Remote Sensors Bring Wildlife Tracking to New Level

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Trove of data yields fresh insights—and challenges.

Sharper images of Earth from space—and other improved technologies—are transforming how scientists study the behaviors of wild species during seasonal and longer-term changes.

Around the world, scientists are outfitting animals with telemetry devices, linked to satellites and other space-based instruments, that record and transmit animal migrations and other movements across oceans, forests, deserts, and mountainous terrain. Researchers are tracking birds, bats, ungulates, and carnivores in thousands of studies across hundreds of taxa. Animal-tracking devices have become smaller, lighter, sturdier, cheaper, and more accurate, and they can store and transmit more data.

Over the past decade, many remote-sensing data sets from satellites that were once unavailable or expensive have become free of charge from NASA and other agencies.

Scientists are now combining animal-tracking and remote-sensing data to create models showing how individuals, animal groups, and species respond to seasonal or climatic changes. Researchers are also building models to forecast how these animals might fare as climate change accelerates.

Animal-movement data and remote-sensing images have become easier to combine and study. “If you know where an animal was in space...”
and time, then you can load remote-sensing data of the same space and time into a model,” says Roland Kays, a zoologist at North Carolina State University and the North Carolina Museum of Natural Sciences.

“Combining remote sensing with animal tracking, we’ve learned that certain places are really special [in biological productivity] for just a moment in time. Bird migrants from Europe that cross the Sahara use parts of the Sahel non-desert zone as stopover sites for just a little while and then move on. You could visit that place on an average day and not see anything special, yet it could still be a critical habitat over a short time for species and may need conservation protection.”

Some long-distance African migrants “surf the green wave,” as it is known, of blooming plants during the time of their most nutritious growth. Thrush nightingales (Luscinia luscinia) and red-backed shrikes (Lanius collurio) closely follow the progressive green-up of fresh vegetation across the African landscape after monsoon rains.

The average monthly normalized difference vegetation index (NDVI), which draws on data from NASA satellites, is frequently used to track the amount and productivity of plant life in specific places. A satellite sensor sends pulses of infrared light to the Earth’s surface, which reflect back to the sensor. Brighter reflections from the surface mean that vegetation is more abundant and growing more vigorously. This tool allows scientists to view greening and browning patterns changes in spaces over time at various scales. Some scientists have also combined NDVI with satellite data of wind direction and wind speed in models to understand how birds time their migrations to reach nutritious food resources at particular times.

The data challenge

A new journal, Remote Sensing in Ecology and Conservation, focuses on collaborations among ecologists and remote-sensing scientists. Ecologists, though, often struggle to understand how best to use these tools. “Remote-sensing technologies are great eyes on the Earth, but conservation scientists need to know the limitations and challenges of these technologies to use them effectively,” says Ilaria Palumbo, a European forest ecologist and remote-sensing specialist. She is cochair of the Remote Sensing Conservation network, a 500-member global effort to help ecologists, conservationists, and nonprofit members broaden their skills in applied remote sensing and to locate, process, integrate, and analyze data.

“A major challenge is correctly linking the animal-position data in space and time to the environmental data in space and time,” says Wiebke Neumann, an ecologist at the Swedish University of Agricultural Sciences in Uppsala. “Environmental data vary in source, format, and projection system, and that can make it difficult, if not impossible, for anyone other than remote-sensing experts to make use of [raw data] directly.”

But training for conservation scientists is often focused on “pure” remote-sensing principles—such as working with raw satellite data and processing—without sufficient concrete examples of conservation applications where they can be or have been applied, says Palumbo.

To download and explore remotely sensed data, scientists need access to advanced computer systems with high storage and processing capacity. The next problem is locating and extracting a small fraction of available remote-sensing data that can be matched up in time and space with animal-tracking data.

Cara Wilson, a research oceanographer, leads a 3-day class each year to help marine scientists combine remote sensing with animal-tagging studies at the Environmental Research Division’s Data Access Program (ERDDAP) of the National Oceanic and Atmospheric Administration’s (NOAA’s) Southwest Fisheries Science Center, in La Jolla, California.

