National Aeronautics and
Space Administration

Improving Conservation, Managing Natural Resources, & Supporting Human Well-Being

A Special Booklet for the IUCN World Parks Congress 2014

NASA Earth Science
Applied Sciences Program

FOREWORD

Welcome to this special booklet on ways that Earth science research, space-based Earth observations, and ecological models support conservation, natural resource management, protected areas, and human well-being. NASA is proud to be part of the IUCN World Parks Congress 2014.

NASA's significant endeavors in Earth science are discovering new insights about the planet and the complex interactions within the Earth system. The NASA enterprise involves sustained and experimental space-based Earth observations, technology development, and fundamental and applied research to characterize, understand, and improve predictions of the Earth system and its processes. These efforts collectively provide new data, expand new knowledge, and improve science-based models to anticipate changes in the environment and inform organizations' decisions and actions.

As an integral part of NASA Earth Science, the Applied Sciences Program advances innovative and practical uses of Earth science data and knowledge. The Program serves as a broker between the data and tools generated by Earth science and the information and decision-making needs of public and private sector organizations. All Program activities support goals to deliver near-term uses of Earth observations, contribute to research priorities and future satellite missions, and build workforce and capabilities with less-developed countries to apply Earth observations and models. The Program addresses themes including ecological forecasting, water resources, health and air quality, disasters, wildfires, and food security, among others.

The innovation and expansion in use of Earth observations and models since the last World Parks Congress has been remarkable. This document features examples of some notable achievements and progress in the use of Earth observations and models for protected areas, protected species, human health, development, and other key themes of the World Parks Congress.

We appreciate the project teams and our partners for their dedication and enthusiasm in applying Earth observations to improve their decisions.

As NASA continues to advance our understanding of the Earth, we're excited about the many opportunities to apply the data and knowledge to support organizations' conservation and development goals. If your organization uses Earth observations, share your examples with us. If you want to begin or improve your use of Earth observations, contact us. We welcome you in the exploration and discovery of ways for Earth observations to serve our parks, people, and planet.

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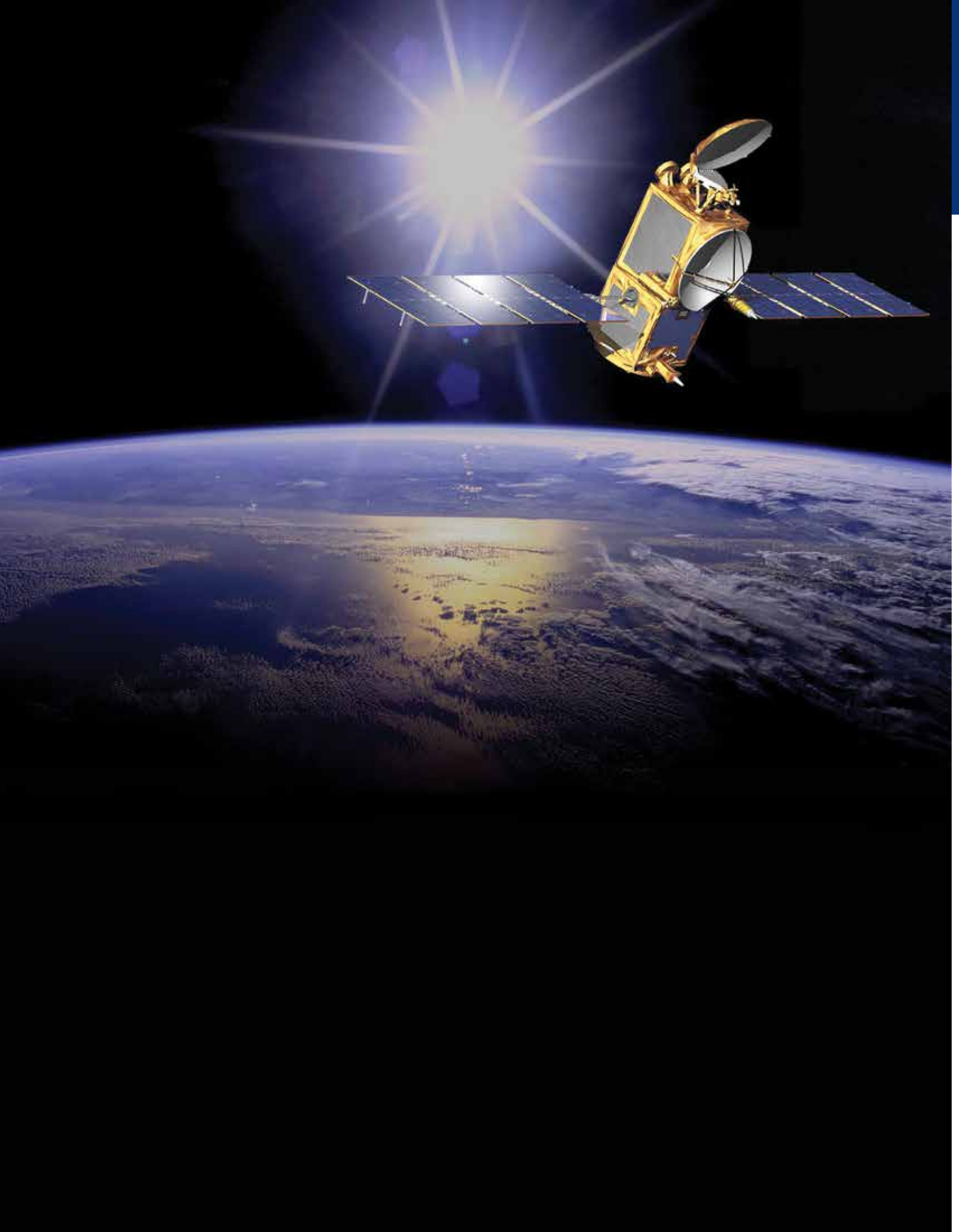

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FURTHERING WILDLIFE HABITAT CONSERVATION AND MANAGEMENT

The U.S. Fish and Wildlife Service (USFWS) manages the 150 million-acre National Wildlife Refuge System and initiatives by states, territories, and tribes for fish and wildlife monitoring and conservation. In general, efforts to sustain species populations through habitat management depend on an understanding of the environmental factors that affect these populations.

Together with USFWS, an Applied Sciences project developed a system of tools supporting applications of Earth observations and ecological forecasting for fish and wildlife management. The project team utilized features of satellite remote sensing to provide environmental information on broad areas and large ecosystems, such as national parks and wildlife refuges, and at finer, species-level spatial and temporal scales. The project team created an adaptable, unifying architecture known as EAGLES—the Ecosystem Assessment, Geospatial analysis, and Landscape Evaluation System. The team validated key aspects of the system in 2012.

Enabling Data Access and Use

EAGLES provides a series of linked software applications in ArcGIS and Web-enabled environments, incorporating Earth observations for ecological forecasts. For example, EAGLES includes data products from MODIS (snow and vegetation), SRTM (elevation), and AVHRR (solar radiation), among other sources. It also includes geospatial covariates (explanatory variables) from remote sensing data, data products, and ecosystem models using MODIS and *Landsat* data. The satellite observations complement data from conventional monitoring of large ecosystems through field plots and aerial surveys.

The new EAGLES system broadens ways for fish and wildlife managers to apply Earth observations for habitat management and species conservation.

EAGLES allows biologists and managers direct control and access to powerful data processing and modeling capabilities for landscape planning and management of focal species and their habitats. The system reduces the data storage and computation capabilities needed to create customized environmental covariates.

The EAGLES system incorporates legacy data—data in older formats that state and federal agencies have collected over several decades, largely from ground-based surveys. For instance, the team enabled access to legacy data on focal species populations such as bison and pronghorn sheep. In validating the system, the team merged the legacy species data with the covariates to carry out diagnostic analyses and predictive modeling of habitat distribution and birth and death rates. Such capabilities can help EAGLES users to better understand the impacts of climate and other environmental factors on species populations.

"The Fish and Wildlife Service manages trust resources . . . at the continental scale that are constantly responding to a changing environment. And COASTER allows you to conduct rapid assessments of environmental effects such as climate change almost anywhere in North America."

