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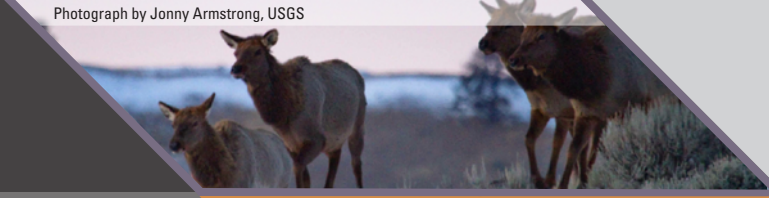
Photograph by Jonny Armstrong, USGS

By Land, Air, and Water—U.S. Geological Survey Science Supporting Fish and Wildlife Migrations Throughout North America


Photograph by Jim Hudgins, U.S. Fish and Wildlife Service


Photograph by Michael Humling, U.S. Fish and Wildlife Service

Countless species of animals—big game, birds, bats, insects, amphibians, reptiles, and fish—migrate to reach suitable habitats to feed, reproduce, and raise their young. Animal migrations developed over millennia commonly follow migration corridors—unique routes for each species—to move among seasonal habitats. Changes along those corridors, whether from infrastructure we rely on (buildings, roads, dams) or increased natural disturbances because of climate change (for example, drought, fire, flooding, or invasive species), can make them harder to navigate.

The U.S. Geological Survey (USGS) Ecosystems Mission Area provides science that assists land managers in mapping, enhancing, protecting, and reconnecting migration corridors critical for diverse fish and wildlife populations that migrate, such as *Odocoileus hemionus* (mule deer) and *Antilocapra americana* (pronghorn), trout and salmon, salamanders, tortoises, bats, and *Danaus plexippus* (monarch butterflies). The USGS is deploying new cutting-edge technologies and approaches to detect, track, and map wildlife species movements. Our scientists develop new methods and diagnostic tools, using everything from acoustics to environmental genetics to satellite transmitters, to obtain accurate and often near-real-time data to track wildlife. Using high-performance computing, these data are used to predict animal movements under different habitat, climate, and land use scenarios.

Over Land

Animals that migrate across land face unique challenges because their migratory paths often cross or are interrupted by roadways and other human developments. Not only does this development impede or alter migration routes, but in the case of road crossings, it also can be a dangerous situation for animals and humans. USGS scientists are working with Federal, State, and private entities to provide solutions and mitigate these roadway hazards. For small animals, human developments can be an even bigger challenge, limiting seasonal movements to reach critical habitat for breeding. The USGS is improving our understanding of how certain species are connected across the landscape at different times of the year and is developing strategies that provide options for safe migration routes that avoid barriers to movement.

Surfing the Green Wave and Safe Wildlife Crossings

In the American west, human-made barriers that impede movements of migrating ungulates—hooved animals such as *Cervus elaphus* (elk), mule deer, *Rangifer tarandus* (caribou), and pronghorn—make it harder for herds to complete their annual migrations. The USGS is working with State and Federal wildlife managers and other research partners to understand how and when animals migrate and how residential housing developments and roadways alter migratory behaviors. Scientists are collaborating with State wildlife managers to analyze migration data and develop tools to identify conservation and management opportunities to protect ungulate migration corridors.

USGS research in Wyoming revealed that migrating ungulates follow the availability of peak vegetation during spring "green up," a behavior termed "surfing the green wave (Middleton and others, 2018)." When migrating herds encounter residential housing, energy development, and other barriers such as roads and fences, their feeding behavior can change, and they lose the benefits of migration, which threatens the long-term persistence of migratory corridors. In collaboration with scientists at the University of Wyoming, the USGS developed a Migration Mapper (https://migrationinitiative.org/content/migration-mapper) that synthesizes multiple migration paths using global positioning system (GPS) data from collars worn by the animals to help visualize migration corridors used by the entire population. Landowners, managers, policymakers, land trusts, hunting conservation groups, and others are now using such corridor maps to help make conservation and planning decisions.


Photograph by Jonny Armstrong, USGS


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Highway crossings by ungulates can put humans at risk of fatal car collisions. About 200 drivers, and more than 1 million large animals, die annually from collisions with wildlife nationwide (Huijser and others, 2008).

Photograph by Cheryl Brehme, USGS

A road sign indicating that this region in California is home to sensitive amphibians (namely, the rare Anaxyrus canorus *[Yosemite toad]). USGS scientists have helped launch a new project with the U.S. Forest Service to test whether erecting low bridges over roadkill hotspots can protect Yosemite toads and other sensitive amphibians from vehicle strikes.*

Using GPS information from collared mule deer and pronghorn, scientists with the USGS, University of Wyoming, and Wyoming Game and Fish Department have determined that many migrating animals are unable to cross major highways because of high traffic levels. GPS data also have indicated that although smaller roadways are not yet barriers, they can be a substantial source of mortality for herds because of vehicle collisions. This knowledge about migration movements is helping planners from State Departments of Transportation construct under- and overpasses where animals prefer to cross the roadway, helping to create safer roadways by reducing collision risk between motorists and ungulates, as well as other wildlife.