Wilson and the rest of the NOAA team have developed codes written in Matlab and R, which are programming languages and software for statistical computing and graphics, that allow a scientist to extract specific environmental data—sea surface temperatures, for instance—for a given animal track with a comma-separated values (CSV) file of latitude, longitude, and date. With these aids, the researcher can download only the remote-sensing data that he or she needs to match up with specific tracking data points. The codes work with the ERDDAP server, managed by Wilson’s lab, which can draw on more than 1000 remote-sensing data sets.

“Scientists in our classes usually already have some system to analyze their tracking data,” says Wilson, “but they don’t have coding experience to extract the environmental data.” Still, scientists rarely get everything they hoped for. “The time series don’t go back as far as they would like, or scientists have issues with cloud cover that blocks satellite images. I hear a lot of, ‘Damn cloud cover.’”

Mule deer, mountain lions, and plants

Mule deer (Odocoileus hemionus) migrate to higher elevations to forage on new vegetation as spring arrives and mountain ice packs melt in the US Southwest. Months later, when mountain snow returns, mule deer migrate to lower elevations searching for food. Mountain lions (Puma concolor) also follow these changes in vegetation, according to an unpublished study led by David Stoner, a wildlife ecologist at Utah State University, in Logan. He presented the study’s findings at the fall 2016 American Geophysical Union meeting.

According to Stoner, this is the first study to use remotely sensed data to describe links between climate and ecosystems across three trophic levels—primary producer, herbivore, and predator—over such a large geographic space.

Stoner is studying relationships among mule deer and mountain lion populations and greenery in Utah,
Nevada, and Arizona—a vast, arid, drought-prone region with extreme variations in terrain and vegetation. Mule deer are the primary food resource for mountain lions in the West.

To track mule deer movements, Stoner deployed global positioning system (GPS) collars on 30 individuals. He combined these tracking data with NDVI imagery of the region downloaded from the Moderate Resolution Imaging Spectroradiometer, which is flown on NASA’s Terra and Aqua satellites. The data confirmed what the researchers assumed: that mule deer closely follow seasonal changes in plants as shown in the NDVI images. Greener vegetation supported higher densities of mule deer on average.

“It’s a very strong correlation,” says Stoner. “You have a greater abundance of deer when there is more vegetation because there’s simply more food.”

To understand mountain lion movements, Stoner used more than 15 years of records collected from 50 tracked individuals across the region and combined those data with NDVI images.

“Mountain lions are not directly tracking the phenological stages of plants,” says Stoner. “They are following ungulates through space. Although mountain lions are carnivorous, their abundance follows closely with changes in vegetation productivity”—because their most important prey respond to those changes.

“If you had to choose one prey species that could give you predictive power in depicting mountain lion abundance,” says Stoner, “it would be the mule deer. NDVI did a very good job of predicting population abundance of both species” across spatial gradients in vegetation productivity. Game managers could use this model, he says, to provide more accurate and inexpensive population-density estimates of mule deer and mountain lions.

The southwestern United States is expected to face more intense and longer-lasting droughts with climate change. To study future climate impacts on mule deer and mountain lions, Stoner and his colleagues modeled their populations using measurements of vegetation stressed by severe drought in 2002, when precipitation declined by 30 percent. Their model predicted a 22 percent decrease in deer density but a 43 percent decline in mountain lion population.
density if the drought conditions that prevailed in 2002 became the climatic norm in the region. The carnivores were more sensitive to changes in vegetation than were their herbivorous prey.

By tracking plant phenology, researchers can gain insight into animal populations—their abundance, migrations, and reproduction—says Joseph Sexton, coleader of the study and senior scientist at the University of Maryland's Global Land Cover Facility. Sexton managed remote-sensing data and devised algorithms for the study's image analysis. "What we've learned," says Sexton, "is just how much of the variability of animal abundances and behavior in a water-dependent environment [is] driven by changes in plants."

**Fatty layers, seals, and sea ice**

In winter, a pregnant ringed seal builds her lair in a deep snowdrift along a ridge of Arctic sea ice. Her lair arcs over a breathing hole that she has dug in the ice floor so that she can slip into the water, undetected by predators, to hunt Arctic cod and other prey and return safely. Her lair is warmed by a snowy insulating roof and the higher temperatures of the water below. In late March or early April, she births a single pup, which must soon learn to swim. Her pup needs 6 weeks of mother’s milk to build a protective layer of fat before the sea ice breaks up—and then it must survive on its own. One of the polar bear's most successful hunting tactics is to smell out a ringed seal lair, break through its roof, and snatch the pup before it can escape through the breathing hole in the ice.

