

Science integration into US climate and ocean policy

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The pace of environmental change lends urgency to the need for integration of climate considerations into ocean policy and management. A recent rapid expansion of ocean and climate policies provides a timely window of opportunity for the scientific community to inform and support these efforts. Lessons can be learned from successful initiatives, where scientists are working hand-in-hand with decision makers and managers to enhance ocean resilience. Looking ahead, the most pressing decision-needs associated with oceans and climate change should serve to prioritize and drive scientific efforts.

We live on a blue planet. The oceans cover 71% of Earth's surface and contain 97% of the planet's water. Oceans provide many critical services on which people depend, including jobs in fishing and tourism, places for recreation and enjoyment, opportunities for commerce and transportation, global climate regulation, and carbon sequestration¹. Globally, seafood provides nearly two billion people with almost 20% of their intake of animal protein². Oceans are inherently linked to economic productivity and to the vibrancy of coastal communities. The ocean and coastal economy contributed 2.8 million jobs and over \$282 billion to the US gross domestic product in 2011³. In the United States, coastal watershed counties make up only 18% of the nation's land area, but are home to more than 50% of US citizens⁴.

However, oceans are threatened by the impacts of climate change and acidification, which have already affected ocean health^{5,6}. These changes are compromising the ability of oceans to provide valuable ecosystem services, with ecological and socio-economic consequences⁷. Now and in the coming decades, the impacts of climate change on global oceans will lead to numerous challenges for sectors such as natural resource management, energy production, human health, transportation and national security^{8–10}. These changes could drastically impact ocean services, as well as the societies that depend on them.

Science is playing an increasingly important role in informing policy and management of the world's oceans. The realization that oceans are rapidly changing^{11,12} has prompted calls for better international collaboration, integration across scientific disciplines and strengthened partnerships across ocean science, management and policy communities. Nevertheless, despite increasing political interest in the expanding body of knowledge on the impacts of climate change and ocean acidification, scientific understanding is often not reflected in policy and management decisions, and misperceptions among both scientists and decision makers impede the two-way exchange of information. In many instances, decision makers and managers lack access to scientific information that meets their specific needs, or they may expect information with higher certainty or resolution (for example, local-scale projections of climate and sea-level rise) than is feasible or necessary for addressing their planning needs. Conversely, scientists often view the pathway from basic research to enactment of policy as opaque and frustrating, and

academic researchers, in particular, frequently are not encouraged, and do not always understand if and how, to engage in the policy dialogue. There is often a misperception that details and caveats inherent in scientific studies and models render such information useless in the policy-making process, a factor that, ironically, may have resulted from the lack of effective dialogue between scientists and decision makers in the first place. Such disconnects can hamstring efforts to develop and implement climate adaptation policies and practices based on best-available science.

Ocean management needs to become more climate-smart; in other words, it needs to reflect and integrate current and projected impacts of climate change. This depends on multiple forms of scientific information that are spatially and temporally relevant and easily accessible, consistent methodologies that allow for cross-study comparisons, policies that reflect scientific understanding and are sufficiently flexible to accommodate uncertainty, and meaningful engagement across multiple sectors of society.

The need for improved partnerships between scientists and society has been raised numerous times in recent decades^{13,14}. Innovative partnerships have been put into place to address this need and to enhance coordination and inform decision making. As a result, policies and practices are beginning to more accurately reflect scientific understanding. This provides an unprecedented chance for action, as the scientific understanding of climate impacts on oceans has improved, policies that depend on best-available science are being developed and early efforts to integrate climate information into ocean management provide transferable lessons learned.

Here, we discuss emerging US science and policy initiatives associated with enhancing ocean resilience to climate change. In addition, we describe several examples where climate information has successfully been incorporated into ocean policy and planning efforts. Finally, we articulate opportunities for advancing partnerships between scientists, policy makers and society to address ocean and climate issues.