Kurt Johnson, U.S. Fish and Wildlife Service

Assessing Alternatives

The team developed tools to forecast species distributions based on habitat and climate projections. Users can devise and analyze "what-if" scenarios (e.g., future climate conditions, land development, and wildfire disturbances) and their associated outcomes. These and other capabilities inform decisions by USFWS and similar entities to, for example, regulate land use, develop climate adaptation strategies, or restore habitats.

"We are using data provided by [the project team] to better determine how waterfowl populations in the North American prairies will respond to system change," said Kathy Fleming, landscape ecologist, USFWS. "Our ability to sustain waterfowl populations through harvest and habitat management depends on an understanding of the environmental factors that influence these populations annually, over continental scales."

Within EAGLES, the Customized Online Aggregation & Summarization Tool for Environmental Rasters (COASTER) system allows users to visualize spatial and temporal patterns in environmental data sets. The system contains data that would take months to compile and weeks to analyze. It can process large data sets and facilitate cost-effective generation of customized environmental covariates for analysis.

COASTER can characterize ecosystem circumstances in a specific area of interest, such as a national park, by using real-time manipulations of 77 geospatial biophysical variables. As the project and partners demonstrated in 2012, such data allow wildlife managers, biologists, and land managers who use COASTER and other EAGLES tools to make their own ecosystem assessments and examine the appropriate explanatory variables in species population models. A test of the system in 2012 showed it reduced the average processing time from six months to six weeks.

Supporting Users

"The design of the COASTER system was based on feedback from a number of federal biologists, including USFWS biologists and managers," said Kurt Johnson, national climate change scientist, USFWS. "We wanted something that was free, on the Internet, in GIS-ready formats, and most importantly, a user friendly analysis tool set that provided access to enormously large data sets on changing environmental and habitat conditions."

Over the course of the project, the team also integrated or created enabling data products to assist managers, applied researchers, and other users of the system. For instance, the team loaded temporal and spatial meteorological data on COASTER. The team created a 60-year climate data set at daily, 1-kilometer resolution for the contiguous United States. Derived from MODIS data, the project team also created a fractional surface water product, giving the percent of open surface water. Particularly supportive of continental waterfowl population models, this product covers most of North America at 500-kilometer resolution and provides estimates every eight days.

Beyond USFWS, potential end users of the system include the U.S. Forest Service, Bureau of Land Management, National Park Service, state fish and

wildlife departments, tribal governments, universities, and nongovernmental organizations focused on conservation.

To help people employ EAGLES, COASTER, and all the tools to inform their decisions, the project team conducted training sessions with tribal colleges, USFWS, conservation agencies, and other organizations.

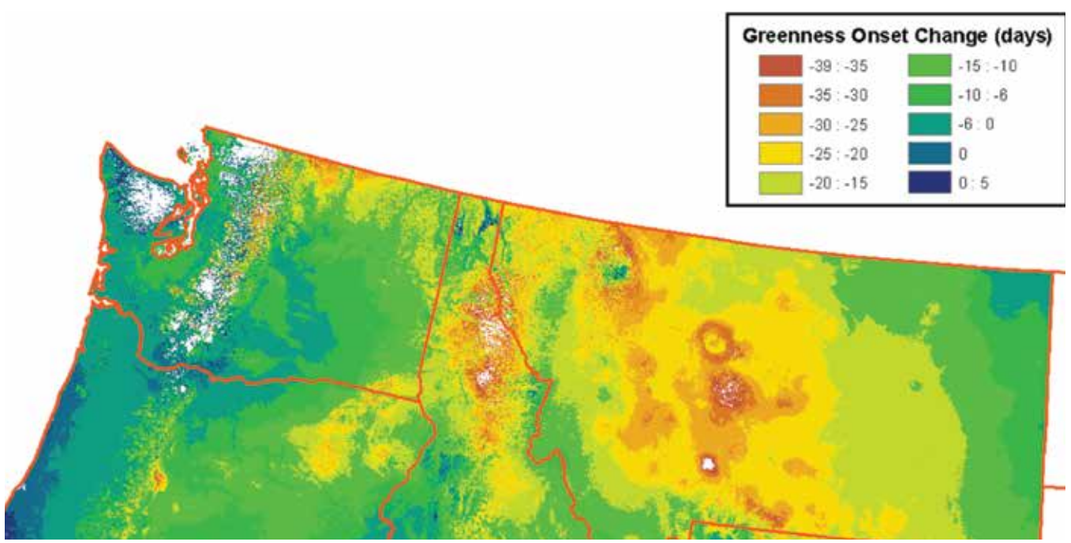
To learn more about EAGLES tools, visit *www.yellowstoneresearch.org/eagles.html.*

Migrating Bison

Using the EAGLES system, the project created a means to generate estimates of annual forage production using MODIS vegetation data. Applying the forage estimates (along with estimates of the amount of water stored in snow) in models, the team predicted the seasonal migration of bison from Yellowstone National Park.

The team concluded that the significant variables for predicting bison movement were herd size, annual forage biomass, and changing snowpack. Wildlife managers can now better understand how bison decide to leave or stay in the park, depending on how hard it is for the bison to access forage through the snow as well as compete with each other.

P.J. White, chief of wildlife resources at Yellowstone, said: "The forage and snow estimates . . . were useful for predicting seasonal migrations by Yellowstone bison within and outside the park, and in improving collaborative policies with other federal, state, and tribal agencies to manage transboundary movements based on considerations of bison conservation, disease transmission to cattle, human safety, and property damage."

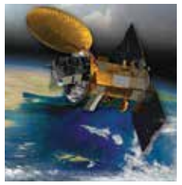


COASTER supports ecosystem assessments. This example shows the 55-year trend (1955–2009) in spring greenness onset in the Pacific Northwest and Northern Rockies.

ADVANCING MARINE MAMMAL AND PROTECTED SPECIES MANAGEMENT

The U.S. Navy, Bureau of Ocean Energy Management, NOAA, and other entities use a Spatial Decision Support System (SDSS) in assessing the density and distribution of marine mammals, including whales, porpoises, and dolphins. Supporting efforts to reduce impacts on marine species from seismic surveys, naval exercises, oil drilling noise, and other human activities, a Program-funded project improved SDSS predictive models through new indices using satellite observations. In 2012, the U.S. Navy began using the modeling system for environmental impact compliance.

Developed to support marine mammal conservation, SDSS is a data management and statistical modeling system that allows users to visualize and explore predicted habitats for marine mammals around U.S. waters. Model results yield predictive maps for the likelihood of encounter from parameters such as depth, distance to shore, sea surface temperature (SST), and chlorophyll concentration. SDSS uses observations from the space-based sensors MODIS and AVHRR as well as data from NOAA surveys. As an interactive map server, the system enables examination of model outputs across multiple time scales and usable spatial formats.



An Applied Sciences project worked to improve cetacean population density estimates in SDSS. Together with partners at the U.S. Navy, Bureau of Ocean Energy Management (BOEM), and NOAA, the project team combined remote sensing data from *Aqua* and other satellites with *in situ* oceanographic measurements to create indices applicable to protected species in the northeast Pacific Ocean, northwest Atlantic Ocean, and Gulf of Mexico.

The team incorporated these indices into predictive models of species density, abundance, and habitat. SDSS also improved through the team's work to add a near real-time predictive capability based on the indices derived from available Earth observations. The team's habitat-based density models combine remote sensing data and ecologically significant variables.

Overall, the team enhanced the effectiveness of SDSS, increasing both the spatial and temporal perspective of

"We see this project as part of an ongoing effort to improve spatial density estimations, and NASA's Earth observations will play an important role in it."

James Michael Price, U.S. Bureau of Ocean Energy Management

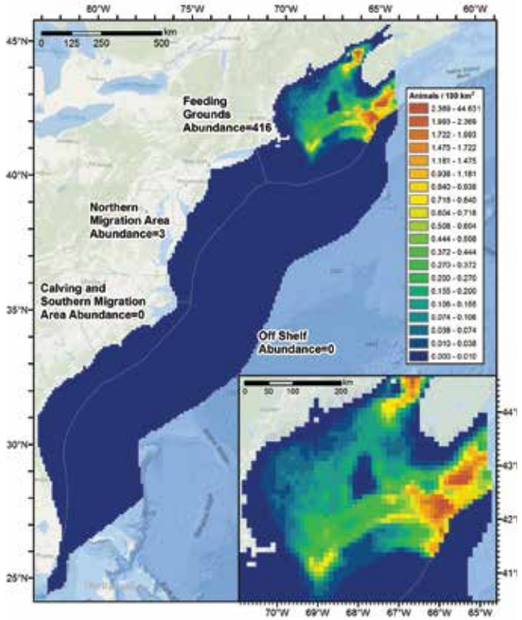
models. SDSS now offers improved perspectives on past events and insights on the next month and next season.

