermal fumigation could cause snakes to exit cargo, but the method does not work well with tightly packed cargo. More recently, researchers have shown that radiative heating at temperatures of 111–118 °Fahrenheit (44–48 °Celsius) can cause snakes to exit cargo; however, passive solar heating of cargo does not reach high enough temperatures. An active radiant-heating system has promise as a reliable way to treat tightly packed cargo. Treatment times are short enough that the method would not interrupt normal cargo-handling procedures.
Contact: Randy Stahl

NWRC research is evaluating the use of active radiant heating systems to flush stowaway invasive brown treesnakes from tightly packed shipping containers on Guam. *Photo by USDA, Shane Siers*

Pesticides

- **Toxic Bait for Feral Swine.** Invasive feral swine cause extensive damage to natural resources and agriculture. The development and registration of a toxic bait offers a practical and cost-effective tool to control this invasive species. NWRC researchers and partners tested a newly formulated bait containing the microencapsulated active ingredient, sodium nitrite (HOGGONE; Animal Control Technologies Australia P/L, Victoria, Australia). Researchers examined palatability, lethality, and stability of the bait on groups of captive feral swine in Texas. HOGGONE was a preferred food item, averaging 1 pound (475 grams) of toxic bait consumed per animal during the first night offered. Bait consumption resulted in 95-percent mortality. Camera evidence documented that deaths occurred within 3 hours after bait consumption.

These results support current efforts to register HOGGONE for reducing damage from invasive feral swine in the United States and Australia. Further research is needed to evaluate the toxic bait on free-ranging feral swine with bait stations that exclude nontarget species.
Contact: Nathan Snow

NWRC researchers examined the palatability, lethality, and stability of a sodium nitrite toxic bait on groups of captive invasive feral swine in Texas. *Photo by USDA*

- **Finding Alternative Rodenticides for Pocket Gophers.** Pocket gophers (*Thomomys* spp.) are considered one of the most damaging wildlife pests in California. Yearly damage estimates to crops from pocket gophers range from 5 to 8 percent. Trapping and burrow fumigation are effective at controlling pocket gophers, but are usually more time-consuming and costly than baiting. As a result, growers, pest control advisors, and pest control operators often prefer baiting. Three toxicant baits are used to control pocket gophers: strychnine, zinc phosphide, and first-generation anticoagulants (such as chlorophacinone and diphacinone). Of these, strychnine has been the preferred bait for controlling gophers given its acute toxicity, more palatable flavor, and effectiveness. However, the cost of imported strychnine has increased considerably, and in some areas, gophers have developed a behavioral resistance to strychnine baits.

  The need for an effective, alternative bait for pocket gophers led NWRC researchers to investigate the efficacy of combining an anticoagulant rodenticide with an acute active ingredient such as cholecalciferol. A series of laboratory trials with currently registered rodenticides and several experimental bait combinations showed that the experimental bait was more efficacious. Bait with either a combination of diphacinone and cholecalciferol or brodifacoum and cholecalciferol performed better than existing stand-alone rodenticides. In addition to having higher efficacy rates, the combination bait contained lower concentrations of the active ingredients. This is good for two reasons: (1) it lowers the cost of the bait, and (2) less toxicant is being put into the environment.

  In field tests, researchers found combination baits to be effective. However, the use of cholecalciferol plus diaphacinone may be preferable since diaphacinone is less toxic and has a shorter half-life in animal tissues than brodifacoum.
  Contact: Gary Witmer

Woodpeckers damage telephone poles and other structures. To determine if woodpeckers are sensitive to ultraviolet cues when selecting excavation sites, NWRC and University of Missouri researchers studied the foraging behavior of 21 captive pileated woodpeckers.
Photo by USDA, Clint Turnage

Repellents

- **Ultraviolet Cues and Woodpecker Excavation Behavior.** Woodpeckers damage telephone poles and other structures when excavating cavities for nest sites or foraging. Most birds are sensitive to near ultraviolet (UV) wavelengths (300–400 nm), and the level of UV reflectance (the amount of light reflected by substrates) can influence mate selection and foraging preferences in birds. To determine whether woodpeckers are sensitive to UV cues when selecting excavation or foraging surfaces, NWRC and University of Missouri researchers compared the foraging behavior of 21 wild-caught pileated woodpeckers to food hidden under UV-reflective and UV-absorptive surfaces. Researchers determined that pileated woodpeckers are visually sensitive to UV wavelengths, with UV-absorptive substrates in particular being useful foraging cues for the birds.

  This is the first time UV sensitivity has been documented in the Order Piciformes, which includes woodpeckers, barbets, and toucans. The information will aid in developing and designing repellents to prevent woodpecker damage. *Contact: Scott Werner*

Other Chemical and Biological Methods

- **Oral Wildlife Contraceptive for Black-Tailed Prairie Dogs.** Black-tailed prairie dogs (*Cynomus ludovicianus*) exist in prairies throughout the Great Plains, from northern Mexico to southern Canada. In some areas, their burrowing, grazing, and damage to ornamental vegetation can lead to conflicts with people. In many urban areas, where prairie dog densities can be up to 5 times higher than in rural environments, wildlife managers prefer using nonlethal methods to reduce conflicts. DiazaCon (20, 25-diazacholesterol) is a cholesterol-inhibiting compound shown to reduce fertility in gray squirrels. To determine if it would be effective in reducing reproduction in black-tailed prairie dogs, NWRC researchers fed DiazaCon-coated rolled oats to free-ranging prairie dogs at a natural area in Fort Collins, CO. For comparison, prairie dogs on an adjacent site were fed nontreated bait. Researchers observed a 96-percent reduction in the number of pups per DiazaCon-treated adult prairie dog, compared to animals in the nontreated site. Blood samples taken 11 months after treatment showed lower levels of cholesterol in treated animals. However, the levels were not high enough to prevent successful breeding in subsequent years. DiazaCon may offer an alternate tool to help manage urban prairie dog populations in locations where lethal control is undesirable. *Contact: David Goldade*

- **Fertility Control for Rats.** About 7 billion rats roam the planet on any given day. Many cause damage to agricultural crops and property, as well as spread disease. Throughout the world, people try to prevent damage by using rodenticides to reduce rat populations. Yet, these toxicants are nonspecific and a hazard to nontarget species, such as dogs, cats, hawks, and owls that may feed on rodents. To find a nonlethal damage management method, NWRC scientists teamed up with the University of Arizona and private partners to test the effectiveness of a liquid bait to control fertility in Norway rats.

  Two chemicals (4-vinylcyclohexane diepoxide and triptolide) known to target ovarian function in female rats were fed to captive Norway rats via a liquid bait. Triptolide also affects sperm production in males. No offspring were born to treated females that mated with treated males, while control pairs produced normal litter sizes of 9 to 10 offspring. The number of primordial follicles in the ovaries of treated females was less than control females; the weights of testes and epididymis taken from treated males were lower than in control males.

  These results show that the liquid bait reduces fertility in both male and female rats and may be a feasible alternative to rodenticides for reducing rat populations. The U.S. Environmental Protection Agency (EPA) recently granted a registration for the liquid bait formulation for use with Norway rats and black rats under the product name ContraPest. *Contact: Gary Witmer*

- **Determining the Level of a Fertility Control Compound in Birds.** Wildlife contraceptives are an emerging tool for minimizing human-wildlife conflicts. One promising bird contraceptive compound—DiazaCon—reduces fertility by inhibiting cholesterol synthesis. In support of efforts to register DiazaCon with the EPA for use with pest bird species, NWRC chemists developed a reliable analytical method for measuring DiazaCon in bird tissues. This method extracts DiazaCon from the tissue and then uses a solid phase extraction cleanup, followed by analysis via a liquid chromatography-tandem mass spectrometry system.

  Using the method, NWRC chemists analyzed whole body samples from crows, monk parakeets, and quails and liver samples from crows and quails. Whole body tissue residues gave an estimate of the DiazaCon dose a predator would receive if it ate a treated animal. Liver data showed the highest DiazaCon dose a nontarget species might receive under normal field conditions. The method was

In many urban areas, where prairie dog densities can be up to five times higher than in rural environments, using nonlethal methods to reduce conflicts is preferred. NWRC researchers found that an oral contraceptive reduced birth rates by 96 percent. *Photo by USDA, Gail Keirn*

NWRC researchers evaluated pentosidine concentrations in the skin of 117 female yellow mud turtles of known age in western Nebraska to see if the naturally occurring compound may be useful for estimating the age of reptiles. *Photo by Earlham College, John Iverson*

highly accurate at quantifying DiazaCon residues in the carcasses of target bird species that ingested DiazaCon-treated feed. These data are essential for evaluating the potential impacts on predators or scavengers and have advanced the use of DiazaCon as a wildlife damage management tool. *Contact: Ben Abbo*

- **Use of Pentosidine as a Biomarker for Aging Turtles.** Pentosidine is a naturally occurring compound in an animal's skin. Differing concentrations of pentosidine have been useful for estimating the age of bird and mammal species, but no study has examined its usefulness for estimating the ages of longer-lived species, such as turtles. Such a tool could be useful in understanding age distributions for species of conservation concern.

  NWRC researchers evaluated pentosidine concentrations in the skin of 117 female yellow mud turtles of known age in western Nebraska. Although pentosidine levels were low, they correlated positively to age. Results were too variable to allow for precise age estimates. Further studies using pentosidine to estimate the age of both long-lived coldblooded and warmblooded animals are needed to determine its usefulness. *Contact: Randy Stahl*

- **Concentrating eDNA From Turbid Waters.** In trials with captive feral swine, NWRC researchers tested many ways to capture and purify environmental DNA (eDNA) found in turbid or muddy water. The best method for capturing eDNA in a turbid water system was to (1) concentrate DNA from a 15-milliliter (mL) water sample via centrifugation, (2) purify DNA with the DNeasy mericon Food Kit, and (3) remove inhibitors with Zymo Inhibitor Removal Technology columns.