Policy initiatives

In the United States, an increasing spotlight on the importance of marine resources and ocean ecosystem services has led to a number of recent national-level initiatives with relevance to climate-related ocean change. Examples include the National Fish,

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Table 1 | Emerging landscape of national and federal US climate adaptation and ocean science policy initiatives (modified from ref. 15).

Initiative	Description	Status and timeframe	Information
National Climate Assessment	The US National Climate Assessment (NCA) is required by law (Global Change Research Act of 1990) to be conducted every four years. The NCA assesses the impacts of climate variability and change across US regions (including coasts and oceans) and sectors and projects major trends over the subsequent 25 to 100 years.	Major technical input reports on coasts and oceans and marine resources, developed as contributions for the third NCA, were published in Spring 2013. The third NCA report, including the first-ever chapter on oceans, was released in May 2014. Over 240 authors were involved in the report development.	http://www.globalchange.gov/what-we-do/assessment
Interagency Working Group on Ocean Acidification	The Federal Ocean Acidification Research and Monitoring Act (FOARAM Act) of 1990 directed the creation of an Interagency Working Group on Ocean Acidification (IWG-OA), the development of progress reports, a strategic research plan for federally funded ocean acidification research and monitoring activities, and the formation of a National Oceanic and Atmospheric Administration (NOAA) Ocean Acidification Program.	The NOAA Ocean Acidification Program was established in May 2011 and serves as a platform for advancing ocean acidification research and engagement. The IWG-OA has released two progress reports, which include summaries of federally supported ocean acidification research and monitoring efforts, for Congress. The Strategic Plan for Federal Research and Monitoring of Ocean Acidification was released in March 2014.	http://oceanacidification.noaa.gov/IWGOA.aspx
National Ocean Policy	The National Ocean Policy was established in July 2010 under Executive Order 13547 to create an integrated framework for the stewardship of US oceans, coasts and Great Lakes.	An implementation strategy was released in April 2013, including a set of interagency actions and milestones focused on enhancing the resilience of oceans and coasts to climate change and ocean acidification.	http://www.whitehouse.gov/administration/eop/oceans/policy
National Fish, Wildlife, and Plants Climate Adaptation Strategy	The National Fish, Wildlife, and Plants Climate Adaptation Strategy was initiated through Congressional directive in 2009. The strategy provides a blueprint for coordinated, national action among US federal, state, tribal and non-governmental entities to safeguard valuable natural resources, including marine resources, against a changing climate.	After extensive public review and comment, the strategy was released in April 2013. A Joint Implementation Working Group has been formed to oversee strategy implementation.	http://www.wildlifeadaptationstrategy.gov/index.php
Interagency Climate Change Adaptation Task Force	The Interagency Climate Change Adaptation Task Force (ICCATF) was initiated in Spring 2009 to advance US federal leadership on climate adaptation. The ICCATF was composed of over 20 federal agencies and executive branch offices, involved over 300 federal employees, and delivered two progress reports. One outcome of this effort was a mandate under Executive Order 13514 for all federal agencies, including those with ocean-related responsibilities, to develop adaptation plans.	The first-ever federal agency adaptation plans were submitted in June 2012 and released for a public comment period from February to April 2013. Agency adaptation plans are now being updated and expanded under the President's Climate Action Plan.	http://www.whitehouse.gov/administration/eop/ceq/initiatives/adaptation
President's Climate Action Plan	In June 2013, President Obama announced the Climate Action Plan, including a series of executive actions to reduce carbon pollution, prepare the United States for the impacts of climate change, and lead international efforts to address global climate change. The plan was followed by Executive Order 13653 on climate preparedness. Several ocean-related actions were included in the plan and executive order, such as conserving land and water resources and identifying vulnerabilities of key sectors (including oceans) to climate change.	Executive Order 13653 includes an action on 'Managing lands and waters for climate preparedness and resilience', which calls for an inventory and assessment of proposed and completed changes to agencies' policies, programs and regulations necessary to enhance resilience of natural resources in the face of climate change. An NCA technical input report on oceans and marine resources ¹⁵ serves as an important contribution to the plan's action on identifying vulnerabilities of key sectors to climate change. Additional ocean-related contributions to the Climate Action Plan will be developed in the coming months and years.	http://www.whitehouse.gov/share/climate-action-plan

