LIFE IN A CHANGING OCEAN

Credit: Jason Bradley (www.bradleyphotographic.com)

LIFE IN A CHANGING OCEAN

Life in a Changing Ocean **is an international scientific program to advance discovery and expand marine biodiversity knowledge to support healthy and sustainable ecosystems. It will provide a new, integrated global view of marine life that will fill knowledge gaps and answer important questions needed to effectively manage and sustain our ocean ecosystems. Scientific data, research, and findings will be integrated across four interrelated and interconnected themes that will enhance knowledge and provide new, innovative tools to understand** ***Life in a Changing Ocean:*** **Biodiversity and Ecosystem Services, Biodiversity in Ocean Spatial Planning, Biodiversity Observation, and Biodiversity and Sustainable Ocean Use.**

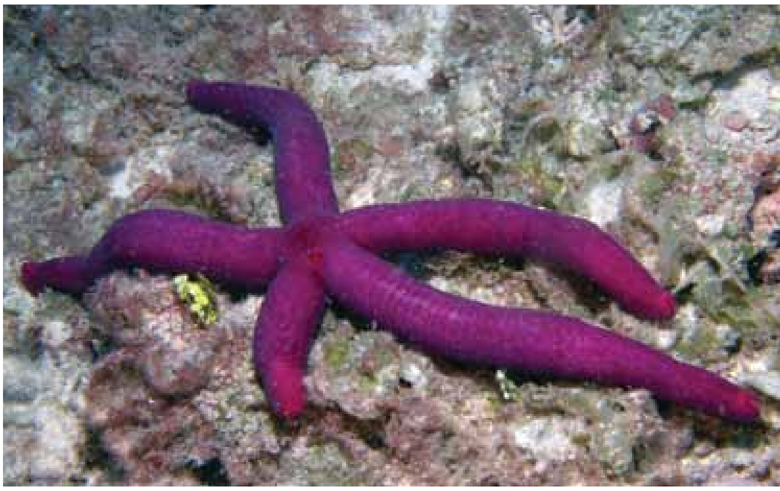
The leatherback sea turtle *(Dermochelys coriacea)*, the largest of all living sea turtles, is the only living species in the family *Dermochelyidae.* Its image was chosen to represent the challenges and opportunities for *Life in a Changing Ocean* and its four cornerstone themes. As a critically endangered species, the leatherback turtle is an iconic image of the beauty and aesthetics provided by the global ocean. Its nomadic nature, crossing international boundaries and linking ecosystems, illustrates how ocean life contributes to **Biodiversity and Ecosystem Services** and represents how scientists can learn more about where species live and move by mapping their patterns to identify high-use habitats, integral elements of **Biodiversity in Ocean Spatial Planning**. Today, leatherback turtles serve as oceanographic "ships" collecting data, via attached oceanographic sensors and sophisticated satellite tracking and biologging devices, from remote ocean environments where scientists rarely venture, providing a novel strategy for successful **Biodiversity Observation**. Knowledge of status and spatial movements can lead to action, and, in this case, fishery closures and gear mitigation techniques during the turtles' migration may help to preserve this species, a foundation of **Biodiversity and Sustainable Ocean Use**. As demonstrated by the leatherback turtle example, these four biodiversity themes are intertwined and reflect how the *Life in a Changing Ocean* program will work across themes to better quantify and understand marine biodiversity to support healthy and sustainable ecosystems.

LIFE IN A CHANGING OCEAN

From the shoreline to the abyss and from the surface to the bottom, Earth's ocean is changing. Some change is natural as seasons progress, as storms pass, and as natural disasters such as hurricanes, tsunamis, and underwater mudslides destroy old habitats and create new. Human activities also contribute to these changes, from introduction of non-native species to climate change, to habitat and species loss associated with fishing disturbance and coastal pollution. Life in the global ocean also changes, sometimes in ways we can predict or control, but often in ways we do not understand. Environmental change can be positive for some species, neutral for others, and at times catastrophic for the way the ocean functions and for its many living resources upon which humans depend. Much remains unknown about life in a changing ocean. Estimates are that at least 750,000 species are yet to be discovered, not even considering vast unknown microbial diversity. Without expanding this knowledge base about what lives in the ocean and the importance of species in their environments, it is virtually impossible to identify change when it occurs, determine if the change is significant, or predict what the impact of the change may be.

The *Census of Marine Life*, which concluded in 2010 after a ten-year program of discovery, represented a large step forward in marine biodiversity science. Some 2,700 scientists from around the world worked together to document patterns of diversity, distribution, and abundance of marine life and found an ocean more diverse, more connected through migration highways, and more impacted than previously thought. The *Census* also provided the first global baseline of what lives in the ocean against which future change can be measured—a solid foundation upon which to build. Equally important, the *Census* exposed critical gaps in knowledge of life in the global ocean, providing the impetus for a timely new research initiative on *Life in a Changing Ocean.*

Life in a Changing Ocean research will increase understanding of marine biodiversity, the importance of species, habitats and their connectedness, and the role of different organisms in the functioning and sustainability of ecosystems, while at the same time filling critical gaps in our basic knowledge about what lives in the ocean. By focusing on emerging marine biodiversity research needs, bringing together existing scientific information, and stimulating innovative, interdisciplinary research, *Life in a Changing Ocean* will provide a new, integrated view of marine life that will answer important questions needed to effectively manage and sustain our ocean ecosystems. The program will integrate scientific data and report findings across four interrelated and interconnected cornerstone themes:



Two articles in *Science* reported a dire future for coral reefs. In 2007, Hoegh-Guldberg *et al.* predicted that based on current trends in greenhouse gas emissions, coral reefs would cease to meaningfully exist by 2050. In 2008, Carpenter *et al.* reported one third of all corals were at risk of extinction, making them the most endangered group of animals on the planet. If these predictions hold true, the future of this large and colorful new species of purple sea star, *Leiaster sp.* found in the French Frigate Shoals, and many other coral inhabitants is uncertain. Credit: Gustav Paulay, Florida Museum of Natural History.