Lending a Hand to Help Small Animal Migrations

Many species of amphibians and reptiles—frogs, toads, salamanders, and tortoises—migrate to breeding locations during the spring and summer months. Movements at night increase mortality from vehicle strikes. Although most people associate vehicle strikes with mammals, many amphibians and reptiles are either too small or too slow to avoid oncoming traffic. USGS scientists and partners are evaluating the use of innovative road-building strategies and citizen-science efforts to help wildlife and land managers reduce amphibian and reptile deaths from vehicle strikes during migration.

In the northeastern United States, spring nightly migrations of amphibians, such as the *Ambystoma maculatum* (spotted salamander), can lead to mass mortality events because they cross the road to reach breeding habitat. Local community groups have developed programs to reduce mortalities directly by safely moving salamanders across roads in the spring during these "big nights" of salamander migration. Scientists with the USGS Amphibian Research and Monitoring Initiative have determined that although these efforts help to reduce the deaths of adult salamanders, assisting the movement of juvenile salamanders in the summer after they emerge from ponds would be even more effective in conserving the population (Sterrett and others, 2019).

Photograph by Evan Grant, USGS

Small waterbody used by salamanders for breeding adjacent to a road.

In the desert southwest, increasing demand for renewable energy, housing, recreation, and military training sites is placing greater pressures on this ecosystem shared with the endangered *Gopherus agassizii* (Agassiz's desert tortoise). The barriers created by these changes may make it harder for tortoises to find a mate. In collaboration with the University of Nevada, Reno; the Bureau of Land Management; the U.S. Fish and Wildlife Service; and private industry, USGS scientists are working to determine how desert tortoises and other species are connected across the landscape and if creating conservation corridors as a mitigation tool can help to maintain genetically diverse populations.

Photograph by Zachary Cava, USGS

Radio transmitters are attached to adult tortoises so researchers can track their movement throughout the landscape.

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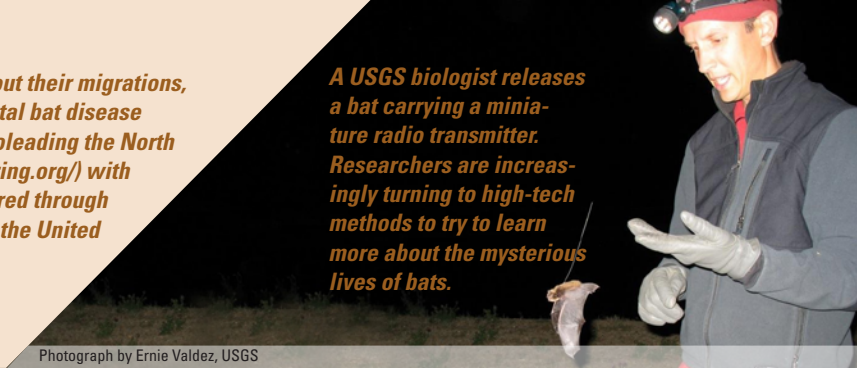
Bats are cryptic species and there is much scientists do not know about their migrations, including how migration interacts with existing threats such as the fatal bat disease white-nose syndrome. To help answer these questions, the USGS is coleading the North American Bat Monitoring Program (NABat; https://www.nabatmonitoring.org/) with the U.S. Fish and Wildlife Service. Data collected by partners and shared through the NABat are used to map bat species distribution and abundance in the United States and Canada and help us evaluate the status of bat populations.



A USGS biologist releases a bat carrying a miniature radio transmitter. Researchers are increasingly turning to high-tech methods to try to learn more about the mysterious lives of bats.

Photograph by Ernie Valdez, USGS

In the Air

Thousands of species of birds, bats, and butterflies take long migratory flights across North America and beyond, and these events are a source of recreation for millions of outdoor enthusiasts such as hunters, birders, and butterfly watchers. The USGS is leading research that provides baseline information on the health, behavior, and population status of flying migratory species throughout North America. One focal area of research is on the detection, spread, and control of diseases such as avian influenza in birds (https://www.usgs.gov/centers/nwhc/science/distribution-highly-pathogenic-avian-influenza-north-america-20212022#overview) and white-nose syndrome in bats (https://doi.org/10.3133/fs20183020). This science is helping wildlife managers prevent the potential spread of these wildlife diseases through migratory pathways.

A Century of Information Shapes Today's Bird Conservation

The USGS manages the Bird Banding Laboratory (BBL; https://www.usgs.gov/bbl), which provides more than 100 years of information on long-distance migratory movement of birds across the globe. By supporting a broad community of researchers, the BBL provides information on migratory behavior and life histories of individual birds and areas that are critical for breeding, wintering, and stopover along their journeys. Along with other wildlife management agencies, the BBL supports banding activities that are key to bird conservation such as sustainable harvest management and surveillance of disease in migratory waterfowl.

Bat, bird, and insect activity can be monitored with pairs of thermal-imaging cameras mounted on the wind turbines and automatically recorded to a computer inside the base of the turbine.