Wildlife, and Plants Climate Adaptation Strategy, the Interagency Working Group on Ocean Acidification, the Interagency Climate Change Adaptation Task Force, the National Ocean Policy and the President's Climate Action Plan (Table 1). In addition, existing US federal laws, such as the Clean Water Act, the Endangered Species Act, the Federal Ocean Acidification Research and Monitoring Act, and the Magnuson-Stevens Fishery Conservation and Management Act, are being applied to manage the impacts

of climate change and acidification on ocean waters¹⁵. New climate-smart policies and practices that reflect the need for sustainable ocean management in a changing climate are being developed and implemented. Collectively, these initiatives provide a framework for planning and action, with the goal of enhancing climate resilience.

Ocean adaptation (that is, preparedness and resilience) efforts may include integration of climate information into stewardship

Box 1 | National Climate Assessment (NCA) efforts related to coasts and oceans.

- Two relevant comprehensive syntheses and assessments were developed as technical inputs to the third NCA report:
 - ‘Oceans and marine resources in a changing climate’¹⁵ authored by a team of 63 scientists, led by the National Oceanic and Atmospheric Administration (NOAA). The report addresses the impacts of climate change and ocean acidification on US ocean physical, biological and social systems.
 - ‘Coastal impacts, adaptation, and vulnerabilities’³⁶ authored by a team of 79 scientists, led by NOAA and the US Geological Survey. The report articulates major climate impacts on coastal ecosystems’ economies and communities.
- The third NCA report¹⁸ includes a chapter on ‘Oceans and marine resources’ and a chapter on ‘Coastal zone development and ecosystems’. These chapters articulate key findings and vulnerabilities associated with climate impacts on oceans and coasts, respectively.
- A set of global sea-level rise scenarios³⁷ was developed as input to the NCA; the scenarios include estimates of future increases in global average sea level up to 2100, as well as descriptions of selected regional and local differences from the global trend.
- The sustained NCA process will include the development of a national system of climate indicators, planned for launch in a pilot phase in summer 2014. As part of this effort, an oceans and coasts technical team has been formed to identify climate-sensitive indicators of relevance to marine resource management and decision making. Information available at: <http://www.globalchange.gov/what-we-do/assessment/indicators-system>
- The NCAnet, a network of more than 80 organizations (for example, research institutions, non-governmental partners, government agencies, professional societies) working with the NCA, has been established to engage producers and users of assessment information across the United States. The NCAnet includes an affinity group on coasts, oceans and marine resources to advance ocean science and stewardship through application of NCA findings. Information available at: <http://ncanet.usgcrp.gov/>
- The NCA, in partnership with NOAA, held a workshop in April 2013 to bring together federal, state and tribal governments, academic institutions, and non-governmental organizations to discuss opportunities and needs, including science gaps and decision needs, associated with sustaining national climate assessments of coasts and oceans. Workshop report available for download at: http://downloads.globalchange.gov/nca/townhall_reports/Oceans_Coasts_Workshop_Report.pdf

and management practices, reduction of non-climatic stressors (for example, nutrient pollution, destructive fishing processes) to enhance ecosystem resilience, and working with natural resource-dependent communities to raise awareness and address current and future climate impacts, among other approaches¹⁶. Relatively few climate adaptation actions have been developed for marine systems, when compared with terrestrial systems¹⁷, so land-based efforts can provide transferable methods and valuable insight. Opportunities currently exist where there is sufficient scientific information to develop management actions that reduce current and future impacts of climate change and acidification on oceans. Even in cases where considerable uncertainty exists, flexible policies and practices can be developed that include guard rails to encompass variability and the potential for different futures; these policies can evolve as new scientific understanding emerges.

