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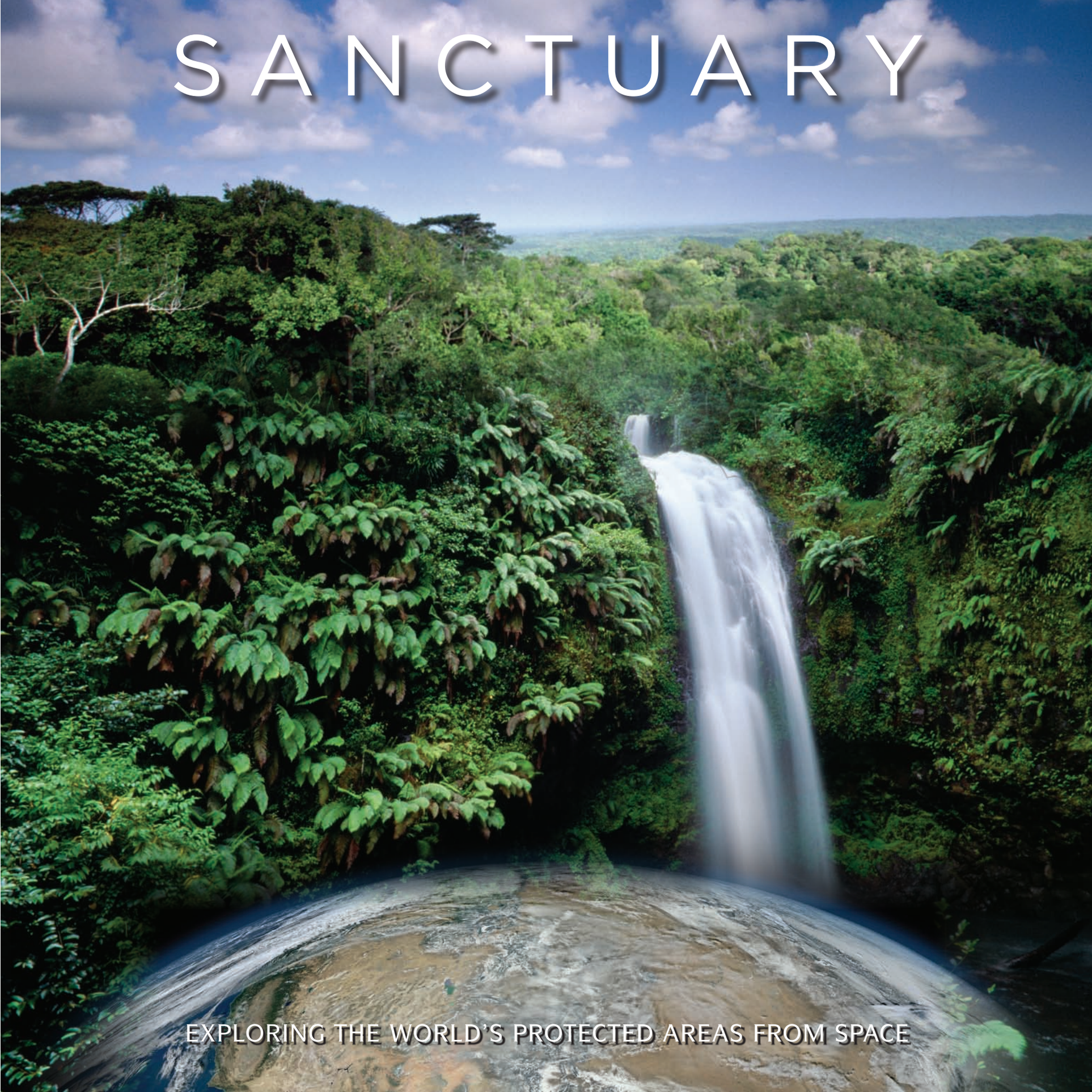
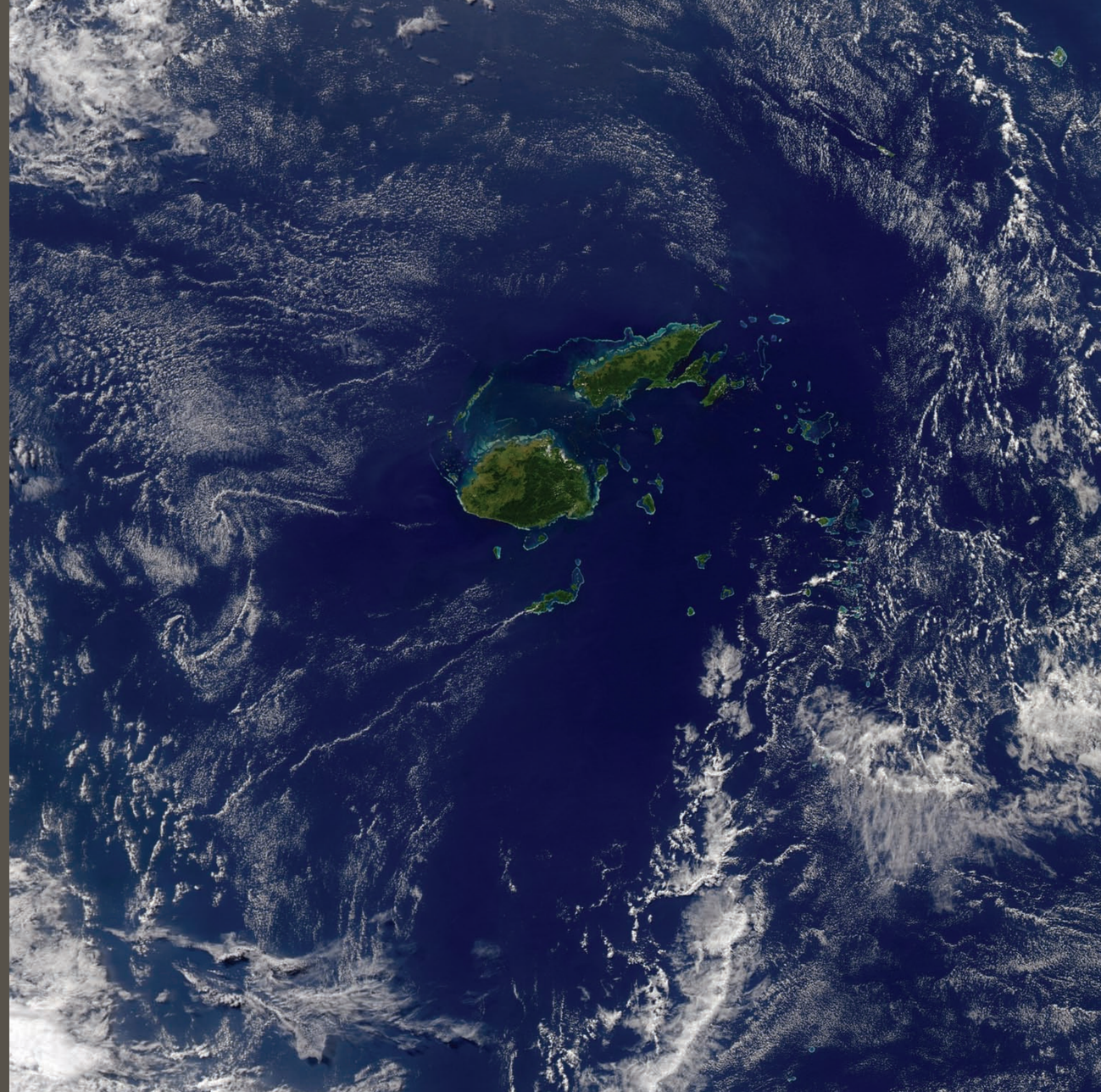


EXPLORING THE WORLD'S PROTECTED AREAS FROM SPACE



SANCTUARY

EXPLORING THE WORLD'S PROTECTED AREAS FROM SPACE

Nancy S. A. Colleton and Andrew Clark

THE INSTITUTE FOR
GLOBAL ENVIRONMENTAL
STRATEGIES (IGES)
Arlington • Virginia • USA

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1600 Wilson Blvd., Suite 600
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info@strategies.org
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Front cover: A composite image created by Susie Duckworth from the following: *Top:* Rainforest canopy in Panama. (Art Wolfe); *Middle:* Waterfall in the rainforest of Madagascar. (Art Wolfe); *Bottom:* A "Blue Marble" image created from images taken January 4, 2012, using the Visible Infrared Imaging Radiometer Suite (VIIRS) on the Suomi National Polar-orbiting Partnership satellite. (NASA/NOAA)

Back cover: A "Blue Marble" image created from multiple images taken at different times using the Moderate Resolution Imaging Spectroradiometer (MODIS) on NASA's Terra and Aqua satellites. Data from the Defense Meteorological Satellite Program, the space shuttle *Endeavor,* and the Radarsat Antarctic Mapping Project are also integrated into this image. (NASA/NOAA)

IUCN WORLD PARKS CONGRESS SYDNEY 2014

To further commemorate the IUCN World Parks Congress 2014, the logo design has been integrated throughout the book.

Left: *The Tian Shan, or "celestial mountains," stretch across the border region of Kazakhstan, Kyrgyzstan, and western China. Image acquired September 7, 2011, by Envisat's Medium Resolution Imaging Spectrometer (MERIS). (ESA)* • ***Overleaf of title page:*** *A rare cloud-free image of Fiji was captured on July 21, 2011, by the Moderate Resolution Imaging Spectroradiometer (MODIS) on NASA's Aqua satellite. It includes Viti Levu (largest island) and Vanua Levu (second largest), and the Cakaulevu Reef that shelters Vanua Levu. A series of protected marine areas ensure the reef will continue to provide food for the thousands of people who depend on it. (NASA)* • ***Title page:*** *Photo illustration of Earth from space. (Shutterstock/Hunor Focze)*

A GROVE of giant redwood or sequoias should be kept just as we keep a great and beautiful cathedral.

Theodore Roosevelt, *A Book-Lover's Holidays in the Open*, 1916

CONTENTS

Old-growth redwood grove at dusk, Humboldt State Park, Northern California, U.S.A. (Ved Photography)

FOREWORD

This year, 2014, marks an exemplary period for NASA. For the first time in more than a decade, we will launch five Earth science missions in the span of 12 months, further advancing our understanding of our home planet and the challenges we face now and into the future—climate change, extreme weather events, biodiversity loss, sea level rise, diminishing freshwater resources, and sprawling development.

In 1987, when the World Commission on Environment and Development published its groundbreaking report, *Our Common Future,* the view of Earth from space helped world leaders as well as ordinary people think differently about the planet. The authors stated, "From space, we see a small and fragile ball dominated not by human activity and edifice but by a pattern of clouds, oceans, greenery, and soils."

Now, more than 25 years later, NASA and numerous other space agency partners from around the globe have used this view from space to make incredible scientific advances in our understanding of how our planet works. As a result, we can now better gauge the impact of human activity on our environment and measure how and why our atmosphere, oceans, and land are changing.

At the time of the IUCN World Parks Congress 2014, I—as a former astronaut who has looked upon our beautiful planet from space—hope we can advance the use of space-based remote sensing and other geospatial tools to study, understand, and improve the management of the world's parks and protected areas as well as the precious biodiversity that thrives within their borders. NASA is grateful to the many colleagues and organizations contributing to this important effort and celebrating the world's parks and protected areas through *Sanctuary: Exploring the World's Protected Areas from Space*.

Charles F. Bolden, Jr.
NASA Administrator
United States

Commander Charles F. Bolden at the flight deck of space shuttle Discovery, *February 1994. (NASA)*

This "Blue Marble" image was created from images taken January 23, 2012, during six orbits of the Suomi National Polar-orbiting Partnership satellite, using the Visible Infrared Imaging Radiometer Suite (VIIRS). (NASA/NOAA)

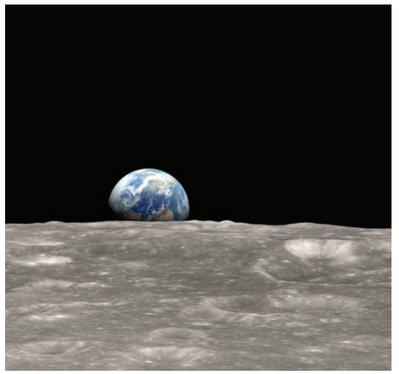
INTRODUCTION

For decades, astronauts of all nationalities have been returning to Earth profoundly changed by the experience of seeing Earth from space. This view permanently alters their perspective of what it means to share life on this small planet. This mental and spiritual shift is known informally as "The Overview Effect."

The famous Earthrise image captured by Apollo 8 astronauts 46 years ago enabled people all over the world to experience "The Overview Effect." That one image changed the way people perceived the planet and inspired the first wave of Earth-observing satellites. A view of Earth in its entirety captured, in the most simple and powerful way, the fact that we are all in this together.