"These analyses identify primary variables influencing marine mammal distribution, thereby providing the context for successful accommodation of whales and dolphins in marine spatial planning frameworks," said Tim Cole, aerial survey team lead at the NOAA Northeast Fisheries Science Center.

A multi-agency team applied satellite observations to improve assessments of marine mammal habitats and reduce human impacts on whales, dolphins, and other species.

To conduct training exercises at sea, the U.S. Navy files environmental impact statements (EISs) to obtain permits from the NOAA National Marine Fisheries Service. In 2012, the Navy began using the team's models for estimating whale and dolphin density in EIS development. The use supports assessments of potential impacts of sonar-related training and testing, ensuring that its activities comply with environmental and conservation legislation. Improvements to density models and predictions in SDSS support the Navy's submissions of quality EISs, helping reduce revisions and streamlining EIS reviews and permit issuance. The Navy has already benefited from improved data on the density and ranges of Dall's porpoises off the U.S. West Coast.

During this project, the team participated in a working group to map cetacean density and distribution in U.S. waters, particularly to gauge the cumulative effects of sound on cetaceans. The group established a hierarchy of data, identified the best available data, and arranged to make the data available to users via a NOAA website interface. Working group members unanimously agreed that SDSS and enhancements developed through the NASA project represented the best available estimates of cetacean density.



Example of a cetacean density model output for the North Atlantic right whale summer season. This seasonal forecast model uses dynamic oceanographic features (SST fronts, eddies, eddy kinetic energy, etc.) derived from Earth observations.

A May 2012 symposium, Mapping Cetaceans and Sound, featured the models and data hierarchy. It involved more than 200 managers, scientists, and decision makers from the oil and gas industry, Navy, NOAA, and BOEM, among others. This event helped to unify management community and federal agency responses to the assessment and management of ocean noise and potential interactions with protected species. Attendees noted that the accumulation of existing data and density models of cetacean species and ocean noise models in a single repository provides an authoritative baseline source for future protected species management.

"The NASA-funded project . . . has significantly advanced our understanding of how marine mammals are utilizing the ocean," said James Michael Price, marine mammals studies coordinator at BOEM. "With more reliable knowledge of where and when these animals are feeding, breeding, or migrating through, BOEM can better assess possible adverse impacts to them and, hopefully, take administrative action to avoid the impacts or at least mitigate them."

In 2012, NOAA and BOEM integrated data from the project into the Multipurpose Marine Cadastre, an integrated marine information system that provides legal, physical, ecological, and cultural information. Originally created to support offshore renewable energy siting, this tool provides a common geospatial framework for broader coastal and marine spatial planning, aiding people working on regional and state coastal and marine spatial planning efforts. The integration of the project's data in this mapping tool helps improve ocean navigation and lower risks of ship-marine mammal collisions and the associated impacts on the animals.

The Spatial Decision Support System provides information on cetacean densities and habitats. The density estimate depicted is for sperm whales, an endangered species, in the summer season in the California Current system. Warmer colors indicate higher density.

NOAA also reviewed the density models and incorporated them into a new NOAA tool to gauge the cumulative effects of sound on cetaceans. The U.S. Coast Guard indicated it planned to assess applications of the team's methods to help forecast fishing areas for more efficient enforcement.

The Strategic Environmental Research and Development Program, a DoD-EPA-DOE partnership, sponsored the development of the Spatial Decision Support System.

To learn more about the system, visit *http://seamap.env.duke.edu/seamap2.5/serdp/serdp_map.php.*

Enhancing Conservation

Marine Geospatial Ecology Tools (MGET) is an open-source toolbox for marine research, conservation, and spatial planning. The system supports activities from downloading and conversion of data into popular formats to modeling species habitats and calculating species diversity grids.

Duke University's Marine Geospatial Ecology Lab, which managed the SDSS project, expanded the development of MGET and access to Earth observations for the development of models and analysis in marine ecosystems.

The MGET toolbox includes more than 300 tools and key algorithms. There are tools to identify fronts and eddies in satellite images, evaluate models of species habitats, model biological connectivity, simulate hydrodynamic larval dispersal, build grids to summarize fishing effort, and create habitat maps.

For example, MGET supports forecasting activities for scientific larvae surveys in the Gulf of Mexico and Caribbean. Forecasts use data on ocean conditions derived from satellite data in models to help guide research ships to the most favorable locations to conduct their sampling. MGET tools automate steps to process satellite imagery and oceanographic model outputs to provide the forecasting products.

In 2012, the Wildlife Society's Spatial Ecology and Telemetry Working Group recognized the MGET development team, led by Jason Roberts, with an award for a "spatial function, tool or service that has significantly enhanced the field of wildlife conservation and management."

In addition, Esri honored the Marine Geospatial Ecology Lab with a Special Achievement in GIS Award, in recognition of contributions to marine science and its "outstanding work with GIS technology."

To learn more about MGET, visit *http://mgel.env.duke.edu/mget.*

MONITORING ECOSYSTEMS IN NATIONAL PARKS

An Applied Sciences project is pioneering the integration of remote sensing data into the National Park Service's park management and decision-making processes. This cutting-edge environmental monitoring helps illustrate changes in park ecosystems and leads to more effective management of park resources.

The National Park Service (NPS) plays a critical role in protecting biodiversity and rich natural resources in more than 394 areas, covering more than 84 million acres in the United States. However, the health of national parks and protected areas is often dependent on the ecosystems of their surrounding lands. As these neighboring lands become more developed, there is an increased need to monitor the ecosystems around the parks.

To help NPS better understand the connection between national parks and surrounding lands, the Applied Sciences-funded Park AnaLysis and Monitoring Support (PALMS) project monitors and visually depicts the impacts of rapid changes in and around park boundaries.

"Mapping and then managing park-centered ecosystems is critical for maintaining the condition of these parks under land use pressures," said Andrew Hansen, principal investigator for the PALMS project. Hansen is a professor of Ecology at Montana State University.

PALMS integrates NASA remote sensing data into the NPS Inventory and Monitoring (I&M) Program that collects, organizes, and makes available natural resource data for analysis, synthesis, and modeling.

PALMS and I&M teams identified park conditions, or indicators, that remote sensing data would be most effective in monitoring, such as weather and climate, water and streams, land use, and land cover. Hansen said that an initial PALMS analysis of climate scenarios produced for Yosemite National Park showed shifts in the timing of snowmelt and runoff that reduce summer streamflow and water availability. The projected reduction of water affects not only Yosemite's wildlife, but also surrounding communities that rely on snowmelt for water supplies and agricultural use.

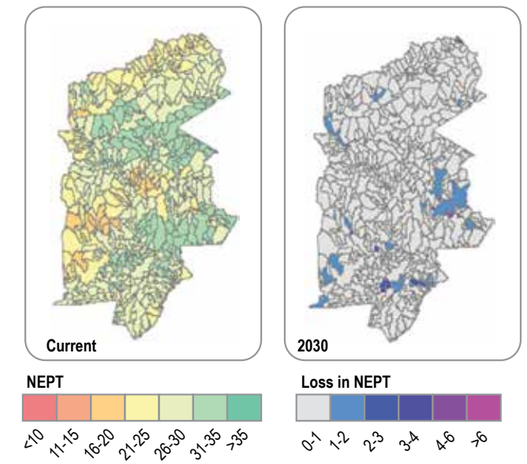
> "PALMS provides decision support tools that help us understand how to make decisions in individual parks and how those decisions connect to other parts of the surrounding land."
>
> Tom Oliff, Greater Northern Landscape Conservation Cooperative

Tom Oliff, NPS landscape coordinator at the Greater Northern Landscape Conservation Cooperative, says NASA's data also gives NPS managers a unique opportunity to see their parks in a regional context.