Below, we describe several examples where climate information is being advanced and/or integrated in support of sustainable coastal and ocean management. These cases focus on different mechanisms — scientific assessments, the development of early-warning systems and long-term planning — for advancing consideration of climate information for decision making. Each of these examples highlight processes in which scientists and decision makers are working together to support and inform the development of policies and practices, providing useful lessons for how such collaborative efforts can be leveraged in other areas.

Climate assessments. Both scientific advancement and the development of effective policies require periodic evaluation of the current state of knowledge and the identification of information needs and gaps. Decision makers often look to assessments as trusted sources of information to support planning and policy development. Climate assessments convene groups of scientists, occasionally in partnership with decision makers, to analyse and communicate the most recent science associated with past, current and/or future climate change and associated impacts. The products of assessments can serve as the current state of knowledge and function as

go-to sources of best-available information for experts from a wide diversity of backgrounds. They also offer insights into where critical knowledge gaps exist, thus providing a means for prioritizing paths forward. To date, assessments of ocean climate impacts have been relatively rare, especially in the United States, and many of those conducted have not been developed with the primary goal of informing societal decisions.

The most comprehensive climate assessment process in the United States is the National Climate Assessment (NCA), which is mandated by the Global Change Research Act of 1990 and conducted under the auspices of the US Global Change Research Program. The NCA reviews the current state of the knowledge on climate change, investigates impacts already being observed in specific sectors and regions, and anticipates trends for the next 25 to 100 years. The goal of the NCA is to inform the efforts of decision makers, communities and businesses working to enhance the resilience of the nation to climate change.

The third NCA, released in May 2014, is the most integrative and comprehensive US climate assessment to date¹⁸. The third NCA process differed markedly from previous US climate assessments in three important ways: (1) the NCA covered new topics, including a chapter specifically addressing oceans and marine resources, that had not been explicitly addressed in previous NCA reports; (2) the report included assessment of societal responses to climate change through adaptation, mitigation and decision support; and (3) this NCA was designed to evolve into a sustained, forward-looking process, as opposed to a periodic, report-writing activity. A number of ocean-related activities and products have contributed to and stemmed from the third NCA report (Box 1), and oceans are an important theme of emerging efforts associated with the development of a sustained NCA process that looks beyond the third NCA report (Box 1). The NCA is a substantial effort that has already reached hundreds of experts (800+ were called on to participate in the third NCA report). The NCA will continue to serve as a platform for communication of knowledge and collaboration among diverse stakeholders in the coming years. While the NCA is not the only US

Box 2 | Impacts of a 2012 heat wave on the Gulf of Maine lobster fishery.

An unusually warm summer in the Northwestern Atlantic offers insights into the impacts of extreme events on marine ecosystems. In the summer of 2012, water temperatures in the Gulf of Maine were 1–3 °C higher than the 1982–2011 average climatology³⁸, stimulating lobsters to molt earlier and grow faster in shallow coastal waters³⁹. In normal years, peak harvests in the United States and Canada are offset, as the Canadian fishery closes prior to the peak in the US catch. In 2012, the unanticipated synchronization of peak harvests in the United States and Canada, coupled with the higher rate at which lobsters reached market size, led to a price collapse when supply outstripped demand. As a result, record landings flooded the markets simultaneously in both Canada and the United States. While complex, these physical–biological processes are relatively predictable and could perhaps have been integrated with socio-economic information to support the development of early-warning systems, forecasts and spatially explicit models⁴⁰. Early warning could help to support flexible and responsive management under changing conditions, when possible.



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Figure B2 | Gulf of Maine lobsterman.

climate assessment activity underway, it is the most comprehensive and provides valuable and credible information to support scientific, policy and management efforts at the national scale (for example, Table 1), as well as place-based efforts at local to regional scales.

