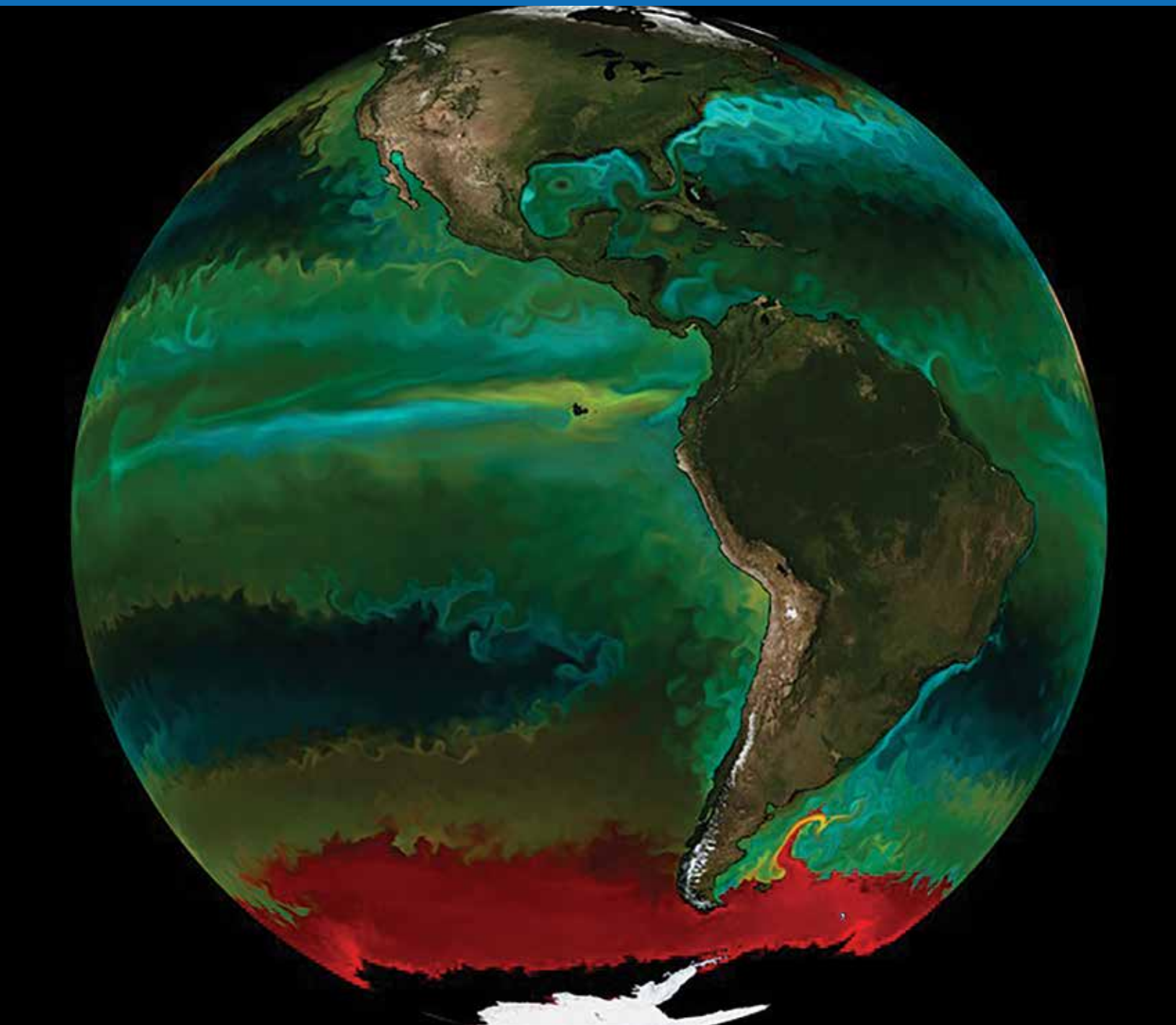
National Aeronautics and Space Administration

NASA EARTH SCIENCE

Using Satellite Observations for Conservation



FOREWORD

Welcome to this special feature highlighting examples of how space-based Earth observations support conservation and natural resource management.

NASA generates new insights into our planet and the complex interactions within the Earth system. Our approach involves spaceborne Earth observations, technology development, and basic and applied research to characterize, understand, and improve predictions of Earth system processes. These efforts expand understanding and improve science-based ecological forecasts to inform and support better management and policy decisions.

NASA Earth Science and its Applied Sciences Program advance innovative and practical uses of Earth science data and knowledge. Applied Sciences serves as a broker among Earth scientists, applications specialists, and decision makers. It addresses the following themes: ecological forecasting, water resources, health and air quality, disasters, wildfires, food security, and capacity building.

The stories included here represent a sample of resource management and conservation research and applications activities, from around the world and pole to pole. They underscore how NASA works with external partners to accomplish positive conservation and resource management outcomes. Additionally, many of the projects leverage discoveries stemming from the Research & Analysis Program, demonstrating how NASA helps connect applications and research. The feature concludes with an overview of the Applied Sciences' Capacity Building program, which enables professionals in the U.S., developing countries, and worldwide to make more and better use of Earth observations.

We thank everyone involved for their dedication and achievements. We hope this sparks ideas for how you and your organization can use Earth observations.

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On the Cover: Phytoplankton are the base of the marine food web and are crucial players in the Earth's carbon cycle. This visualization shows dominant phytoplankton types from 1994-1998 using a high-resolution ocean and ecosystem model. The model contains flow fields from 1994-1998 (generated by the ECCO2 model), inorganic nutrients, 78 species of phytoplankton, zooplankton, as well as particulate and dissolved organic matter. Colors represent the most dominant type of phytoplankton at a given location based on their size and ability to uptake nutrients. **Credit:** NASA Scientific Visualization Studio, MIT Darwin Project, ECCO2, MITgcm

GIVING WHALES A VOICE

EARTH-OBSERVING SATELLITES ARE REDUCING OUR IMPACTS ON THREATENED MARINE MAMMALS

The largest animal ever to have lived on Earth is not a long-extinct dinosaur, but a mammal that's found throughout the world's oceans—the blue whale. An adult can weigh up to 180 metric tons and stretch nearly 6 full-sized cars in length. Despite its massive size, this gentle giant is listed as endangered by the IUCN.

"The biggest threat to whale populations…is still humans." said Monica DeAngelis, a marine mammal biologist with NOAA's National Marine Fisheries Service. And the threats are numerous, she added: "Vessel collisions, climate change, habitat loss or destruction, entanglement in any kind of gear—marine debris or fishing gear." In fact between 1988 and 2012, there were 100 documented large whale ship strikes along the California coast alone.

No ship's crew wants to risk a whale strike during its operations, and in terms of protecting both vessel and marine mammal, the largest obstacle has been knowing where the whales are located. "The whale swims underwater most of the time and the ships don't have a sensor that they can see it," explained Kip Louttit, executive director of the Marine Exchange of Southern California, which oversees maritime commerce through the region. "In the same way that the ships are very conscious about the weather, they're very conscious of the whales…and if they know where the whales are, they can avoid them."

The practice of tagging the whales has helped both scientists and mariners track whale movements through satellite telemetry, but now a joint NASA/NOAA project is using Earth observations to predict where the whales will likely be. Led by Research Assistant Professor Helen Bailey of the University of Maryland Center for Environmental Science, the project integrates the tagging database with NASA satellite information to generate an online tool called WhaleWatch.

"We have tracking data from 1993 to 2009 that was collected by Bruce Mate and his team at Oregon State University," said Bailey. "[With WhaleWatch] we are combining the satellite telemetry data for the whales with satellite-derived environmental data to understand not just where are the whales going, but why are they going there."