"PALMS provides decision support tools that help us understand how to make decisions in individual parks and how those decisions connect to other parts of the surrounding land," Oliff said. "To protect a resource, we may need to partner with a land trust or another federal agency, like the U.S. Forest Service."

Components of the project were transferred to NPS in 2010. Since launching, PALMS has delivered many indicators of landscape conditions to park resource managers, including innovative approaches for hindcasting and forecasting land use changes.

The tools generate video simulation models that illustrate changes in the park and surrounding lands. Hansen thinks the power of visually illustrating a changing ecosystem can lead to greater cooperation for improvements, such as conservation easements. "The products developed from this applied research help people understand the connection between parks and the land outside," he said.



This map shows the use of the PALMS tool to illustrate the predicted loss of stream diversity in the Upper Delaware River Basin. The data tracks the presence of NEPT, a collection of species known to be sensitive to stream pollution and sedimentation that are often used as indicators of aquatic health and overall ecological health within a watershed. The Delaware River Watershed provides water to over 17 million people, and the Upper Delaware Scenic and Recreational River is part of the NPS National Wild and Scenic Rivers System.

AUGMENTING MANAGEMENT AND MONITORING OF CORAL REEFS

Coral reef managers use environmental information to monitor conditions and threats to reef ecosystems, taking actions where possible to minimize human impact and support reef health. Increased ocean temperature is an important factor in bleaching, a threat to coral health. Broad-scale temperature data helps reef managers assess regional conditions and trends, and finer-scale data gives them insights for targeted actions, such as redirecting divers and snorkelers to suitable reefs.

"Reef managers can implement various strategies during times of coral bleaching to reduce or mitigate the potential negative impacts additionally caused by human use," said Scott Donahue, science coordinator at the Florida Keys National Marine Sanctuary.

Coral Reef Watch (CRW) is an online tool that provides near-real-time and long-term monitoring, forecasting, and reporting of environmental conditions of coral reef ecosystems. Operated by NOAA, CRW uses satellite data, climate models, and *in situ* tools to provide bleaching alerts to the public and reef managers.

The University of South Florida and CRW staff led an Applied Sciences-sponsored project to apply *Terra*, Aqua, and other satellite data to enhance the spatial and temporal resolution and density of temperature data in the tool. The top need identified in user surveys was higher resolution information, and the project has since achieved 100-times greater spatial resolution.

Water temperatures that exceed thresholds for sustained periods lead to thermal stress in corals, and the CRW system helps pinpoint reefs likely to bleach. "Coral Reef Watch is very informative for what we are trying to do," said Karen Bohnsack, [Southeast Florida] BleachWatch Program coordinator for the Florida Department of Environmental Protection's Coral Reef Conservation Program.

With coral bleaching, corals lose the symbiotic algae that give them their distinctive colors. If a coral is severely bleached, disease may become more likely, and the entire colony may die.

"The new data products provide observations closer to the scale of coral reefs. Managers want to know as much as we can tell them to help their management of reef resources."

Mark Eakin, Coral Reef Watch

The project team developed global, 5-kilometer sea surface temperature (SST) products based on combinations of data from NASA, NOAA, and foreign geostationary and polar-orbiting satellites, including *Suomi NPP*, *GOES*, *NOAA-19*, *MSG*, *MTSAT*, and *Metop-A*. The combination helps users better visualize and quantify thermal stress conditions around the world. The team also created a 1-kilometer product using Aqua/MODIS and AVHRR imagery for the Gulf of Mexico and reefs in the Florida Keys, Caribbean Sea, and off Mexico.

Applications of Earth observations enhanced a decision support system for management of coral reefs, supporting ecosystem health and economic activity.

CRW's new products build on the 50-kilometer products it has provided, which allow reef managers to understand conditions of offshore waters around the resources under their jurisdiction. The new products show what is happening closer to shore and within actual reef ecosystems. The new products also provide 25 to 100 times more satellite data per pixel than the old products. The new products also directly cover up to 95 percent of coral reefs around the world.

Enhancing Research and Public Support

As a result of the CRW improvements, reef managers can now make more informed decisions, including taking steps to protect coral ecosystems or target monitoring. In the short term, there are actions managers can take for immediate effect, such as reducing allowable pollutant loads or alerting recreational dive vessels to change locations.

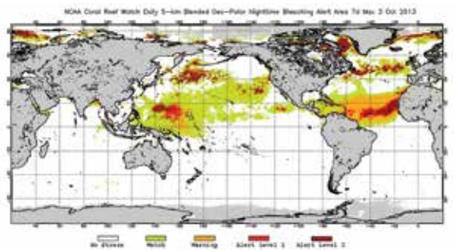
"One example would be working with local diving and snorkeling operators to redirect on-water tourist activities away from natural reef areas normally subject to high visitation to artificial reefs and shipwrecks," said Donahue of the Florida Keys National Marine Sanctuary. "This could reduce unintentional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

CRW enables decisions on where to conduct extensive monitoring and ways to engage the public to support reef health and collect information. "In times of severe thermal stress, that higher [5-kilometer] resolution helps us manage where we request researchers and citizen scientists alike to look for potential thermal stress in corals," said Donahue. "Also, over the long term, it may help reef managers refine where they place *in situ* temperature monitoring devices to help better correlate remotely sensed data with conditions experienced at depth."

In 2013, CRW released the new products. CRW introduced its 5-kilometer Bleaching Alert Levels in October 2013. The team will enhance its products and add new ones, including a long-term mean SST climatology product, based on user input.

Climate change has contributed to rising ocean temperatures and growing ocean acidification, which affect coral reef health. People are now using space-based information from Coral Reef Watch to reduce further human impacts on the reefs—and the broader ecosystems and local economies they support.

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



The coral bleaching alert area product shows ocean regions where thermal stress is high enough to impact corals. At this time, coral bleaching was ongoing in the U.S. territories of Guam and the Commonwealth of the Northern Marianas Islands.

ADVANCING MANAGEMENT OF CHINOOK SALMON FISHERIES

Wild Chinook salmon from central California, an important commercial and recreational fishing species, face the risk of extinction in some areas. Accurately estimating the size of populations for future years, which can inform management actions, has proved difficult.

A NASA-sponsored project worked with the Pacific Fishery Management Council (see callout on page 18) and NOAA to apply Earth observations from *Jason-2* and *Aqua* in a stock assessment model, aiding fishery forecasting. Use of the combined observations has added one to two years to forecasts, aiding adaptive management practices to better support the sustainability of Chinook stock.

A novel approach applying satellite observations of ocean environmental conditions improved Chinook salmon stock assessments, aiding management of the fishery.

Siblings and Partners

Management of the central California Chinook fishery has largely relied on a sibling model: the number of three-year-old fish available in a given year is based on the number of two-year-old fish returning to spawn the prior year. In other words, the model that managers have used to estimate the fishable abundance of central California Chinook salmon is only a year ahead of the fishery. As such, abilities for earlier adaptive management are limited.

Using data from satellites, the Applied Sciences project developed ways to better predict three-year-old fish based on the abundance of krill for juvenile salmon to eat in their first year of life. The project's model adds an additional one to two years to the prediction periods of three-year-old fish. The extended prediction periods allow fishery managers to adapt management practices earlier and reduce variability in the fishery.

Led by Francisco Chavez of the Monterey Bay Aquarium Research Institute, the project team included applied researchers from the NOAA National Marine Fisheries Service (NMFS), Farallon Institute, University of Maine, and Remote Sensing Solutions, Inc. Primary end users were NMFS and PFMC, which manages fisheries off the coasts of Washington, Oregon, and California.

In 2012, PFMC technical experts incorporated the

"The project directly addresses some of the highest priority Council stock assessment and management needs, and could greatly assist the fishing industry in long-term planning."