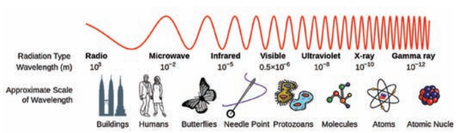
The international community is joining together to help ensure that the unity of Earth's natural ecosystems will continue to provide life-support systems for the benefit of all humankind. Designing a comprehensive planetary protection system, necessary for continuing beneficial natural processes, requires global cooperation and a shared vision. The World Parks Congress convened by the International Union for Conservation of Nature (IUCN), an event held only once every decade, is the archetype of collaborative conservation that will allow us to develop a common global vision.

Given that the conservation of Earth's natural systems and their resident biodiversity is a global challenge, Earth-observing satellites are the tools for global conservation. A space-borne perspective is empowering, leading to evidence-based decision making and quantitative evaluation of progress toward conservation goals. The integration of remotely-sensed data with on-the-ground experience and knowledge enables scientists, park managers, and policymakers to identify and conserve key areas. It also gives them the ability to determine just how well protected our protected areas really are. With increasing connectivity and availability of global data, the reach and positive impact of remote-sensing data are still at an early stage, but replete with possibility.



Left: *From space, Egmont National Park in New Zealand shows the benefits and limitations of protected areas. The park, with Mt. Taranaki at its center, was established in 1900. This isolated island of protected forest (dark green areas) is surrounded by once-forested pasturelands (light and brown green). Landsat 8 image acquired July 3, 2014. (NASA/JPL)* • ***Right:*** *Two "Earthrise" images. Top: the iconic image captured by Apollo 8 astronauts in 1968. Bottom: Recreated image in 2013. (NASA)*

Remote sensing is a natural and vital part of human activity. Every time we use our eyes to inspect our environment, we are using a form of remote sensing. Humans, however, are biologically limited to discerning color from only a small range of the electromagnetic spectrum—the visible light that corresponds to the range of peak output from the sun. Scientists and engineers have created electronic sensors that allow us to overcome our biological limitations and detect light beyond what our eyes can see.



"The electromagnetic spectrum is the range of traveling waves of energy that include gamma and x-rays, ultraviolet light, infrared radiation, microwaves, and radio waves. Human eyes are adapted to see a narrow band of this spectrum called visible light. Soils, different plant types, water, bare rock, ice, and many other types of land cover each have their reflected or emitted 'signatures' in the electromagnetic spectrum and scientists can observe and analyze these reflectances or emissions to detect changes in the land surface." (NASA/"Understanding Earth: Biodiversity")

What we have found is a remarkable bounty of information about the natural world. Every shade of color we could have imagined in the past pales in comparison to what we now know. Plants, for example, are not simply green. Different types of vegetation have their own electromagnetic signatures across a broad range of frequencies. Soils and minerals are also unique in the way they absorb or reflect radiation. Human-made sensors can even "see" heat, measuring surface temperatures without ever making physical contact. Modern technologies have opened up a new view of the natural world.

Launching these sensors aboard remote-sensing satellites paints a more vivid picture of the planet than ever before. Scientists and planners can use geospatial software to display satellite information in a way that human eyes can see—making the invisible visible to us.

The following chapters present current global conservation challenges and explore the role that information generated by remote-sensing satellites plays in effective terrestrial and marine conservation.

The Power of Perspective

Along the ephemeral Kuiseb River in the Namib Desert, live the Topnaar People. They are among the earliest indigenous groups in southern Africa.

Most Topnaars live on small-scale livestock farming and indigenous plants, nowadays often subsidized by family incomes from work in coastal towns and government pensions.

Anna Bees. (Juliane Zeidler)

The Topnaars were among the first people to be allowed to reside in a formal national park in Namibia. About 400 live along the river, at the bottom of the sand dunes, and at the border of the gravel plains of the central Namib Desert.

Anna Bees is one of these people.

Now in her mid-sixties, Anna has worked as a domestic worker at the Gobabeb Training and Research Centre for most of her life. Gobabeb is a research facility that was founded in the late 1950s by scientists of the Transvaal Museum in South Africa. Dedicated to desert and drylands research, the center has undergone more than a fifty-year journey of change and development, with Anna being a big part of it.

Juliane Zeidler, chair of the IUCN Commission on Education and Communication (CEC) recalls that when she was a young researcher at the Gobabeb Centre in 1996, her sister Sinje arrived in a small Cessna. Sinje made it possible for every Topnaar worker at the station to get into the plane and see the beautiful desert from above.

As much as the flight was intended to leave a great impression on the Topnaar workers, it also left Juliane and Sinje with a profound memory.

The sisters marveled at how Anna—who rarely ventured beyond her village—excitedly pointed out where she lived, where she harvested the endemic !Nara plant, where she would take her goats to graze, and where she would visit her children in their villages.

Juliane recalls, "It was absolutely amazing to see that someone who has never seen anything from the birds' perspective could identify the environment with such precision and confidence."

The memory of her day in the sky lives with Anna today. When Juliane and her daughter Zafari recently visited Anna at Gobabeb, she reminisced about seeing her world from above.

DigitalGlobe satellite image of the Kuiseb River, Namibia, taken on March 15, 2011, by GeoEye-1. The Kuiseb River flows from the Khomas Highlands just west of Windhoek to Walvis Bay. It is bordered on one side by some of the tallest sand dunes in the world and on the other by barren rock. Because of the high winds blowing sand into the riverbed, the river only reaches the sea while it is in flood. This image shows a western portion of the river close to the mouth of Walvis Bay. (DigitalGlobe)

Overview of Protected Areas

> *A PROTECTED AREA IS: "A clearly defined geographical space, recognised, dedicated, and managed, through legal or other effective means, to achieve the long-term conservation of nature with associated ecosystem services and cultural values."*
> IUCN, *Guidelines for Applying Protected Area Management Categories* (Dudley et al 2008)

Since the emergence of our species, a necessary instinct to respect and revere the forces of nature has endured. In contrast to that reverence is an equally necessary drive of civilization to master those forces. In our modern age, it is becoming clear that the two instincts do not have to be incompatible. Industrialization and population growth have spread humankind around the globe. As a result, more than 80 percent of the terrestrial biosphere has been directly impacted (Sanderson 2008). The remaining expanses of true wilderness have been preserved either by deliberate human action or by the serendipity of their remoteness from human contact.

As humans drive natural processes and wild places further to the margins of development, the critical link between civilization and the natural world becomes more obvious. This is where protected areas stand today, a necessary component of global civilization. There are approximately 209,000 protected areas worldwide, covering 14 percent of the planet's land and 11 percent of coastal areas, but covering only 3.6 percent of the world's oceans (UNEP/WCMC 2014). These figures include Antarctica, coastal areas of territorial seas of 0–12 nautical miles, and exclude Man in the Biosphere (MAB) reserves, proposed sites, and points with no reported data. Protected areas are as diverse as they are numerous, each protecting unique and valuable ecosystems, each governed and managed by a variety of actors, and offering different benefits to humankind.

Overview of protected areas as included in the *World Database on Protected Areas (WDPA)*

(UNEP/WCMC World Database on Protected Areas, www.protectedplanet.net)

This image shows the southwestern part of Norway's Saltfjellet-Svartisen National Park, with its diverse topography—fjords, lakes, the Northern Sea, and bedrock. At the top right is a portion of Svartisen Glacier, Scandinavia's largest ice sheet. The image was captured August 23, 2006, by the Advanced Spaceborne Thermal Emission and Reflection Radiometer (ASTER) on NASA's Terra satellite. (GSFC/METI/ERSDAC/JAROS, and the U.S./Japan ASTER Science Team)

THOUSANDS of tired, nerve-shaken, over-civilized people are beginning to find out that going to the mountains is going home; that wildness is a necessity; and that mountain parks and reservations are useful not only as fountains of timber and irrigating rivers, but as fountains of life.

John Muir, *Our National Parks,* 1901

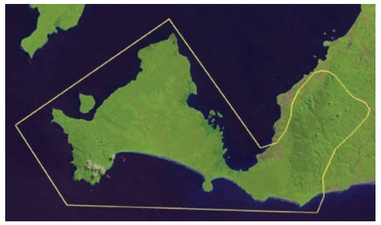
Above: *Early visitors to Mammoth Hot Springs, Yellowstone National Park, U.S.A. (U.S. National Park Service)* • ***Center top:*** *Hayden Valley, Yellowstone National Park. (U.S. National Park Service)*

A protected area is not a stand-alone entity; it is an artifact of human culture, a product of social, political, and economic forces. What people understand, they value and protect. The more people understand about the natural world, the more they value natural processes and the contributions these processes make toward sustaining our species. As a result, people have been protecting the natural world for millennia, yielding the rich tapestry of sites that we can now observe.

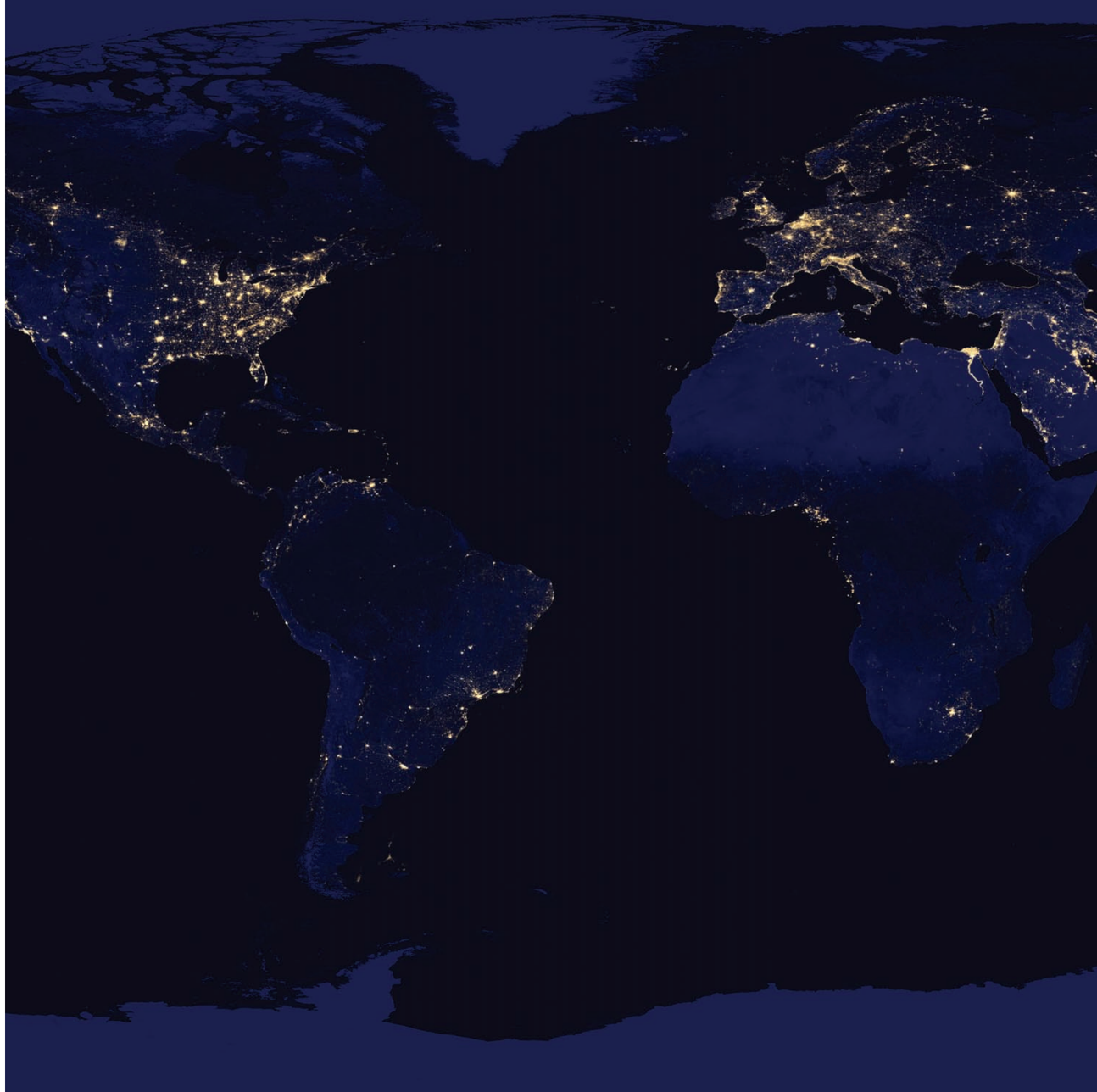
The soaring granite cliffs of Yosemite arouse deep feelings of awe in people who visit the valley, conjuring something more profound than logic would ascribe to a blank face of rock. The natural power of the place led to the early protection of the Yosemite Valley by the United States in 1864, forever preserving the natural majesty of this unique area.