  Furthermore, researchers compared the sensitivity of conventional polymerase chain reaction (PCR) to quantitative PCR (qPCR). They found that qPCR was more sensitive in detecting lower concentrations of eDNA. Such tools help managers monitor feral swine distributions nationwide. They are especially useful in areas declared free of feral swine, where managers must conduct surveillance and be able to confirm any new introductions rapidly. *Contact: Toni Piaggio*

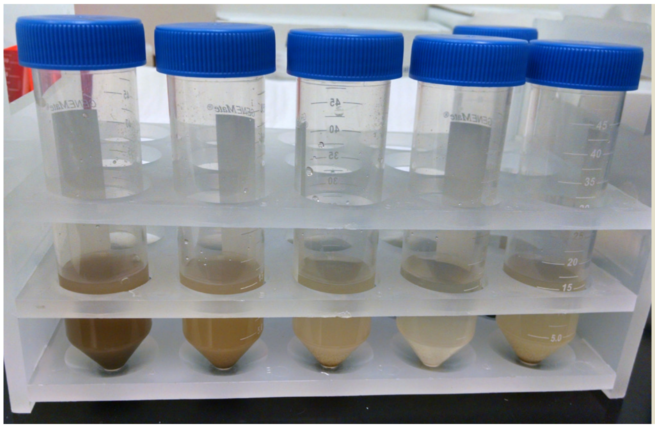
- **Measuring Stress Hormones From Hair.** Hair samples may provide an alternative to fecal samples for measuring the stress and reproductive hormone profiles of captive, zoo-housed, and wild mammals. NWRC researchers extracted and analyzed both cortisol and testosterone in coyote hair for the first time. Samples were collected from 5-week-old coyote pups housed at the NWRC Utah field station. Each individual pup was shaved in six different locations to assess whether concentrations varied by body region. Researchers found that pup hair cortisol and testosterone levels did not differ as a function of body region. Male pups generally had higher cortisol concentrations than females, but researchers did not find any differences between male and female testosterone concentrations. These

techniques could be a useful method to describe long-term stress and reproductive profiles of captive, zoo-housed, and wild mammal populations.
Contact: Julie Young

- **Monitoring Movements of Invasive Carp Using Cormorants**. Invasive carp (*Hypophthalmichthys* spp.) are a major species of concern in North America, and managers often monitor their spread by using tools to detect their DNA in water. Environmental DNA (eDNA) refers to DNA that is shed by an organism into the environment (i.e., water, soil, or air). The genetic material could come from shed skin, hair or scales, mucous, urine, or feces. The potential movement of carp DNA by fish-eating birds, such as double-crested cormorants, may impact eDNA monitoring data.

  Researchers with NWRC, the U.S. Army Corps of Engineers, and Cook County Forest Preserve District collected throat and cloacal swabs, as well as feathers, from cormorants in Illinois to test for the presence of DNA from invasive bigheaded carp (*H. nobilis*) and silver carp (*H. molitrix*). Swabs tested positive for DNA from silver carp, but not bigheaded carp. *Hypophthalmichthys* DNA was not detected on feathers.

  This is the first recording of silver carp as part of the cormorant diet in the United States. The information will help improve eDNA monitoring techniques and help assess the electric dispersal barrier and other control efforts to prevent invasive carp from entering the Great Lakes.
  Contact: Brian Dorr



In trials with captive feral swine, NWRC researchers tested many ways to capture and purify eDNA found in turbid or muddy water. *Photo by USDA, Kelly Williams*

NWRC, U.S. Army Corps of Engineers, and Cook County Forest Preserve District researchers collected throat and cloacal swabs, as well as feathers, from cormorants in Illinois to test for the presence of DNA from invasive carp.
Photo by USDA, Brian Dorr

Disease Diagnostics, Surveillance, Risk Assessment, and Management

- **Potential Spread of Pathogens Between Feral Swine, Livestock, People, and Wildlife.** In North America, at least 79 percent of reportable domestic animal diseases are linked to wildlife, and of these, at least 40 percent are zoonotic—meaning they can be spread from animals to people. Invasive feral swine are an increasing threat to animal and public health due to their range expansion and role in disease transmission. In the United States, as much as 57 percent of all farms have been visited by feral swine, and 77 percent of all agricultural animals have co-occurred with feral swine. These interactions are a growing risk for cross-species disease transmission.

  NWRC, APHIS Veterinary Services, and U.S. Geological Survey researchers studied 84 pathogens most likely to be spread by feral swine to native wildlife, domestic animals, and people. Results showed 87 percent of swine pathogens cause clinical disease in other species and people; however, this transmission potential was not evenly distributed across species. The co-occurrence of feral swine with cattle, goats, and sheep—and their susceptibility to more than 82 percent of feral swine-related pathogens—makes these livestock species at high risk for disease transmission. Developing a comprehensive national monitoring system that integrates domestic and wild animal surveillance and prioritizes pathogens based on transmission risk, potential consequences, and knowledge of occurrence could yield economic benefits for livestock health. In particular, such a system could help reduce disease "spillover" events through early detection and risk mitigation.
  Contact: Stephanie Shwiff

- **Infection Hazards in Wildlife Populations.** Wildlife is a major source of emerging infectious disease in people and animals, yet little is known about why and how the number of infected individuals changes

Invasive feral swine are an increasing threat to veterinary and public health due to their range expansion and role in disease transmission. In the United States, as much as 57 percent of all farms have been visited by feral swine, increasing the risk of disease transmission to livestock and people. *Photo by USDA, Wendy Anderson*

over time. Understanding disease dynamics, such as how many and when individuals become infected and how often they spread the disease to others, is critical for assessing risk and predicting disease outbreaks. Of particular interest is the force of infection (FOI)—the rate at which susceptible individuals become infected. Knowing how FOI changes over time would help improve disease prevention and emergency response.

In a new modeling approach, NWRC researchers and collaborators used antibody concentrations (against influenza A in lesser snow geese and plague in coyotes) from captive animal studies and field surveillance to infer changes of FOI over time in populations. By incorporating individual disease response into population-level models of disease dynamics, researchers can better understand and predict the spread of disease. The approach can combine a variety of antibody response curves and sources of individual variation, making it useful for a number of host-pathogen systems.
Contact: Kim Pepin

- **Importance of Population Density for Disease Risk Assessments.** Trapping is a common way to control wildlife populations and lower the risks of disease spread. Although wildlife abundance can be estimated by analyzing trap data, inference is limited by the extent to which a trap attracts animals on the landscape. If this "area of influence" were known, abundance estimates could be converted to densities, which are important predictors of animal contact rates and disease spread.

Using data from WS' feral swine damage management activities (i.e., trapping and aerial gunning) in Texas, NWRC researchers developed a method for estimating the "area of influence" for traps. First, researchers estimated feral swine densities by counting the number of swine seen during aerial operations and dividing that number by the size of the search area. Combining these density estimates with abundance estimates from trapping data, researchers calculated the area impacted by the traps. Based on the study, the estimated "area of influence" for corral traps in late summer in Texas is around 8.6 km^2. By quantifying other factors that may impact the "area of influence," managers can obtain more accurate density estimates for disease risk assessments and plan more efficient disease prevention and control strategies.
Contact: Kim Pepin

Using data from Wildlife Services' feral swine damage management activities (i.e., trapping and aerial gunning) in Texas, NWRC researchers developed a method for estimating the "area of influence" for traps. The "area of influence" refers to the extent to which a trap attracts animals on a landscape. *Photo by USDA*

- **Wildlife Use of Mortality Pits and Implications for Pathogen Exposure.** NWRC researchers used trail cameras to capture wildlife use and species interactions around carcass disposal pits used for carcass disposal at various animal production facilities and for road-killed animals. The data were used to evaluate disease risks to wildlife visiting the sites. Researchers observed 43 species visiting in or near the pits. Mammals were often solitary visitors, while birds were more likely to be in mixed flocks, putting them at higher risk of pathogen spread. The most common species visiting the pits were raccoons, coyotes, domestic dogs, mule deer, bald eagles, black-billed magpies, American crows, and common ravens.

Findings indicate that many animals come in contact with other species at these sites, which can expose them to disease. When possible, carcasses should be buried daily to avoid attracting scavengers. *Contact: Jeff Root*

- **Rabies Risks to Scavenging Skunks.** Rabies is a deadly viral disease that impacts human and animal health worldwide. In the Americas, bats are a common reservoir for rabies and sometimes cause spillover infections in other animals, such as striped skunks, raccoons, foxes, and domestic cats. Most rabies cases result from the bite of an infected animal; however, animals can also contract rabies by feeding on infected carcasses.

  To better understand these risks, experts with NWRC, Northern Arizona University, and WS Operations placed uninfected bat carcasses at 104 locations in suburban Flagstaff, AZ. This area had recently experienced rabies outbreaks in wild carnivores associated with bats. The researchers then monitored the carcasses with infrared, motion-sensitive trail cameras. Fifty-two of the carcasses (54 percent) were scavenged. Striped skunks were the most frequent visitor to the carcasses and removed or ate the bats 91 percent of the time. Other species that visited the carcasses included domestic cats, raccoons, gray foxes, coyotes, domestic dogs, American crows, rock squirrels, chipmunks, mice, and woodrats.