Every marine animal has an intriguing story. This large northern red anemone, *Urticina felina,* is found from the Arctic to Cape Cod along the eastern North American coast. Nearshore they grow up to 15 centimeters in diameter, and offshore tend to be even larger. They are equipped with powerful stinging cells. Expandable mouths open wide enough to allow them to feed on small fish, urchins, crabs, jellies, and other invertebrates that venture too close. Credit: Andrew J. Martinez (www.andrewjmartinez.com).

Biodiversity and Ecosystem Services

How do species affect ocean health and the services the ocean provides?

Recognizing that marine organisms sustain ocean and human health by keeping the ecosystem functioning (water processing, filtering of contaminants, and biomass production) and by providing services (fisheries, pharmaceuticals) that directly and indirectly support human needs, how can we identify when changes in functions occur? When are those changes natural? When are they critical? How do different species contribute to diverse and functioning (or "healthy") ocean ecosystems, and how do changes in species influence the delivery of key ecosystem functions and services? In the Gulf of Mexico, a team of researchers worked for years to compile an inventory of species present throughout the Gulf, largely inspired by scientific curiosity. But with the subsequent Deepwater Horizon oil spill in 2010, this baseline will prove invaluable in assessing the impact of the spill on the biodiversity in the Gulf, and in following changes in ecosystem function and services as the Gulf recovers.

Marine life exhibits amazing adaptive abilities that allow it to exist in extreme environments. The Antarctic ice fish, *Pagetopsis macropterus,* for example, has no red blood pigments (hemoglobin) and no red blood cells, adaptations to low water temperatures. As a consequence, its blood is more fluid and the animal conserves energy as it pumps blood through its body. Credit: Julian Gutt, AWI/Marum, University of Bremen.

Biodiversity in Ocean Spatial Planning

What information is needed to successfully balance the use of the ocean by humans with the needs of the organisms that live there and the ecosystems they support?

Marine animals traverse the global ocean with no regard for political considerations or geographic boundaries, and countries only control 200 nautical miles of ocean off their shores, leaving the majority of the ocean without jurisdiction. What information would be useful to help countries better manage their coastal oceans? How can we continue to use the ocean and extract its many resources without broadly compromising its health and the health of planet Earth? How can we predict where important habitats occur and how populations within a region are linked to populations elsewhere? How can we identify the highest priority areas for marine management and conservation in the high seas, deep sea, and within exclusive economic zones?

Ocean spatial planning is forward-looking planning that addresses the multiple, cumulative, and potentially conflicting uses of the sea and requires information about how humans use the global ocean, the needs of the organisms that live there, and the ecosystems they support. Such planning is integral for designation of marine protected areas and other conservation areas. In 2010, for example, the United Kingdom established a marine protected area of 545,000 square kilometers in the British Indian Ocean, which effectively doubled the coverage of the global ocean under protection. It is anticipated that this area will help repopulate vulnerable coral systems along the East Coast of Africa and enhance the recovery of the marine food supply in sub-Saharan Africa.

Biodiversity Observation

How can we predict where and when changes will occur and what the consequences may be on ecosystems and humans?

Climate change, ocean acidification, sea level rise, and marine pollution are creating new ocean conditions, some of which are happening fast. We must fill knowledge gaps about what lives in the ocean, and where, in order to document the effects of these new conditions and to predict what species and ocean areas might be susceptible. For example, scientists recently confirmed an astonishing biodiversity of microbes in seawater and ocean sediments. This microbial diversity was comprised of mostly rare and unique species rather than common ones. Microbes play significant roles in the balance of the global ocean, however, it is uncertain how these roles will be altered or how their dominance might change under different ocean conditions. The challenge is how to make better use of emerging technologies to know when changes happen in biodiversity and to know when those changes have major ramifications not only for the health of the ocean but also for the well-being of humans. How can we use better observational tools to identify species, habitats and animal movements, predict future change and what the consequences will be, understand how natural and human impacts alter marine biodiversity, and develop new sensors to address emerging observational needs?

Biodiversity and Sustainable Ocean Use

What information do we need to know to advance the sustainibility of the ocean?

Every second breath we take comes from oxygen produced by marine microbes, including phytoplankton, and the sea is an important source for the world's protein. Recognizing that the global ocean is vital to our own survival as a species, what knowledge is needed to better sustain the balance of the ocean and preserve marine resources? What effects are climate change, ocean acidification, and other human-induced changes having on marine biodiversity? How can these effects be measured, quantified, and understood to facilitate mitigation? What data are needed to advance sustainable exploitation of marine resources (fisheries, mining, and various other ocean uses), while maintaining the overall health of the marine ecosystem?

Data are essential for managers to maintain and sustain fisheries and other ocean resources. A 2009 study, for example, examined global fish populations and fishing trends in ten large marine ecosystems and found fish stocks rebuilding in five of the areas where intensive management is taking place.