The protection of this natural cathedral for the human spirit paved the way for the 1872 creation of Yellowstone National Park in the United States, encompassing and protecting a great diversity of wildlife and unique landscapes. Widely regarded as the world's first national park, Yellowstone led the way for a new wave of landscape protection by governments around the world. Nationally protected lands are only one part of the global conservation landscape today, although they are often at the heart of broader protected-area networks that include sacred natural sites, community conserved areas, indigenous peoples' territories, and privately conserved areas, many of which have roots in ancient cultures and traditions.

Protected areas are created for diverse reasons, from conserving endangered species and rare ecosystems to ensuring a reliable, sustainable food source—the latter being the reason for many marine protected areas. The diversity of protected area types and governance ensures greater resilience and more rapid adoption. Since the work done at the IUCN World Parks Congress 2003 in Durban, South Africa, and the global targets for protected lands and waters set forth by the Convention on Biological Diversity in 2010, the world community has made meaningful and measurable progress toward a protected and sustainable natural world.



Ujung Kulon National Park at the westernmost tip of Java, Indonesia. Covering about 1200 square kilometers, it contains the largest lowland rainforest in Java. Named a UNESCO World Heritage Site in 1991, the park is critical to maintaining the area's biodiversity. It protects the Javan rhinoceros (top) and 57 rare plant species. The natural color satellite image (above) was acquired July 31, 2013 by Landsat 8. (WWF/Ujung Kulon National Park; NASA)



Earth at night as seen in a composite assembled from data acquired by the Suomi NPP satellite during April and October 2012. The satellite's "day-night band" of the Visible Infrared Imaging Radiometer Suite (VIIRS) detects light in a range of wavelengths and uses filtering techniques to observe dim signals such as city lights, gas flares, auroras, wildfires, and reflected moonlight. (NASA Earth Observatory/NOAA NGDC)

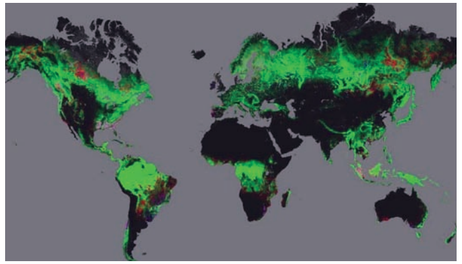
Reaching Conservation Goals

> *FOR THE FIRST TIME in my nearly 40 years of work in the National Park Service, the four U.S. land management agencies are working together, applying the newest geospatial technologies to identify and protect critical corridors of connectivity between protected areas.* Jonathan B. Jarvis, Director, U.S. National Park Service

In 1987, the UN World Commission on Environment and Development published *Our Common Future,* a report that redefined the relationship between humans and the environment as an inseparable pair. The report also established targets for a sustainable planet, with at least 12 percent of the land area to be protected for conservation. This goal has been reached, but many ecosystems and habitats are under-represented in the global protected-area network. The 2010 Convention on Biological Diversity, held in Nagoya, Japan, established a new and updated set of goals in the Strategic Plan for Biodiversity and its 20 Aichi Targets. (Nagoya is the capital of Aichi Prefecture.) Achieving just one of those targets—Target 11—will also contribute to the goals of many other Aichi Targets.

Aichi Target 11 reads: "By 2020, at least 17 per cent of terrestrial and inland water, and 10 per cent of coastal and marine areas, especially areas of particular importance for biodiversity and ecosystem services, are conserved through effectively and equitably managed, ecologically representative and well connected systems of protected areas and other effective area-based conservation measures, and integrated into the wider landscape and seascapes."

Setting numerical and quality targets for conservation has at least one major asset—the ability to monitor progress toward the overall goal. Satellite technology products such as those developed by NASA are essential to identifying, understanding, and protecting biodiversity, its patterns of distribution, and its integrity and connectivity.



A time-series analysis of 654,178 Landsat images shows forest extent and change, 2000–2012. Red = forest loss 2000–2012, blue = forest gain 2000–2012, pink = loss and gain, green = forest extent. (Hansen/UMD/Google/USGS/NASA)

The high biodiversity of Pearl and Hermes Atoll in Papahanaumokuakea Marine National Monument, Hawaii, U.S.A. (NOAA)

Top: *Pronghorn fording the Green River in western Wyoming, U.S.A, during their annual spring migration north to Grand Teton National Park. (Joe Riis)* • ***Middle:*** *A granite inselberg (isolated mountain) rises from the undulating expanse of rainforest in Tumucumaque Mountains National Park, Brazil. (WWF/Zig Koch)* • ***Above:*** *Mount Roraima rises from the Guiana Shield at the triple border point of Venezuela, Brazil, and Guyana. (Shutterstock/Harald Toepfer)*

Pronghorn provide an example of why connectivity in U.S. national parks is so crucial. The elegant pronghorn (not a true antelope) migrate the longest distance of any terrestrial animal in the United States—more than 350 miles roundtrip between Grand Teton National Park and land south of Pinedale, Wyoming. They have followed this route for the last 6,000 years. As the land becomes more developed, their migration is being disrupted. Without intervention, the future of the pronghorn population in the park looks grim. The biggest challenge in intervening in this migration pattern is the massive amount of land it covers. The migratory route weaves through private land, a national forest, the national park, and other public land. Protecting this connectivity will help migratory species such as the pronghorn successfully complete their migration.

The rapid expansion of protection for sensitive ecosystems has necessitated creating protected areas of immense scope. The Tumucumaque Mountains National Park in Brazil and the Papahanaumokuakea Marine National Monument in Hawaii, U.S.A., are recent significant contributions toward achieving these ambitious goals.

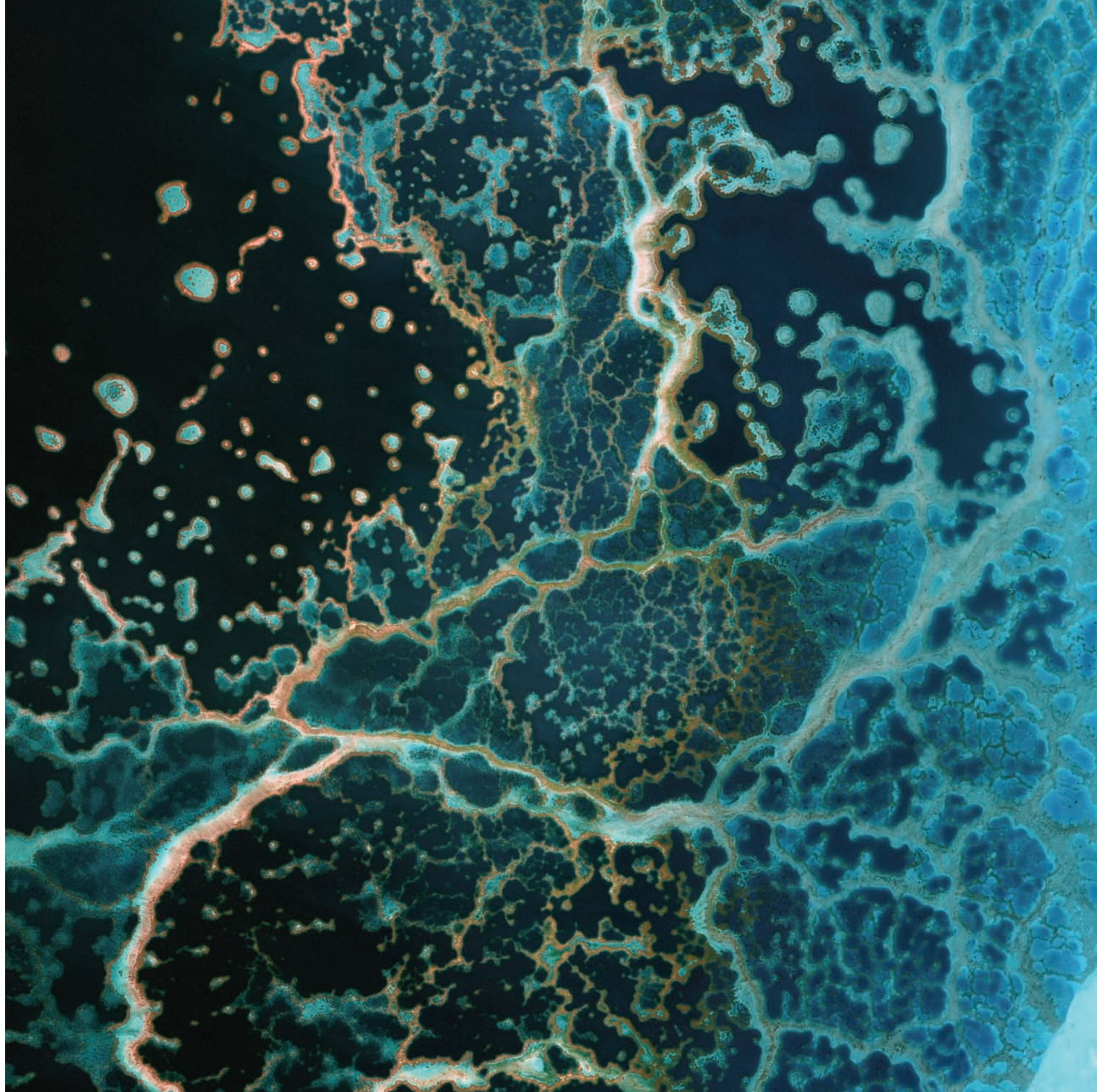
Perched atop the ancient core of the South American continent sprawls the greatest expanse of undisturbed tropical forest left in the world. Here the forests still feel ancient, inhabited by giant armadillos, anteaters, and giant river otters. The rugged elevation of the Guiana Shield has nurtured and protected this unique ecoregion and its evolution. The rivers are fraught with waterfalls, making passage treacherous. Massive rock outcroppings, called tepuis, erupt from the surrounding landscape and give the region its name. In the local Apalaí and Wayana languages, Tumucumaque means “the rock at the top of the mountain” (WWF).

This remote forest has so far escaped human pressure. In 2002 Brazil established Tumucumaque Mountains National Park, the largest tropical forest national park in the world. Protecting such large areas of high biodiversity is a critical element in achieving Aichi Target 11, both in marine and terrestrial systems.

Grand Teton National Park, U.S.A. This visualization combines imagery from the Landsat 7 Enhanced Thematic Mapper Plus (ETM+) instrument with elevation data from the Shuttle Radar Topography Mission (SRTM) and the U.S. Geological Survey's Digital Terrain Elevation Data (DTED). (NASA/GSFC)

Halfway between Asia and the west coast of North America, a handful of emerald islands lay scattered across the deep blue waters of the Pacific Ocean. Tropical palms sway in the cooling trade winds. More beauty lies beneath the waves. Submerged coral reefs teeming with life fringe the outlines of each island, the now peaceful remains of extinct volcanoes. In 2006 the United States officially recognized the tremendous ecological value of the region by protecting 140,000 square miles (360,000 km^2) of ocean surrounding the Northwestern Hawaiian Islands in Papahanaumokuakea Marine National Monument.

Designating protection for these ocean areas is just a first step toward conservation. Enforcing protection is a challenge itself, and is essential to reaching conservation goals and replenishing fish stocks in surrounding areas. Satellite technologies offer a potential source of enforcement: they can locate ships at sea, and thus could allow managers of remote areas to monitor fishing vessels in their resource areas. Through innovative enforcement, these mega parks will serve as the foundation for future protected-area networks. Satellite remote sensing will be the key to their success.



The WorldView-2 satellite image of Pearl and Hermes Atoll, Papahanaumokuakea Marine National Monument, Hawaii, U.S.A. September 2011. (DigitalGlobe)

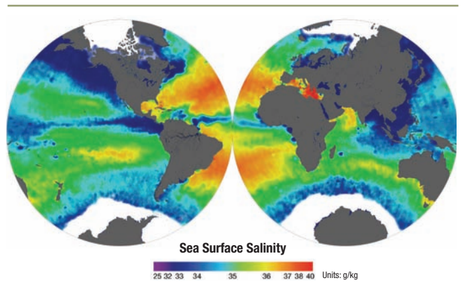
Responding to Climate Change

> *CLIMATE CHANGE is the single greatest threat to a sustainable future. But, at the same time, addressing the climate challenge presents a golden opportunity to promote prosperity, security, and a brighter future for all.*
>
> Ban Ki-moon, United Nations Secretary-General, Climate Leaders Summit, April 11, 2014

Climate is a complex, global system that requires an equally sophisticated and worldwide monitoring network to disentangle its causes and effects. Every component of the Earth system impacts climate and vice versa. As the climate shifts, so will habitats and species populations, and the human communities that depend on them. As weather patterns change, some areas will become drier while others will become wetter. Either way, today's ecosystems may not be those of tomorrow.