  Findings suggest that the chance for disease spread via bat carcasses is likely to vary depending on the type and abundance of scavengers in the area. Since many bat species roost in or near single-family homes, sick or dying bats that fall from these roosts tend to land near buildings or in yards where skunks come in contact with carcasses more often. Reducing skunks' access to human-provided dens and food sources may decrease rabies spread from bats to skunks due to scavenging or other contacts. Because skunks, bats, and other rabies reservoir hosts often live near people, it is also important to maintain current rabies vaccinations in pets and properly report potential human or pet exposures to this disease. *Contact: Amy Gilbert*

- **Predicting the Spread of Skunk Rabies.** In 2012, an outbreak of skunk rabies established in northern Colorado and spread rapidly through

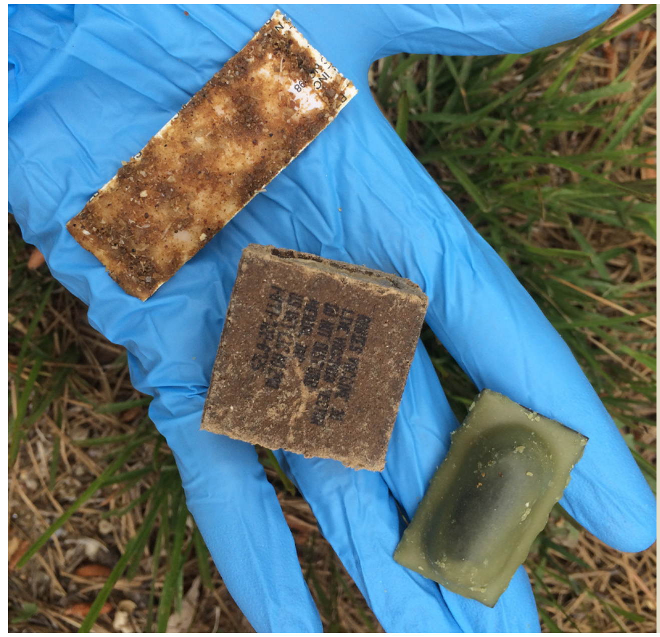
NWRC researchers studied a 2012 outbreak of rabies in striped skunk in Colorado to determine the virus' rate of spread. Results showed the virus moved south at a little over 20 km per year. The framework helped predict where and when skunk rabies would occur next.
Photo by National Park Service, Wallace Keck

three counties. Officials documented the outbreak through the public's reports of dead skunks. NWRC researchers examined the reports to determine how quickly rabies was moving and which factors could explain the patterns of spread. The researchers compared two different methods to estimate spatial movement: (1) using only the location reports and (2) analyzing rabies genetic sequences from some of the public's reports.

By both methods, researchers found the virus was moving south at a little over 20 kilometers (km) per year and that most transmission between skunks occurred at short distances (< 4 km). Rabies was most likely to spread to new areas during the first half of the year, when skunk offspring were born. The genetic model suggested that roads and rivers in the area did not affect how fast the virus spread. Researchers developed a framework that used the spatial data from public reports to predict where and when skunk rabies would occur next. This framework could be used on similar public health surveillance data for other diseases.
Contact: Kim Pepin

- **Management and Modeling Approaches for Controlling Raccoon Rabies.** The WS National Rabies Management Program works to prevent the westward spread of raccoon variant rabies in the United States. Central to this program is the use of oral rabies vaccination (ORV) in raccoon populations north to south, along the Appalachian Mountains. WS is now strategizing how best to move this oral rabies vaccine zone eastward to eliminate raccoon rabies over the next 30 years.

  To aid in this effort, NWRC and WS Operations disease experts summarized management and modeling strategies used to control or eliminate rabies in wildlife. Management strategies tend mainly to use ORV, along with trap-vaccinate-release and local population reduction where ORV proves challenging. Modeling strategies focus on predicting rabies dynamics through simulated interactions among the host, virus, environment, and control strategy. The results of this assessment will help the WS National Rabies Management Program develop and refine optimal strategies for eliminating raccoon rabies in the United States.
  Contact: Amy Gilbert



The Wildlife Services' National Rabies Management Program and its partners distribute more than 10 million oral rabies vaccination baits for wildlife each year. NWRC research helps to evaluate the effectiveness of those baiting programs. *Photo by USDA*

- **Tools for Evaluating ORV Baiting Programs.** At this time, tools for researchers and wildlife managers to evaluate the effectiveness of ORV baiting programs are limited. They can measure the amount of rabies antibodies an animal produces in response to vaccination or the reduction in rabies cases after several baiting campaigns. In rabies-free vaccination zones (in place to stop the further spread of rabies), researchers and managers can only evaluate population-based immunity using population-level antibody prevalence. NWRC, Kansas State University, and international partners reviewed and synthesized published and unpublished data on the induction of rabies antibodies after ORV. Specifically, they looked at data from captive-animal experiments that used live attenuated or recombinant rabies vaccines, as compared to the animals' level of protection against a lethal rabies challenge.

The analysis revealed several key points about tools to evaluate ORV programs. While it's generally accepted that antibody test results show animal protection accurately, the strength of this relationship varied across the tests and species analyzed. NWRC and its research partners also evaluated the best time to measure antibody levels post-vaccination for inference to protection. They found that antibody levels at Day 28 post-vaccination predicted animal survival better than other time points. And lastly, although managers often measure neutralizing antibodies to monitor ORV programs, the study found another method that may be more effective. That is, measurement of binding antibodies using an enzyme-linked immunoabsorbant assay (ELISA) predicted rabies protection more reliably. Given these results, it may be helpful to use ELISA kits for vaccination monitoring. The kits are more precise and standardized, which allows for comparing results among different studies and laboratories. *Contact: Amy Gilbert*

- **Costs and Benefits of Rabies Vaccination Campaigns in Dogs.** Rabies continues to cause significant human and animal deaths in many parts of the world. For many countries in Asia, Africa, and Latin America, canine rabies is endemic, and the majority of human rabies exposure comes from dog bites to children. Although fatal, rabies is completely preventable with timely intervention of post-exposure prophylaxis (PEP). Yet, preventing rabies in people is complicated by the fact that those most commonly exposed to canine rabies (for example, children and the poor) also lack the resources needed to treat the disease or prevent exposure to it. To help address this issue, an NWRC economist and international partners analyzed dog vaccination and human PEP costs for dog bite patients in the Philippines.

  Findings showed that eliminating rabies in dogs through mass vaccination programs is more cost-effective than treating rabies exposures in people. The average costs per human life saved through PEP ranged from US$1,498.00 to $1,620.28, while the average cost per dog vaccinated ranged from US$1.18 to $5.79. The costs of dog vaccination can be reduced further through bulk vaccine purchases by the national government or a large donor agency. As communities succeed in eliminating canine rabies, more judicious use of PEP will result in significant public savings. This study affirms the willingness of local governments to invest in disease prevention programs and work together with donors to sustain these efforts. *Contact: Stephanie Shwiff*

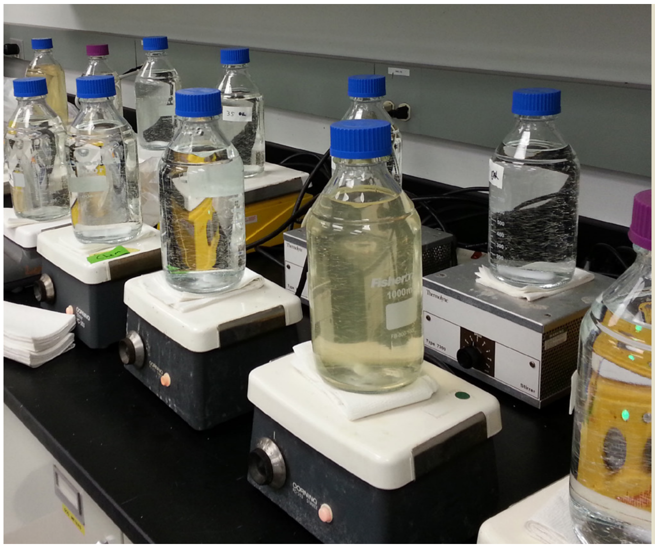
- **Genetic Diversity and Expanding Vampire Bat Populations.** The common vampire bat feeds on the blood of livestock and other wildlife in Latin America. These bats also sometimes feed on human blood and are an important reservoir

NWRC, APHIS International Services, university, and Mexican researchers studying vampire bats in Mexico are finding evidence that the bats are expanding northward and may colonize suitable habitats in the United States.
Photo by USDA, Luis Lecuona

and vector of rabies to cattle and people in Latin America. Recently, vampire bats have been documented within 35 miles of the Texas border. This has caused concern and speculation about their potential movement to areas within the United States due to rising global temperatures. The "leading-edge model" is often used to describe genetic changes in expanding populations. Populations that expand rapidly from a core population may lose genetic diversity as particular genes or individuals die off or fail to reproduce due to chance.

To determine whether the leading-edge model accurately describes vampire bat populations in northeastern Mexico, NWRC worked with APHIS International Services, university partners, and researchers in Mexico to investigate demographic processes (i.e., distances between roosts) and genetic diversity of 600 vampire bats captured in the Mexican states of Neuvo Leon, Tamaulípas, and San Luis Potosí. Results indicated random mating across the sampling area with low genetic diversity, low population differentiation, loss of intermediate-sized alleles at microsatellite loci, and very low mitochondrial DNA haplotype diversity (with all haplotypes being closely related). These results support leading-edge model predictions and concerns that the species is expanding northward and may colonize suitable habitats in the United States.
Contact: Toni Piaggio

- **Method for Concentrating Contaminants Found in Water.** Fecal contamination of water by wildlife is a significant public health risk. Having sensitive, reliable, and user-friendly methods to test water safety and quality is important. NWRC, EPA, and university researchers developed and tested an anion exchange resin-based system to aid in detecting male-specific F+ RNA (FRNA) coliphages (i.e., a virus that parasitizes *E. coli* bacteria) from water. FRNA coliphages are microbial indicators of fecal contamination.