Humpback whale (*Megaptera novaeangliae*) off California. Credit: Helen Bailey

That environmental data includes sea-surface height, sea-surface temperature, chlorophyll concentration, and water depth. These factors help characterize habitats the blue whales favor or travel through during different times of their migration. With this information, the team is able to determine suitable locations for the whales, and then predict where they are moving along the California Current System, from Washington State southward to Baja California.

The benefit of the satellite data is that it fills the gaps in the telemetry data—providing new insights into blue whale migration and behavior. During the project's research, the team found that "the most important variables were sea-surface temperature,

which helped to explain the seasonal migration…chlorophyll concentration, which was related to the abundance of food, and…ocean winds," Bailey remarked. The winds were important because they produced the upwelling that supports the whales' food source, krill. In addition, information on seabed slope determines where the krill aggregate.

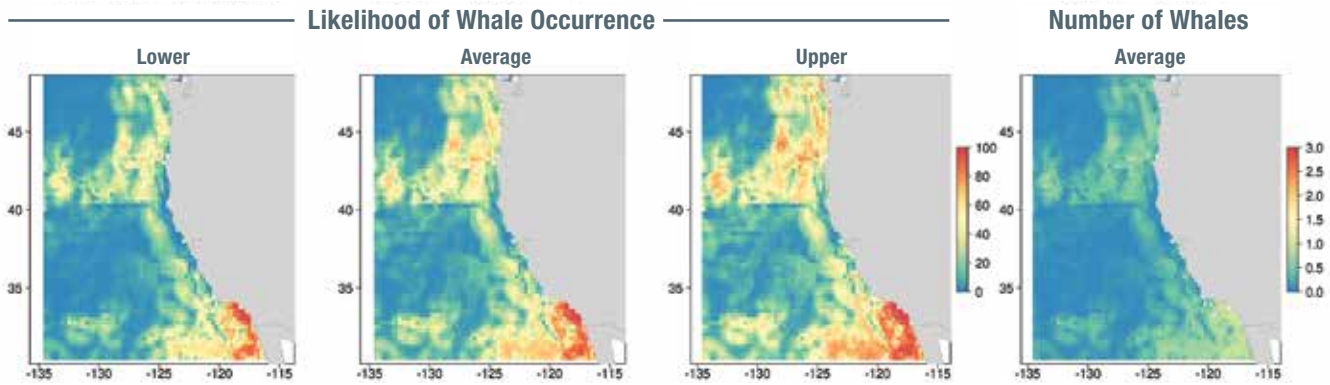
With this combination of multiple data sources, the project team was able to create maps of standardized daily blue whale locations and habitat-based models of population density and probability of occurrence—a blue whale forecast, so to speak.

Marking the culmination of this project, these forecast model maps are now online and publicly available on NOAA's website, so the question of knowing where the whales are located and headed can be solved by the click of a mouse. In fact, with its success with the blue whale, this approach is now being used for other species.

"The bottom line is, this is the best available science," DeAngelis noted. "We are now able to use that information to give whales a voice, so that humans can change their behavior to reduce the threat to whales."

Helen Bailey (*hbailey@umces.edu*) leads this project. To check out WhaleWatch, visit *http://www.westcoast.fisheries.noaa.gov/whalewatch/index.html*

Blue whale (*Balaenoptera musculus*) off California. Credit: Craig Hayslip, Oregon State University. NOAA/NMFS Permit No. 14856



WhaleWatch model estimates from June 2016 for blue whales off the U.S. West Coast. X-axis represents longitude; y-axis represents latitude. Image courtesy of WhaleWatch

CONSERVING THE WORLD'S CORALS

SATELLITES ARE HELPING PRESERVE THE HEALTH AND BEAUTY OF CORAL REEFS

Coral reefs are some of the most diverse ecosystems on Earth. Known as the "rainforests of the sea," they are home to more than a quarter of all marine species. Yet the beauty and vitality of the coral reef environments are threatened—and the reasons are numerous. Rising water temperatures due to climate change, land-based pollution, and indiscriminate fishing practices are the primary threats to coral reef health. Recreational activities like boating, scuba diving, and snorkeling, if done carelessly, can also seriously stress coral reefs. If these stressors continue, they can lead to coral bleaching, and recently the world's corals have been facing more frequent and severe bleaching events.

When corals bleach, they lose their color because they lose symbiotic algae that live inside the coral animal tissue. When this happens, the coral animal is unable to grow, reproduce, and build its limestone skeleton making it more easily damaged or killed. "Some diseases occur when corals lose their resistance to pathogenic bacteria and fungi, that may be natural," noted Frank Muller-Karger, biological oceanographer at the College of Marine Science, University of South Florida. "But in other cases, diseases are related to human discharge of sewage and other refuse into coastal waters."

To maintain coral health, reef managers track global, large-scale temperature fluctuations, allowing them to assess conditions and monitor trends across the world's oceans. Recent advances in satellite images have given managers finer-scale details and insights to carry out more immediate, targeted actions. Those include rescuing corals at risk of fatal bleaching, redirecting divers or snorkelers to unstressed reefs, and educating the public about the damage that fishing in stressed areas may cause.

When bleaching becomes imminent, however, "reef managers can implement various strategies…to reduce or mitigate the potential negative impacts additionally caused by human use," said Beth Dieveney, deputy superintendent for science and policy at the Florida Keys National Marine Sanctuary.

An important resource is the NOAA Coral Reef Watch (CRW) program, which uses satellite data, climate models, and *in situ* observations to provide bleaching alerts to reef managers and scientists, as well as the general public. CRW's satellite-based products include near-real-time and historical data and images of temperature and temperature anomalies for monitoring the risk of coral bleaching and disease in coral reef ecosystems. They also issue bleaching outlooks based on expected climate conditions up to four months in advance.

In a partnership to better conserve coral reef health, NASA has collaborated with NOAA to improve the CRW program and its products. The College of Marine Science of the University of South Florida and CRW staff worked together with NASA's Ames Research Center to develop higher spatial and temporal resolution satellite data products that are now routinely included in the CRW analyses of global coral reef conditions.

NOAA 60% Probability Coral Bleaching Thermal Stress for Jul-Oct 2016

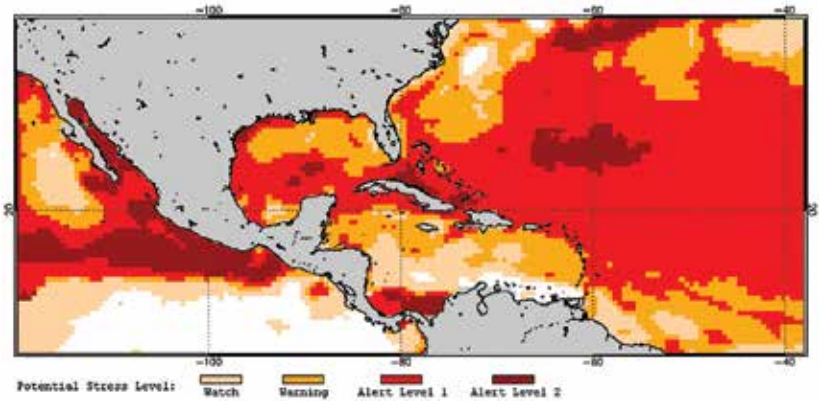


Image from Coral Reef Watch

NOAA Coral Reef Watch Daily 5–km Geo-Polar Blended Night-Only Bleaching Alert Area 7d Max 20 Jun 2016