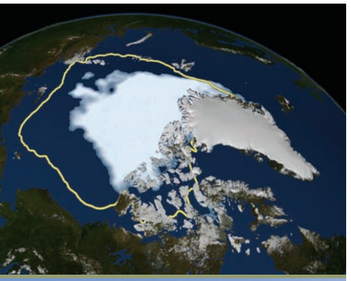
To better understand the changes taking place across the globe and to better predict change and derive adaptation strategies, NASA and numerous other space agencies and science organizations are contributing to a multinational Earth-observing system that monitors Earth's vital signs. The data gathered from space, in the air, on the ground, and in the ocean help inform advanced models used to identify and predict change. The conservation community can use this information to develop adaptation strategies and prepare for impacts such as disrupted migrations or increased wildfires, floods, and drought.

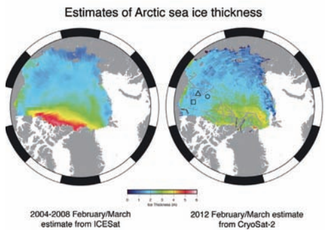
By integrating climate model forecasts with an understanding of species habitat ranges gained from ecological models and local knowledge, scientists can estimate where species may live in the future, where today's protected areas might suffer stress, or where future protected areas may need to be sited.



Salinity is key to studying the water cycle and ocean circulation, both of which are related to climate. This map was developed with October 2012 data from Aquarius/SAC-D, which is a joint U.S.-Argentina mission. (NASA Goddard Space Flight Center)

Sheldon Glacier and Ryder Bay, Antarctica, with Mount Barre in the background. (British Antarctic Survey)





Top: *Arctic sea ice in September 2012 when it reached the smallest extent ever recorded during three decades of satellite measurements. The yellow outline shows average sea ice minimum 1979–2010. (NASA/Goddard Space Flight Center Scientific Visualization Studio)* • ***Middle:*** *Emperor penguins in Antarctica. (iStockphoto/© Coldimages)* • ***Above:*** *ICESat and CryoSat-2 images show ice cover thickness diminishing over the Arctic Ocean. (American Geophysical Union)*

Far right: *Top: Camel train in the desert of Tadrart Acacus, Algeria. (IUCN Photo Library/© Catherine Gras)* • *Below: Black-footed rock wallaby in the Ningaloo Coast World Heritage Area, Australia. (IUCN/© Rainer von Brandis)*

Consider the changes taking place in Earth's polar regions. The polar ice caps have melted faster in the last 20 years than in the last 10,000. This was confirmed by the Gravity Recovery and Climate Experiment (GRACE), a joint partnership between NASA and the German Aerospace Center, DLR. Using data from GRACE satellites, researchers measured ice loss in all of Earth's land ice between 2003 and 2010, with particular emphasis on glaciers and ice caps outside of Greenland and Antarctica. The total global ice mass lost during the study period was about 4.3 trillion tons (1,000 cubic miles), adding about 0.5 inches (12 millimeters) to global sea level (NASA 2012).

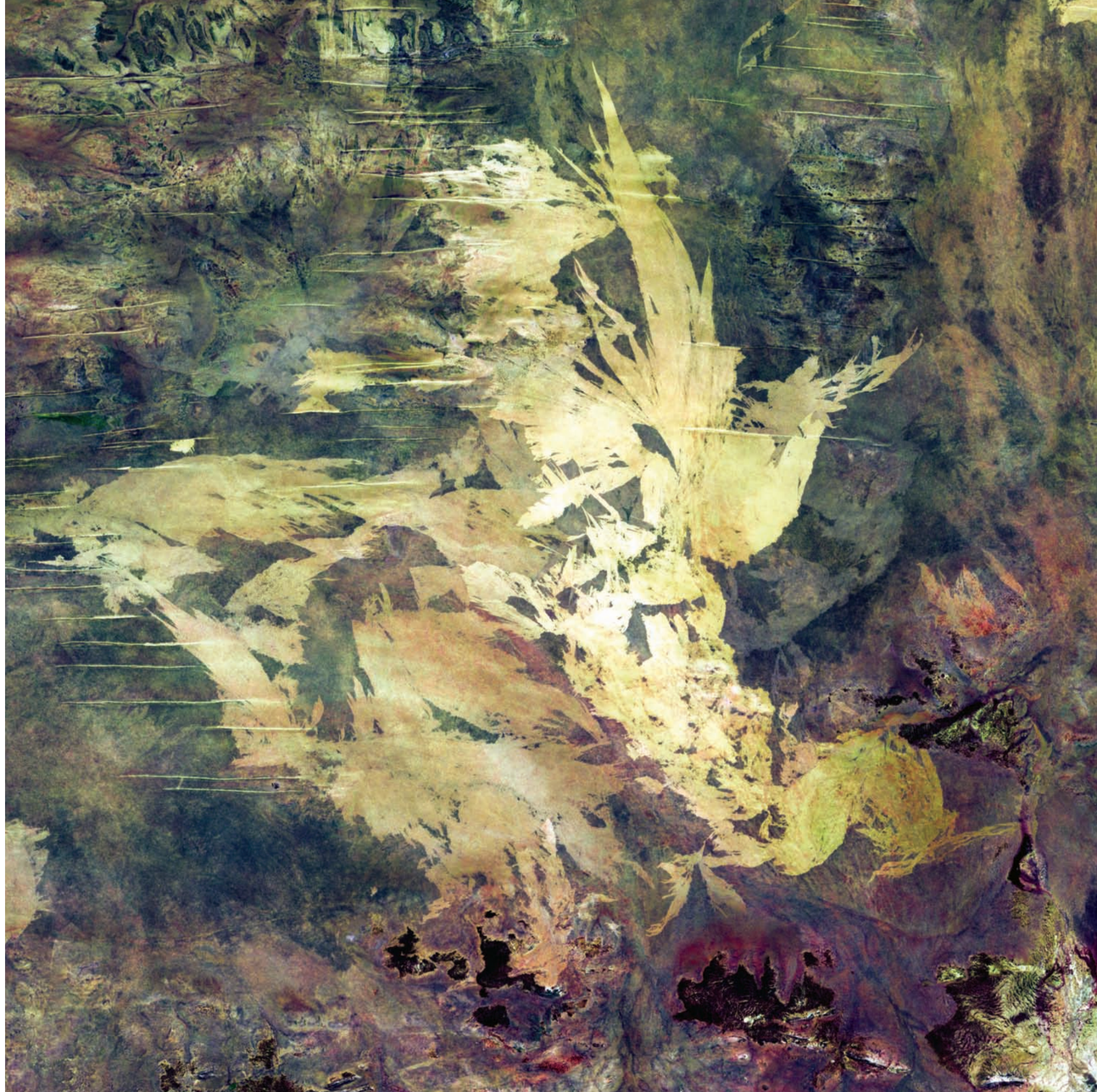
The consequences of this extensive melting are painfully clear to those who live nearby. Ringed by the black gravel beaches of Barter Island, Alaska, U.S.A., the village of Kaktovik is the only settlement within the Arctic National Wildlife Refuge. Standing on the shore, an Iñupiaq hunter peers through his binoculars, scanning the horizon for the plumes of steam that would reveal a pod of bowhead whales. But in recent years, the pack ice has been receding more than 100 miles from the shore, putting any migrating pods well beyond the range of a traditional umiaq or seal skin canoe. But this hunter isn't the only one with eyes on the Arctic ice pack. The effects of increasing Arctic ice melt are felt far beyond the shorelines of the Arctic.

With newly opened seas, governments and corporations are jockeying for position to benefit from this climatic change, which is unlocking potential mineral wealth. This will increase human pressure on critical summer breeding and feeding grounds for Arctic animals, which are increasingly pressured by a radically changing environment. Already, boat and whale traffic has increased in the highly productive Chukchi Sea (Clarke 2013). The opening of the Arctic Ocean presents the conservation community with a key opportunity to apply proven policies by creating new marine protected areas.

The U.S. and other nations have put forward proposals to the Commission for the Conservation of Antarctic Marine Living Resources (CCAMLR) to establish a marine protected area (MPA) in the Ross Sea region of the Southern Ocean. As reported by the U.S. State Department, this proposed MPA would cover approximately 1.8 million square kilometers (700,000 square miles) and would protect animals such as Emperor penguins, Weddell seals, and killer whales.

While polar regions are increasingly facing climatic pressures, climate change is also affecting the world's deserts. Already, drylands are a dominant feature comprising more than 45 percent of Earth's land surface (UNEP 1997). They are often predicted to be among the most responsive ecosystems to global climatic change because even small changes in temperature or precipitation will impact plants and animals (Whitford 2002). Warming temperatures and more extreme climatic events are likely to spread drought and desertification, which will increase the challenges for communities struggling to make a living in dryland environments (Davies et al 2012).

Far from the abundance of water found in the polar north, the parched red soil of the Australian Outback is a lingering reminder of the fragile balance of life in desert regions. Due to geographical conditions, Australia is the most arid of the inhabited continents. The changing climate is expected to leave Australia even warmer and drier. Owing to this susceptibility to climate change, Australia has become a world leader in climate change preparation. Using the latest climate models and informed by satellite remote-sensing data, Australian scientists have been able to anticipate the shifting of habitats and are already planning for the protected areas of the future (Reside et al 2013).



Australia's Great Sandy Desert as seen by satellite, showing the only sand dunes in a desert of scrub and rock. Acquired August 22, 2000, by the Enhanced Thematic Mapper plus (ETM+) on Landsat 7. (USGS EROS Data Center)

Improving Health and Well-Being

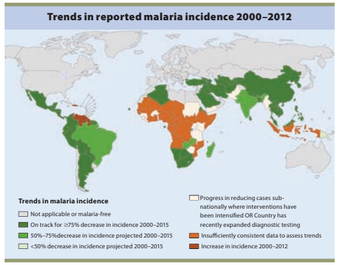
> *KNOWLEDGE AND APPRECIATION of the critical link between parks and protected areas and human physical, mental, and spiritual health can help people cope in an increasingly challenging and stressful world.*
> Kathy MacKinnon, Deputy Chair, IUCN World Commission on Protected Areas

Humans are deeply connected to the natural processes of Earth. From the air we breathe, to the water we drink, to the soil that grows our food, human health is a function of environmental health. The reverse is also true. According to the World Health Organization, diminished human health and well-being tends to increase the immediate dependence on ecosystem services. A sustainable world requires healthy people and a healthy environment, with each supporting the other. One of the more subtle services offered by a healthy ecosystem is disease regulation.

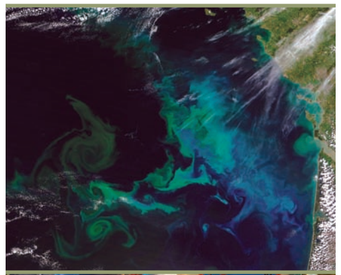
A breeze drifts lazily through the open doors and windows, barely stirring the humid air. Riding in on the breeze are dozens of mosquitoes, searching for a meal of protein-rich blood. Mosquitoes drain human health worldwide by serving as the vectors of infectious diseases like malaria, transmitting the deadly *Plasmodium* parasites to the circulatory systems of their victims. But no human buffet is here; the villagers are sleeping peacefully in their hammocks, protected by insecticide-treated mosquito netting.

A mother in Mali tucks in her triplets beneath the safety of mosquito nets. (Justin Douglass, World Vision)

Using satellite data acquired by Envisat's MERIS instrument, scientists can identify and monitor red tides like this one spreading from the Gulf of Oman into the Persian Gulf in November 2008. (C-wams Project, Planetek Hellas/ESA)



Malaria is decreasing in over half its range. Earth-observation assists this effort by identifying habitats where people and malaria overlap. (World Health Organization)



***Top:** Algal blooms in the Bay of Biscay, 2013, as observed by MODIS (Moderate Resolution Imaging Spectroradiometer) on the Terra satellite. (NASA)* • ***Above:** Fresh seafood on sale at the Mercado Central in Santiago, Chile. (iStockphoto)*

***Top right:** A red tide, or HAB (harmful algal bloom), rolls ashore in Puget Sound, Washington, U.S.A. (SuperStock/Don Paulson)*

The netting isn't just a barrier against insects looking for a meal; it's a guardian of the present and future health and well-being of this village, protecting the young children who are most susceptible to the parasite's deadly course. Ninety percent of all malaria deaths are children aged five or younger. Scientific research has been able to help focus critical preventive efforts where they are most needed, conserving valuable resources in already poverty-stricken regions, while at the same time ensuring that the communities are protected against mosquito-borne disease. Associated with poverty, malaria is a double threat to developing nations, hindering economic development and public health with devastating consequences. In 2012, the disease took an estimated 627,000 lives (World Health Organization 2014), and the majority of victims were children.