A WAY FORWARD

A newly formed Global Marine Biodiversity Consortium will carry forward the *Life in a Changing Ocean* research agenda. With a vision of advancing discovery and expanding marine biodiversity knowledge to support healthy and sustainable ecosystems, the Consortium is open to all researchers and strives to bring together marine biodiversity researchers from around the globe, along with colleagues from related disciplines, to share data, ideas, and knowledge so that a greater understanding of life in a changing ocean can be achieved through a collective, global effort that maximizes resources and collaboration.

The Consortium reflects its multifaceted approach to research. It requires the expertise of many disciplines to understand the processes and functions in the biological components of the ocean and better determine the effects of ongoing environmental changes on marine life and the ecosystem as a whole. At the same time, it will perform research to fill critical gaps in knowledge, including species discovery and distribution, changes in habitats and populations, and the roles that individual and groups of species play in the ecosystem. Importantly, it will work together to answer global questions that cannot be answered by individual researchers or countries.

Most of the world's bottom ocean habitat remains unexplored, a critical gap in marine biodiversity information. As evidenced near Deer Island Archipelago, benthic habitats often support very diverse communities—from lobsters to sponges, tunicates, coralline algae, and tubularians—that enhance their productivity and resiliency. Credit: Mike Strong and Maria-Ines Buzeta, Department of Fisheries and Oceans, Canada.

Novel and exciting scientific questions will drive the science but researchers will reach out to stakeholders and policy makers to ensure that the questions asked can inform management of the global ocean and help ensure its sustainability. The Consortium will work with established policy-driven organizations, such as the International Council for Exploration of the Sea, the North Pacific Marine Science Organization, the International Union for Conservation of Nature, and others, to provide information to decision makers. It will simultaneously seek engagement of ocean stakeholders to maximize the utility and timeliness of the scientific research. The Consortium will encourage the sharing of data and the continued growth of the Ocean Biogeographic Information System (OBIS), the world's largest repository of geo-referenced biological data, created by the *Census of Marine Life*.

An interim governance structure will operationalize the program, but it, too, will evolve in response to needs and demands as support is secured for the scientific priorities of *Life in a Changing Ocean*. A Science Planning Committee has developed the scope of *Life in a Changing Ocean* and will spearhead the initial scientific effort. A Secretariat will serve as the communications and administrative infrastructure to hold the Consortium together. The Consortium plans to gather every three years in conjunction with the anticipated World Conferences on Marine Biodiversity, at which time researchers will present the *Life in a Changing Ocean* report covering the integration of knowledge gained across the four cornerstone themes. An annual meeting of governing members is also planned to assess progress, assign tasks, review science priorities, and report on advancements in knowledge about life in a changing ocean. In the long term, *Life in a Changing Ocean* is envisioned as a ten-year program.

The global marine science community experienced, through the first *Census of Marine Life*, the power of collaboration, sharing of ideas, techniques, resources, and knowledge, and working together toward a common vision and goal. This powerful equation will continue as *Life in a Changing Ocean* and the Global Marine Biodiversity Consortium are formally launched at the second World Conference on Marine Biodiversity on September 30, 2011. Now is the perfect time and opportunity for the equipped, integrated, and committed international marine biodiversity community to expand its horizons, advance research and discovery, increase understanding about *Life in a Changing Ocean*, and provide much-needed science to aid policy makers in their quest for effective strategies for sustainability of the global ocean and the many vital services it provides for future generations.

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WHAT IS NEEDED?

To reach its ambitious and far-reaching goals, *Life in a Changing Ocean* will require a long-term dedicated commitment from both the marine biodiversity community and a suite of funders including governments, academic institutions, private funders, and other ocean stakeholders and users. The community is ready to step forward to implement a program with specific goals, milestones, and outcomes based on the themes and questions documented here. To carry out these tasks, financial support is needed for meetings, workshops, and other communications to allow scientists the opportunity to share data, discuss ideas, and come to collective agreement about the new program. These activities would be coordinated through an international Secretariat. Once the program is in place, it is anticipated that much of the science will be funded in traditional ways—through financial support of governments and research institutions. The *Life in a Changing Ocean* program will maximize these investments through global scientific coordination to synthesize and report results on taxonomic and geographic scales that could not be achieved by any single country or project.

BIODIVERSITY AND ECOSYSTEM SERVICES

From the smallest microbes to the largest marine mammals and from the shoreline to the deep sea, marine life is essential for a healthy global ocean and for the survival of life on Earth. Many marine organisms sustain ocean and human health through their roles in the biosphere. These roles are collectively known as *ecosystem functions,* examples of which are the production of living biomass (and food) and recycling of organic matter, which provide the nutrients that sustain life and stability on Earth. For example, marine microbes, including phytoplankton, contribute about half of the oxygen produced on Earth through photosynthesis, and these microscopic organisms also form the base of the food webs that support almost all ocean life from shellfish to the great whales. Organisms that live on, and in, the sediments that cover most of the seafloor on Earth also help to cycle nutrients and provide vital sustenance to the many fishes (flatfish, cod) and crustaceans (lobster, crab, and shrimp) that feed on the bottom and provide important food sources for humans. Corals, sponges, seagrasses, mangroves, and many other "habitat building organisms" not only provide habitat for a wide range of species, but also provide essential benefits for human beings. The functions provided by living organisms are collectively known as *ecosystem services*. Marine ecosystem services include the production of oil and gas and mineral resources, climate regulation, disease prevention and predator control, provision of food, pharmaceuticals to treat human diseases, water purification, and a spectacular array of recreational and cultural support. Fisheries production, carbon dioxide sequestration, and pollution abatement are perhaps among the best known examples of marine ecosystem services.