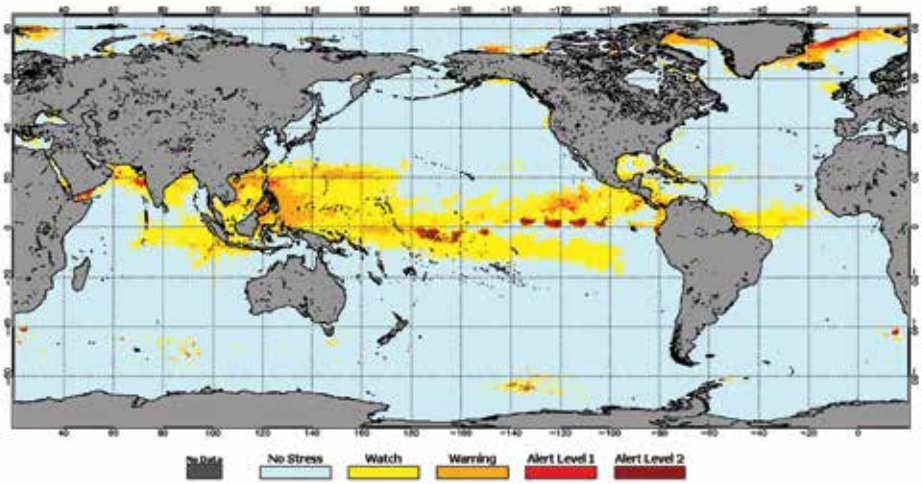


Image from Coral Reef Watch

Building on the 50-kilometer products that CRW already provided, the project created global, 5-kilometer sea surface temperature products based on the observations from NASA, NOAA, and international geostationary and polar-orbiting satellites. The team also created and is continuously validating finer-scale, 1-kilometer products based on NASA and NOAA real-time data for the Gulf of Mexico, Florida Keys, and the Caribbean Sea.

CRW's new products now allow Florida reef managers to better understand conditions of offshore waters under their jurisdiction, as well as within actual reef ecosystems. The new products also provide finer-scale satellite data than the old products and directly monitor more than 98 percent of coral reefs around the world.

In fact, during the project, researchers and reef managers reported widespread coral beaching in the summer and fall of 2014 and 2015 in the Florida Keys and Hawaii, as well as in the U.S. territories of Guam, and the Commonwealth of the Northern Mariana Islands. The new CRW products accurately predicted and helped monitor coral bleaching in all of these regions.

As a result of these improvements, reef managers are able to take earlier and more targeted approaches to protecting coral ecosystems through methods such as reducing the allowable pollutant loads, alerting recreational dive vessels to change locations, or rescuing rare corals before they are killed by bleaching.

"One example would be working with local diving and snorkeling operators to redirect on-water tourist activities away from natural reef areas, normally subject to high visitation, to artificial reefs and shipwrecks," said Dieveney. "This could reduce unintentional physical damage to corals until favorable thermal conditions return."

CRW also allows the public to help support reef health and collect information. "In times of severe thermal stress, that higher resolution helps us manage where we request researchers and citizen scientists alike to look for potential thermal stress in corals," Dieveney added. "Also, over the long term, it may help reef managers refine where they place temperature-monitoring devices to help better correlate remotely sensed data."

Frank Muller-Karger (*carib@usf.edu*) and Mark Eakin (*mark.eakin@noaa.gov*) lead this project.

To learn more about Coral Reef Watch, visit *http://coralreefwatch.noaa.gov.*

TOO WARM TO SURVIVE

A PARTNERSHIP OF CONCERNED SCIENTISTS IS HELPING THE ENDANGERED CHINOOK SALMON

Few things in nature are as impressive as watching salmon valiantly leap upstream through raging rivers to spawn their next generation. Their journey can be thousands of kilometers long, and once completed, most salmon species die within a week after spawning. The largest of the Pacific species, the Chinook salmon are an important food source for marine mammals, bears, birds, and other fish. Along the California coast, however, their population is declining due to threats from overfishing, habitat loss, and human development.

Dams and water diversions in particular pose a significant threat to the salmon that spawn in Northern California rivers, as they block access to the historical spawning areas, and also provide water that can be too warm downstream to maintain the fish's viability. "When water reaches certain temperatures it is lethal to developing embryos," explained Eric Danner, a research ecologist with NOAA's Southwest Fisheries Science Center. "Warmer temperatures result in higher metabolic demands within the egg, and they use up the available dissolved oxygen in the water and die."

Shasta Dam, with a view of Shasta Lake

Since 1991, the Sacramento River's Shasta Dam has had a temperature control device that allows dam managers to selectively withdraw water of various temperatures from different elevations in the reservoir, and then channel it through the turbines to generate electricity. Despite the innovation, the temperature of the water released from the dam can still impact ecosystems many kilometers downstream, and until recently, managers did not have the data to see the small-scale details and the long-term effects of their releases.

In an effort to change that, a joint NASA and NOAA project developed a model called the River Assessment for Forecasting Temperature (RAFT). RAFT integrates medium-scale weather information and ecological data to not only provide support for daily dam operations but also to forecast river temperatures well downstream from release facilities. "In the past, we could only model water temperatures at coarse time steps at some particular location on the river," Danner said. "RAFT now includes the entire river at sub-hourly time steps."

For the Chinook salmon, water temperature is the key to survival. In the laboratory, research has indicated that a river temperature of about 14 C or less protects eggs from dying in the spawning nests, called redds. Redds are more vulnerable to temperature than any other stage of salmon development, and the "winter run" Chinook variety are the most threatened because they lay their eggs in the summer, when the river water is at its warmest.

In the wild however, the team discovered that due to environmental stressors, Chinook salmon redds need the water to be even cooler than what was considered survivable in the lab, and RAFT has helped compensate for this disparity. "We used a retrospective analysis to fit a model of egg survival that better explains why survival was lower than what you would expect from laboratory experiments," noted Danner. "We took the known locations of the salmon redds during those years, the thermal

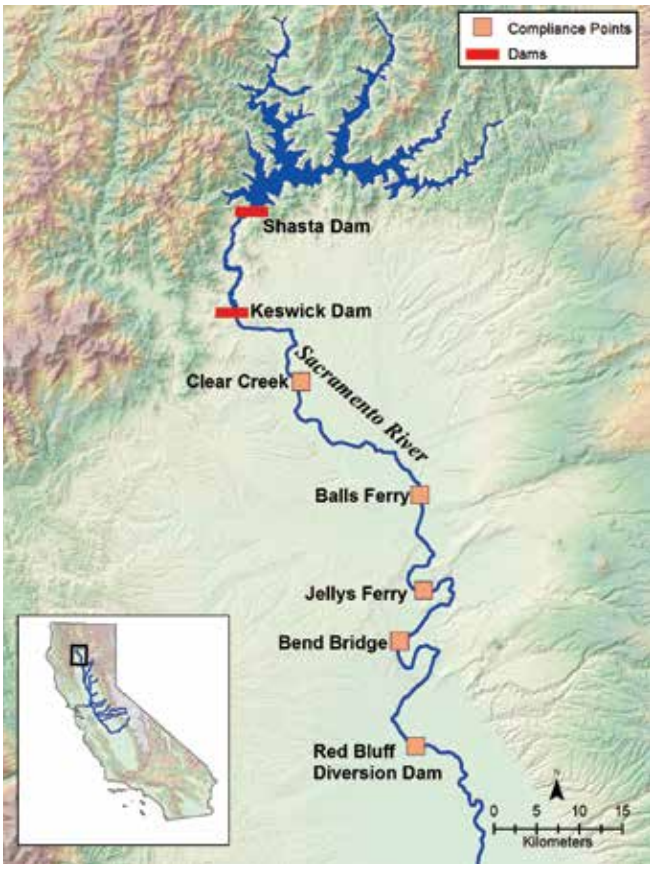
exposure from RAFT, and the number of surviving juveniles observed downstream to fit the survival model."