Earth-observation is playing a greater role in this health improvement effort. Satellites provide a rapid and wide-ranging characterization of the environment such as temperature and rainfall, identifying areas most conducive for mosquito breeding and where human and mosquito habitats may overlap. This allows the limited resources available to combat this disease to be spent where they can be most effective.

Perhaps most importantly, the way humans manage their own habitats can influence the level of risk of contracting malaria. Deforestation in support of agriculture creates new habitat for mosquito larvae, with farmers especially susceptible as they move into new forest clearings. A variety of studies have shown that village-level forest conservation reduces disease risk (Stefani 2013). For example, Indonesia's Ruteng Park on the island of Flores confers a reduction of childhood malaria on the surrounding communities (Pattanayak and Yasuoka 2005)—a clear example of how protecting healthy ecosystems can protect human health.

Human health around the world is also impacted by food-borne illness through the ingestion of environmental toxins. Shellfish that are normally safe to eat can become lethal when harvested following certain algal blooms. Red tide is the common name for harmful algal blooms (HABs). HABs are potentially dangerous to people who consume shellfish and also to beach goers, boaters, and coastal residents exposed to the resulting airborne toxins.

With seafood comprising a major component of the global food supply and an increasing interest in recreational activities at the seashore, a system to predict and avoid these dangerous algal blooms is imperative. Many developed countries already regulate the harvesting of seafood during bloom periods and close tourism to affected areas, thereby protecting the public from consuming unsafe seafood and being exposed to airborne toxins.

Space-based sensors are capable of measuring subtle variations in the water color and temperature preceding HABs. National Oceanic and Atmospheric Administration (NOAA) scientists have now applied these technologies to forecast the occurrence and location of a wide variety of different species of HABs. The goal is to give communities advance warning so they can adequately plan for and manage the adverse environmental and health effects associated with these 'red-tide' events.

The Democratic Republic of Congo, which has one of the world's highest incidences of malaria, is shown in this image acquired by the French SPOT-4 in June 2011. Lighter green areas are deforested, and darker green areas are dense vegetation. (ESA)

Supporting Human Life

> *LOCAL PEOPLE perceive the Sundarbans to be central for their existence.* Iqbal Hussain, WildTeam, Bangladesh

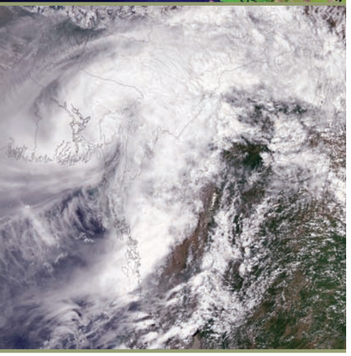
The conservation movement has come a long way since the earliest days of exclusionary protection. Conservation is truly about people—changing thoughts, behaviors, and lives for the better. Protected areas are a natural solution for improving human circumstances. Providing food and water security, sustainable income, and protection from natural disasters are just some of the contributions made by protected areas to support human life. Mangroves, for example, provide multiple benefits.

At first glance, a mangrove forest is a dark and foreboding place, easily playing into the historically adversarial relationship between civilization and nature. The perspective on this relationship is shifting, due in part to viewing these vital areas from space and better understanding their critical role as fish and prawn nurseries. Perhaps the prime example of this nexus of civilized and natural landscapes lies on the coast of the Bay of Bengal—the sprawling Sundarbans mangroves.

Spanning from West Bengal, India, into Bangladesh, a mosaic of protected areas covers 10,000 square kilometers of forest, wetlands, and waterways (UNESCO 2014). This productive habitat supports a great diversity of IUCN red-listed species, and is one of the last key strongholds of the Bengal tiger. The ecosystem here is so unique and so vibrant that it has been designated as a UNESCO World Heritage Site, a national park, a biosphere reserve, a tiger reserve, and a forest reserve.

An endangered Bengal tiger swimming in the Sundarbans. This tiger is the national animal of both India and Bangladesh. (Mark Tegenfeldt)

This March 2014 mosaic from Landsat 8 shows the breadth of Sundarbans mangroves (bright green) along the Bay of Bengal. Encroaching development and agricultural clearing are pink; agricultural fields (perhaps rice paddies and shrimp farms) are dark blue. (NASA/JPL)



Top: *Matang Forest Reserve, Malaysia, is a sustainably managed mangrove forest. In this Landsat 8 image, acquired February 27, 2014, recently harvested areas are deep pink, regrowing forest is shades of green, cleared or developed areas are pink. (NASA/JPL)* • ***Above:*** *In May 2013, clouds from tropical cyclone Mahasen stretched across Bangladesh to northeastern India (outlined areas). The Moderate Resolution Imaging Spectroradiometer (MODIS) on NASA's Aqua satellite captured this natural-color image. (NASA)* • ***Top center:*** *Working with fish nets in the Sundarbans. (WildTeam/Samiul Mohsanin)*

The system that sustains the life of the mangroves also sustains the lives of millions of people. Monsoon rains and glacial melt erode the mighty Himalaya, supplying great quantities of water that run down to the Bay of Bengal, carrying sediment and fresh minerals from the mountains. Along the length of the river, soil is enriched by these nutrients, which benefits agriculture. Where the river meets the ocean, the river drops its sediment, creating the largest river delta on Earth. This rich soil and reliable source of fresh water supports the largest and most biodiverse swath of tidal mangrove forest on the planet.

Upstream of the Sundarbans lies a seasonal floodplain with fertile soil that supports one of the world's most populous regions. The millions of people living here have long relied on the forest for food, fuel, and fodder, and their pressures on the forest continue to grow. The fates of the people and the land are intertwined. In recent years, satellites have tracked the course of several typhoons directly across the heart of the Sundarbans into India and Bangladesh. Without the tremendous energy-absorbing and land-stabilizing effects of the forest, the impacts inland could have been even more severe.

Fisheries rooted both inside and outside of the Sundarbans protected areas are equally important to addressing the development challenges faced by the surrounding communities. As an inexpensive protein, fish are a major component of the Bangladeshi diet. Nearly 40 percent of the fish consumed is raised aquaculturally (Belton 2011). These farm-raised species are considerably less expensive than their commercially caught counterparts, and they are key to alleviating hunger and poverty (Sen 2010). Commercial fisheries also provide jobs and much needed income for thousands. Both aquaculture and wild-caught fisheries are essential to the local diet. Dozens of commercial and subsistence fish species spend part of their lifecycle protected by the roots of the mangroves. Both the farmers and the forest now face the prospects of a changing climate and rising sea level (Chand 2012, Agrawala et al 2003).

With Sundarbans fisheries being so critical to the local food supply, the fisheries are under considerable pressure. Already, near-shore fisheries are showing reduced rates of return for time and effort, most severely impacting artisanal and subsistence fishermen. Satellites are critical to the solution. The Indian Space Research Organization uses satellite-derived data over a wide swath of ocean to create weekly reports identifying areas of high fish density. These efforts have improved the efficiency of small-scale offshore fishing (Choudhury et al 2007), which helps protect the Sundarbans.

Millions of people are connected to and through the forest in ways as intricately interwoven as the channels of the delta. The challenges facing parks and people may seem oppositional, but the solution may be complementary. Despite changes in sea level and sedimentation, mangroves have responded and rebounded by shifting their territories and colonizing new land and sea (McIvor et al 2013). This resiliency and adaptability has benefited many species that live within the seemingly impenetrable forest. Mangroves—a natural solution—have been their own best defense. They may also be one of our best defenses, protecting coastal communities from severe storms and aiding human resiliency and adaptability.

As we have seen in the Sundarbans, mangroves have great potential to serve as a natural solution to the human development challenge. Another well-managed mangrove forest is the Matang Forest Reserve in Malaysia, which yields over US$20.5 million worth of sustainable products yearly (UNEP 2014). But around the world, mangroves are rapidly being cleared for aquaculture farms, contributing to about 52 percent of mangrove loss worldwide (Ellison 2008, as cited in UNEP 2014). These high-density monoculture ponds trade the long-term stability and resiliency of the forest for a prolific short-term food supply and attendant profit. Unfortunately, the high-intensity methods often used in aquaculture lead to pervasive pollution and disease, ultimately forcing the ponds to be abandoned.

One of the many streams that flow through and around the mangrove forest, Andamans Island, India. (iStockphoto)

Reconciling Development Challenges

> *THE "ENVIRONMENT" is where we all live; and "development" is what we all do in attempting to improve our lot within that abode. The two are inseparable.* Our Common Future

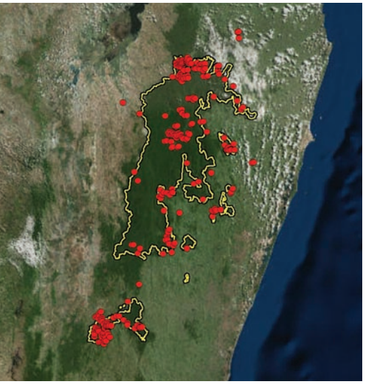
More than ever before, humans are redefining the ecosystems of the world. Every action people take has an impact and creates challenges for managing a sustainable environment that reliably functions in a way amenable to human life. Reconciling these challenges takes planning and deliberate efforts.

Hooves thunder over the savannah, throwing up clouds of dust. Grunts, groans, and indignant snorts merge into cacophonous protest, as over a million wildebeest, zebras, and gazelle trek across the arid ground in search of water and fresh forage. This annual migration takes them 500 miles from the Masai Mara National Reserve in Kenya to the Serengeti National Park in Tanzania and back again. But this iconic great migration and several others are at risk.

Throughout East Africa, wildebeest populations are being pushed into decline as their migratory routes have been divided by fences and converted to agriculture. A proposed road through the Mara would link the coast to the interior, but would increase pressure on the migration by disturbing patterns. This story is not uncommon; habitat losses to human development activities pose the greatest threat to biodiversity around the world. In East Africa, an array of community mechanisms and financial incentives is already emerging to help protect these wildebeest migration corridors.

Wildebeest (tiny black dots) spread out over the land as they cross from Serengeti National Park, Tanzania, into Masai Mara National Reserve, Kenya, on their annual migration. Taken by GeoEye-1, August 2009. (DigitalGlobe)

During their migration, wildebeest gather as they prepare to cross the Mara River in Kenya. (Shara Dillon)



Top: *NASA satellites provided data to create this October 2013 image of fires in the Corridor Ankeniheny-Zahamena (CAZ), a protected area in eastern Madagascar. The CAZ is threatened by slash-and-burn agriculture and illegal logging. (Conservation International Firecast)*

Above: *These two composite Landsat images of the same area in Borneo were taken 23 years apart: in 1990 (top) and 2013 (below). Jungle is dark green, cultivated vegetation (like palm oil) is light green, smoke is blue, and bare fields are reds and pinks. (NASA/JPL)*

UNEP documents some of these new means of conservation in its report, *Emerging Environmental Issues 2013:*

> *For example, in the Mara, eight wildlife conservancies have been formed, which offer land lease payments of US$25–40 per hectare (ha) per year to landowners. These schemes, financed by ecotourism operators, aim to keep land open for wildlife and provide landowners with a regular income stream. They now cover over 90,000 ha, securing vital migratory corridors and dispersal areas for wildebeest from both the Serengeti and the Loita Plains. . . . In another approach, environmental easements are being applied to protect privately owned land adjacent to Nairobi National Park, including placing it under park management. Also in this ecosystem, the community and other stakeholders have recently developed the first community driven land use master plan to sustainably manage wildlife dispersal areas alongside livestock grazing, settlements and other land uses in the ecosystem.*

The motivation for preservation is clear because the migration is the major source of hard currency. In Tanzania in 2008, safari tourism brought in an estimated US$550 million, nearly half of all tourism income for the country (Mitchell 2009 as cited in UNEP 2014). Wildebeest are not the only animals being impacted by land-use change.