Donald McIsaac, Pacific Fishery Management Council

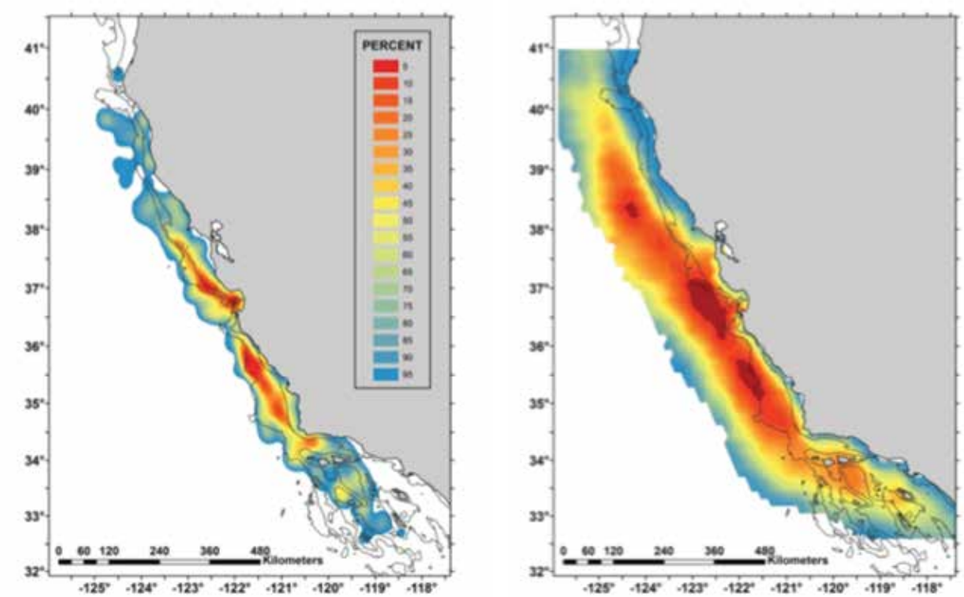
project's findings and methods in developing prior season data reports and estimates of the number of fish for the next season. In addition, NOAA began using the project's models in an integrated ecosystem assessment tool it developed for the California Current.

"The California Current Integrated Ecosystem Assessment (CCIEA) is excited about the results of the NASA project," said Brian Wells, NOAA science lead for the CCIEA. "The CCIEA uses the results to advise management of salmon for central California. Specifically, using the krill-salmon models developed by the project, the CCIEA can gain a predictive understanding of how the productivity of the California Current varies year to year."

Applying Earth Observations

To create its advanced model, the project team used oceanic environmental data from sources including *Aqua*, *Jason-2*, and *GOES*. The team enhanced the sibling model by incorporating sea surface height, while taking into account variables such as temperature, wind speed and direction, and upwelling. The team also used the Regional Ocean Modeling System, developed in part by NASA's Jet Propulsion Laboratory, to simulate and forecast the ocean environment.

The project team improved estimates of fish returning to spawn by examining the variables that affect salmon returns. It analyzed regional winds, krill data from ship surveys, and ocean circumstances due to climate oscillations. The team noted the wind and ocean layer temperature conditions related to lower coastal sea level. A lower coastal sea level and a large quantity of adult krill provide juvenile salmon with the optimal environment for growth and survival.



Comparison between the relative concentration of krill along central California estimated using acoustics on ship surveys (left) and a similar measure estimated from the project's model simulations (right). Using percentiles of krill abundance from a cumulative histogram approach, the colors indicate the percentage of the concentrations at 5 percent intervals (highest in the 0 to 5 percent range, lowest in the 90 to 95 percent range). Warmer colors indicate higher concentrations of krill.

The team's findings allow for a two-year lead on the sibling model. In the spring, as adult salmon return to spawn, fishery managers can combine estimates of krill abundance and forecasts of sea level height for the fall—with time to amend, if necessary, harvest rules.

Increasing Accuracy

Using its model, the project improved forecasting accuracy by 20 percent in comparative hindcasts. The fit of the sibling model results to the observed data accounts for 60 percent of the variability in the data. Fishery managers generally consider that a reasonable fit, and the simple approach works well during periods of average or above average abundance. However, in a period of significantly reduced stock, fishery managers need to ensure the survival of enough spawning fish to allow the population to recover.

"The project has and will continue to provide valuable insight into the effects of ocean environmental conditions on Sacramento River fall Chinook, the most important Chinook stock supporting ocean fisheries in California and Oregon," said Donald McIsaac, executive director, PFMC.

Adoption of the project's predictive techniques should support long-term planning in the fishing industry. Due to its enhancements to the sibling model and ecosystem perspective, the project also has implications for other forage species and managed stocks.

Managing Fisheries

The Magnuson-Stevens Fishery Conservation and Management Act of 1976 established eight regional fishery management councils. The councils manage fisheries with the best available science and incorporate ecosystem management practices when possible. NOAA NMFS implements the management measures recommended by the councils.

One of the eight councils, the Pacific Fishery Management Council, has jurisdiction over approximately 315,000 square miles of exclusive economic zone off Washington, Oregon, and California. It manages fisheries for about 120 species of salmon, groundfish, coastal pelagic species (sardines, anchovies, and mackerel), and highly migratory species (tunas, sharks, and swordfish).

PFMC scientific and technical groups use models and other forecasts and simulations. At the beginning of every year, PFMC uses the technical experts' data and estimates to make recommendations on management measures, such as fishing quotas, gear restrictions, and curtailment of season length.

To learn more about PFMC, visit *www.pcouncil.org.*

MAPPING AND FORECASTING FROST WITH SATELLITE OBSERVATIONS

In 2013, public and private sector organizations in Kenya began using an automated frost mapping system that incorporates satellite data. The system generates maps to help farmers and businesses manage the risk of frost damage to Kenyan crops such as tea and coffee.

Within a few hours of satellite data collection, the system emails user-friendly maps pinpointing areas with high potential for frost to the Kenya Meteorological Service (KMS) and other stakeholders. KMS worked with an Applied Sciences team and the Regional Centre for Mapping of Resources for Development (RCMRD), based in Nairobi, to develop the system using land surface temperature data from the Aqua and *Terra* satellites.

This past year, the Meteorological Service used the frost maps to identify areas of potential frost in the highlands of Kenya. In addition, the Tea Research Foundation of Kenya (created by the Ministry of Agriculture) incorporated the maps in efforts to improve crop yields and avoid losses. The maps were also useful to agricultural insurance providers in their assessments of claimed losses, allowing them to serve their clients more effectively.

The Kenya Meteorological Service, Tea Research Foundation of Kenya, and insurance providers utilized maps incorporating MODIS data to improve crop risk management.

"The frost maps are excellent tools," said James Kiguru, an accounts manager and agronomist at AON Risk Solutions, a global provider of insurance and risk management services. "[The maps] give us a much stronger basis to conduct our assessments and will boost development of frost insurances. . . . We are able to assist our clients—particularly farmers—when it comes to frost claims which otherwise would be attributed to negligence."

The frost maps are part of KMS activities to respond to requests every winter from farmers and businesses for

"[The frost maps] give us a much stronger basis to conduct our assessments and will boost development of frost insurances. . . . We are able to assist our clients—particularly farmers—when it comes to frost claims which otherwise would be attributed to negligence."

James Kiguru, AON Risk Solutions

information regarding where and when frost conditions will occur.

"I shared these maps with colleagues in tea research, and we are excited to have an attempt in this direction," said Ayub Shaka, assistant director, KMS.

Supporting Agriculture

In addition to reducing losses to current crops, the project's frost maps can help farmers avoid frost-prone times and locations for future planting. The result will be better crop yields, supporting people and livelihoods in African countries.

Kenya is ranked third in annual world tea production, and it has the highest tea productivity (yield per hectare) worldwide. The industry provides for the livelihoods of an estimated 4 million Kenyans, or about 10 percent of the total population.

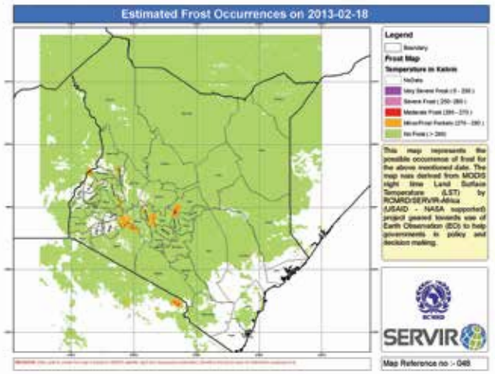
Applied Sciences funded this project through its SERVIR initiative, a NASA–USAID endeavor. In East Africa, SERVIR partners with RCMRD.