This analysis has also shown a large discrepancy in how the Chinook salmon have been faring over the decades. Danner confirmed this finding and added, "We have applied this approach to the past 25 years to estimate the temperature-dependent egg mortality during each year—in some years there was zero mortality, in others it was as high as 95 percent." And in recent years, the historic California drought has left so little cold river water available that concerns for the salmon have risen again.

Chinook salmon (*Oncorhynchus tshawytscha*)

There is some good news for the endangered Chinook, though. The project team has adjusted RAFT to provide forecasts of water temperature over seasonal time periods in addition to the much shorter time periods needed for day-to-day dam maintenance. Managers can now see how temperatures will evolve over the warm summer months under a variety of water release scenarios, and can balance the cold water withdrawals required for salmon survival against the water needs of agriculture. "RAFT can take the planned operations for the coming season to estimate water temperatures and their associated impacts on eggs," Danner remarked. "This would not be possible without the comprehensive space and time coverage of the model."

Eric Danner (*eric.danner@noaa.gov*) leads this project.



Map of California showing the Chinook salmon study area of the Sacramento River for the RAFT model analysis. Credit: Eric Danner

ARE THERE PLENTY OF PENGUINS?

SATELLITES ARE HELPING TO TRACK AND MAP PENGUIN ABUNDANCE

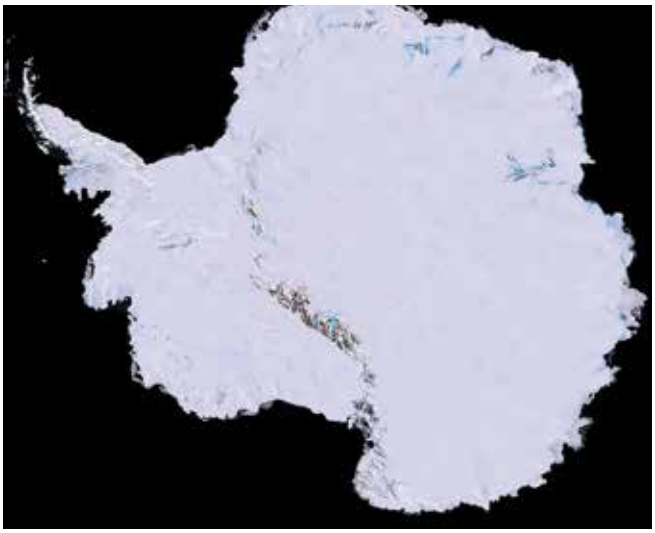
Antarctica is a cold and barren landscape for much of its 14 million square kilometers. Along its coastline however, marine mammals, seabirds, and other sea life thrive in the icy, nutrient-rich waters. The continent and associated islands have four species of penguin, which are important indicators of their environment's health.

One of those species, the Adélie penguin, is distributed around the entire Antarctic and has been used for decades as an early-warning signal for ecological health in the Southern Ocean. The species nests in some of the world's most remote places, and so surveying them using traditional field surveys is both economically and logistically infeasible.

Recent advances in interpreting satellite imagery have allowed scientists, in a joint project with NASA and the conservation foundation, Oceanites, Inc., to now remotely detect not only where Adélie colonies are located, but also the population abundance.

"[Our project] was the first to use *Landsat 7* to estimate the abundance of Adélie penguins and to compare that to estimates derived from higher-resolution, but less widely available, commercial satellites," said Heather Lynch, project lead and assistant professor of ecology and evolution at Stony Brook University. "The *Landsat* satellite program provides unmatched historical coverage over a period of time where we don't have good coverage from other satellites and when much of Antarctica wasn't being surveyed."

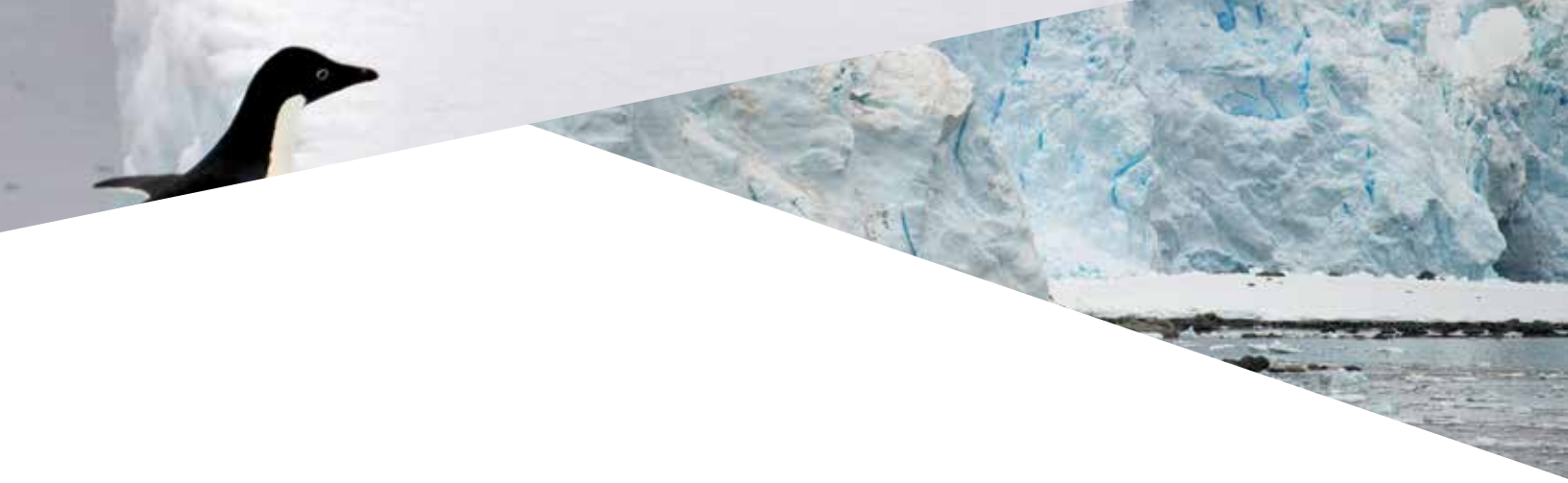
So how does *Landsat 7*, at an altitude of about 700 kilometers, monitor the abundance of a bird that is about the size of a small dog? It detects the "signature" of its excrement.



Landsat mosaic of Antarctica. Credit: USGS, NASA, National Science Foundation, and the British Antarctic Survey

"Satellite-based penguin surveys are detecting the guano [excrement] left behind by penguins nesting at the colony," Lynch explained. "Male and female penguins take turns incubating the nest…and the guano left behind builds up in exactly the same areas occupied by the nests themselves. The guano is quite characteristic…and we can use the area of the colony (as defined by the guano stain) to work back to the number of pairs that must have been inside the colony."

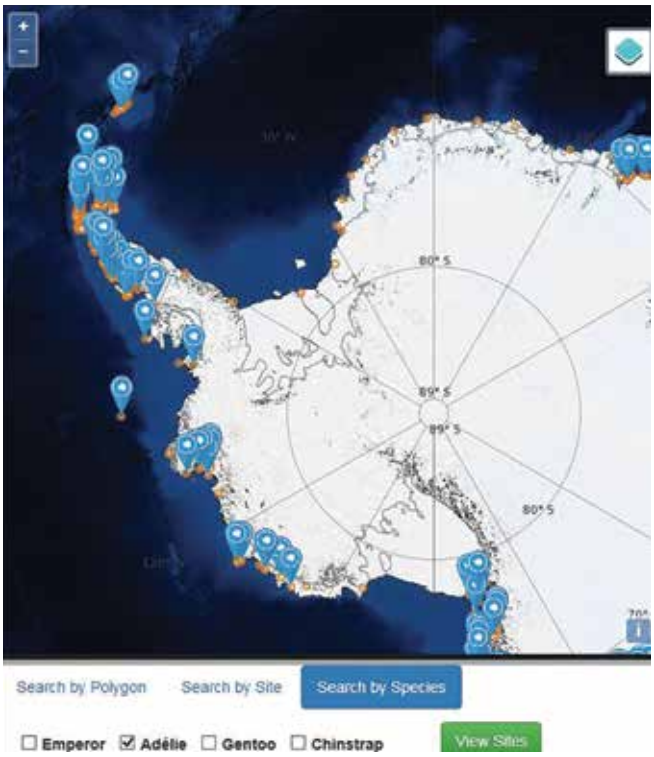
Lynch's review of various satellite surveys has led to surprising results. "We have discovered some incredibly large Adélie colonies that were not before known to exist, and this is in many ways the most exciting new finding." She added, "While Adélie populations have declined, and continue to decline on the Antarctic Peninsula, they are actually increasing in abundance in the Ross Sea and in Eastern Antarctica, and it appears that these gains are at least canceling and perhaps even more than compensating for losses on the Peninsula."