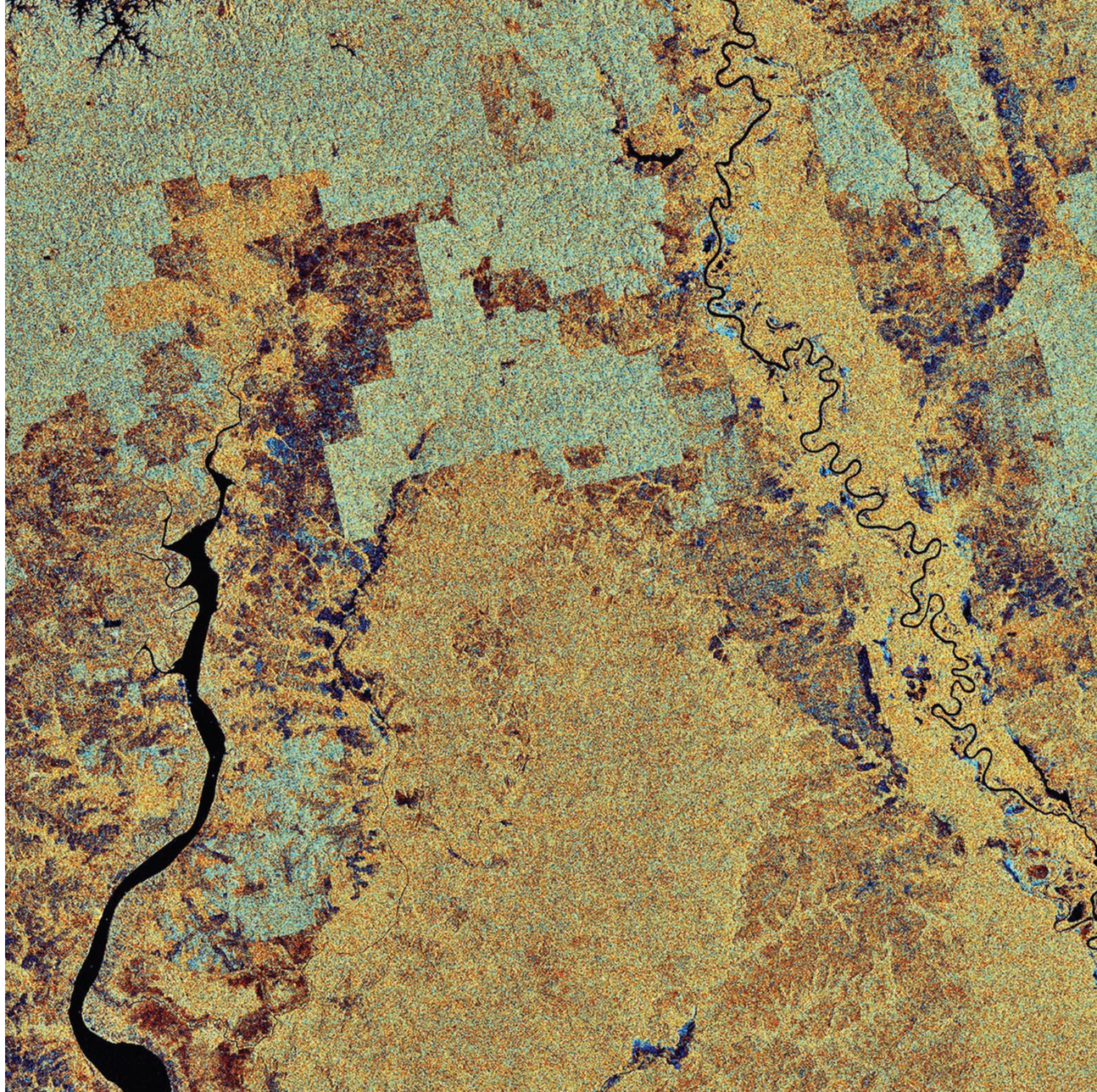
Far removed from the savannah, acrid smoke fills the humid tropic air along with the rumble of a diesel engine. A dying fire dances, crackling over charred timber. Today this scene is common in the rainforests of Borneo, far more common than that of orangutans cavorting through the trees. Even the forest within the borders of the Tanjung-Puting National Park, renowned for its orangutans, has not escaped the pressures of development.

The dramatic increase in global demand for palm oil has spurred a rapid expansion in the size and number of oil palm plantations in tropical rainforests. Offering a greater yield of high-value oil per hectare than any other food-oil crop makes the oil palm an incredibly valuable crop. Unfortunately, palm oil production comes at a great cost when plantations replace rainforest.

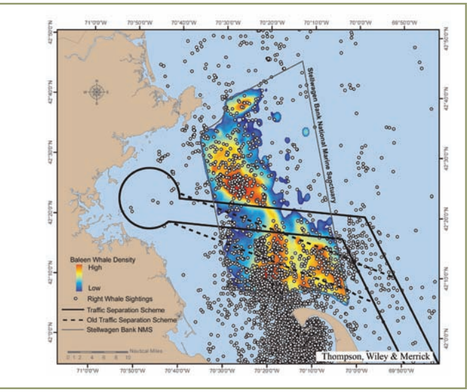
Lemurs, like this white sifaka, are endemic to Madagascar. (Ved Photography)

Satellite monitoring plays a key role in tracking and documenting these dramatic changes and the plumes of smoke generated by the burning forest. This narrative of images has contributed greatly to global awareness of the extent and severity of this problem. Increased global awareness has advanced the dialogue between business and conservationists and many businesses are pledging to use oil that does not come at the cost of primary forest.

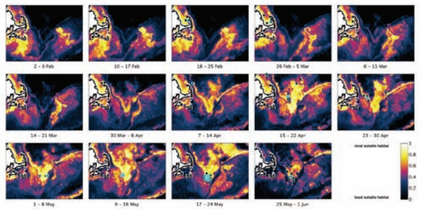
The human relationship with fire is a complex one that is both creative and destructive. Around the world, fire is used to clear land and release nutrients for agriculture. It is often the quickest and easiest way for subsistence farmers to increase crop yields, but it depends on a continued supply of new land. The view from space shows the extent and impact of these small-scale intentional fires. NASA's Moderate Resolution Imaging Spectroradiometer (MODIS) instrument aboard the Terra and Aqua satellites is being used to help detect fires anywhere on Earth as small as one-tenth of a hectare. Early detection of fires, whether deliberate or wild, allows protected-area managers to respond quickly and effectively. Programs already exist to immediately alert decision makers to fires in areas of interest through automatic email alerts. These services are a boon to managers in Madagascar, who have found realtime information to be essential in protecting the island's remaining biodiversity.



This satellite image of Borneo's Kalimantan region, captured April 2009 by Envisat's Advanced Synthetic Aperture Radar (ASAR), shows the extent of deforestation from the spread of agriculture such as palm oil plantations (green squares). (ESA)



Predictions of weekly right whale habitat



Top: *Over two decades of surface observation was augmented by satellite data to map shipping routes that avoid whales. (NOAA)*

Above: *This series of images combine predictions and actual observations of right whales during 8-day periods in 2002. Squares = whale; black = low habitat suitability, white = high habitat suitability. (Pendleton)*

Direct human conversion of wild lands into agricultural lands is one of the most visible and extensive development challenges in the world today, but human activity also impacts the natural world in less obvious ways. Nearly half the world's population of the endangered North Atlantic right whale travels through Stellwagen Bank National Marine Sanctuary to winter feeding grounds in Cape Cod Bay, near the busy shipping port of Boston, Massachusetts, U.S.A. Collisions between shipping vessels and the large whales had become increasingly common. An extensive study identified regions in the sanctuary where whales were most commonly seen. In response, the shipping lanes were rerouted through an area of the sanctuary less used by whales. This minor adjustment has dramatically reduced whale strikes without inhibiting the flow of goods (Wiley et al 2013).

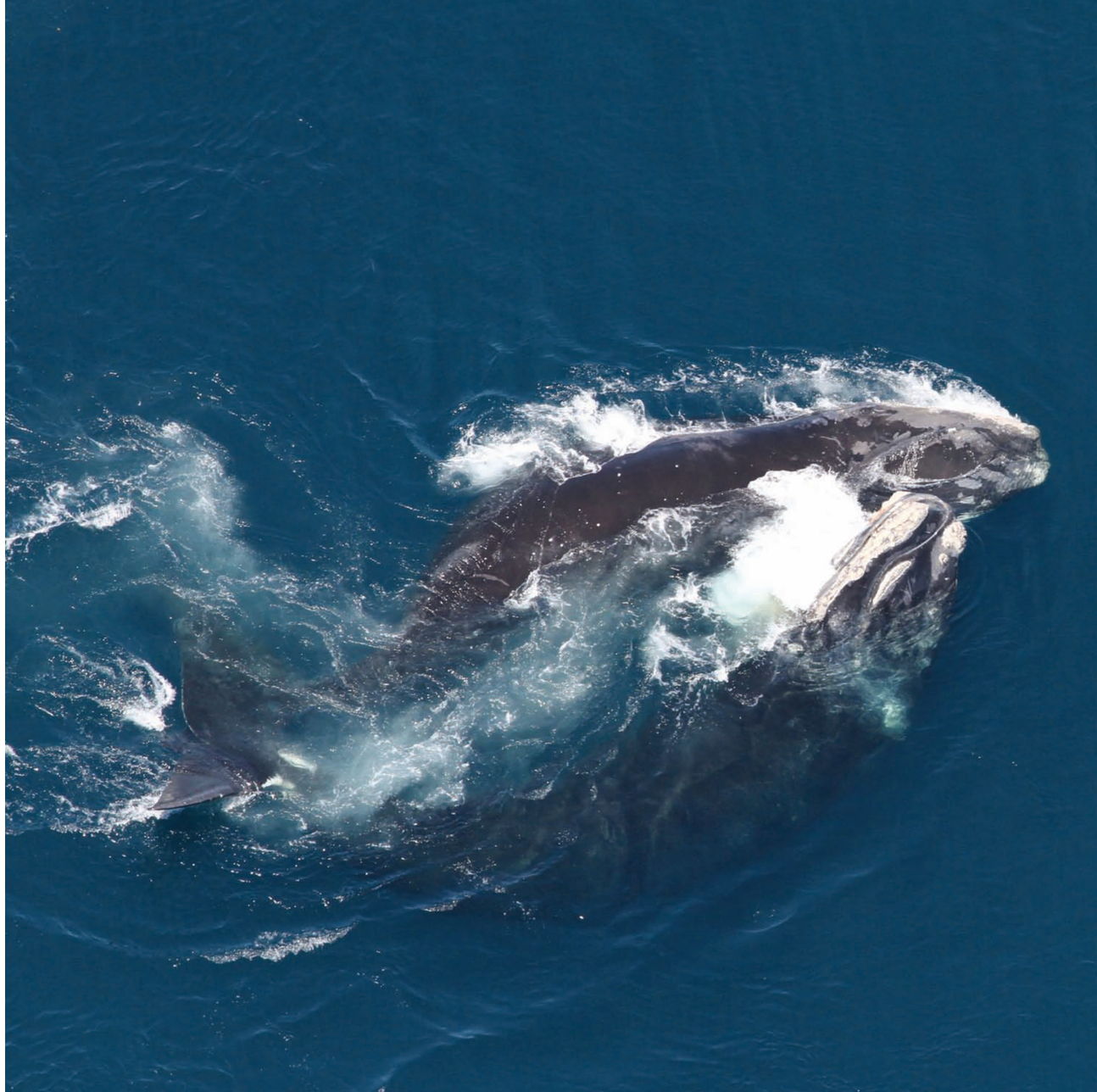
The Stellwagen Bank study used current satellite data and whale sightings that had been recorded by the whale-watching industry over 23 years. Scientists have now developed an algorithm to help identify whales using high-resolution satellite imagery (Fretwell 2014). This new technique can help monitor whale populations and route traffic safely through whale habitat, even in areas that don't have an extensive whale-watching record. Development and expansion of international trade does not have to come at the cost of increased marine mammal fatalities.

Additional studies have also contributed to improving knowledge of right whales and better guiding shipping and fishing activities. A model was developed of rice-grain sized copepod *Calanus finmarchicus*, the preferred prey of right whales, to help predict its population and location (Pershing et al 2009). The model is combined with sea surface temperatures from

Top: *Image taken from the International Space Station; Stellwagen lies just north of the tip of Cape Cod. (NASA)*

Above: *Shipping lanes are being rerouted away from key whale habitat, thereby reducing ship collisions with whales. (J. Calambokidis/Cascadia Research)*

MODIS and chlorophyll measurements using MODIS and SeaWiFS to estimate growth and egg production of *C. finmarchicus*. Embedding these estimates into an ocean circulation model provided estimates of this right whale prey in space and time. Weekly right whale habitat suitability was then predicted for eight-day periods between 2002 and 2006 using a species distribution model that considered modeled prey density, satellite-derived sea surface temperature and chlorophyll, and depth (Pendleton et al 2009).



In June 2014, the Northeast Fisheries Science Center (NEFSC) embarked on their North Atlantic right whale survey. Their aerial team spotted these two right whales on the surface circling each other. (NOAA, NEFSC)

Enhancing Diversity and Quality of Governance

> *OVER THE PAST DECADES there has not only been a significant increase in the number of protected areas around the world, but also a dramatic change in understanding about how protected areas can and should be governed and managed.*
> IUCN, *Governance of Protected Areas: From Understanding to Action* (Borrini-Feyerabend et al 2013)

Designating and protecting natural areas has a long tradition in human history. Through trial and error, there have been hard lessons learned about the need to govern shared resources. Without effective protection, these areas would have been lost long ago.