NWRC, U.S. Environmental Protection Agency, and university researchers developed a sensitive, reliable, and easy-to-use method for detecting and quantifying fecal contaminants in water. *Photo by USDA, Jeff Chandler*

Different genotypes of these coliphages are associated with specific animal hosts, making FRNA coliphages useful for identifying and tracking sources of fecal contamination.

This new system disperses anion-exchange resin in water samples. The resin absorbs the FRNA coliphages, which concentrates these organisms into a small sample. Reducing sample volume effectively is critical for improving downstream detection with modern molecular methods. In field studies, the anion-exchange resin method concentrated and detected FRNA coliphages equally or better than existing strategies and at a lower cost. Also of note, this system was effective in diverse water sources known to contain a variety of chemicals that can inhibit FRNA coliphage detection. Therefore, such a tool may be useful for frequent or continuous water testing and identifying sources of wildlife-associated fecal contamination.
Contact: Alan Franklin

- **Method for Detecting Aerosolized Avian Influenza Viruses.** The 2014–2015 outbreak of highly pathogenic avian influenza (HPAI) in U.S. poultry,

A custom-built aerosolization chamber was used to test a new method for detecting airborne avian influenza viruses. Airborne viruses may play a large role in the spread and continuation of the disease within and between poultry facilities. *Photo by Colorado State University, Molly Hischke*

where approximately 48 million birds were euthanized with economic losses estimated at $3.3 billion, highlighted the important role of aerosols in influenza virus transmission and the continuation of the disease within and between poultry facilities. Accordingly, aerosol sampling has been suggested as a surveillance tool to monitor influenza viruses in agricultural production systems.

To address this need, researchers from the NWRC, Colorado State University's High Plains Intermountain Center for Agricultural Health & Safety, the University of Wyoming, and McGill University developed and tested a system to sample aerosolized influenza viruses. The researchers paired liquid impingement (a widely used system in which aerosolized viruses are deposited into a liquid substrate) with anion exchange resin-based virus concentration (see **Method for Concentrating Contaminants Found in Water)**. To test this new system, various quantities of type A and type B influenza viruses were aerosolized within a custom-built container and sampled using liquid impingers (devices used to collect viral aerosols) with and without anion exchange resin.

Ultimately, adding anion exchange resin to the sampling devices improved detection of type A and type B influenza viruses by more than six times and three times, respectively. The new technique is also simple to perform, adaptable to existing methods, and cost-effective.
Contact: Alan Franklin

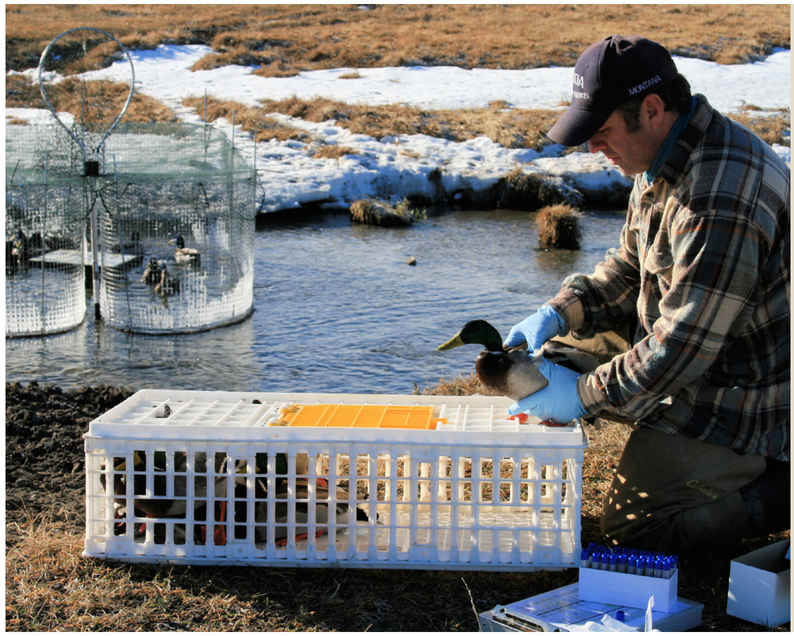
- **Impact of Body Condition on Influenza Infection in Mallards.** Migratory waterfowl, such as mallards, are known to carry and spread influenza A viruses (IAV). To better understand the impact of body condition on a mallard's immune system and its ability to shed IAV, NWRC and Colorado State University researchers manipulated the weight of captive mallards naturally exposed to these viruses. Changes in weight simulated natural fluctuations in body conditions that happen during migration. The birds were then experimentally infected with an IAV.

  Results showed that body condition in mallards did not impact viral shedding in response to the secondary exposure. Although migration may be a driver in maintaining and spreading IAVs, its energetic demands likely do not make mallards more susceptible to these viruses.
  Contact: Susan Shriner

- **Detecting Bovine Tuberculosis in Cattle Feces**. *Mycobacterium bovis* is a bacterium that causes bovine tuberculosis (bTB) in cattle, deer, and other species. The economic costs of bTB in livestock are significant, with more than $40 million in U.S. losses alone from 2008 to 2009 (most recent figure available). NWRC researchers evaluated whether fecal volatile organic compounds (VOCs) could be used to distinguish between Bacillus Calmette-Guerin (BCG)-vaccinated and non-vaccinated cattle before and after *M. bovis* inoculation. VOCs are chemicals that emit unique odors and release patterns. Because of these unique characteristics, VOCs could be used in disease surveillance.

Using gas chromatography and mass spectrometry, researchers were able to identify suites of VOCs to distinguish among groups of vaccinated and non-vaccinated cattle fecal samples before and after inoculation. Detecting disease-specific VOCs in feces could offer a simple method for testing cattle. *Contact: Kurt VerCauteren*

- **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 2017 efforts.



Wildlife Services disease biologists sampled more than 29,000 wild birds for highly pathogenic avian influenza in 2017. *Photo by USDA*

Issue	Surveillance Efforts
Avian Influenza	In 2017, NWDP continued to follow the Interagency Wild Bird HPAI Surveillance Plan, Wild Bird HPAI Implementation Plan, and HPAI Procedures Manual. Program officials sampled more than 17,300 wild birds for HPAI and completed avian influenza diagnostics on 514 raptor serum and swab samples. A subset was sent to the National Veterinary Services Laboratories for further confirmatory testing and avian influenza subtyping.
Avian Health	NWDP collected over 2,600 serum samples and 790 paired swabs from wild birds in 2017. The program plans to test for several avian diseases of interest, including *Salmonella* and paramyxovirus.
Feral Swine Diseases	NWDP sampled more than 3,800 feral swine in 35 States and Guam for classical swine fever, pseudorabies, swine brucellosis, leptospirosis, IAV, trichinellosis, and toxoplasmosis. Other subsets were tested for porcine epidemic diarrhea, Seneca virus, and Japanese encephalitis virus. NWDP biologists also collected over 2,300 ear clips from feral swine for genetic testing.
Plague and Tularemia	NWDP routinely tests wildlife for exposure to plague and tularemia along with other surveillance activities. In fiscal year (FY) 2017, NWDP biologists and their cooperators collected blood samples from over 2,600 animals across the United States. While this sample set was spread over 50 different species, the vast majority of samples came from coyotes.
Cervid Health	NWDP sampled more than 900 deer in 14 States for epizootic hemorrhagic disease, bluetongue virus, and leptospirosis.
Leptospirosis	NWDP tested more than 500 raccoons, 30 red foxes, 300 coyotes, 70 gray foxes, and 15 mongooses for exposure to leptospirosis.

Forty-two percent of the 293 archeological sites studied at Eglin Air Force Base in Florida were disturbed by invasive feral swine, potentially threatening valuable historical artifacts. *Photo by USDA, Michael Avery*

Wildlife Damage Assessments

- **Feral Swine Damage to Archaeological Sites.** Feral swine are one of the most destructive invasive species, spreading disease and damaging plants, animals, agriculture, and property. Yet, until now, little was known about their impact on archaeological sites. From 2010 to 2016, an NWRC researcher and colleagues from Eglin Air Force Base in Florida gathered data on feral swine damage at 293 archaeological sites.

  Results showed 42 percent of the sites had been disturbed by feral swine. Even more, at three historical homestead sites, feral swine rooted up to 26 percent of the total surface area. The vast majority of sites (90 percent) have artifacts at depths of less than 8 inches—and feral swine rooting usually exceeds that depth. Given this, most sites are highly vulnerable to artifact damage or displacement. These results shed light on feral swine damage to archaeological sites and aid managers in their efforts to protect these unique resources.
  Contact: Richard Engeman

- **Feral Swine Damage to Endangered Salamander Habitat.** The endangered reticulated flatwoods salamander (*Ambystoma bishop*) and frosted salamander (*A. cingulatum*) are threatened by the activities of invasive feral swine in Florida. Although feral swine eat salamanders, the bigger danger likely comes from the destruction of sensitive habitats where the salamanders live and breed. In 2014, experts with NWRC, Virginia Polytechnic Institute and State University, and WS Operations monitored 28 sites for feral swine damage on Eglin Air Force base in Florida. Long-leaf pine-wiregrass flatwoods and scattered ephemeral wetlands comprised the sites. Of those surveyed, 68 percent of the sites showed signs (i.e., tracks, scat, rooting) of feral swine, and 54 percent had damage from feral swine rooting. Of the 11 sites occupied by flatwoods salamanders in 2013 and 2014, 64 percent had been visited by feral swine, and 55 percent were damaged by feral swine rooting.