SERVIR will use its Wireless Sensor Network (WSN) to more clearly define frost condition thresholds through the collection of temperature, wind speed, and humidity observations in sample locations. (The WSN is a ground-based network of sensors that can be spread over three or four square kilometers to measure environmental conditions.) SERVIR will correlate the observations with the forecasts and satellite data products.

SERVIR has sponsored training workshops and will continue to train regional officials in the use of the frost alert system. SERVIR will also develop a decision guide for using WSN frost data and satellite frost risk maps.

In 2014, the frost mapping system will use KMS numerical prediction model forecasts, in addition to the satellite data-derived frost products, to help map areas of potential frost up to three days in advance.

To learn more about the daily frost maps, visit *http://41.206.34.124/frostmaps.* To learn more about SERVIR, visit *www.SERVIRglobal.net.*



Estimated frost in Kenya and parts of adjacent countries, February 18, 2013. The map is based on MODIS land surface temperature data.

IMPROVING MANAGEMENT OF ATLANTIC BLUEFIN TUNA

An Applied Sciences project used NASA Earth observations in an application to improve assessments of the Atlantic bluefin tuna population. Fisheries authorities now use techniques developed by the project team to support stock assessment and management.

The Atlantic bluefin tuna is one of the largest and most valuable fish in the sea. The species is important to commercial and recreational fisheries in the United States and abroad. The species is slow growing with a long life expectancy, making it susceptible to overfishing. Populations of Atlantic bluefin tuna have been declining since the 1970s, necessitating annual fishing quotas.

The project team applied data from the *Aqua*, *Terra*, and *Jason* satellites to a population assessment technique and coordinated the transfer of the technique to NOAA's National Marine Fisheries Service (NMFS). The NMFS Southeast Fisheries Science Center is responsible for Atlantic bluefin tuna assessments and makes recommendations to the International Commission for the Conservation of Atlantic Tunas (ICCAT), the governing body for stock management.

Developing Applied Techniques

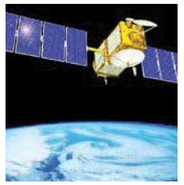
The U.S. Sustainable Fisheries Act stipulates that fish populations be managed to produce maximum sustainable yield. Accurate population assessments are critical to fisheries management decisions, and an understanding of Atlantic bluefin tuna spawning supports the population assessments. Bluefin tuna larvae are a primary indicator of the spawning and show apparent fluctuations in population.

Applying a combination of larvae catch information, satellite observations, and *in situ* data, the project team developed a habitat classification model of larval occurrence to predict where larvae could be captured. The team used sea surface temperature and ocean color data (i.e., chlorophyll) from *Terra* and *Aqua*, sea surface height from *Jason*, and *in situ* measurements of salinity, bottom depth, and other factors.

"By applying daily satellite sea surface temperature and chlorophyll, we have been able to construct real-time models of larval bluefin tuna abundance…. This capability greatly expands our understanding of larval bluefin ecology, and has allowed us to target specific areas resulting in the development of an improved larval index."

John Lamkin, NOAA National Marine Fisheries Service

"Satellite-derived data provides an overview of ocean conditions that are not available from traditional shipboard measurements. By applying daily satellite sea surface temperature and chlorophyll, we have been able to construct real-time models of larval bluefin tuna abundance in the Gulf of Mexico," said John Lamkin, a fisheries oceanographer at the NMFS Southeast Fisheries Science Center.



Improving Efficiency of Larval Surveys

Variance in estimates of larvae and "larval abundance" (i.e., individuals per area) are key measures of larval surveys. The project team used the model and satellite observations to forecast larval occurrences, and the new method to classify spawning habitats proved successful. The team caught over 13 percent more larvae in 2011 than in 2009. Additionally, the team used the technique to capture larvae from an area off the Yucatan Peninsula, where larvae had not previously been documented. In combination with NMFS' long-term *in situ* data records, the team reduced the variance in estimates of larval abundance by approximately 14 percent, which is considered to be a substantial reduction.

An Applied Sciences project delivered a new method using satellite data to support fisheries stock assessment and management of Atlantic bluefin tuna.

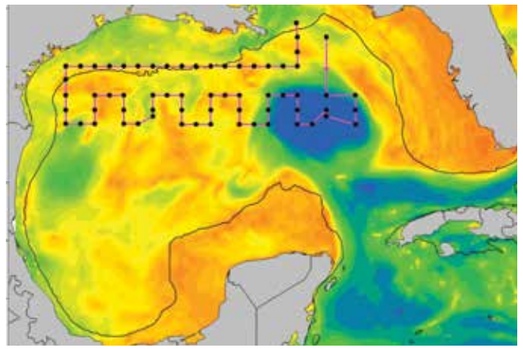
Transferring the Application

Led by Mitchell A. Roffer of Roffer's Ocean Fishing Forecasting Service, Inc., the project team involved a group of academic researchers, NMFS scientists and managers, and commercial scientists.

The collaborators worked with the NMFS Southeast Fisheries Science Center to transfer the techniques and habitat classification models for their adoption. They worked with and trained fisheries management and research personnel at NMFS on the techniques, which have been adopted as standard practice in deriving the U.S. national stock assessment used by the ICCAT. The techniques are also being used for other fisheries management applications.

"This capability greatly expands our understanding of larval bluefin ecology, and has allowed us to target specific areas resulting in the development of an improved larval index. This index is used by the ICCAT as part of the stock assessment process and is the only fisheries independent survey for Atlantic bluefin tuna," Lamkin said.

NMFS now routinely uses satellite observations in its surveys and stock assessment process for Atlantic bluefin tuna. NMFS representatives have presented their Atlantic bluefin Tuna assessments to the ICATT using the techniques adopted from this project.



The project team applied satellite infrared and ocean color data (May 1–7, 2011) to derive a larvae habitat model. The model helped explain the variation in catches of the fixed sampling sites (black dots) in the Gulf of Mexico. Warm (orange-red) colors depict higher probability areas; cool colors (blue and green) depict lower probability areas.

APPLYING RESEARCH FOR IMPROVED FOREST MANAGEMENT

The U.S. Forest Service (USFS) manages the National Forest System (NFS) of more than 190 million acres, which is greater than a quarter of all forestland in the United States. Law, regulation, and internal policy require the agency to monitor carbon storage across national forests.

In 2012, USFS adopted an Earth Science Division (ESD)-developed carbon assessment tool, known as ForCaMF (Forest Carbon Management Framework), which uses satellite imagery as part of an approach to enhance forest management. In adopting it, USFS extended the tool from the pilot area to the entire NFS.

Forests help mitigate greenhouse gas emissions by absorbing and storing carbon in soil and trees. ForCaMF tracks forest conditions and provides information about the effects of forest disturbances, such as wildfires and timber harvests, on carbon storage. It creates fine-scale maps of biomass and disturbance maps using *Landsat* data products calibrated with field data from the USFS Forest Inventory and Analysis (FIA) program. Complementing FIA, ForCaMF provides information about the factors that influence carbon stocks over time—information that is critical to managers and is administratively required in the NFS planning process.

The ForCaMF maps combine with carbon dynamics programmed into the USFS Forest Vegetation Simulator to make historical and forward-looking carbon storage assessments. Building on the Forest Service's expertise with satellite remote sensing, USFS can utilize ForCaMF for strategic carbon assessments at sub-regional and local scales, where most forest planning occurs.

"ForCaMF provides defensible estimates of recent stock changes for individual national forests," said Jim Morrison, regional climate change coordinator, USFS Northern Region.

The origins of ForCaMF began with research sponsored by NASA's Carbon Cycle Science program (under ESD Research & Analysis). In later years, the project transitioned to ESD Applied Sciences for support of the

"ForCaMF is an important component of our applied carbon monitoring and assessment efforts."

David Cleaves, U.S. Forest Service

application development and validation. In 2011, NASA and USFS collaboratively funded a pilot of ForCaMF for NFS lands in the Northern Rockies.

The success of the pilot led USFS in 2012 to fund the expansion of ForCaMF across the entire NFS, enhancing FIA operations and other long-standing management processes. ForCaMF map resources are the first of their kind to be produced consistently across the NFS. USFS is archiving these resources for other broad forest planning uses that might involve timber, water quality, or even habitats for endangered species.