As a result of this NASA-funded project, the first free, publicly accessible online Antarctic database of penguin population size information was developed. Called Mapping Application for Penguin Populations and Projected Dynamics (MAPPPD), it provides an assessment of all penguin species across the frozen continent. "When [its interface is] fully complete, MAPPPD will ingest satellite imagery, automatically classify penguin areas, generate abundance estimates, and push those to the database so models can be updated in real time," said Lynch. "MAPPPD will also continue to serve as a hub for ground-based surveys, and for data coming from citizen science efforts."

For MAPPPD partner and end user, Oceanites, Inc., this is an exciting new tool for its Antarctic inventory project. Ron Naveen, its founder and president remarked, "MAPPPD keeps Oceanites and the Antarctic Site Inventory on the 'front lines' of Antarctic science." And this data will be available to a host of other end users, such as the Antarctic Treaty System and krill fisheries. Naveen added, "MAPPPD…will immediately assist a wide range of Antarctic stakeholders, from other researchers and governments to NGOs and the public at large."

Adélie penguin (*Pygoscelis adeliae*)



MAPPPD image of Adélie colonies in the Western Antarctic Peninsula

Heather Lynch (*heather.lynch@stonybrook.edu*) leads this project. Check out MAPPPD here: *www.penguinmap.org.*

A MELTING HOME AT THE TOP OF THE WORLD

CRITICAL ARCTIC HABITAT IS DIMINISHING. CAN SATELLITES PROVIDE HELP FROM ABOVE?

Many human communities want information about the current status and future of Arctic marine mammals, including scientists who dedicate their lives to study them and indigenous people whose traditional ways of subsistence are intertwined with the fate of species such as ice seals, narwhals, walruses, and polar bears.

But there are many unknowns about the current status of 11 species of marine mammals who depend on Arctic sea ice to live, feed, and breed, and about how their fragile habitat will evolve in a warming world.

The Arctic sea ice cover, made of frozen seawater floating on top of the Arctic Ocean and its neighboring seas, naturally grows in the fall and winter and melts during the spring and summer every year. But over the past decades, the melt season has grown longer and the average extent of Arctic sea ice has diminished, changing the game for many Arctic marine mammals—namely beluga, narwhal, and bowhead whales; ringed, bearded, spotted, ribbon, harp, and hooded seals; walruses; and polar bears.

A recently published *multinational study* attempted to gauge the population trends of Arctic marine mammals and changes in their sea ice habitat, identify missing scientific information, and provide recommendations for the conservation of Arctic marine mammals over the next decades.

"Sea ice is critical for Arctic marine mammals because events such as feeding, giving birth, molting, and resting are closely timed with the availability of their ice platform," said Kristin Laidre, lead author of the new study and a polar scientist with University of Washington in Seattle. "It is especially critical for the ice-dependent species—seals and polar bears. Ice seals use the sea ice platform to give birth and nurse pups during very specific weeks of the spring, and polar bears use sea ice for feeding, starting in late winter and continuing until the ice breaks up."

Laidre's team used the Arctic sea ice record derived from microwave measurements taken by NASA and Department of Defense satellites. This record began in late 1978, is uninterrupted, and relies on NASA-developed methods for processing the microwave data.

"It's really our best global view of the Arctic sea ice," said Harry Stern, author of the paper with Laidre and a mathematician specializing in sea ice and climate at University of Washington.

A pod of narwhals (*Monodon monoceros*) swimming in Admiralty Inlet, Canada. Credit: Kristin Laidre/University of Washington

They divided the Arctic Ocean into 12 regions. Using daily sea ice concentration data from the satellite record, they calculated changes in the dates of the beginning of the melt season in spring and the start of the fall freeze-up from 1979 to 2013. In all regions but one, the melt season had grown longer (mostly by 5 to 10 weeks, and by 20 weeks in one region).

Longer melt seasons are troubling for the Pacific walrus. They use the floating pack ice both as a platform on which to rest between

feeding bouts and as a passive transport around their habitat. "Loss of sea ice has resulted in walrus hauling out on land in Alaska and Russia in massive numbers—these land haul outs result in trampling of their young," Laidre said. "Also, now walrus must travel a longer way to reach their feeding areas, which is energetically costly."

Polar bear (*Ursus maritimus*)

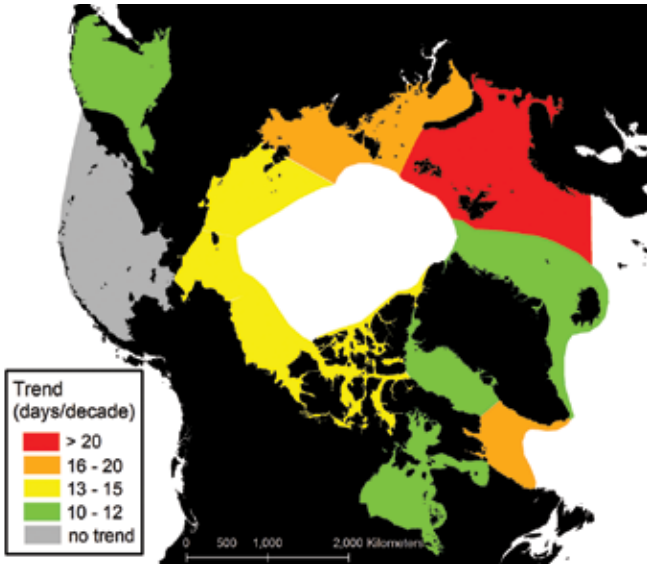
In the case of Arctic whales, the changes in sea ice might benefit their populations, at least in the short term: the loss and earlier retreat of sea ice opens up new habitats and, in some areas of the Arctic, has also led to an increase in food production and the length of their feeding season.

In the future, Stern said higher-resolution satellite microwave data might come in handy when studying the interactions of Arctic marine mammals with their icy habitat.

"For example, we know that narwhals congregate in specific areas of the Arctic in the wintertime, so maybe a higher spatial resolution in these areas might help us better understand their relationship with the ice," Stern said. "But mainly, just continuing daily coverage is what's important for the long-term monitoring of habitat changes."

As for the new insights learned from this study, Laidre noted, "This research would not have been possible without support from NASA." These research efforts were also funded by the Greenland Institute of Natural Resources and the Danish Ministry of the Environment.

Kristin Laidre (*klaidre@uw.edu*) leads this research.



Circumpolar map of the change in duration of the Arctic's low sea-ice season (days per decade). Credit: Laidre et al. (2015) Conservation Biology 29:724-737

FOR THE BENEFIT OF BIRDS

SPACE-BASED TECHNOLOGY AND COMPASSIONATE CITIZENS ARE AIDING WATERFOWL CONSERVATION

During their annual migration, more than 300 species of birds are estimated to use the Pacific Flyway as their connection between the Arctic and South America. Along this plumed pipeline lies the Central Valley of California, a flat valley stretching more than 650 kilometers through the middle of the state, and its wetlands are ideal for waterbirds to rest, feed, and overwinter. In fact, it's believed that the Central Valley hosts up to 60 percent of the total Flyway population in some years.