  To help protect habitats, personnel at Eglin have since installed exclusion fencing in two areas. The fencing encloses 5 of the 11 known flatwoods salamander breeding sites. Other efforts there include feral swine trapping and removal.
  Contact: Richard Engeman

- **Positive and Negative Impacts of Bird Use of Orchards.** Fruit damage by wild birds can have serious economic impacts on producers, yet in return, birds can help control pests in orchards—making small but valuable impacts on both insect numbers and fruit yield. Orchards can also offer quality habitat for bird communities, depending on property size, plant diversity, management practices, and surrounding land cover. NWRC and Colorado State University researchers examined the tradeoffs associated with birds in organic apple orchards in Colorado. Specifically, the researchers observed how birds may positively influence fruit production through the control of an insect

A metal barrier is used to protect endangered reticulated flatwoods salamanders (*Ambystoma bishop*) and frosted salamanders (*A. cingulatum*) from rooting and foraging by invasive feral swine in Florida.
Photo by USDA, Richard Engeman

pest (codling moth) and negatively through fruit damage.

Results showed that organic apple orchards in this region give habitat for a large number of bird species, including species typically sensitive to human activities. A small subset of bird species foraged on apples, but their effects appeared minor, and birds did not reduce codling moth damage. Apple damage by both birds and codling moths was consistent within and across different-sized apple blocks. In short, organic apple orchards could offer habitat for diverse bird communities with little apparent effect on production.
Contact: Scott Werner

- **Bird Use of Grain Fields at Airports.** Airport properties often include areas of agricultural crops that can attract wildlife species hazardous to aircraft. To better understand the impacts of these crop fields to aviation safety, NWRC, Mississippi State University, and University of Georgia researchers compared bird species and use among corn, wheat, and soybean fields. The researchers observed more than 4,000 birds from 40 species in fields, with most in wheat fields and the standing stubble of all crops. The most common species among crops included European starlings and red-winged blackbirds.

  Results suggest that all three crop types are used by birds hazardous to aircraft, and crop height enhances bird use. Increasing crop height from 0 to 45 centimeters corresponded to an increasing abundance of hazardous bird species, including European starlings, red-winged blackbirds, American robins, common grackles, and mourning doves. Land management at airports may benefit by switching from agricultural crops to alternative land covers, such as biofuel and biomass crops, that are less attractive to these birds.
  Contact: Travis DeVault

- **Wildlife Strike Damage to Rotary-Wing Aircraft.** Rotary-wing aircraft (i.e., helicopters and tilt-wing aircraft) make up an important part of military and civilian flights. NWRC researchers analyzed the damage rate, airframe models, and impact locations on rotary-wing aircraft associated with 4,256 wildlife strikes from 1990 to 2011. Birds

NWRC researchers analyzed the damage rate, airframe models, and impact locations on rotary-wing aircraft associated with 4,256 wildlife strikes from 1990 to 2011. Birds and mammals (primarily bats) accounted for 93 percent and 7 percent of the wildlife strikes, respectively. *Photo by USDA*

and mammals (mainly bats) accounted for 93 percent and 7 percent of the wildlife strikes, respectively. Although all parts of civil and military rotary-wing aircraft had damage from wildlife strikes, some specific areas had more damage than others. Researchers recommend that airframe manufacturers and maintenance personnel consider reinforcing and redesigning rotary-wing aircraft windscreens and main rotor systems to better withstand the impact of a wildlife strike. *Contact: Brian Washburn*

- **Predation Effects on Greater Sage-Grouse Nest Survival.** Greater sage-grouse populations in North America have declined and now occupy only 56 percent of their historical range. Low nest survival is one factor limiting sage-grouse population growth. NWRC, Oregon State University, and Utah State University researchers attached transmitters on female sage-grouse to identify and monitor the fate of 204 sage-grouse nests in Bighorn Basin, WY. The researchers also used trail cameras to identify predators at nest sites.

  Results showed coyotes to be the greatest contributor to nest failure, followed by common ravens, abandonment, and female mortality. The direct effect of nest depredation by coyotes in this study was greater than other reported sage-grouse studies, yet the nest survival rates were consistent with others reported throughout the species range. Coyote removal to protect livestock and big game did not appear to have indirect effects on nest survival, such as increased depredation by other species (i.e., badger, raven, red fox).

A greater sage-grouse hen cautiously watches a nearby coyote. NWRC and its partners studied the impacts of coyotes and other predators on sage-grouse nest and chick survival. *Photo by USDA trail camera*

Nest survival was lowest on a site where coyotes and ravens depredated nests at nearly the same rate, and where ravens were observed nesting on infrastructure close to nesting sage-grouse.
Contact: Jimmy Taylor

- **Little Competition Between Invasive Frogs and Native Birds.** The Puerto Rican coqui frog has colonized the island of Hawaii. To better understand if this invasive frog competes with three native insectivorous birds and the endangered Hawaiian hoary bat, NWRC and Utah State University researchers used stable isotope analyses to determine dietary overlaps among the species.

  Results showed no overlap between the coqui frog and hoary bat diets. Data also indicated that there was more dietary overlap between the three bird species than any of the birds and the coqui. More than 90 percent of the coqui diet consisted of Acari (mites, ticks), Amphipoda (crustaceans) and Blattodea (cockroaches, termites). Araneae (spiders) made up only 2 percent of the coqui diet compared to 25 percent for two of the three bird species. Also of note, coquis share few food resources with insectivorous birds, but occupy a similar trophic position (i.e., place in the food chain), which could indicate weak competition among the species.
  Contact: Aaron Shiels

Wildlife Management Methods and Evaluations

- **Reducing Collisions Between Birds and Vehicles.** Bird-car collisions pose serious financial and conservation concerns, but their causes are poorly understood. NWRC researchers investigated how a bird's experience with vehicles influences its collision-avoidance behavior. Researchers trained three groups of captive pigeons with 32 near-missed vehicle approaches over 4 weeks and also included birds that heard but did not see the vehicles (control birds). Using a specially designed simulation chamber, researchers then measured bird flight initiation distances (FID) and whether individual birds "collided" with a virtual vehicle approaching them at 120 or 240 kilometers (km) per hour. Researchers then compared the FIDs of control birds and experienced birds (i.e., those that had experienced near-miss vehicle approaches).

  Results indicated that control birds had longer FIDs than experienced birds, suggesting a habituation-like effect in experienced birds. However, even the heightened avoidance response of control birds was generally inadequate to cope with and avoid vehicles approaching at high speeds. Future research will focus on developing vehicle lighting systems designed to elicit an earlier avoidance response to high-speed vehicles, thus minimizing bird mortality.
  Contact: Travis DeVault

- **Reducing Electrocution of Birds at Power Lines.** Electrocution on power lines is an important human-related cause of bird mortality worldwide, especially for raptors. Identifying and correcting dangerous electrical pylons can significantly reduce the number of bird electrocutions. NWRC researchers and international colleagues developed a method for identifying high-risk mortality areas in eastern Spain by combining spatial electrocution risk models with bird species sensitivity maps. A risk prediction map was built using bird electrocution records associated with 1 km × 1 km spatial grids from 2000 to 2009. The species sensitivity map was built with data on the presence and habitat use of four raptor species. The researchers then compared a combination of both maps to the distribution of Special Protected Areas, which local experts validated to identify any gaps. About 16 percent of the study area was deemed a high-priority protection area for birds. Results

To better understand how biofuel crops affect grassland bird reproductive success and conservation, NWRC and Mississippi State University researchers compared nest success, density, and productivity for dickcissels using switchgrass fields (a biofuel crop) versus native warm-season grasslands. *Photo by Wikimedia Commons*

support the use of predictive models and sensitivity maps to help identify high-priority wildlife protection areas over large landscapes.
Contact: Travis DeVault

- **Influence of Biofuel Crops on Grassland Bird Nest Survival.** Recent focus on energy production has increased interest in developing biofuels, such as switchgrass, to boost energy production while maintaining ecosystem function and biodiversity. To better understand how biofuel crops affect grassland bird reproductive success and conservation, NWRC and Mississippi State University researchers compared nest success, density, and productivity for a grassland songbird, the dickcissel, using switchgrass fields versus native warm-season grasslands.

  Results showed no difference in nest success between the two vegetation types. However, both vegetation composition and harvest frequencies influenced nest density and productivity. Native warm-season grasses contained 54–64 times more nests relative to switchgrass fields, and nest density and productivity were 10 percent higher in single harvest plots. Based on these results, fields that contain a mixture of natural grasslands and biofuels can help meet the country's energy production goals while offering important habitat areas for grassland birds.
  Contact: Travis DeVault

- **Blackbird Response to Predation Risk During Breeding.** Blackbirds reportedly cause between 1 to 2 percent of crop damage per year, but the distribution of it varies widely, with some fields experiencing damage as high as 20 percent. Many of the nonlethal management techniques for preventing bird damage take advantage of natural predator-prey systems. One area in need of research is the physiological response of birds to visual and auditory scare devices designed to imitate predators.

  To look into this issue, NWRC researchers studied the physiological and behavioral tradeoffs of female red-winged blackbirds in North Dakota when exposed to various predation risks. Breeding colonies were exposed to three different treatments: an avian predator, an avian nest parasite, or a nonthreatening avian effigy with corresponding bird call. Researchers introduced the treatments at the beginning of the breeding season and then monitored the colonies throughout the season for reproductive trade-offs in response.