Assessing and Managing

The FIA program produces detailed assessments of carbon stocks, and it is the source of information about U.S. forests in reports to the U.N. Framework Convention on Climate Change. With four decades of *Landsat* data available for disturbance maps, USFS can use ForCaMF to assess the effect of management and natural disturbance upon historical trends in carbon stocks in biomass and wood products. In other words, USFS can supplement the in-depth FIA information with a perspective on what is happening to carbon stocks and why.

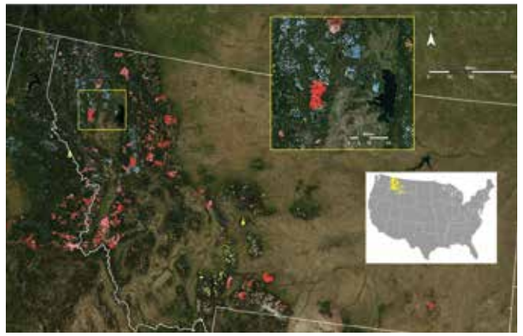
The U.S. Forest Service adopted a NASA-developed forest carbon assessment tool, expanding its application to the entire National Forest System.

Landsat-based maps also contribute to the measurement of management-related emissions by quantifying, for example, forest road construction activity and pinpointing how far harvested timber must be hauled to move it from the forest to the mill. ForCaMF allows annual assessment of carbon stocks and fluxes as they respond to particular harvest strategies. Managers can enter alternative hypothetical scenarios into ForCaMF for comparison against each other and against actual disturbance trends tracked by *Landsat*. This capacity is critical for establishing the net carbon benefit of one management approach over another.

ForCaMF is part of a larger USFS effort to monitor carbon stocks. Carbon assessment and stewardship is one element of the Climate Change Performance Scorecard, a program to help rate USFS management units in readiness and adaptability to climate change. As part of this, managers use baseline assessments of carbon stocks and the effects of disturbance and management activities on those stocks. In this way, ForCaMF can support their integration of carbon stewardship into overall resource management.

"ForCaMF is an important component of our applied carbon monitoring and assessment efforts," said David Cleaves, USFS climate change advisor to the chief.

To learn more, visit *www.fs.fed.us/climatechange/advisor/scorecard/carbon-assessment-stewardship.html.*



Map of forest disturbances, 1990–2011.

SUPPORTING EARLY WARNINGS OF INFECTIOUS DISEASES WITH NEW GLOBAL RISK MAPS

The World Health Organization and nations' health officials now have access to global risk maps of infectious diseases associated with viral hemorrhagic fevers on a biweekly basis. Applying data on environmental conditions derived from *TRMM* and other satellites, the risk maps support early warnings of outbreaks and aid health officials' preparedness.

Viral hemorrhagic fevers—such as Rift Valley fever, Marburg hemorrhagic fever, and Ebola—involve bleeding disorders and elevated body temperatures. The diseases affect humans and are especially deadly for livestock. Agents of transmission include types of insects and bats, and inter-annual climate variability and ecological dynamics influence spatial and temporal factors in disease outbreaks. For instance, heavy rainfall can create breeding sites for mass hatchings of mosquitoes that carry the Rift Valley fever virus.

Earth-observing satellites collect data on surface temperature, precipitation, vegetation, and other environmental parameters associated with the diseases' hosts and vectors. An Applied Sciences team applied and tested combinations of these data products that correlated with historical records of outbreaks. The risk maps the team developed show the probability of environmental patterns related to outbreaks at a given time and place.

Available every two weeks beginning in 2012, the risk maps offer a warning of up to nine weeks prior to an outbreak. Such lead times facilitate timely disease control and prevention, such as collection of surveillance data and preparations to mitigate the effects of disease. For example, in days preceding outbreaks, public health officials in affected countries can pursue WHO-directed actions such as public education campaigns to mitigate the risks of infection. WHO can coordinate with national institutions to have early warning information, and it can issue international travel guidance.

Satellite-based risk maps of viral hemorrhagic fevers help health officials anticipate outbreaks and take timely actions for disease control and prevention.

"WHO supports development of the [viral hemorrhagic fever] forecasting efforts that improve capacities of existing models to increase the period between a forecasting alert and an outbreak onset," said Pierre Formenty, lead of the WHO team for emerging and epidemic zoonotic diseases. "The NASA risk maps are an important element towards this end."

Mapping Risks

WHO, DoD, and the USDA Agricultural Research

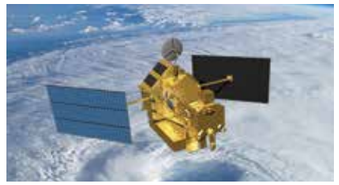
"WHO supports development of the [viral hemorrhagic fever] forecasting efforts that improve capacities of existing models to increase the period between a forecasting alert and an outbreak onset. The NASA risk maps are an important element towards this end."

Pierre Formenty, World Health Organization

Service actively participated as technical partners and end-user representatives in the project, which NASA's Jorge Pinzon led. The team analyzed multiple factors to identify patterns that correlated with outbreaks. The team used *TRMM* precipitation data, land surface temperature from *Terra* and *Aqua*, SRTM topography, and vegetation indices from *Terra*, *Aqua*, and NOAA's AVHRR satellite sensor. Web mapping services supported the display of data and maps through Google Maps, Google Earth, Virtual Earth, and other platforms. Overall, the project proved the feasibility of applying satellite observations to create risk maps, leading to routine production of the maps.

The early warnings enabled by the risk maps also aid livestock management. Officials of veterinary services can allocate resources to FAO guidance such as immunization of livestock and spreading of larvicide at breeding grounds prior to outbreaks.

"The [project's] risk map is a good alert forecasting tool of potential outbreaks [of Rift Valley fever]," said Ken Linthicum, director of the USDA Center for Medical, Agricultural, and Veterinary Entomology.



Broadening Applications

The project team expanded its epidemiological model to other regions and diseases with maps in 2012. The team assessed hantavirus with field data from Ukraine as well as Crimean–Congo hemorrhagic fever with field data from Turkey. In both cases, the project modeled the capacity dynamics of the vectors (rodents and ticks, respectively) as a function of temperature, precipitation, and vegetation. The project reported results of these and other case studies at the 2012 Health & Air Quality applications team meeting.

In 2012, the team also partnered with DoD health officials for advanced awareness of developing infectious disease threats, involving DoD's Global Emerging Infections Surveillance and Response System. DoD officials indicated that they, EU partner militaries, and the Afghan military would apply the risk maps in 2013, informing decisions from use of tick repellent to the mobilization of medical personnel.

Captain Clara Witt, U.S. Public Health Service Commissioned Corps, and senior scientist, DoD Center for Disaster and Humanitarian Assistance Medicine, said of the risk reporting of the project's maps: "It's the 'next generation' of thinking about how remote sensing technology can be used to identify and detect the pre-factors for conditions that lead to disease emergence."

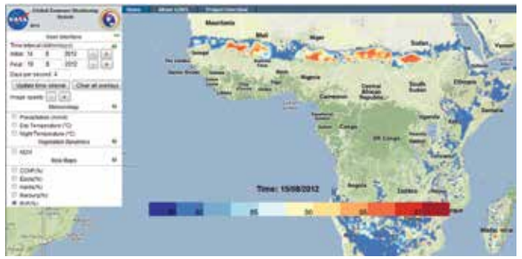
Increasing Capabilities

The maps represent new capabilities for early warnings of outbreaks, especially in areas like sub-Saharan Africa, allowing action prior to the first symptoms. WHO, FAO, and various countries' ministries of health and agriculture have begun using the risk maps and related predictions to prepare for and mitigate the effects of outbreaks.

Increasing awareness, acceptance, and use of the risk maps are key challenges. In July 2012, maps indicated risks of Rift Valley fever in portions of Africa. They showed higher-risk conditions moving west from Mali to Mauritania over the summer. The first human cases appeared in mid-September, and the Mauritanian Ministry of Health declared an outbreak in early October.

The project experienced a setback in 2012 on the Web-based hosting for the risk maps. Late in the project, a key partner organization notified NASA that due to resource reductions, it would not be able to host the maps as originally planned. Applied Sciences will seek to secure a long-term host for sustained distribution of the maps. Until then, NASA has made the risk maps available at *http://rs4gzm.org/gzm* so they remain accessible to health and veterinary officials.