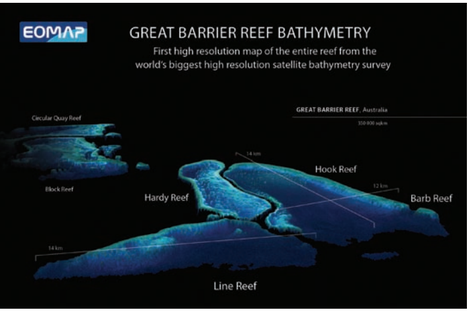
The IUCN recognizes four broad categories of protected-area governance: ***governance by government, shared governance, private governance, and governance by indigenous peoples and/or local communities.***

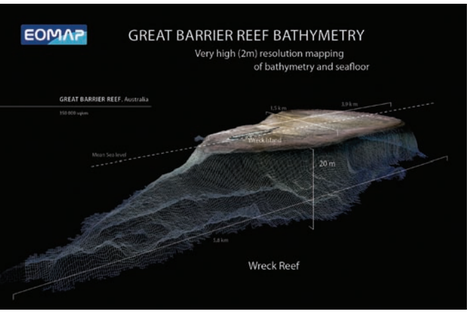
Legitimacy and voice, direction, performance, accountability, fairness and rights are all principles of good governance and recognized by the IUCN, Convention on Biological Diversity, and others. Across all forms of protected-area governance, satellite remote sensing is a valuable tool for assisting and ensuring the quality of governance as a readily available measure of the effectiveness of protection against ecosystem degradation. (Borrini-Feyerabend et al 2013)

The oceans are our largest continuous global resource, but their size and remoteness makes conservation a challenge. One of the recent trends in conservation of marine resources has been developing community-conserved areas around developing island nations.

Kayangel Atoll, in the western Pacific island country of Palau, is an important part of the Palau Protected Areas Network's (PAN) Ngaruangel Reserve. PAN, established in 2003, is designed to protect the nation's critical biodiversity and ensure effective conservation of resources. (IUCN/© Kevin Davidson)

Indigenous people participate in land-use planning for the nearby YUS Conservation Area and Landscape, Papua New Guinea. (IUCN/© Ashley Brooks)





***Above**: NASA's Landsat 7 satellite provided data for these two bathymetric images of Australia's Great Barrier Reef. These images are part of the first high-resolution maps of the entire reef. (EOMap)*

***Top right:** A community member talks about a social marketing campaign aimed at motivating people to reduce destructive fishing practices in Cakaudrove, Fiji. (Rare.org)*

***Below right:** Community members wear T-shirts with the slogan "I love my tabu area." The shirts are part of a social marketing campaign to promote sustainable fishing by instituting traditional "tabu" (forbidden) areas in Cakaudrove, Fiji. (Rare.org)*

Fiji, in particular, has been a leader in locally managed marine areas (LMMA) in the South Pacific. After the first pilot project outside the village of Ucunivanua in 1997 demonstrated that persistent community management can be highly effective, LMMA have now expanded to cover more than 25 percent of Fiji's inshore area (Corcoran 2012). The positive socioeconomic impacts include diversified and increased income, empowerment of women, strengthened community cohesion, and an increased prominent political profile. The Fijian LMMA network is a model for conservation throughout the Pacific.

These smaller, locally managed areas are effective because they are close to home, with a tight feedback loop between action and impact. The cultures of these island nations hold millennia of seafaring experience and traditional fisheries knowledge. But here too, satellite remote sensing can enhance mapping and local understanding of the inshore environment through a low-cost approach. Small island developing states can employ scientifically sound mapping methods for their own conservation purposes (Richardson and LeDrew 2006). Establishing this level of self-reliance in all nations is an essential element in diversifying and strengthening the quality of protected-area governance, matched with capacity development.

Satellite imagery of inshore habitat is being used to characterize reef structure and model biodiversity richness, ensuring that high-value areas are being protected. In the largest and most detailed study of its kind, the entire three-dimensional structure of Australia's Great Barrier Reef has been mapped using only satellite data. The output demonstrates the extent of what is already possible using existing technologies.

The Great Barrier Reef stretches from wet tropical to dry tropical environments, and is subject to a wide range of strong weather patterns. These weather patterns drive flooding that reduces water quality and threatens reef health. Satellites are being used to assess the movement of flood plumes in the marine environment, the levels of contaminants being carried into the reef waters, where these contaminants go as they dilute and transform, and the risk they pose to sensitive marine ecosystems.

Claremont Isles National Park, located in Princess Charlotte Bay, Australia, protects coastal waters and is part of the Great Barrier Reef World Heritage Site. Image acquired April 20, 2013, by the Operational Land Imager (OLI) on Landsat 8. (NASA/USGS)

Respecting Indigenous and Traditional Knowledge and Culture

> *OUR WORK WITH INDIGENOUS OWNERS showcases to the world how "joint management" can combine traditional knowledge and modern practice.* Sally Barnes, Director of National Parks, Australia

Traditional knowledge and lifestyles are a vital element of any ecological system long inhabited by native peoples. The deep ties of a culture to the land are one of the securest systems of land protection known. These traditional ways can also be protected through technology.

Torrential rains bombard the forest. One hundred and twenty feet (40 m) above the ground, clear droplets cascade down the outstretched palms of the cecropia trees, dampening the torrents to a gentle shower as they reach the ground below. As the afternoon storm subsides, the air is thick with swarming insects and the smell of huddled damp bodies and close breath. Sensing the storm has passed, members of the Paiter (also known as the Surui) venture out into the humid air, treading quietly over water-saturated earth redolent of spring and fall at once, here in this land without seasons. Dense tangles of lianas, festooned with white blossoms, decorate the verdant walls of the rainforest. The excited calls of countless species, interwoven with the sights and smells of the forest, create an integrated concert for the senses. It is an overwhelmingly foreign place for most visitors, but to the Paiter these are the sights and sounds of home.

Isolated indigenous maloca (longhouse) found in the Colombian Amazon. (Amazon Conservation Team)

WorldView-2 satellite image of an isolated indigenous settlement near the Brazil-Peru border. (DigitalGlobe)

***Above images**: These Landsat satellite images show the progress of deforestation in the Brazilian state of Rondônia over a 23-year period (1990, top, and 2013, above)—and where it stops at the borders of Paiter (Surui) lands. (NASA/JPL)*

***Top center:** An indigenous Australian park ranger shows traditional Ubirr rock art to park visitors. Many of Australia's parks are managed by traditional owners and the government agency Parks Australia, showcasing to the world how joint management can combine ancient culture and modern practice. (Parks Australia)*

This tract of rainforest is a remaining stronghold of minimally disturbed forest in one of the most deforested sectors of the Amazon. It has been home to the Paiter for generations. The band has set out on a foot patrol of their home territory, inside the Sete de Setembro Indigenous Reserve. These are not simply rangers, but benefactors and beneficiaries, set on preserving the natural and cultural elements of this place. Today, the Paiter continue to be an integral part of this landscape as they have been for generations.

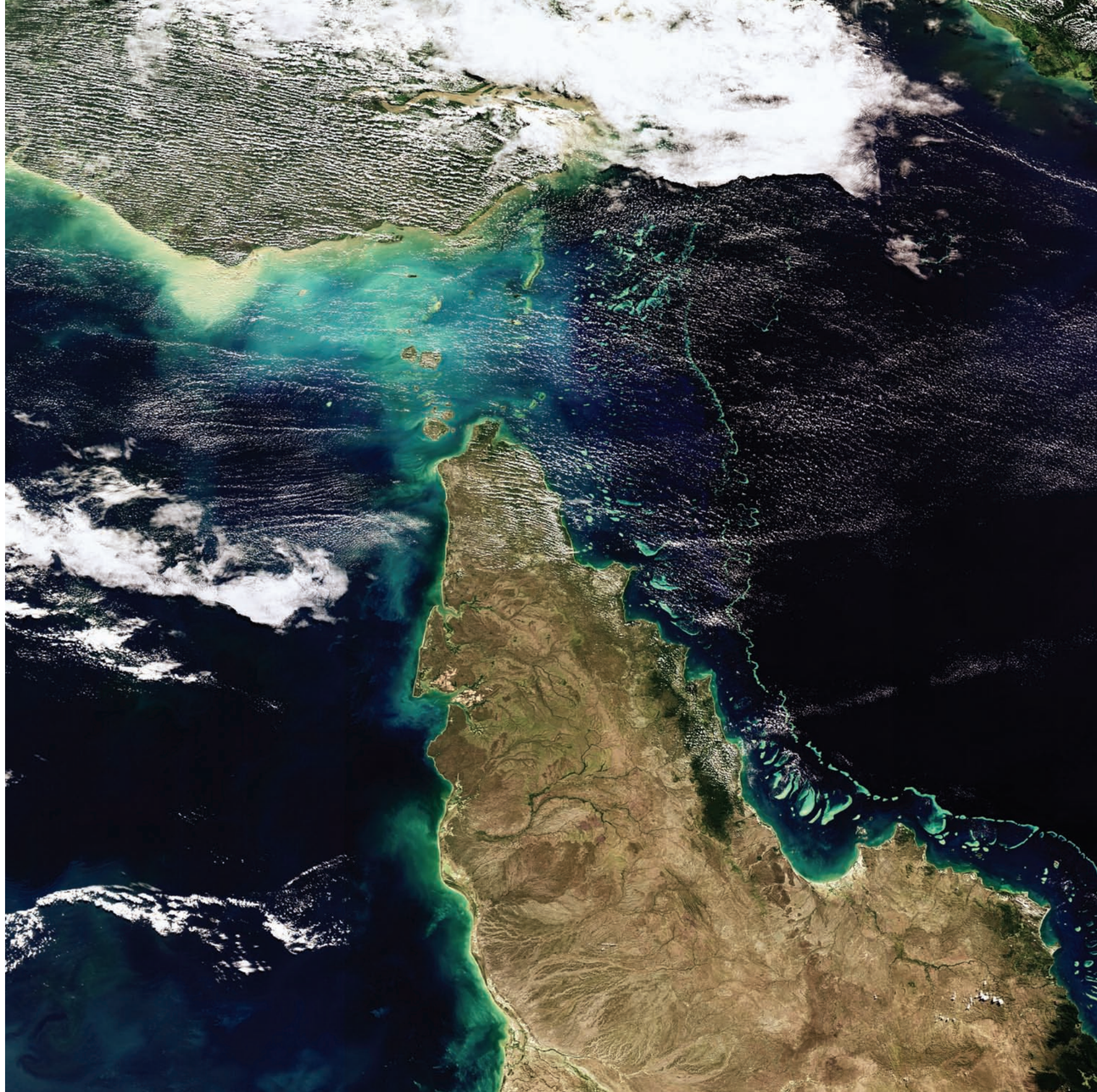
Through a modern-day collaboration with nonprofit agencies, spearheaded by the Amazon Conservation Team (ACT), the Paiter mapped out the boundaries of their traditional lands using satellite technology and deep local knowledge developed over generations and passed down through oral history (ACT 2011). Patrol by foot has its limitations, so Paiter tribal leaders also use freely available satellite imagery to identify unauthorized activities that could forever change their cultural and natural landscape (Zwick 2013).

ACT employs satellite and other geospatial technologies to help indigenous communities create maps of their territories. These maps record traditional land-use patterns to help preserve indigenous medicinal and agricultural practices, and help communities manage and preserve the natural resources of their territories.

ACT also is using high-resolution satellite imagery provided by DigitalGlobe to identify and study the isolated indigenous groups of the Amazon rainforest, focused on Colombia. Satellite imagery has allowed ACT to locate several isolated settlements without risk of disturbing the inhabitants. These findings have guided the implementation of protective measures to help preserve these groups' basic human right of voluntary isolation and self-determination.

On the other side of the world, a different kind of protected zone is providing the same invaluable security. The Torres Strait Islanders reside in the chain of islands directly above the northern tip of Australia. Like their Aboriginal neighbors, the islanders consider land and sea to be a life source that is one and the same. Their lore and creation myths are centered on the sea, and their economy relies on the sea just as deeply. This spirituality and connection to the environment provides the link between the elders and the new generation. Now a marine protected zone and treaty protect the Torres Strait Islands and shield the islanders from exploitation of the area around them. They can continue their traditional way of life that flows from the sea.

The efficacy of such nontraditional partnerships is indisputable—protected areas designated as indigenous lands often become the most resistant to exploitation. The integrity of the cultural and natural landscape that results from these actions is evident within the territory itself, with impacts visible from space (Nolte et al 2013). The strength of an indigenous protected area comes from the strength of the human spirit and the fearless defense of home. It is a lasting benefit to our species that we can still call these places home.