  Results suggest that red-winged blackbirds have a greater response to the perceived risk of predation than to nest parasites or control treatments. Nest success and lay date did not differ between females under the different treatments.

However, NWRC researchers did see a trend for larger clutches in nests found within the predator treatment, suggesting that females may actually make a trade-off for the current rather than future breeding seasons. These findings will aid in improving bird damage management tools.
Contact: Page Klug

- **Adaptive Strategy for Nonlethal Predation Management.** Although most sheep ranchers use nonlethal methods to protect their flocks from predators, disagreement still exists about how effective and economically and logistically practical many of these tools are for large-scale grazing operations. To gain a better understanding of how best to use nonlethal methods with large-scale grazing operations on public lands, an NWRC researcher worked with WS Operations field specialists and conservationists to collect 7 years of data on sheep depredations by wolves in a demonstration area that used a variety of nonlethal methods. The research team compared this information to data from an adjacent area where sheep were grazed without nonlethal protections. Wolves occupied both areas. Between 10,000 and 22,000 sheep grazed across nearly 1,000 square miles of the protected demonstration area.

Field specialists strategically applied nonlethal predator deterrents and animal husbandry practices by adjusting for things such as habitat conditions, locations of known wolf packs, and the frequency or type of nonlethal methods used. Nonlethal methods included increasing human presence and the number of livestock protection dogs; fladry and turbo-fladry; spotlighting; scare devices, such as air-horns, blank handguns, flashing lights, and radioactivated guard boxes; and monitoring the movements of radio-collared wolves.

Results showed sheep losses to wolves were 3.5 times higher in the unprotected area than in the protected area. While encouraging, there are some caveats for this case study. Local knowledge of wolf activity, directed management effort, and monitoring were extensive. The presence of one or more field specialists helping to monitor and deter wolves played a critical role in minimizing wolf-sheep interactions, as they could select appropriate deterrents based on site-specific conditions at the time. For instance, by monitoring the location of wolf packs and dens, field specialists could pen sheep and increase spotlighting at night when high-risk wolf encounters were likely. Field specialists and herders concluded that without human presence, especially at night, wolves and other predators tended to prey more heavily on the sheep bands.

Fladry is a simple, nonlethal tool used to protect livestock from predators in smaller areas like calving and lambing grounds. Wolves and coyotes are often cautious about crossing the fladry barrier. *Photo by USDA*

This case study will prove useful in familiarizing livestock producers and sheepherders with the integrated nonlethal methods and effort useful for protecting sheep from wolves. However, this adaptive approach may not be easily repeatable, feasible, or cost-effective for some ranchers. Further studies are needed on the time and costs involved with using such methods within the context of the economic and market realities affecting ranching operations.
Contact: Stewart Breck

- **Understanding Urban Coyote Behavior.** From Los Angeles to Denver and New York City, coyotes are becoming a common sight in cities across the country. Unfortunately, the number of conflicts between urban coyotes and people is also rising. To better understand urban coyote behaviors and the effectiveness of harassment programs to prevent coyote conflicts, NWRC researchers, WS Operations specialists, and numerous local and State partners radio-collared 33 coyotes in the Denver Metro Area and followed their movements. A concurrent Citizen Science program recorded coyote behavior and interactions with people and their pets.

  Results showed how coyotes have adapted to urban living by staying relatively inactive during the day and venturing throughout urban and suburban neighborhoods at night. Not surprisingly, the diet of urban coyotes is quite variable, including rodents and rabbits, a diversity of fruit from native and introduced plants, and occasionally a cat or dog. Findings also showed that some urban coyotes exhibited bold behavior, especially toward people. These results led to a study of how hazing (harassing) performed by citizens in Denver helps to minimize conflict. Researchers found that hazing can be an effective short-term solution for reducing dangerous interactions with coyotes, but that some individual coyotes can become quite bold and do not respond to hazing. They recommend that the humane removal of such individuals is the best management decision for reducing conflicts.
  Contact: Stewart Breck

- **Large Carnivore Science.** Large carnivores, such as wolves and lions, are some of the world's most charismatic and ecologically influential organisms. Through their interactions with other animals, large carnivores may affect whole ecosystems across many levels (e.g., trophic cascade). Studies describing these top-down processes are often used to support wildlife management actions, including carnivore reintroduction or lethal control programs. Unfortunately, there is an increasing tendency to ignore, disregard, or devalue fundamental principles of the scientific method when communicating the reliability of current evidence for the ecological roles that large carnivores may play. This can erode public confidence in large-carnivore science and scientists.

  A group of international researchers, including a research biologist from NWRC, identified six issues that currently undermine available literature on the ecological roles of large carnivores. These include: (1) the limited amount of available data, (2) reliability of carnivore population sampling techniques, (3) disregard for alternative hypotheses to top-down processes, (4) lack of applied studies, (5) use of logical fallacies, and (6) generalization of results from pristine systems to those altered by people. Researchers note that managers and policymakers should exercise caution when relying on this literature to inform wildlife management decisions. They also emphasize the value of manipulative experiments to improve the rigor and communication of large-carnivore science.
  Contact: Richard Engeman

- **Cost and Effectiveness of Rodent Control on Islands.** Invasive rats have been introduced to more than 80 percent of the world's islands and are the leading cause of native plant and animal extinctions on islands. To better understand the cost and effectiveness of rodent control efforts on islands, NWRC researchers and partners in New Caledonia analyzed data from 136 projects conducted over the last 40 years. Most projects targeted black rats and were aimed at protecting birds and endangered ecosystems. The median annual cost of rat control projects was US $17,262 (or US $227 per hectare). Fifty-one percent of the projects showed positive effects on biodiversity. Researchers note the data was limited to a few countries, revealing a need to expand rat control efforts especially on islands rich in biodiversity.

Regular monitoring of the islands would also improve assessments of the short- and long-term effectiveness of rat control.
Contact: Aaron Shiels

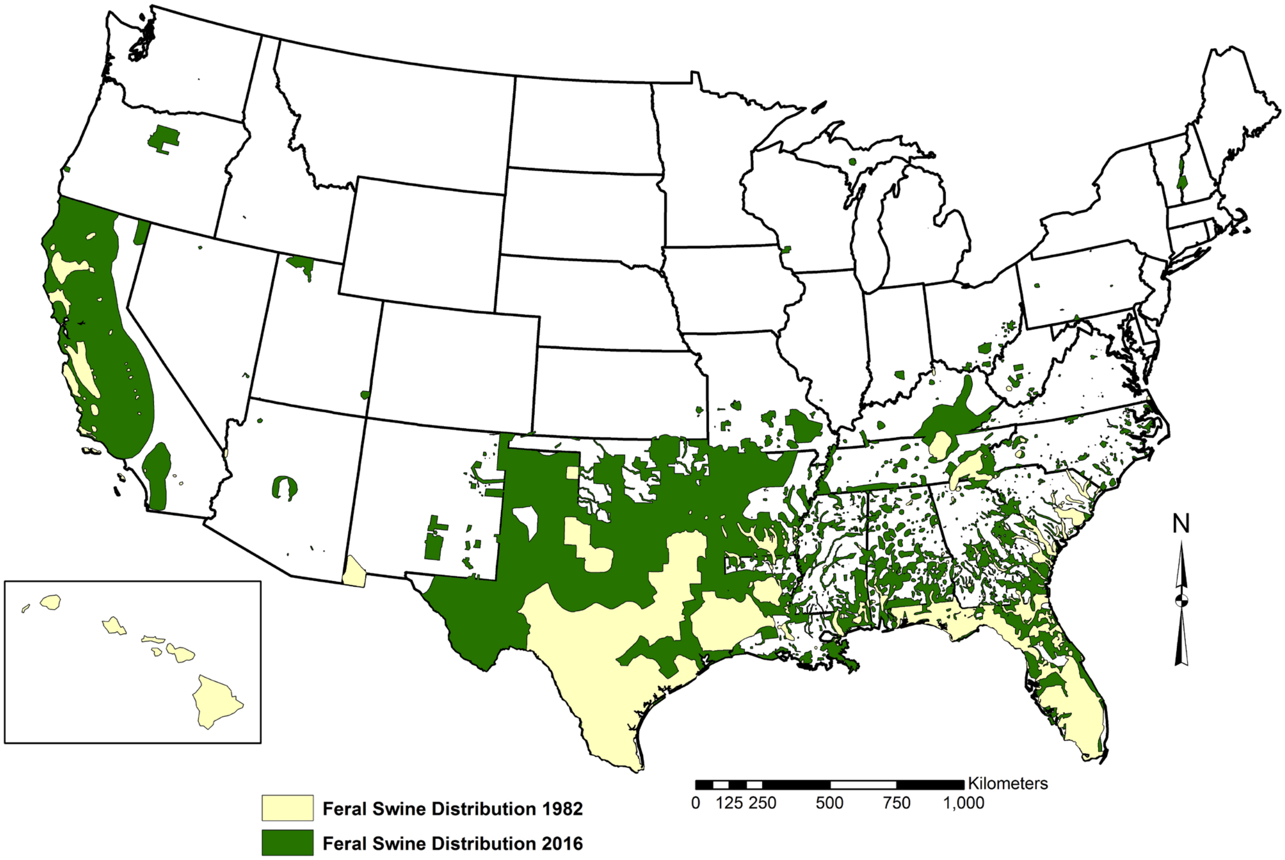
- **Shifts in Invasive Rodent Communities Following Habitat Restoration.** One unintended consequence of forest restoration efforts is a shift in invasive animal populations, which may impact the native plants and animals targeted for conservation. In Maui, HI, researchers with the NWRC, U.S. Geological Survey, and University of Hawaii compared invasive rat and mice communities in a restored native dry forest and adjacent non-native grassland. In the unrestored grassland, house mouse captures outnumbered black rat captures 220:1. In contrast, in the restored native forest, rat captures outnumbered mouse captures by nearly 5:1. The fairly recent native forest restoration increased rat abundance and their total biomass in the restored ecosystem 36-fold, while reducing mouse biomass 35-fold. Such a community shift is worrisome because black rats pose a much greater threat than do mice to native birds and plants, perhaps especially to large-seeded tree species. Land managers should be aware that without intervention, such shifts may pose risks for intended conservation goals.
Contact: Aaron Shiels

Wildlife Population Monitoring Methods and Evaluations

- **Expanding Feral Swine Populations.** Population estimates for the number of feral swine in the continental United States vary; however, the National Feral Swine Damage Management Program states that between 5 and 6 million feral swine exist across at least 35 States. NWRC, Texas A&M University-Kingsville, and Yale University researchers modeled the spread of feral swine in the continental United States from 1982 to 2012. They found that, during this period, the rate of northward range expansion by feral swine accelerated from 6.5 to 12.6 km (4 to 8 miles) per year. If this trend persists, feral swine would reach most U.S. counties in 30 to 50 years.