Applied Sciences plans to investigate the feasibility of risk map distribution through its SERVIR venture. SERVIR will also raise awareness of the risk maps, supporting surveillance and control activities and efforts to reduce effects on humans and livestock. Among other stakeholders, the team will broaden awareness of its findings and risk maps to more potential end users through journals of zoonotic diseases such as publications of the Centers for Disease Control and Prevention.



An example of a risk map for Rift Valley fever in Africa from mid-August 2012. Warmer colors indicate higher probability of risk, based on environmental factors related to disease emergence.

Ugab River, Namibia. *Earth as Art*

FURTHERING ECOSYSTEM MANAGEMENT ON THE APPALACHIAN TRAIL

The 2,175-mile Appalachian Trail spans Springer Mountain in northern Georgia to Mount Katahdin in central Maine. Its path crosses 14 states, eight national forests, six units of the National Park System, more than 70 state parks, forests, and game management units, and 287 local jurisdictions. The trail and its surrounding 250,000 acres of protected lands harbor forests with some of the greatest biological diversity in the country. The Appalachian Trail's variations in elevation, latitude, and moisture as well as its north-south alignment represent a cross-section mega-transect of eastern U.S. forest and alpine areas for monitoring of the health of ecosystems and species that inhabit them.

An innovative decision support system applies NASA data and models to improve management of the Appalachian Trail ecosystem.

In 2013, a NASA Applied Sciences project with the National Park Service, Appalachian Trail Conservancy, U.S. Geological Survey, and U.S. Forest Service applied satellite-based Earth observations data and modeling capabilities to develop an Appalachian Trail Decision Support System (DSS). The DSS facilitates decision making to support natural resource management and biodiversity conservation. The project team integrated MODIS data and TOPS models to target selected representative environmental vital signs, such as phenology and climate change, forest health, and landscape dynamics. The system also provides a means to convey meaningful environmental information to the American public.

Monitoring Resources

The DSS allows detection of large-scale changes taking place along the trail, and for early detection of undesirable changes to the region's natural resources. For example, the invasion of ecosystems by non-native species is a major cause of biodiversity loss. A critical component of effective land management to control invasion is the identification and active protection of areas at high risk of invasion.

The DSS established a monitoring framework focusing on the current status and predicted expansion of tree-of-heaven, a problematic invasive species that was introduced to the United States for ornamental planting. Native to China, the tree has been found to suppress native species and disperse widely by releasing vast quantities of airborne seeds that colonize gaps in forest canopies. The DSS found tree-of-heaven populations in 136 locations out of more than 4,000 monitoring plots established by the U.S. Forest Service along the Appalachian Trail (mostly in the trail's central portion in Virginia, but also in smaller numbers as far south as North Carolina and as far north as New York).

Using NASA Earth observations data and climate models, the DSS predicted a 48 percent increase in suitable habitat area over the Appalachian Trail lands under the climate change scenarios. In particular, it showed a significant expansion along the northern extremes of the Appalachian Trail. Although the tree-of-heaven is currently distributed mostly in lowland areas, it could end up in high elevations to the south of its current range. This example shows that the DSS can be used to target species (whether invasive, native, rare, threatened, or endangered) for monitoring of natural resources.

Notable benefits of the DSS include quick access to information to support natural resource management and decision making; enhanced situational awareness and spatial context of the Appalachian Trail lands; improved ability to communicate the status of Appalachian Trail environment and natural resources; and improved conservation of biodiversity by habitat assessment modeling, evaluation of forest conditions, and identification of areas of concern.

By offering resource managers and citizens the assembled data and tool sets, the DSS helps gain insights into the environmental issues that affect all of us. Questions that the DSS may answer include what is the spatial distribution of rare, threatened, and endangered species, and are distributions shifting? What are the trends in the geographic extent and distribution of invasive exotic species? What is the geographic distribution of forest and high-elevation vegetation communities and how are they changing? What are the trends in land-cover and land-use change, and what are their relationships to key resources and human activities? How is climate change influencing the geographic distribution, composition, and phenology of vegetation communities along the Appalachian Trail?

"Threats to the environment of the Appalachian Trail . . . represent threats to the health of everyone downwind and downstream of the A.T., roughly one-third of the U.S. population. This makes the Trail and its protected corridor an ideal indicator for environmental conditions that directly affect more than 120 million Americans."

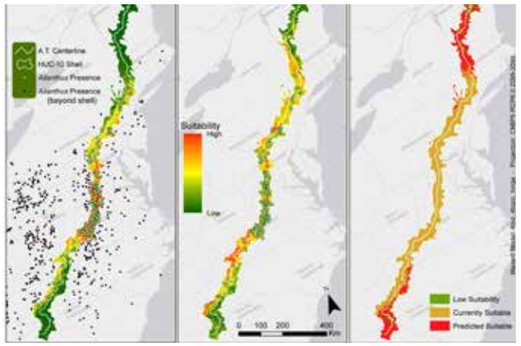
Appalachian Trail Conservancy, *The Appalachian Trail MEGA-Transect*

Engaging Users

The DSS can now be accessed on smartphones and tablets via an Appalachian Trail app. The app helps promote awareness of trail environmental monitoring by engaging professionals and citizen scientists to contribute to the understanding of the trail. The immediate involvement of citizen scientists could include information sharing from the DSS and user feedback through mobile devices for reporting their observations.

The project team successfully completed the DSS and is looking for a final transfer of the system to a hosting facility.

To learn more about the Appalachian Trail Decision Support System, visit *www.edc.uri.edu/ATMT-DSS.* To learn more about the Appalachian Trail, visit *www.appalachiantrail.org.*



The project team used habitat suitability modeling to inform natural resource management by assessing the potential extent of tree-of-heaven invasion within watersheds (HUC-10) along the Appalachian Trail. Suitability was modeled for current conditions using baseline climate data from 1950–2005, which were then substituted with climate projections for 2095–2099 to examine potential future shifts in the distribution. Areas with warm colors (orange shades) are more likely to contain suitable habitats, cool colors (green shades) are less likely, and the dots represent locations where observations of tree-of-heaven were recorded by U.S. Forest Service field surveys

ABBREVIATIONS

AVHRR: Advanced Very High Resolution Radiometer

BLM: Bureau of Land Management

BOEM: Bureau of Ocean Energy Management

CCIEA: California Current Integrated Ecosystem Assessment

COASTER: Customized Online Aggregation & Summarization Tool for Environmental Rasters

CRW: Coral Reef Watch

DoD: Department of Defense

DOE: Department of Energy

DSS: decision support system

EAGLES: Ecosystem Assessment, Geospatial analysis, and Landscape Evaluation System

EIS: environmental impact statement

EPA: Environmental Protection Agency

ESD: Earth Science Division

EU: European Union

FAO: Food and Agriculture Organization of the United Nations

FIA: Forest Inventory and Analysis

ForCaMF: Forest Carbon Management Framework

GIS: geographic information system

GOES: Geostationary Operational Environmental Satellite

I&M: Inventory and Monitoring

ICCAT: International Commission for the Conservation of Atlantic Tunas

KMS: Kenya Meteorological Service

MGET: Marine Geospatial Ecology Tools

MODIS: Moderate Resolution Imaging Spectroradiometer

MSG: Meteosat Second Generation

MTSAT: Multi-functional Transport Satellite

NASA: National Aeronautics and Space Administration

NEPT: Number of *Ephemeroptera*, *Plecoptera*, and *Tricoptera* species

NFS: National Forest Service

NMFS: National Marine Fisheries Service

NOAA: National Oceanic and Atmospheric Administration

NPP: National Polar-orbiting Partnership

NPS: National Park Service

PALMS: Park AnaLysis and Monitoring Support

PFMC: Pacific Fishery Management Council

RCMRD: Regional Centre for Mapping of Resources for Development

SDSS: Spatial Decision Support System

SRTM: Shuttle Radar Topography Mission

SST: sea surface temperature

TOPS: Terrestrial Observation and Prediction System

TRMM: Tropical Rainfall Monitoring Mission

USAID: United States Agency for International Development

USDA: United States Department of Agriculture

USFS: United States Forest Service

USFWS: United States Fish and Wildlife Service

WHO: World Health Organization

WSN: Wireless Sensor Network

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The Applied Sciences Program is part of the Earth Science Division of the NASA Science Mission Directorate.

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