Photograph by Paul Cryan, USGS

Mighty Monarch Migrations

Monarch butterflies from the central United States and Canada undertake spectacular migrations, flying an impressive 2,800 miles each fall to overwinter in central Mexico, while west of the Rockies, monarchs overwinter in groves along the California coast. These journeys are being disrupted by large gaps in needed habitat, by exposure to herbicides and pesticides, or by extreme weather; collectively these threats have resulted in a nearly 80-percent decline in the eastern migratory population (Tracy and others, 2019). The USGS leads the trinational Monarch Conservation Science Partnership (https://www.usgs.gov/centers/umesc/science/monarch-conservation-science-partnership?qt-science_center_objects=0#qt-science_center_objects) whose members from the United States, Canada, and Mexico work together to develop research priorities for addressing information gaps associated with the ecology and conservation of monarch butterflies.

Offshore Obstacles to Bat Migration

Many of the 47 species of bats in North America migrate in the spring and fall to reach roosting and breeding areas. USGS scientists are studying how tall structures such as wind energy turbines affect some tree bats that make long migrations to overwinter in more southerly latitudes or coastal regions where they have been observed flying offshore during spring and fall migration periods. To help assess the potential risk to bats from planned offshore wind energy, researchers tracked bat movements using acoustic recorders placed on structures such as lighthouses on Virginia's barrier islands. Researchers noted that bat visitation offshore or to coastal barrier islands at night is associated with lower wind speed and higher temperature and visibility, and visitation varies seasonally (True and others, 2021). These findings were used to develop a tool to predict occurrence of bats at potential future offshore wind sites. This information can help the offshore wind industry plan for strategies to minimize collisions with bats flying offshore.

Photograph by Chelsea Steinbrecher-Hoffmann, USGS

Photograph by Mike Glenn, U.S. Fish and Wildlife Services

Photograph by iStock.com/JMichl

More than 90,000 dams in the United States support agriculture and hydropower needs. These dams have modified rivers and can create a barrier to fish migration (Normand, 2021).

Photograph by National Park Service

Webcam photograph taken February 7, 2012, during deconstruction of the Glines Canyon Dam by a process called "notching down." The dam was built in 1927 in Olympic National Park.

Through the Water

Flowing rivers and streams are corridors for fish moving between freshwater and salt water and fish moving between streams and lakes. Migratory fish such as herring, sturgeon, paddlefish, trout, and salmon are a resource for commercial fishing and for anglers whose recreational activities add billions of dollars to local economies. Migrating adult and juvenile fish and other aquatic species face increasing threats from climate change, drought, habitat loss, invasive species, and barriers such as culverts and dams. The USGS provides tools and strategies to help fish and water managers understand the effects these barriers have on migratory fish and maintain and restore thriving fish populations and aquatic ecosystems.

Feasibility of Restocking and Reintroductions

Salvelinus confluentus (bull trout) is an example of a species that migrates through rivers and streams to take advantage of food and habitat refuge offered by larger rivers, reservoirs, lakes, and even the ocean. Recovery of threatened fish species commonly involves decisions about capturing and moving species, particularly where natural colonization by migratory individuals is not occurring. To address this challenge for imperiled bull trout, USGS scientists have developed innovative tools that managers can use to assess habitat suitability for fish and make tough decisions (https://www.usgs.gov/publications/probability-streamflow-permanence-model-prosper-spatially-continuous-model-annual). Examples include bull trout reintroduction efforts occurring in the Klamath and Willamette Rivers in Oregon and the Pend Oreille River and Lake Chelan in Washington and translocation of bull trout populations to a new location in Glacier National Park in Montana.

Improving Fish Passage Technologies

Anguilla rostrata (American eel) can be found along the Atlantic coast of the United States and Canada and inland in the Great Lakes and throughout much of the eastern United States. A juvenile American eel's migration commonly begins by traveling from ocean waters to freshwater rivers and streams where it can feed and grow, eventually migrating downstream to the ocean to spawn as an adult. Dams equipped with turbines and spillways in rivers threaten eel migration in both directions. USGS science is focused on designing safe, timely, and effective options for passage of juveniles and adults through these barriers.

Photograph by Joshua Logan, USGS

A USGS scientist was delighted to observe a Chinook salmon carcass upstream from two dams recently removed from the Elwha River in Washington State. River restoration has allowed salmon to reach upstream spawning grounds for the first time in more than a century. After spawning, the salmon perish and are an excellent food source for many animals.

Measuring Response to Dam Removal

For decades in the Pacific Northwest, the Elwha and Glines Canyon Dams prevented salmon migration to the main stem and tributaries upstream. Removal of these dams was aimed at restoring habitat that is culturally and economically important to the communities of Washington's Olympic Peninsula. After the dam was removed, thousands of *Oncorhynchus tshawytscha* (Chinook salmon) took advantage of the now-connected river and migrated upstream to spawn in areas above the former Elwha Dam for the first time in more than a century. The information and tools developed from USGS studies on Elwha Dam removal provide a strong science foundation that could be used to guide other dam removal projects across the country (Wieferich and others, 2021).

By Mona Khalil, Mark Wimer, David Hu, Mike Adams, Melanie Steinkamp, and Suzanna C. Soileau

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