Study results also showed that the spread of feral swine was largely associated with similarities between existing and new habitats. Feral swine were more likely to expand their range into areas that were similar to the ones they already occupied. The most notable exception was the tendency for feral swine to spread into areas with colder winters, something that also reflects their northward expansion. In recent years, the spread also has been associated with trends of milder winters.
Contact: Nathan Snow

Fifty-one percent of rodent eradication efforts on islands show positive effects on biodiversity. *Photo by USDA, Aaron Shiels*



NWRC and university researchers found that the northward spread of feral swine in the United States is accelerating (from 4 miles per year in 1982 to 8 miles in 2012). If this trend persists, feral swine are predicted to reach most counties in 30 to 50 years. *Map by USDA, National Feral Swine Damage Management Program*

- **Factors Influencing Feral Swine Movement.** Many factors influence when or why an animal moves from one location to another. Recent technological advances in GPS devices allow for the collection of increasingly fine-scale location data that includes information on climate, habitat, and time of day. Combined with information on sex and age of individual animals, the data help researchers predict changes in animal distributions over space and time. To learn how multiple factors and scales can affect animal movement, NWRC and numerous State, Federal, and university partners analyzed more than 400,000 GPS locations of feral swine in six southern States collected between 2004 and 2014. Researchers considered local environmental factors such as daily weather data and distance to various resources on the landscape, as well as factors on a broader spatial scale such as ecoregion and season. Results showed that meteorological variables (temperature and pressure), landscape features (distance to water sources), a broad-scale geographic factor (ecoregion), and individual-level characteristics (sex-age class) drove feral swine movement, but relationships between these variables differed across the time scales of data analysis (daily, monthly, etc.). For instance, one female swine's monthly home range size decreased by half when she gave birth, yet this was not observed at larger temporal scales. Researchers emphasize the importance of defining temporal scales for both movement response and related variables depending on the overall goals of the analysis (for example, predicting movement due to climate change or planning local-scale management).
Contact: Kim Pepin

- **Role of People in Feral Swine Population Expansion.** People are playing an increasing role in the spread of invasive species to new areas. This accidental and intentional movement threatens biodiversity and agriculture, modifies habitats, and spreads harmful pests and diseases. NWRC, APHIS Veterinary Services, and University of Wyoming researchers combined population genetic analyses of feral swine in California with information on human-related factors, such as the presence of recreational hunting, game farms, and domestic pig farms, to identify which factors may be linked to feral swine movement.

  Genetic analyses showed several distinct feral swine populations in California, indicating that they exist in small groups and do not naturally disperse large distances. Researchers also found evidence that people have moved feral swine within California and identified several factors related to these movements, including the number of feral swine taken by hunters and the number of licensed game outfitters. The number of game farms and domestic pig farms as well as the amount of public land were also positive predictors of feral swine movement. While researchers have hypothesized that hunting plays a role in feral swine movement, this is the first study to offer quantitative evidence of such a relationship. These findings suggest strongly that future efforts to manage invasive species must consider the potential role of people in their spread.
  Contact: Toni Piaggio

- **Site Fidelity Sheds Light on Animal Activities.** Effective wildlife management requires a good understanding of animals' resource needs in ever-changing environments. Resource requirements vary both daily and over the animal's lifetime. Managers can better understand an animal's needs by observing its movements and habitat use. Site fidelity (i.e., the tendency to return to a previously occupied site) often indicates a specific behavior, such as foraging, breeding, and contacts between species or individuals. Using a novel method for identifying site fidelity patterns, NWRC and Utah State University researchers studied the activities of GPS-collared cougars and coyotes.

  Results showed that site fidelity data could be used to predict prey species related to cougar kills (short-term, high-intensity fidelity), as well as differentiate between pup-rearing sites (intermediate fidelity) and scent-marking sites (long-term, low-intensity fidelity) in coyotes. The approach offers a useful method for identifying site fidelity patterns associated with specific behaviors without having to directly observe an animal.
  Contact: Julie Young

- **Differences in Vulture Activities and Home Ranges.** In the United States, black vulture and turkey vulture populations have increased since the 1970s. These increases have led to a rise in conflicts between people and vultures, including aviation risks from soaring vultures. Information on vulture activity patterns (i.e., time spent flying versus perched/roosting) reveals a lot about a bird's effort to find and get important resources, such as food, nest sites, or roost sites within its home range. Using 2.8 million GPS locations recorded over 2 years for tagged black and turkey vultures, NWRC researchers discovered that monthly home range sizes for turkey vultures were about 50 percent larger than for black vultures. Activity patterns also revealed that turkey vultures spent more time in flight and switched between flight and stationary activity more often than black vultures. This information is useful in reducing vulture-related conflicts and improving conservation of these ecologically valuable species.
  Contact: Travis DeVault

Using 2.8 million GPS locations recorded over 2 years for tagged black and turkey vultures, NWRC researchers learned about the birds' home range sizes and activity patterns. The information is useful in reducing vulture-related conflicts with aviation. *Photo by DoD*

Registration Updates

- **Availability of DRC-1339 Pesticide.** The availability of DRC-1339 for use in bird damage management has been limited since its original manufacturer ended production in 2016. The NWRC Registration Unit played an integral role in identifying new potential manufacturers of DRC-1339 and helping the WS Management Team, especially the WS Regional Directors, distribute remaining stocks. The unit directed WS' work to purchase and distribute this pesticide in line with Federal regulatory requirements. It also continues working through the process to gain EPA approval for the new DRC-1339 source and is working actively to secure more sources as well. These efforts will better position WS Operations to continue its work with this product if another availability issue arises.
Contact: Jeanette O'Hare

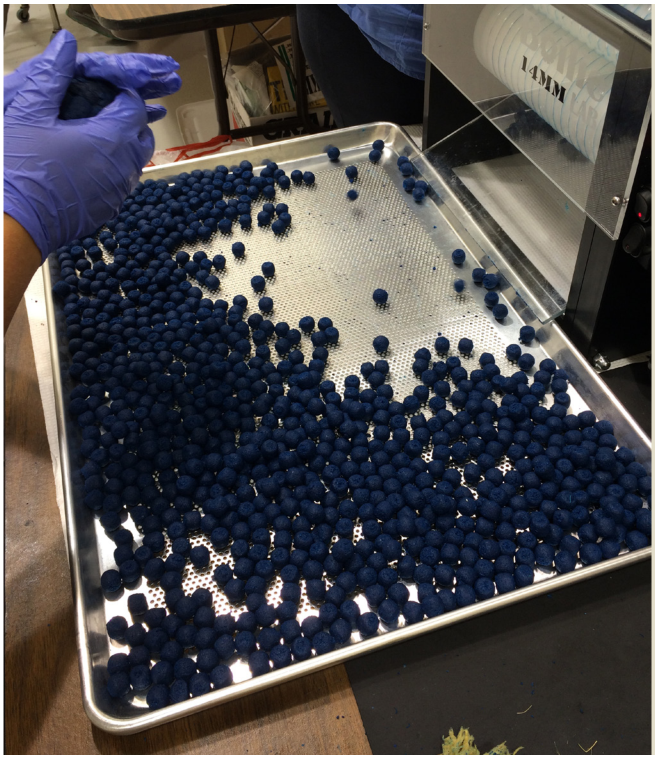
- **Funding EPA Registration Review.** Every 15 years, the EPA must reevaluate all active pesticide registrations based on new available science and to ensure products are still eligible for registration. In the course of these reviews, EPA often requires registrants to submit new data. Costs depend on assessment outcomes, but can easily exceed several hundred thousand dollars. Pesticide registrants typically have 2 to 4 years to submit requested data to the EPA. Delays in data submissions can lead to product cancellations or highly conservative label use restrictions. The NWRC Registration Unit helped WS Operations create a mechanism to pay for current and future data requirements. It involves a sliding-scale registration fee of 4 to 9 percent on all APHIS pesticide product sales. This solution ensures timely compliance with Federal laws and allows for continued availability of APHIS pesticide products.
Contact: Jeanette O'Hare

Technology Transfer

- **Regulatory Consultation With USDA Center for Veterinary Biologics.** In September 2016, NWRC took part in a delegation to meet with USDA's Center for Veterinary Biologics (CVB) about vaccine licensing for products used to manage wildlife diseases. The group included colleagues with WS Operations and APHIS Veterinary Services, along with others from the U.S. Geological Survey, U.S. Fish and Wildlife Service, Colorado Parks and Wildlife, Edge Veterinary Consultants Group, and Tufts University. As a result of this meeting, CVB now offers an alternative regulatory path called "Conditional Licensing." Conditional licensing allows a CVB-licensed facility to produce and license vaccines, such as the sylvatic plague vaccine (SPV), and then sell them for further manufacturing into bait products. This option offers a way to use vaccines and other CVB-regulated products in large-scale wildlife conservation efforts.
Contact: John Eisemann

- **Sylvatic Plague Vaccine Manufacturing.** NWRC is an active member of the Black-Footed Ferret Recovery Program's SPV Subcommittee. In FY 2016, the NWRC Technology Transfer Program, in concert with the NWRC Chemistry and Registration units, assumed the role of regulatory lead for the subcommittee and established a pilot manufacturing facility at the NWRC's headquarters campus in Fort Collins, CO. The facility has produced 300,000 SPV baits to distribute over 6,000 acres of prairie dog habitat in 6 Western States.