In addition to being highly productive and diverse ecosystems, coral reefs provide habitat and food for a wide variety of marine life. Reefs also serve as important barriers that help protect the coast from the effect of waves, storms, and even tsunamis. Shown here are views of coral reefs at Los Roques, off the coast of Venezuela. Credit: Eduardo Klein, Universidad Simón Bolívar.

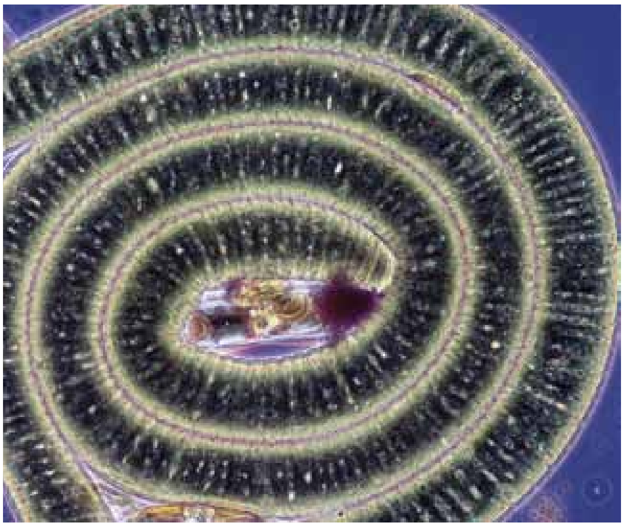
The role of biodiversity in the delivery of these ecosystem functions that underpin the many ecosystem services that benefit humans is thought to be crucial but largely unknown for marine systems, despite excellent examples of species loss or overexploitation of marine resources compromising important services and functions (such as collapse of fisheries, erosion of shorelines, or dead zones).

In the last decade, marine scientists shifted their focus to understanding how biodiversity and ecosystem function are related to ecosystem services and therefore, ultimately, to human well-being. The goal of this new research initiative is to predict "which", "when", and "where" biodiversity loss, from genes to species to ecosystems, is likely to compromise ocean functions and services and ultimately the planet as a whole. This means filling in the large gaps in our knowledge about which species—some still unknown to science— occur in which environments and what they do in the ecosystem through their complex life cycles.

Scientists investigating the connection between biodiversity and ecosystem functions and services are banding together to address concerns of altered ecosystem functions and services over large time and spatial scales that are particularly urgent for a changing global ocean. We must identify the baseline functions provided in different ecosystems and which species provide them. Simultaneously we can capitalize on new ocean observation tools to identify changes quickly and effectively, whether they involve anthropogenic disturbances, catastrophic and episodic events such as earthquakes, tsunamis, underwater landslides, and blooms of toxic algae and jellyfish. We aim to investigate global marine ecosystems and their life to address the following key questions:

- Can we link and predict changes in biodiversity and ecosystem functions with global change and anthropogenic impacts?
- How is biodiversity linked to ecosystem services?
- Are diversity hot spots also ecosystem services hot spots?
- How do species of differing sizes (from microscopic to large) interact, from the shallow ocean to the deep?
- Which functions and services are most vulnerable to loss, and which can be restored?
- How can we monitor the loss of functions or services in marine ecosystems?

Current environmental policy and legislation at local, national, and international levels rarely take into account this ecosystem-based view of life in the global ocean and how it affects humankind. It is our hope that through new research linking biodiversity and ecosystem functions and services we will provide policy makers with the necessary information to reduce and halt declines in ocean and human health, to increase ocean sustainability, and to provide the knowledge needed to improve degraded environments where key functions and services have been lost. This knowledge is vital to effective spatial planning and sustainable ocean use.



Possibly up to a billion kinds of microbes inhabit the global ocean, and by weight, comprise up to 90 percent of marine biomass. Their roles in ecosystem functions and services are many and varied, most important being their roles in key nutrient cycles in the global ocean, with much more to be learned about how they help to maintain balance. This photosynthetic cyanobacterium *Lyngbya*—about a half millimeter long—serves as an example of the beauty, variety, and uniqueness of the ocean's hidden majority.
Credit: David Patterson, MBL, used under license.

Bluefin tuna, *Thunnus thynnus,* are highly prized fish that have fed human populations around the world, a vital ecosystem service. As a result of their popularity, numbers are decreasing and many international initiatives have been proposed to manage stocks to help ensure their survival.
Credit: Richard Hermann, Galatée Films.

BIODIVERSITY IN OCEAN SPATIAL PLANNING

The first global baseline of information on marine life provided by the *Census of Marine Life* offers a snapshot against which changes in marine biodiversity, distribution, and abundance can be measured. The baseline is timely amidst increasing human impacts that compromise the health of ocean ecosystems. Even with a baseline, however, much remains unknown about life in the global ocean. The vast water column and deep seafloor, the largest habitats on the planet, remain largely unexplored and uncharted. Yet our limited knowledge suggests that these habitats support a rich diversity of species intermingled with valuable biological and mineral resources and provide important ecosystem services. Some coastal areas are better known, but knowledge of other more remote areas remains poor, including polar regions, eastern Africa, and large parts of the Indian and Indo-Pacific Oceans. In all ocean habitats, knowledge is concentrated within the most visible taxonomic groups, such as fish and large vertebrates, crustaceans, molluscs, and plants. Our knowledge of smaller organisms is scant, despite indications that many are important to ocean health. These gaps in our knowledge point to the need for improving regional lists and maps of known and newly discovered species along with basic knowledge of their biology and ecological role, information on species migration and population connectivity, and greater knowledge of poorly known or sensitive habitats, including areas in the high seas or outside of national jurisdiction, which can be derived from global ocean observation activities.