In the last 150 years, things like flood control efforts, agricultural irrigation, and a booming Golden State population have left migrating waterbirds with much less stopover space than before. What's more, the high real estate values of the region mean that conservation projects such as property easements and land purchases are prohibitively expensive, especially given that these birds stay only brief periods of time.

eBird smartphone application

Trying to tackle this hurdle, The Nature Conservancy (TNC) of California stepped in. Mark Reynolds, the lead scientist for TNC California Migratory Bird Program, knew it would be a challenge: "How do you help things that move around and create habitat in places that may only be important for a few weeks or a few months out of the year?"

Enter eBird—a mobile application the Cornell Lab of Ornithology developed that asks avid birders to record bird sightings on a smartphone app and send the information to its database. Since its inception, eBird has logged 200 million bird observations; the largest biodiversity dataset in existence. Through a grant from NASA, the lab developed a computer-modeling system using eBird data combined with data from the *Landsat*, *Aqua*, and *Terra* satellites. These models and tools can predict what locations in the Central Valley would be the most popular water habitats during the annual spring and fall migrations.

TNC was also concerned about identifying places where the much-needed, temporary wetlands could be located. For this it turned to TNC partner Matthew Reiter, an ecologist for the conservation group Point Blue, who had been using *Landsat* observations to determine where the potential wetlands were in the Central Valley.

"The real value of the satellite…archive is that we're able to look at the water distribution at a very fine spatial scale…which is really relevant in terms of understanding habitat for migratory waterbirds," said Reiter.

Matching the geography and timing of surface water with the route and seasonality of migrating waterbirds from eBird, the research found key locations where extra surface water would provide perfect havens for the birds. In an effort to secure these "pop-up habitats," TNC developed its BirdReturns program which relies on rice farmers to flood their fields for a two-week period during prime migratory season through a reverse auction.

How does a reverse auction work? First, rice farmers submit their bids for how much they would like to be paid for allowing their fields to temporarily remain idle by shallowly flooding them. Then TNC collects the most reasonable bids and selects the fields with the most desirable bird habitat, based on the eBird and Point Blue analysis. TNC then pays farmers to keep their fields flooded during critical migration times in the spring and fall.

Dunlin (*Calidris alpina*)

For the rice farmers, the financial reward is their compensation for the potential liability they face by delaying field preparations for next season's planting. "By holding our water, we're taking a risk," said Doug Thomas, a participating farmer in the Sacramento Valley. "Everything that goes along with that has to be factored into your economic equation."

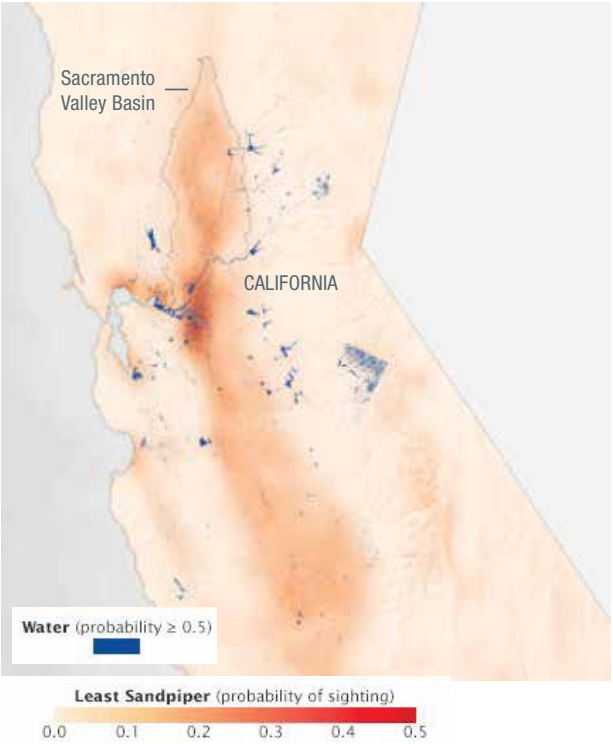
This novel method of renting temporary wetlands allows TNC to provide Flyway habitat for less than one percent of the cost of purchasing conservation easements. Moreover, the farmland is idle only during bird migration, and can produce rice at any other time of the year.

During its initial season, the BirdReturns program was an immediate success—more than 4,000 hectares of additional wetlands were acquired. For control purposes, the project group surveyed those participating fields and compared them to fields where water was not applied. It found that more than 180,000 waterbirds comprising more than 50 different species used the temporary wetlands—30 times more than were counted on the dry fields.

Follow-up auctions continued to see rice farmers renting thousands more hectares, with a cumulative total of more than 12,000 hectares of temporary wetlands gained by the end of 2015.

"It's been a pretty astonishing success," said Reynolds. "Farmers participated, and we were able to put habitat out there at a fraction of the cost to purchase that land or put an easement on it."

Steve Kelling (*stk2@cornell.edu*) leads this project.



Model showing the probability of spotting a least sandpiper in late August overlaid with areas where there is likely to be standing water. Credit: Joshua Stevens, NASA Earth Observatory

WEATHERING CHANGE IN WESTERN U.S. PARKS

SCIENTISTS ARE MONITORING THE EFFECTS OF CLIMATE CHANGE AS OUR PARKS CELEBRATE 100 YEARS

The craggy silhouettes of iconic whitebark pines rise from the mountain ridges of Yellowstone—the first National Park in the U.S. Those trees fill a niche in the environment that was left vacant by other species. Grizzly bears share in that success, ambling through stands of the pines to gather their nutritious pine nuts.

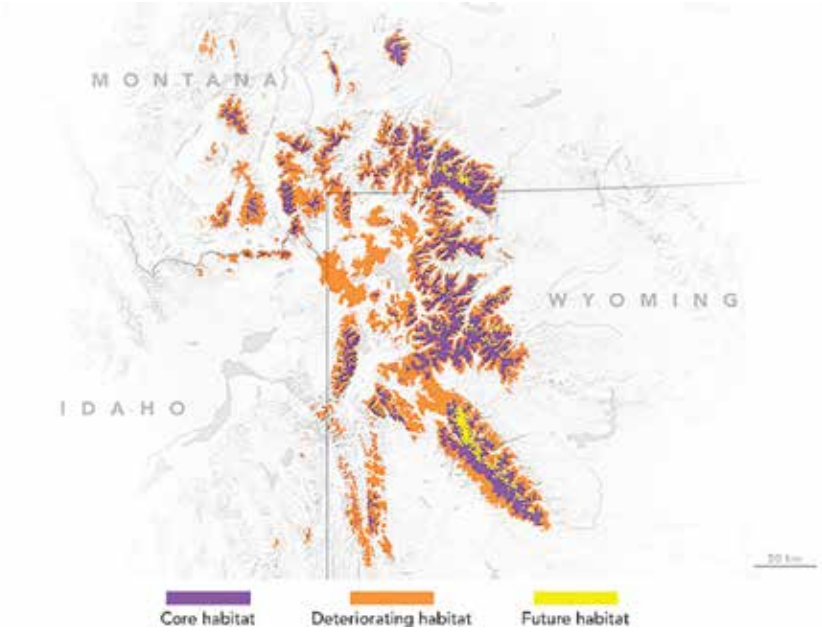
But stands of whitebark have been faring poorly since about 2004. The trees have been extensively damaged by mountain pine beetles and white pine blister rust. The U.S. Forest Service has tried to combat the problem by developing and planting whitebark varieties that are more resistant to the fungus. Now, the species is further threatened by climate change.