  In FY 2017, the Technology Transfer Program worked with WS Operations' Western Region to manufacture SPV bait at the WS Pocatello Supply Depot in Idaho. As a result, WS established a high-volume SPV bait production facility and potential bait distribution program similar to that of the WS National Rabies Management Program. This effort was a success not only for the NWRC but also for WS Operations and black-footed ferret conservation. *Contact: John Eisemann*



In 2017, NWRC helped with the production of 300,000 sylvatic plague vaccine baits for distribution over 6,000 acres of prairie dog habitat in 6 Western States. The vaccine bait is fed to prairie dogs, which are the primary food source for endangered black-footed ferrets. *Photo by USDA, John Eisemann*

- **Brown Treesnake Aerial Baiting.** NWRC's Technology Transfer Program worked in recent years with a private company to create and test an automated aerial bait manufacturing and delivery system for brown treesnake control efforts on Guam. This year, the Technology Transfer Program helped hand over the technology to WS Operations and make it fully operational. NWRC and its partners can now manufacture upwards of 1 million baits per year for delivery over hundreds of acres of tropical rainforest. This effort supports habitat conservation and endangered species recovery on Guam. *Contact: John Eisemann*

- **Development of a "Daughterless Mouse."** NWRC signed a formal Memorandum of Understanding (MOU) to partner with conservationists and university researchers in exploring the use of genetically modified mice to eradicate invasive mice on islands. The genetically modified mice produce only male offspring. The MOU includes six entities: USDA, two U.S. universities, one Australian university, an Australian government research center, and a U.S.-based nonprofit organization. Through this MOU, NWRC's genetics and rodent projects will receive $1.4 million from the Defense Advanced Research Projects Agency (part of the U.S. Department of Defense) and house the genetically modified mice for captive breeding trials at NWRC's biosecure facility in Colorado. *Contact: John Eisemann*

- **Patents, Licenses, and New Inventions.** In 2017, the U.S. Patent and Trademark Office allowed one NWRC patent (USPTO Patent #9,730,438) for development of a "Container Apparatus" that delivers baits to brown treesnakes using a mechanized, aerial system. NWRC also presented four new inventions to

A new automated aerial bait delivery system for controlling invasive brown treesnakes on Guam is expected to be fully operational in 2018. Wildlife Services and its partners are capable of manufacturing approximately 1 million baits per year for delivery over hundreds of acres of tropical rainforest. *Photo by USDA*

USDA's Agricultural Research Service and the Forest Service for consideration to patent.
Contact: John Eisemann

- **FLC Mid-Continent Deputy Regional Director.** The Federal Laboratory Consortium (FLC) elected NWRC's Technology Transfer Program Manager John Eisemann as its Mid-Continent Deputy Regional Coordinator. Eisemann began serving a 2-year term on October 1, 2017. His work will help promote, raise awareness about, and support technology transfer from Federal laboratories to the private sector.

NWRC Technology Transfer Program Manager John Eisemann is serving as the Federal Laboratory Consortium's Mid-Continent Deputy Regional Coordinator.
Photo by USDA

Awards

- **FLC Regional Partnership Award.** In August 2017, NWRC and four Federal, State, and private partners received the FLC Mid-Continent Region's Regional Partnership Award for their role in developing, testing, registering, manufacturing, and distributing a new oral plague vaccine for prairie dogs. Black-footed ferrets are one of the most endangered mammals in the United States. They feed almost exclusively on prairie dogs. When plague sweeps through a prairie dog colony, it can severely impact black-footed ferret reintroduction efforts. The new vaccine holds promise as a cost-effective way to reduce plague impacts in certain areas, and thus protect black-footed ferrets.

  In 2017, NWRC and its partners manufactured and distributed over 1 million baits to more than 20,000 acres of ferret habitat. The effort

In August 2017, NWRC and four Federal, State, and private partners received the Federal Laboratory Consortium Mid-Continent Region's Regional Partnership Award for their role in developing a new oral plague vaccine for prairie dogs. The new vaccine aids in efforts to recover endangered black-footed ferrets.
Photo by U.S. Fish and Wildlife Service, Kimberly Fraser

NWRC researchers studying birds and mammals found on HPAI-infected farms received the 2017 NWRC Publication Award for their groundbreaking work. *Photo by USDA*

highlights widespread and effective cooperation among multiple Federal and State agencies and nongovernment entities. Laboratory and field testing of the vaccine bait was robust, and the group succeeded in developing cost-effective and large-scale bait manufacturing and delivery options.

- **2017 NWRC Publication Award.** Each year, the NWRC Publication Awards Committee, composed of NWRC scientists, reviews over 100 publications generated by their NWRC colleagues. The resulting peer-recognized awards honor outstanding contributions to science and wildlife damage management. In 2017, the award was presented to Susan Shriner, Jeff Root, Mark Lutman, Kaci VanDalen, Heather Sullivan, Thomas Gidlewski, Thomas DeLiberto, and their external partners for the article "Surveillance of highly pathogenic H5 avian influenza in synanthropic wildlife associated with poultry farms during an acute outbreak" (*Scientific Reports* 6:36237).

  Sampling wildlife around farms in a zone experiencing an outbreak of HPAI is important for understanding the potential role of wildlife species in spreading avian influenza viruses. The authors were thorough in sampling farms that tested both negative and positive for HPAI (five farms each) and applied a community ecology perspective to the problem. Wildlife surveillance for disease around farms is a fairly new activity in the United States; thus, this study and publication lay the foundation for how to improve data collection and surveillance design in the future.

- **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:

  - **Susan Shriner**, Research Grade Scientist; Developing Methods To Evaluate and Mitigate Impacts of Wildlife-Associated Pathogens Affecting Agricultural Health, Food Security, and Food Safety Project; Fort Collins, CO

  - **Eric Tillman**, Support Scientist; Methods Development and Population Management of Vultures and Invasive Wildlife Project; Gainesville, FL

  - **Robert Sugihara**, Technician; Methods and Strategies to Manage Invasive Species Impacts to Agriculture, Natural Resources, and Human Health and Safety Project; Hilo, HI

  - **Charlie Brocious**, Administrative Support Unit; Fort Collins, CO

2017 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: 2016 publications that were not included in the 2016 NWRC accomplishments report are listed here.)

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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 2017 NWRC Research Projects

Methods Development and Population Management of Vultures and Invasive Wildlife
Project Leader: Michael Avery (retired 2018)

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

Improving Rodenticides and Investigating Alternative Rodent Damage Control Methods
Project Leader: Gary Witmer

Developing Methods To Evaluate and Mitigate Impacts of Wildlife-Associated Pathogens Affecting Agricultural Health, Food Security, and Food Safety
Project Leader: Alan Franklin

Economic Research of Human-Wildlife Conflicts: Methods and Assessments
Project Leader: Stephanie Shwiff

Defining Economic Impacts and Developing Control Strategies for Reducing Feral Swine Damage
Project Leader: Kurt VerCauteren

Methods and Strategies for Controlling Rabies
Project Leader: Amy Gilbert

Management of Ungulate Disease and Damage
Project Leader: Kurt VerCauteren

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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Appendix 3

Acronyms and Abbreviations

APHIS	Animal and Plant Health Inspection Service
bTB	bovine tuberculosis
BCG	Bacillus Calmette-Guerin
CRISPR/ Cas9	a genome editing technology that allows permanent modification of genes
CVB	Center for Veterinary Biologics
DiazaCon	20, 25-diazacholesterol
DNA	deoxyribonucleic acid
DoD	U.S. Department of Defense
DOI	digital object identifiers
eDNA	environmental DNA
ELISA	enzyme-linked immunoabsorbant assay
EPA	U.S. Environmental Protection Agency
FID	flight initiation distance
FLC	Federal Laboratory Consortium
FOI	force of infection
FRNA	F+ RNA
FY	fiscal year
GBIRd	Genetic Biocontrol of Invasive Rodents
GPS	global positioning system
HPAI	highly pathogenic avian influenza
IAV	influenza A virus
km	kilometer
mL	milliliter
MOU	Memorandum of Understanding
NWDP	National Wildlife Disease Program
NWRC	National Wildlife Research Center
ORV	oral rabies vaccine
PCR	polymerase chain reaction
PEP	post-exposure prophylaxis
PVC	polyvinyl chloride
qPCR	quantitative polymerase chain reaction
RNA	ribonucleic acid
RNA	research needs assessment
SDM	species distribution models
siRNA	small interfering RNA
SPV	sylvatic plague vaccine
UAV	unmanned aerial vehicle
USDA	U.S. Department of Agriculture
UV	ultraviolet
VAH	virulent strain of *Aeromonas hydrophila*
VOC	volatile organic compound
WS	Wildlife Services

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