Organisms move at different stages of their life, either actively through migration or passively with currents, or in response to environmental changes caused by human activities, such as changes in water temperature and acidification that are resulting from climate change. These movements, regardless of cause, play a critical role in how ocean ecosystems function. On the one hand, larvae and highly migratory species often move across international boundaries unimpeded, presenting tremendous challenges for marine managers. On the other hand, managers must also consider strategies to minimize the impact of heavy trawling gear and other human activities that damage sessile and often sensitive seafloor fauna such as corals and sponges, which provide habitat for a wide range of other species. Improved global and regional oceanographic datasets now allow the development of predictive relationships between organisms and their surrounding environments. For

In the Southern Ocean, Weddell seals, *Leptonychotes weddellii*, and other large marine animals have been equipped with electronic tags that allow scientists to examine the state of the ocean on a continuous basis in near real time, providing a means to construct the past, current, and future models of high use habitats for highly migratory species. Credit: Daniel Costa, University of California, Santa Cruz.

Obtaining robust data on larval ecology and their colonization potential is essential to understand the maintenance of populations and the relative isolation of habitats such as canyons, cold-water corals, seamounts, hydrothermal vents, or cold seeps. Larval ecology remains a major challenge, however, due to the obstacles presented by the microscopic size of larvae and the complexity of the processes taking place in the vast open sea. Shown are *Lamellibrachia luymesi* tubeworms from cold seeps in the Gulf of Mexico. Other *Lamellibrachia* species are also found at hydrothermal vents. Credit: Chuck Fisher, Pennsylvania State University.

example, improved understanding of animal behaviors and related ecological patterns is enhancing our capacity to model movements of animals such as tuna, billfish, marine turtles and sharks, and to integrate that knowledge with oceanographic and statistical fisheries data, providing a means to better predict animal movement in the face of climate change, and manage fisheries, reduce bycatch, and preserve stocks. This knowledge is also proving crucial for developing sound management and conservation strategies such as Marine Protected Areas.

New Geographic Information System (GIS) and modelling tools tailored for biodiversity and for marine resource decision makers will help revolutionize how new data can be used in practical ways. These tools, with additional information from marine research, can differentiate spatial changes in marine ecosystems caused by natural events largely beyond human control (tsunamis, hurricanes, and underwater landslides) from those caused by human activities (oil spills, fisheries, hydrocarbon and mineral exploitation, and litter) that can be managed effectively with sufficient knowledge and motivation. They can also illustrate competing uses of the marine environment (transportation, fishing, recreation, and conservation) and quantify their effects on the ecosystem and its inhabitants. Such information is critical for developing new models of ocean governance that can mitigate impacts, help restore ecosystems, and provide for sustainable ocean use.

The knowledge gained from biodiversity data will address the following key questions:

- How and where do human impacts affect environmental variables that influence the movements/distribution of marine life and, in turn, ocean ecosystem services?
- Can we use knowledge from well-known regions to predict species distributions, biodiversity patterns, and hotspots in lesser-known regions by relying on easily measured predictors that quickly characterize large ocean areas?
- How do movements of species connect ocean locations and populations of organisms and how can that knowledge advise conservation and management?
- What information about individual and overlapping impacts and their severity on marine species will facilitate ocean management and spatial planning?
- Where are high priority areas for marine management and conservation based on diversity, productivity, and size of critical habitat?

Marine polar biodiversity is under growing pressure from both climate change and resource development. A decrease in ice cover is already diminishing the habitat of polar bears, *Ursus maritimus*, and further decreases will allow more shipping along the Northwest Passage and subsequent increases in the potential risk of oil spills, introduction of alien species, and the exploration and exploitation of seafloor resources. These last pristine areas are under threat and our knowledge of species and ecosystem function and resilience is very limited. Without better knowledge, it will be difficult to craft sound management actions for these under-explored regions. Credit: Rolf Gradinger, University of Alaska, Fairbanks.