The Torres Strait, home to the indigenous Torres Strait Islanders, lies between the northern tip of Australia and Papua New Guinea. Envisat satellite image. (ESA)

Inspiring a New Generation

> *It is our privilege and responsibility, young and old, to protect this natural heritage for future generations.*
> Alan Latourelle, Chief Executive Officer, Parks Canada

There is an innate human gravitation toward natural areas (Wilson 1984), and children are especially in tune with this instinct (Townsend and Weerasuriya 2010). When urban children were asked to draw their favorite place in the city, nearly all depicted outdoor spaces (Moore 1986, as cited in Maller et al 2008). Promoting this fondness for unstructured outdoor play in the living environment benefits childhood development in all stages (Louv 2008). These outdoor experiences also help shape the next generation of conservation leaders by creating a personal connection to nature. Once this connection is forged, it can inspire lifelong respect and care for the natural world.

Competing for the attention of today's children are the alluring possibilities of both the natural world and the world of digital technology. Both worlds richly reward curiosity, creativity, and imagination. The leaders of the future will be natives of both worlds, inspired by both the power of technology and the power of nature. Alan Latourelle, Chief Executive Officer, Parks Canada, during his speech at the 2013 World Wilderness Congress, said: "We are stewards of the planet's most precious gift—life itself, in all its magnificence, beauty, and diversity. It is our privilege and responsibility, young and old, to protect this natural heritage for future generations. But if future generations do not value this gift, if they've never been given the opportunity to walk quietly through a forest or swim in a cold clear lake, then in a world hungry for resources they will undo all we have accomplished."

Camping in Fundy National Park, Canada (©Parks Canada/Chris Reardon)

High school science students experience weightlessness and conduct experiments during a NASA-sponsored, zero-gravity flight in Houston April 9, 2014. (NASA)

Top: *Before the start of the June 2012 Earth science research mission, a college student in NASA's Student Airborne Research Program assists in the installation of air quality instruments on board the aircraft. (NASA/NSERC Jane Peterson)* • ***Center:*** *Middle school students participate in Family Science Night once a month during the school year at NASA's Goddard Visitor Center in Greenbelt, Maryland, U.S.A. Through the activities and experiments, the students discover what NASA scientists and engineers do. (NASA)* • ***Above:*** *GLOBE Partner Lori Maxfield of Minnesota, U.S.A., shows students how to measure water temperature. (GLOBE)*

The sustaining optimism of new technologies has opened an incredible opportunity for today's youth. Never before has it been so easy to reach a global audience. The prospects of using technology to aid conservation have never been brighter. Dozens of outreach programs are educating students at all levels about Earth science and remote-sensing technologies. NASA Wavelength is one such comprehensive resource complete with lesson plans, web-based activities, and direct access to the latest data. Another program is Global Learning and Observations to Benefit the Environment (GLOBE), where nearly 28,000 schools participate worldwide and involve teachers and students in hands-on science and data collection.

Already, young conservation leaders are using satellite remote-sensing data to highlight and design solutions to conservation issues around the globe. With the increasing accessibility of satellite data, no project is too large or too small to take advantage of a comprehensive view. Another positive development has been the creation of crowd-sourced remote-sensing image classification platforms. When it comes to pattern recognition, the human eye outperforms computer algorithms. DigitalGlobe's Tomnod platform hosts numerous conservation and environment related campaigns enabling millions of users to analyze and tag high-resolution imagery for everything from forest fires, invasive species, and search and rescue efforts.

Zooniverse projects such as the Whale Song Project enlist the help of amateur marine researchers to listen and classify sounds. Another example is the Open Landscape Partnership. Volunteers are monitoring high resolution images to detect any unlawful activity that may threaten remaining tiger habitat in Asia. These contributions dramatically accelerate research and encourage public involvement.

As the Prophet River flows across northern British Columbia, Canada, it flows through Prophet River Hotsprings and Prophet River Wayside provincial parks. Image collected September 14, 2010 by WorldView-2. (DigitalGlobe)

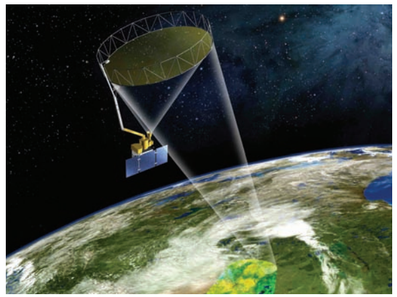
Looking to the Future

> *BIG BREAKTHROUGHS happen when what is suddenly possible meets what is desperately necessary.*
>
> Thomas L. Friedman, "Come the Revolution" (New York Times, May 16, 2012)

The continuous Landsat imagery record, which began in 1972, has established a critical baseline for studying trends. In 2013, NASA launched Landsat 8, the latest iteration of its flagship Earth-observing satellite that continues to record Earth's changing land cover.

NASA plans to launch five new Earth-observing missions in 2014. These missions, combined with those from other nations and a rapidly expanding private sector, will enable unparalleled advancement in observing and studying protected areas. Data and imagery further combined with geospatial capabilities and high-fidelity visualizations will enable scientists and park managers to view a full 3D model of Earth's surface and atmosphere. The scientific understanding of our planet will be more comprehensive and rapidly updated than ever before.

Long-term investments in space technology continue to pay dividends, with new uses for satellite records invented regularly. The costs of launches and satellites are decreasing as NASA is adopting an agile, iterative approach to satellite and sensor design, speeding up development and innovation. NASA is also deploying advanced sensors and pioneering new remote-sensing techniques aboard remotely piloted vehicles.



The SMAP (Soil Moisture Active Passive) satellite mission will provide global measurements of soil moisture and its freeze/thaw state. Launch date early 2015. (NASA)

In August 2013, the Operational Land Imager (OLI) on Landsat 8 captured this image of the Yakutat Glacier in Alaska, U.S.A.—one of the fastest retreating glaciers in the world. (NASA/USGS)

Above: *Venice, Italy, appears as a red island in this image acquired September 4, 2013, by the Operational Land Imager (OLI) on Landsat 8. The large white structures in the Lido Inlet are new gates designed to close when exceptionally high tides or storms from the Adriatic Sea threaten this World Heritage Site. (NASA)*

Top center: *Students learn earth science via simulation on NOAA's Science on a Sphere. (NOAA)*

Top right: *NASA scientist Ved Chirayath developed this four-rotor remote-controlled UAV, outfitted with cameras that can film coral reefs from up to 200 feet in the air. He uses this pioneering technology, along with the innovative software he designed, to precisely map, measure, and study at-risk coral reefs and stromatolite beds. (Ved Photography, Reactive Reefs Project)*

Unmanned aerial vehicles (UAVs) are being used more widely in the conservation field because they are inexpensive, available on demand, and can be launched from remote areas that may not have a runway. This allows the remotely piloted vehicles to provide realtime or near realtime data that supplement satellite coverage. In Kruger National Park, South Africa, inexpensive UAVs are being used to patrol large areas for poachers (Kohn 2013). In tropical regions worldwide, they are patrolling for illegal logging and mining operations (UNEP 2014). Several countries are exploring the potential for these remotely piloted vehicles to patrol vast ocean territories.

In all areas of conservation, collaboration between public, private, and nonprofit sectors is increasing. Diverse partnerships founded on shared objectives have expanded expertise and capacity. One of the biggest changes in satellite remote sensing currently unfolding is a marked increase in user friendliness through web interfaces, cloud computing, and integration with mobile devices. Businesses are creating new intuitive ways to interact with satellite data of increasingly high resolutions.

The incredible advances in technology and monitoring techniques are only part of the future of remote sensing. In our constantly changing world, rapid detection of critical issues is imperative. Understanding environmental issues often requires the integration of many different streams of information. To address this problem, NASA is collaborating with an extensive international partnership to create GEOSS: Global Earth Observation System of Systems. The goal of GEOSS is to provide free public access to global environmental data. This new integrated portal to environmental information will generate actionable information for scientists, conservationists, and policymakers worldwide.

Conservation will succeed only if humans are the focus and purpose of conservation efforts, with people uniting to create a sustainable future. Satellites are vital assets, providing conservation insight and evidence-informed decision support in rapid time and enabling researchers, planners, policymakers, and managers to predict future challenges and respond to them effectively. For protected areas, these images are also a powerful means to communicate and motivate action, from individuals acting locally to coordinated action at the planetary scale.

Civilization stands on the cusp of pivotal change. We are not limited by our knowledge or technology, but by our cohesion and cooperation. When people come together to embrace what we have learned about our planet, then coordinated conservation efforts will take root in protected areas and grow until we all profoundly understand what it means to share life on this planet.

Stromatolite beds (ancient living structures built by microbes) in the shallow waters of Shark Bay, a UNESCO World Heritage Site in western Australia. (Ved Photography, Reactive Reefs Project)

AUTHORS

NANCY COLLETON

Often found hiking with her canine companions along the scenic Potomac River in Northern Virginia, U.S.A., Nancy Colleton never needs to be reminded that there's no greater privilege than providing a voice for nature. She is passionate in her mission to promote better understanding of the changing planet through the use of space technologies, science education, and public engagement. As president of the Institute for Global Environmental Strategies (IGES) and the deputy chair of the IUCN Commission on Education and Communication, she has dedicated her career to working with others to inspire and motivate positive change for the planet.

ANDREW CLARK

An engineer by training and roving poet-scientist by nature, Andrew follows his nose to the most fascinating science and scenery. When he is not at his desk at IGES reading and writing about science, you're likely to find him in the field, turning over tundra as an ecologist or inspecting lichen on his way to the summit as a mountaineering guide.

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STEERING COMMITTEE

Michael Abrams. NASA Jet Propulsion Laboratory/California Institute for Technology ASTER Science Team Leader

Robyn Dalzen. Conservation International/ Conservation Leadership Programme, Executive Manager

Susie Duckworth. Duckworth Graphic Design and Illustration

Gary Geller. NASA Jet Propulsion Laboratory/ California Institute for Technology ASTER Team

Ernesto Enkerlin Hoeflich. IUCN World Commission on Protected Areas, Chair

Kathy MacKinnon. IUCN World Commission on Protected Areas, Deputy Chair

Trevor Sandwith. IUCN Global Protected Areas Program, Director

Ashbindu Singh. Environmental Pulse Institute, Director; United Nations Environment Programme (UNEP) (retired)

Carmelle Terborgh. Esri, Manager of Nonprofits and Global Organizations, Lead Account Manager

Compton "Jim" Tucker. NASA Goddard Space Flight Center, Senior Earth Scientist

Lauren Wenzel. NOAA National Marine Protected Areas Center, Acting Director

Keith Wheeler. Paul F-Brandwein Institute, President

CONTRIBUTORS

Annie Apffel. IGES, Intern, Amherst College

Carolyn Duckworth. Editor

Kurt Eckerstrom. Esri, Nonprofit Organization Program, Account Manager

Knut Hartmann. EOMAP GmbH & Co. KG, Head of Bathymetry and Seafloor Group

Brian Hettler. Amazon Conservation Team, Manager of GIS and New Technologies

Diego Juffe-Bignoli. UNEP, World Conservation Monitoring Centre, Protected Areas Programme, Programme Officer

Tim Kelly. American Prairie Reserve, Board Member

Naomi Kingston. UNEP World Conservation Monitoring Centre, Head of Protected Areas

Devon Libby. DigitalGlobe, Senior Corporate Imagery Services Representative and Foundation Manager

Allison Liedner. NASA Earth Science Division, Scientist III with University Space Research Association

Nik Lopoukhine. IUCN World Commission on Protected Areas, former Chair

Brian MacSharry. UNEP World Conservation Monitoring Centre, Protected Areas Information Coordinator

Denise Oliveira. World Wildlife Fund Living Amazon Initiative, Head of Communications

Theresa Schwerin. IGES, Vice President, Education

Keri Thorpe. American Prairie Reserve, Graphic Designer

Woody Turner. NASA, Program Scientist for Biological Diversity and Program Manager for Ecological Forecasting

Mike Wong. Parks Canada, Natural Resource Conservation, Executive Director

Juliane Zeidler. IUCN Commission on Education and Communication, Chair

Above: *Nancy Colleton, Andrew Clark (Freed Photography/Bryan Blanken)*
Left: *Bison grazing on the American Prairie Reserve, Montana, U.S.A. (Dennis Lingohr)*

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Page 48: *Once widespread throughout the Bahamas, the San Salvador rock iguana now survives on just a few small islands. (Andrew David Clark)*

Next page: *Sunrise over Lake Moraine, Banff National Park, Canada. (Shutterstock/Zvia Shever)*

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