The ringed seal is the most abundant and widespread marine mammal in the Arctic. But studies show that climate change appears to be stressing their reproduction in some regions. Increasingly warm spring temperatures can lead to thinner Arctic snow cover, so the pregnant ringed seal may struggle to find deep snowdrifts in which to build her lair. Warmer temperatures also increase the likelihood of “rain on snow,” which can deteriorate and break up lair roofs. As a result, more pups could be born in the open, without lair protection, or forced to fend for themselves before they can build up thick fatty layers, causing them to die of exposure or predation.

The loss of seal pups threatens polar bears as well. Polar bears could lose access to their most valuable prey and dietary fat. A dangerous consequence of climate change for polar bears is that Arctic sea ice is disappearing earlier and returning later, lengthening the season when they cannot catch ringed seals in open water. To understand how polar bears are adapting to rapid climate change, Kristin Laidre, a researcher at the University of Washington’s Polar Science Center in Seattle, and her colleagues at several other institutions tag the bears with GPS collars and other tracking devices. Researchers also rely increasingly on satellite imagery to learn how sea ice and other Arctic environmental conditions are rapidly changing.

"Remote sensing from satellites,” says Laidre, “has been critical for our research—critical for everything we know about changes in sea ice, biological productivity, and the animals of the Arctic. Remote-sensing data give you an unprecedented opportunity to understand these environments and how polar bears and other animals are experiencing them. To do our work in the Arctic, we must be interdisciplinary, bringing together many scientists with different kinds of expertise—biologists, satellite experts, sea-ice experts—who give us the opportunity to link the physics and biology of change."

There are about 26,000 polar bears in 19 subpopulations across the circumpolar Arctic. Laidre and her colleague Harry Stern, a remote-sensing scientist, analyzed daily satellite data from 1979 through 2014 to track changes in polar bear sea-ice habitat across their range. In a September 2016 study in *The Cryosphere*, the researchers reported that there is a trend toward earlier sea-ice retreat and later sea-ice advance in all 19 regions. Retreat is generally coming 3 to 9 days earlier in the spring and 3 to 9 days later in the fall. The number...
of summer ice-covered days is declining in all regions at the rate of 7 to 19 days per decade. The International Union for Conservation of Nature (IUCN) has incorporated these sea-ice data into its Red List assessment of polar bears and status of the subpopulations.

But the relationships between sea-ice loss and polar bear subpopulation numbers can be different from region to region. Three of 19 subpopulations are listed as declining, but there are no data for 9 subpopulations, 6 others are stable, and 1 is increasing, according to the IUCN Polar Bear Specialist Group. Still, many studies have shown that sea-ice loss has negative consequences for polar bear survival, reproduction, and body condition, which are linked to population trends.

“Today, there is not a one-to-one correlation between sea-ice loss and bear population decline,” says Laidre. “It doesn’t look good for bears over the longer term—no way around that.” But, she adds, there is regional variability in the loss of sea ice, and there is regional variability in available food; both can affect polar bear populations.

The polar bear subpopulation in the Chukchi Sea—a region shared by the United States and Russia north of the Bering Strait—appears to be stable despite rapid losses of summer sea ice in its northern stretches. Remote-sensing studies show productive plant life in the Chukchi Sea region that could be key to the bears’ stable numbers.

“Ocean currents help drive nutrients into the Chukchi Sea,” says Laidre. “It’s a very productive region with a large continental shelf and shallow waters where there is abundant prey for seals and bears.” Ringed seal populations also appear to be doing well there. “But this productivity will not buffer the Chukchi Sea

Movebank’s reputation is growing rapidly as a secure online archive and resource for animal-movement researchers. Scientists can store, organize, process, or share movement data uploaded or streamed directly to the Movebank site. Images: Sarah Davidson, Max Planck Institute of Ornithology.
from sea-ice loss indefinitely. I suspect there will be a threshold crossed at some point in the future, assuming we maintain business as usual with our emissions. When the ice loss becomes so large, the productivity of the system won’t buffer longer-term negative impacts on polar bear populations.”