In order to figure out what changes U.S. parks can expect, scientists from Montana State University, the Woods Hole Research Center (WHRC), the National Park Service, and NASA established the Landscape Climate Change Vulnerability Project (LCCVP). They want to use scientific observations and computer models to help the parks adapt to climate change.

As director of the Landscape Biodiversity Lab at Montana State University, Andy Hansen is leading a research team focusing on the western U.S. forests. The Great Northern Landscape Climate Cooperative encompasses almost 300 million acres in the ecosystems of the Northern Rockies, including Grand Teton, Glacier, and Yellowstone National Parks.

The parks in the western U.S. are relatively large and intact landscapes that were set aside before much of the land could be developed or cleared. This means it is theoretically easier for species to migrate to more favorable areas as climate changes. But the landscape is also more extreme, with high mountain elevations and a history of drought.

Temperatures in Yellowstone have warmed substantially since 1980, and some tree species have already responded. Hansen and colleagues have started examining those ecological changes by building on the ecological forecasting capability of NASA's Terrestrial Observation and Prediction System (TOPS). Based on satellite and *in situ* inputs of data on historic climate, land use, and vegetation, this computer system simulates past and projected future ecosystem characteristics such as snow pack, soil moisture, and forest growth rates. The models cover the period from 1950 to 2100.



Whitebark pine habitat changes in the western United States under the representative concentration pathway 8.5 climate scenario. Credit: Joshua Stevens, NASA Earth Observatory, using data from the LCCVP

"TOPS outputs are a unique and important product for federal land managers," Hansen said. "Relatively few groups have done these types of projections to begin with, and certainly not using the latest climate and statistical information for the projections."

Grand Prismatic Spring. Yellowstone National Park, Wyoming

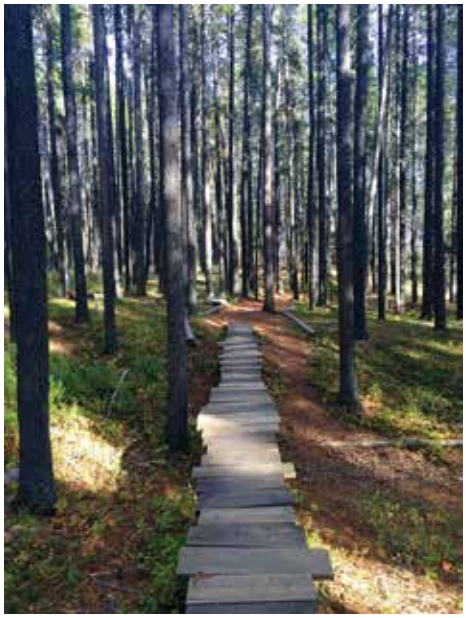
Climate projections typically have coarse resolution, telling you what may be expected over a relatively large area. But Hansen and NASA Ames scientist Forrest Melton have applied a series of additional modeling steps in order to make the projections relevant at scales that work for individual parks. "We delivered sophisticated forecast data in a way that a park manager can readily grasp for his or her place," Hansen said.

In Yellowstone, species like lodgepole pine, Douglas fir, and sub-alpine fir are all expected to lose suitable habitat. But the biggest loser will be whitebark pine. If greenhouse gases continue to accumulate, and temperatures continue to increase as much as some models suggest, the habitat for whitebark pine will rise to higher and higher elevations until the trees are just about pushed off the mountaintops. Juniper trees, by contrast, are expected to thrive and gain more suitable habitat in Yellowstone National Park.

The LCCVP can help keep the researchers and land managers focused on key questions: Where do you thin existing stands of trees? Where do you protect stands from wildfire? Where should seedlings be planted such that habitat is most suitable 50 to 100 years from now?

The effort is slow and complicated, but worthwhile. Parks are increasingly coordinating to plan for climate change, using the new tools and products derived from climate models, large-scale inventory networks from the U.S. Forest Service, and NASA satellite data.

"You'll never find a decision of importance in the National Park System where you can simply say 'someone did this and it led to that,'" said John Gross, an ecologist with the National Park Service's Climate Change Response Program. "The problems we're working on are big, complicated, and involve a lot of people. We're not at the helm of the battleship. We're just one of a number of groups nudging it in the right direction."



A forest of lodgepole pine trees (*Pinus contorta*)

Andy Hansen (*hansen@montana.edu*) leads this project.

IT TAKES A VILLAGE TO CONSERVE CHIMP HABITAT

CONSERVATION STRATEGIES IN AFRICA ARE BEING AIDED BY SATELLITES

For those who live along its shores, Lake Tanganyika in Eastern Africa is the backbone of local transportation and serves as an essential source of household water and food. Every night, fishers lure nocturnal, sardine-like fish called dagaa with compression lamps that are strung between their boats. From the shore, the lake sparkles with the lights of miniature moons as people gather the treasured catch.

Back on shore, their families farm the land—called mashamba—high into the hills, growing staples like cassava, beans and maize. Occasionally, the mashamba are on slopes so steep that the men, women, and children who tend them seem to defy gravity.

This agriculture on steep slopes has, however, led to frequent erosion, flooding, and landslides that degrade or completely denude arable land, while also affecting water quality and quantity and likely hindering stocks of edible fish that spawn near the lakeshore. In the most severe cases, these events damage property and take lives in the process. These landslides also erode habitat for wildlife, including chimpanzees.

The Jane Goodall Institute (JGI) realized that to address this challenge—for the benefit of people and chimpanzees—they needed a higher vantage point and a look back in time.

"We looked at satellite images taken by the NASA-U.S. Geological Survey *Landsat* missions from 1972 and 1999," explained Lilian Pintea, vice president of conservation science for JGI, "and the loss of forest and woodland cover along valleys and steep slopes was clear: eighty percent of the forests were gone. Through our analysis of *Landsat* forest change maps using GIS, we also calculated that the risk of landslide had increased fivefold during that time."

JGI works in villages around Gombe National Park situated along Lake Tanganyika and home to Gombe's world-famous chimpanzees. "When we showed historical *Landsat* and more recent high-resolution images to communities and shared our analysis, people realized what they'd lost over time and wanted to engage in conversations about how to bring the forests back."

Chimpanzee community home ranges and tree cover change derived from 1972 *Landsat* MSS and 1999 *Landsat* ETM+ satellite images in Gombe National Park. Credit: Lilian Pintea/the Jane Goodall Institute

JGI initiated a forest monitoring program in 2005, training and ultimately equipping community members with GPS-enabled smart phones and tablets for capturing observances of forest use and regeneration. These Forest Monitors mark where they see snares for animals, trees that have been cut for timber or firewood, charcoal kilns, and other threats, as well as occurrences of chimpanzees and other wildlife. This information helps efforts to reduce illegal activities, monitor changes, and track progress in the landscape over time. It also helps JGI's crowd-sourcing efforts that combine citizen science with *Landsat* imagery and ecological modeling. A NASA-funded project has helped enable these connections and innovations."We are marrying the latest technologies—using NASA's data and science—with boots on the ground to improve

forest and chimpanzee conservation decisions from village to continental scales," Pintea explained.

Through a democratic land-use planning process in which every village member has a vote—a process supported by the U.S. Agency for International Development mission in Tanzania—JGI worked with communities to facilitate village land use plans. These plans identified areas where people could build homes, areas for agriculture or livestock, areas where firewood and other resources could be extracted, and those to be left to regenerate as communal village forest reserves.

Using GIS and historical *Landsat* imagery, JGI also demonstrated which hillsides have a gradient of more than 45 degrees and which were forested in 1972. These insights further help communities draw the line on where it was safe to plant crops and where trees were needed to regenerate and re-stabilize the watershed.