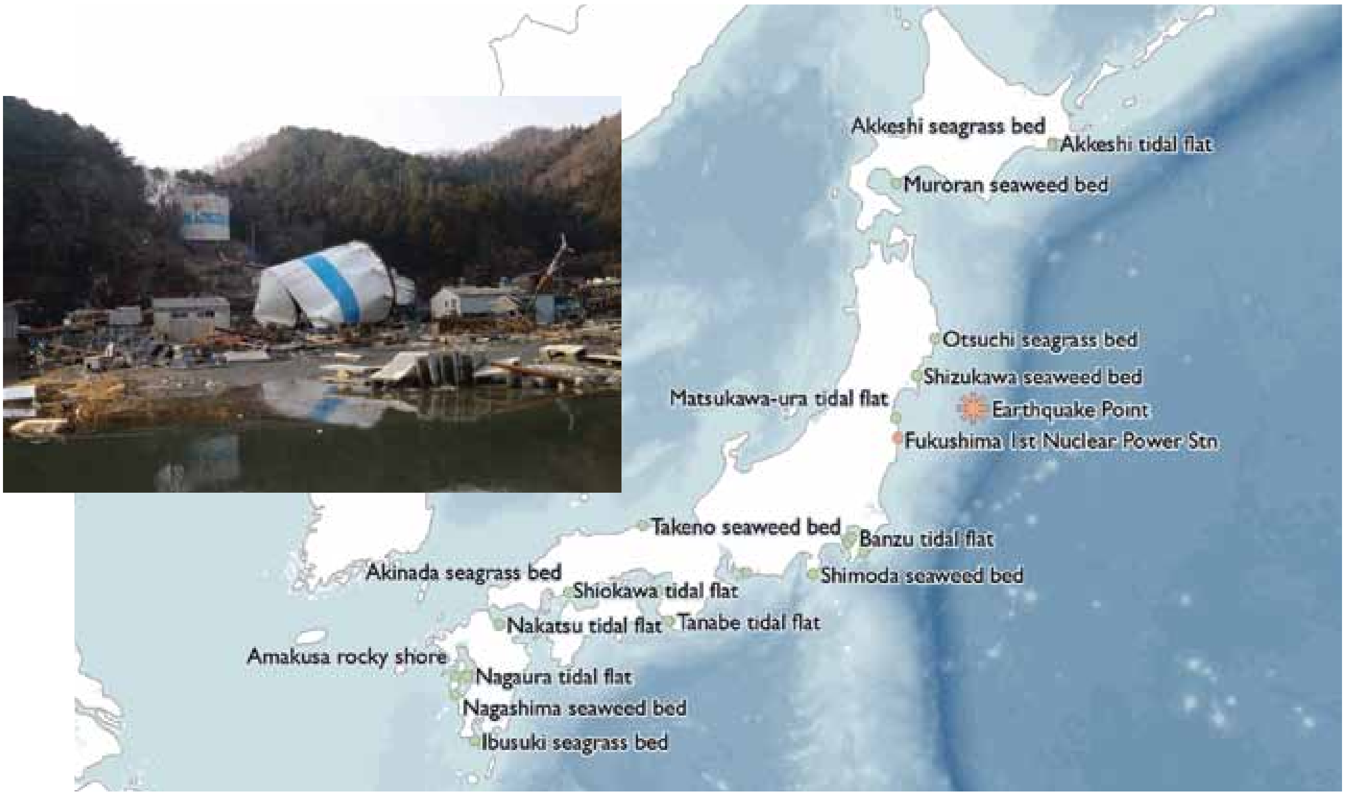
BIODIVERSITY OBSERVATION

The ocean covers 71 percent of Earth and provides 99 percent of the planet's living space by volume. Although the first *Census of Marine Life* provided a baseline of diversity in what should be called "planet Ocean," much remains unknown because a vast part of the ocean is very deep, dark, and remote, and therefore difficult to observe. Because marine biodiversity is vital for maintenance and resilience of the global ocean and human impacts on the ocean continue to expand, it is necessary to quantify biodiversity status and trends. The ability to quantify changes over time facilitates management efforts to recognize early warning of ecosystem changes including the arrival of non-native, invasive or toxic species, or declines in species important for the ecosystem or for the services they provide.

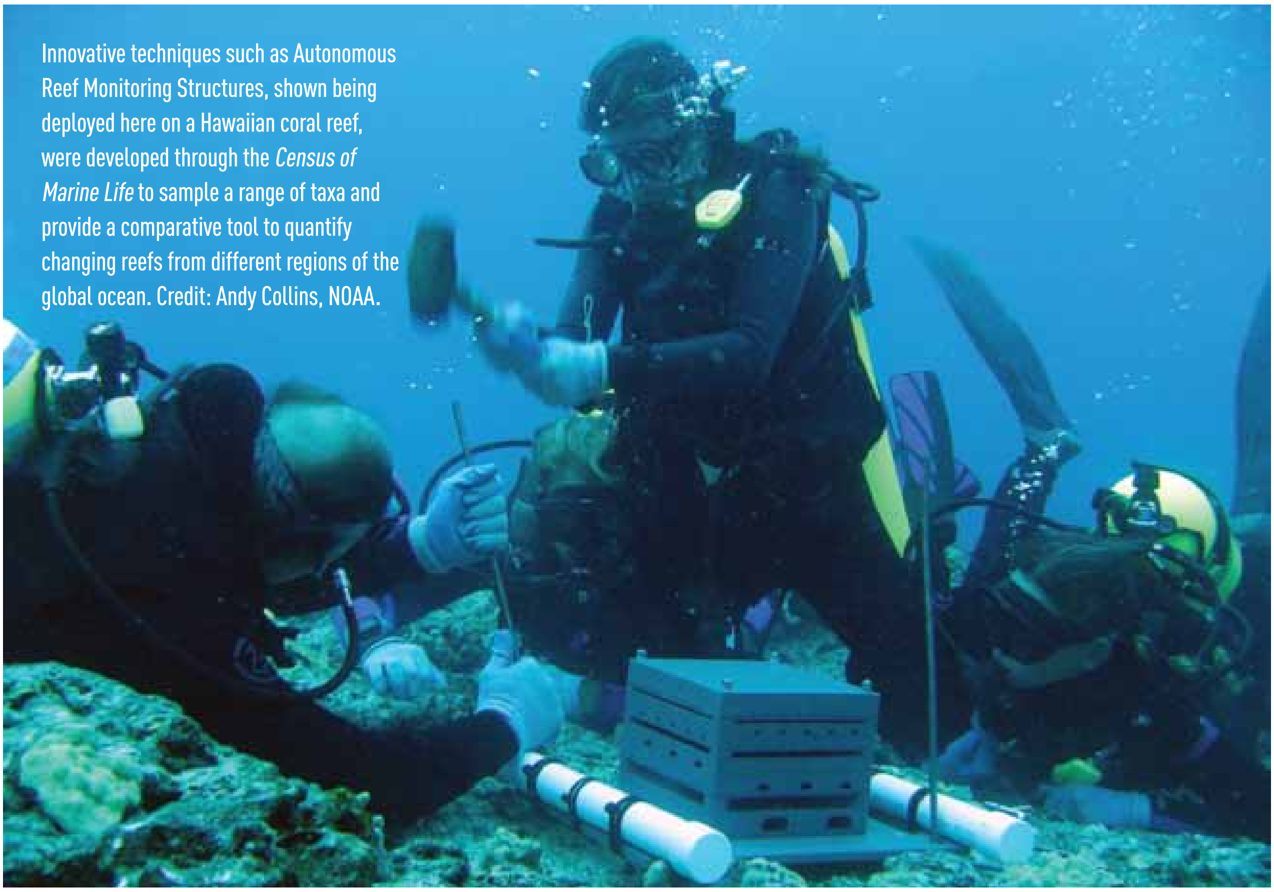
Ocean observations are currently limited in time and space and many changes go undetected or are only recognized long after they occur. The vast majority of what is known about biodiversity comes from studies focused on the coastal and continental shelf near human populations. The number of marine biodiversity observations declines with distance from land and the ocean surface. Unlike ocean temperature, which is easy to measure and model, biological change over time is currently difficult to measure and predict, and few scientific programs support long-term marine biodiversity observations.