**Linking complex data sets**

The Galapagos albatross (*Phoebastria irrorata*) breeds in its namesake archipelago during the summer months. In the fall, the birds fly more than 1850 kilometers to the coast of South America to feed until early summer, when they return to the Galapagos Islands.

To understand why this bird undertakes such a demanding migration, scientists fitted nine individuals with GPS transmitters and tracked them for 4 months. Gil Bohrer, an ecological engineer at The Ohio State University, and colleagues at Max Planck Institute for Ornithology in Germany developed a model that combined tracking data with ocean productivity and wind data.

The modeling was based at Movebank, a secure online archive that researchers can use to store, organize, process, or share animal-movement data uploaded or streamed directly to the site. Movebank is home to information from 2939 studies, 14,619 registered users, 387 million locations, and 635 taxa.

Bohrer and his colleagues also developed the Environmental Data Automated Track Annotation System (Env-DATA) that can automatically link a researcher’s animal-tracking data on Movebank to environmental data from various sources, including NASA, NOAA, and other agencies.

“There is no uniform pool of data in the world,” says Bohrer. “Every data set is posted in a completely different way by each agency, and it takes a lot of effort to access each one properly.” The Env-DATA software provides sets of keys that allow scientists to open many different environmental data sets and combine them with animal tracks.

With Env-DATA, scientists can compare and contrast various environmental factors that could be important in driving an animal’s movement. “If you suspect that an animal’s movement has many different influences but don’t know which to focus on, you can explore environmental data sets and see where the strongest correlations are. Then, you can choose to study one or two different effects that are driving your data.”

The albatross study, published in the 3 July 2013 issue of *Movement Ecology*, was the first to use the Env-DATA system in linking animal movements to various environmental data sets. The researchers learned that albatrosses fly to areas with high concentrations of chlorophyll in seas just off the Peruvian coast. “The birds don’t care about the chlorophyll—they want the fish” that feed on primary productivity, says Bohrer.

The birds use tailwinds to the South American mainland, where they sail south along the coast searching for food. But on the homeward leg, they fight against prevailing winds. The chlorophyll data show why the albatross undertake this long migration to South American coastal waters, and wind data show the relatively higher costs of the journey on the return leg.
Plant productivity, then, is shown to be an unexpectedly powerful driver of this predator's movement and behavior. Movebank will also provide data downloads and storage for the International Cooperation for Animal Research Using Space Initiative (ICARUS), sponsored by the Max Planck Institute. This summer, ICARUS is beta testing 5-gram GPS tags for smaller animals such as birds and bats. The ICARUS project is sending a dedicated receiver to the International Space Station in June to communicate with the lightweight, solar-powered tags.

Today’s telemetry tags have much larger memory storage, allowing them to transmit many more location points more frequently and more accurately than past tags did, according to Kays, a cofounder of Movebank and Env-DATA and a collaborator on the Galapagos albatross study. “GPS data has really revolutionized things,” says Kays. “Instead of one fix [location] per animal a day, we can get thousands or even millions of fixes [over an animal’s lifespan] that give us incredible detail of what they are doing. We know everywhere they go—how they are crossing the roads, what landscape corridors they are using.”

ICARUS tracking data, which are downloaded into Movebank, could be analyzed with Env-DATA, helping scientists learn how climatic and habitat changes are affecting animal movements.

Satellite improvements meanwhile continue to accelerate. NASA has recently launched new Earth-observing systems. One satellite is making frequent global measurements of rain and snowfall. Another is measuring soil moisture. A third one measures how carbon cycles through the Earth’s atmosphere, land, and oceans. NASA and space agencies in Europe and Asia expect over the next decade to launch additional satellites, providing even higher-resolution snapshots of the Earth than have been possible with past technologies.

“People have become more aware of how important remote-sensing data are in helping us look through time at the Earth,” says Laidre. “Remote sensing gives you an unprecedented opportunity to see extreme change and effects on ecosystems and link them to animal movements and behavior.”