"In the 14 villages around Gombe National Park, every village set aside land for conservation along the ridge tops and steep slopes," explained Emmanuel Mtiti, JGI's program manager for the Greater Gombe Ecosystem Program. "Together, these conservation areas are establishing a forest corridor along the Greater Gombe Ecosystem, protecting the watershed for the benefit of all those who call the region home."

Recently, Google Earth added more high-resolution satellite imagery, focusing on the time period since JGI's village land use and community forest monitoring efforts began in 2005. "Instead of the forest cover going away, as it had before, the trees are actually coming back!" said Rebecca Moore, engineering manager of Google Earth Engine.

In communities, people are experiencing this success on-the-ground as well. "There is peace of mind that the land beneath the school won't give way," Mtiti said. "More peace of mind that someone won't lose their crop—their livelihood—in a landslide."

As for the fishers, Mtiti added, "Off Kitwe, where the forest has returned, the fishermen line up every night again. This intricate system of life and resources—it's all starting to work better now."

Village Forest Monitors training to use Android Tablets and ODK app to patrol their Village Forest Reserve. Credit: Lilian Pintea/the Jane Goodall Institute

The conservation of Gombe's chimpanzees goes hand-in-hand with the conservation of the area's watersheds. As tree cover returns to steep slopes, it not only stabilizes soils, it also creates conservation corridors that allow female chimpanzees from outside Gombe to join chimpanzee communities within the park—a vital DNA lifeline to ensure the long-term survival of the chimpanzees of Gombe National Park.

"When I arrived in Gombe 50-plus years ago, looking up at the stars, it never occurred to me that one day, we'd be relying on remote sensing—satellites circling the globe high above—to help unite communities of people and save Gombe's chimpanzees," said Jane Goodall, a UN Messenger of Peace. "NASA—through its resources and data and funding—is helping us to apply the kinds of innovative solutions needed to address the complex problems people and chimpanzees face today."

Lilian Pintea (*lpintea@janegoodall.org*) leads this project.

NASA EARTH SCIENCE CAPACITY BUILDING PROGRAM

The Capacity Building Program sponsors programs and projects that improve the skills and capabilities of current and future decision makers, community leaders, and resource managers in the United States and abroad, related to accessing and applying Earth observations. The Program participates in international capacity building groups through Group on Earth Observations (GEO), Committee on Earth Observation Satellites (CEOS), and Coordination Group for Meteorological Satellites (CGMS), and manages three specific activities:

DEVELOP: FOSTERING TOMORROW'S SCIENTISTS AND LEADERS

DEVELOP is a dual capacity building program fostering skills and capabilities to use Earth observations in environmental decision making through rapid feasibility studies. Project participants extend NASA Earth science research to partner organizations, including state and local governments, federal agencies, and non-governmental organizations. Advisors from NASA and partner organizations assist DEVELOP participants to incorporate NASA science measurements and predictions into interdisciplinary projects that address local policy and environmental concerns.

Throughout DEVELOP's 17-year history, project teams have worked to demonstrate to partners how Earth observations can be used to preserve and manage natural resources, while also saving time and money. The scope of the work covered by DEVELOP projects spans topics such as agriculture, climate, disasters, ecological forecasting, health and air quality, and more. Project teams are comprised of interdisciplinary participants such as students, recent graduates, and early and transitioning career professionals. Participant applications are encouraged from individuals with strong interests in the sciences, technology, and policy.

DEVELOP initiates projects with a wide variety of organizations to conduct feasibility projects focused on applying NASA Earth observations to decision-making processes. DEVELOP seeks engaged project partners who value scientific collaboration and communication during a 10-week term. Any organization interested in partnering with DEVELOP can suggest project ideas as described on the DEVELOP website Projects page.

Learn more about DEVELOP at: *https://develop.larc.nasa.gov/*

In 2016, SERVIR-West Africa, based in Niamey, Niger, joined three other NASA-USAID sponsored hubs operating in developing regions of the world

SERVIR: SCIENCE & TECHNOLOGY SERVING THE NEEDS OF DEVELOPING COUNTRIES

SERVIR connects space to village by making geospatial information—including Earth observation data from satellites, Geographic Information Systems, and predictive models—accessible to developing countries. SERVIR is a joint development initiative of NASA and the U.S. Agency for International Development, working in partnership with leading regional organizations around the globe. SERVIR helps those most in need of tools for managing climate risks and land use.

SERVIR global hubs include the following:

- SERVIR-Eastern and Southern Africa
- SERVIR-Himalaya
- SERVIR-Mekong
- SERVIR-West Africa

SERVIR places science in the service of society by building the capacity of regional organizations, each with an established track record of working with governments and communities, to use Earth observations to understand, predict, and act at the local, national, and regional levels. Through the SERVIR network, experts at SERVIR regional hubs partner with local decision makers and U.S.-based scientists to create new datasets, maps, and decision-support tools that answer critical development questions. SERVIR hubs also provide training to build capacity in local institutions for evidence-based decision making that meets societal needs.

SERVIR strengthens the ability of governments and other development stakeholders to incorporate Earth observations and geospatial technologies to manage challenges in the areas of food security, water resources, land use change, and natural disasters. Improved management of natural resources also helps to identify opportunities to improve economic growth while lowering greenhouse gas emissions and building resilience to climate change.

Learn more about SERVIR at: *www.servirglobal.net*

ARSET: APPLIED REMOTE SENSING TRAINING

ARSET helps professionals build the necessary skills to integrate NASA Earth science data into their decision-making processes. Since 2009, the program has reached more than 7,900 participants from 130 countries—with more than 3,000 participants in 2016 alone.

Through webinars and workshops, attendees learn how to access, visualize, and apply NASA remote sensing data using various web-based tools and open source software. Trainings are intended for professionals—including modelers, water and land managers, forecasters, policymakers, and individuals in non-governmental organizations and the private sector—seeking to incorporate NASA remote sensing into their daily activities. Trainings are available in the areas of disasters, health and air quality, land, water resources, wildfires, and conservation management, as well as best practices training.

ARSET international training for water resources management, Foz de Iguazú, Brazil

ARSET provides online training in introductory and advanced applied remote-sensing topics. Online trainings are 4-5 weeks in length, one-hour per week, and are frequently offered twice a day to accommodate different time zones. Recordings of the live online trainings are also available. Most online training materials are available in Spanish and English.

The ARSET program also regularly partners with organizations to host two-to-four day onsite trainings with curricula tailored to partner needs. Conducted in a computer lab, onsite trainings provide a combination of lectures and hands-on activities and often feature guest speakers from NASA and other organizations. Attendees learn how to access, interpret, and apply NASA data on local to global scales, with an emphasis on case studies.

All ARSET materials are free and available for use and adaptation, ensuring appropriate attribution to NASA ARSET.

Learn more about ARSET at: *https://arset.gsfc.nasa.gov/*

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NASA Earth Science
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NASA Capacity Building
http://appliedsciences.nasa.gov/programs/capacity-building-program

NASA Biological Diversity
http://cce.nasa.gov/cce/biodiversity

NASA Earth Science Data
https://earthdata.nasa.gov/

Image: The Namib-Naukluft National Park is an ecological preserve and includes Namibia's vast Namib Desert. Here, southwest winds have created the tallest sand dunes in the world, with some dunes reaching 300 meters in height. The park hosts a collection of animals that manage to survive in this hyper-arid region, including oryx, hyenas, jackals, and springbok. Credit: NASA Goddard Space Flight Center/USGS

Image: Countless lakes, sloughs, and ponds are scattered throughout this scene of the Yukon Delta in southwest Alaska. One of the largest river deltas in the world, and protected as part of the Yukon Delta National Wildlife Refuge, the river's sinuous waterways seem like blood vessels branching out to enclose an organ.
Credit: NASA Goddard Space Flight Center/USGS

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