Biodiversity observations have typically focused on species we exploit (i.e., commercial fisheries), but ignored environments or organisms that do not have clear economic value. Yet, marine organisms provide important roles beyond their immediate economic value by helping to keep the ecosystem functioning and supplying many valuable ecosystem services. These services extend from helping to regulate climate to improving our quality of life by stabilizing coastlines and breaking down pollutants, to name just a few. Changes in some environments, such as in the Arctic and coral reefs, and the presence or absence of organisms that identify a specific environmental condition or change can serve as early warning signs regarding current or potential trends, providing living gauges ("life gauges") to monitor ecosystem changes.

Biodiversity observations will be most valuable if a wide range of organisms (microbes to mammals) and habitats are sampled at meaningful time scales. Sample processing, including identifications of organisms, standardized data management and interoperability, and training must be coordinated to achieve a truly global view. Technology innovation and implementation, such as the use of molecular barcoding and environmental gene surveys,



The *Census of Marine Life* initiated long-term global nearshore biodiversity observations that can inform changes in species composition and abundance over time. Japan has committed to continue these observations along its coast for the next 100 years, creating a unique opportunity to measure changes in biodiversity associated with climate change and natural disasters, including the recent tsunami. The green dots above show the location of key marine ecosystem monitoring sites that were in the vicinity of the 11 March 2011 tsunami. The tsunami's aftermath in the vicinity of the Onagawa Marine Lab at Tohoku University are shown in the inset. Credit: Yoshiyuki Suzuki, Onagawa Field Center, Tohoku University.



Innovative techniques such as Autonomous Reef Monitoring Structures, shown being deployed here on a Hawaiian coral reef, were developed through the *Census of Marine Life* to sample a range of taxa and provide a comparative tool to quantify changing reefs from different regions of the global ocean. Credit: Andy Collins, NOAA.

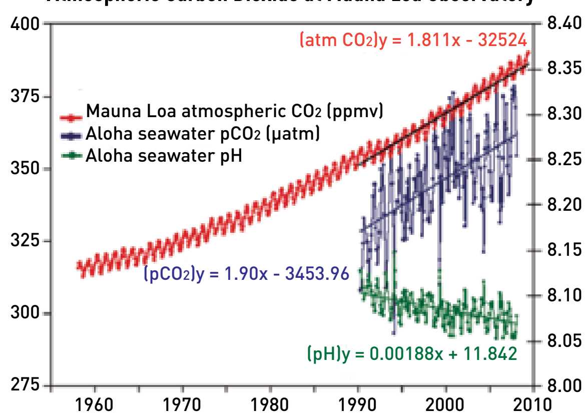
will also be required to simplify exploration, automate sampling, and enhance identification of collected specimens. Data will be useful to the widest array of users if computer software and visualization tools can integrate large datasets from around the world seamlessly and easily. This data, deposited in the Ocean Biogeographic Information System (OBIS) for global access and use, will provide an invaluable legacy for future generations of marine scientists performing ecosystem-based biodiversity assessments and policy makers working toward a sustainable ocean environment.

Many of the technologies to observe biodiversity exist or are within reach, but require investment and coordination to employ them most effectively for the purpose of long-term data gathering. Without this capacity, we lack basic information for immediate management needs and the ability to detect and quantify changes in the future.

Key questions that can be answered through biodiversity observations include:

- How does species diversity, distribution, and abundance vary over time and as organisms move?
- Does diversity influence an ecosystem's capacity to resist or recover from disturbances, from pollution to tsunamis?
- How does biodiversity respond to global climate changes (warming, acidification), and other human influences? What are the consequences for ecosystem function?
- Are there "early warning organisms" that might allow time for mitigating actions?
- What information is needed from biodiversity observation to predict future changes in composition, distribution, and abundance of marine life in the global ocean?

Atmospheric Carbon Dioxide at Mauna Loa Observatory



Long-term observations from Hawaii clearly show increased carbon dioxide in the atmosphere (red line), which has increased the carbon dioxide in the ocean (blue line) and therefore increased ocean acidity (shown as decreasing pH in green). Thus, vulnerable organisms such as coral must not only cope with ocean temperatures that can exceed their tolerance, but also deal with loss of skeletal structure from acidification. These data clearly show the alarming changes in ocean chemistry that confront marine ecosystems. Marine biodiversity data of this type are almost completely lacking, and highlight the need for sustained observation of life in a changing ocean.Credit: Feely *et al.* [2009]. *Oceanography* 22(4): 36–47.

BIODIVERSITY AND SUSTAINABLE OCEAN USE

An expanding human population is affecting life in the ocean. As fishing, energy development, mineral extraction, shipping, and other ocean uses increase to meet human needs so do their impacts on marine biodiversity and marine ecosystems. Human activities near the coast and discharge of greenhouse gases globally also are greatly affecting life in the ocean. Recent studies indicate that human intervention has resulted in the global decline of top marine predators by over 95 percent and consequent changes in the food web and availability of commercially important fish, leading to serious socioeconomic implications for coastal communities. Human-mediated invasion of non-native species has intensified in recent decades with a new invasion front currently moving towards the open ocean. Temperature shifts in the water due to climate change are causing other species to move from warm tropical waters toward warming temperate zones, with implications for those ecosystems. Areas of the global ocean are affected by increased acidification as a result of absorbing carbon dioxide from the atmosphere, which reduces the ability of marine organisms to build skeletons. Human population increases and declining resources on land, particularly in coastal regions, are pushing ocean exploitation to increasing depths, affecting poorly known and often fragile ecosystems. As a consequence of these ever-increasing human demands, marine populations and ecosystems are less able to withstand and recover from human-induced changes and climate change.

The ocean is changing, and in some cases the changes are rapid. We are just beginning to appreciate the potential consequences of both the introduction and removal of living marine resources. While we know that non-native species can prompt changes at the genetic, population, and even ecosystem-wide levels, much more information is needed to gauge the consequences of human activities on marine life and the sound functioning of marine ecosystems. Current and emerging technologies for oil, gas, and mineral extraction,

In 1958, after an excursion on a Key West (Florida, USA) charter boat, a family of recreational fishers displayed their trophies, especially large groupers, subfamily *Epinephelinae*. In 2007, the size of the fish displayed by the same charter enterprise had plummeted, and the mix of species had changed. Credit: Monroe County Library (top) and (right) Loren McClenachan, Simon Fraser University.

especially in deep-sea habitats, are increasing the availability of these resources to human exploitation, with unknown consequences for the viability of these remote and unique, ecosystems, which are part of the interconnected ocean. New pollutants and synthetic substances continue to enter the ocean, but knowledge of their effects on marine biota is limited. The timeliness of learning more and enhancing our ability to predict consequences of actions is illustrated by recent research that suggests that the nature and scale of different human stressors have a greater impact when they act in concert, rather than individually. This is particularly worrisome when considering how the effects of climate change interact with other human-induced changes, with unknown cumulative impacts on marine species and ecosystems.

Several regional and global initiatives are working to establish policies to restore damaged habitats and recover depleted species and populations. To achieve these targets and develop credible plans for a sustainable global ocean will require not only learning from the past, but also continuing exploration and expansion of what is known about ocean life, its vulnerability to multiple threats, and sharing of this critical knowledge with decision makers and broader groups of stakeholders. *Life in a Changing Ocean* will provide scientific information needed for these tasks, as well as a synthesis of lessons learned from past application of fisheries and marine resource management and conservation strategies. This new knowledge will prove useful to management and decision making bodies, providing a better understanding of the effects of human activity on marine biodiversity and subsequent consequences for sustainable use of the ocean.

Increased knowledge and implementation of ocean spatial planning and observation tools provide a path forward toward ensuring the maintenance of ecosystem functions and services upon which life on Earth depends.

The impacts of resource exploitation and other human-induced changes on marine biodiversity and the sustainable use of the global ocean will be investigated through the following key questions:

- How do climate change and other human pressures interact to influence marine biodiversity, and on what spatial and temporal scales?
- How do these effects vary among different species, assemblages, and ecosystems?
- Why do some strategies succeed while others fail in efforts to recover decimated populations and ecosystems?
- How do these strategies vary for different species and ecosystems?

Above: This assortment of marine litter was collected at 2,000 meters depth in the western Mediterranean, illustrating that human impacts extend well beyond the coastal zone and even into remote deep-sea habitats. Credit: Eva Ramirez-Llodra, Institut de Ciències del Mar, CSIC.

Left: Beauty can be deceiving. These brightly colored non-native red harpoon weeds *(Asparagosis armata)*, originating from New Zealand, entered the Mediterranean Sea by the Strait of Gibraltar. In its new environment, this alien species competes for resources with native organisms. Credit: Mario Cormac, Università di Catania.

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Sea nettles, *Chrysaora fuscescens*, Monterey Bay California, October 2007. Credit: Richard Herrmann, Galatée Films.