To ensure that the third NCA was useful for planning and policy development, decision makers were engaged throughout the development of the report, and they will continue to be involved in sustained assessments in future months and years. Federal, state, tribal and local decision makers served in multiple roles, as authors, members of the NCA Development and Advisory Committee, conveners and participants for NCA events in regions across the United States, and partners through the NCA network (NCAnet). As a result, the NCA was shaped by the most urgent information needs articulated by decision makers, including those with ocean management responsibilities. While the NCA process has identified a number of critical knowledge gaps, it has also highlighted that in many cases, scientific knowledge is already sufficient to inform policy development¹⁵.

Early-warning systems. Early-warning systems are an additional mechanism for informing and supporting preparedness for climate variability and change. These systems are designed to enable preparedness and rapid response to weather and climate events and their impacts, even when uncertainty exists as to where and when these impacts will occur over longer timescales. In many regions, mechanisms are in place to detect trends in real time, and capabilities are growing with respect to forecasting extreme events, such as droughts and extreme heat, providing an opportunity to inform management practices (Box 2).

While many citizens typically associate drought with inland areas, recognition of the vulnerability of coastal ecosystems to drought is growing¹⁹. Upriver and inland saltwater intrusion due to reduced freshwater input can affect the coastal flora²⁰, fauna²¹ and aquifers relied on by coastal communities for drinking water²². Despite these impacts, coordinated efforts to study, understand and communicate about drought in coastal areas are currently lacking.

The National Integrated Drought Information System (NIDIS) provides real-time information for the United States by integrating drought information across federal, state, tribal and local levels. NIDIS is currently working through interagency and place-based partnerships to advance the development of Regional Drought Early-Warning Systems (RDEWS) in the United States.

The RDEWS enhance coordination, monitoring, prediction and communication of drought across partners and scales of governance within a region. Seven RDEWS have been initiated to date across the country; two of these pilots include emphasis on coastal drought.

The Carolinas RDEWS pilot project, currently under development, focuses on drought impacts to the coastal ecosystems of North and South Carolina, a region where drought regularly occurs²³ (Fig. 1). The RDEWS is being developed through collaboration between NIDIS and the Carolinas Integrated Sciences and Assessments, a National Oceanic and Atmospheric Administration (NOAA)-funded Regional Integrated Sciences and Assessments program that connects academic and government researchers with stakeholders. To address the need for a comprehensive system of information about drought impacts in coastal areas, Carolinas Integrated Sciences and Assessments has engaged scientists and decision makers (for example, natural resource managers, state and tribal representatives, education and outreach specialists) through interviews, discussions and a workshop to identify key needs, opportunities and vulnerabilities¹⁹. Based on needs identified through this engagement, the pilot project is moving forward with a drought-salinity indicator project and an assessment of ecological indicators for coastal drought, piecing together information gathered from the diverse group of stakeholders involved.

The Carolinas RDEWS pilot is an example of co-production of knowledge; all aspects of these projects are being conducted by, and in collaboration with, people affected by and interested in coastal drought. The pilot has been designed from the outset with the explicit intent of informing drought-related decision making. The methodologies and findings from the Carolinas project are expected to be transferable to other coastal regions in the United States and around the world.

Long-term planning. Scientific information is key to supporting long-range planning for, and management of, climate change impacts on oceans. One tool for long-term conservation of marine resources and associated ecosystem services are marine protected areas (MPAs), which use defined geographical spaces and management of human activities²⁴. Climate-smart MPAs not only seek to improve the long-term resilience of species and ecosystems by ameliorating anthropogenic stressors, but also reflect that sites are not immune from the impacts of climate change. Important to these designs is the challenge of predicting how climate change impacts may occur in space

and time. Many planners have thus moved towards the concept of networks of protected areas, due to the interconnectedness of marine ecosystems and the high spatial and temporal variability in where and when impacts occur²⁵. In other words, even if one portion of an MPA experiences the detrimental impacts of environmental change, other sites may serve as buffers and sources of propagules to repopulate damaged areas. For these networks of MPAs to be successful, basic scientific knowledge on the species and habitats within and near MPAs is needed to understand scales and patterns of factors, such as migration and dispersal, that enhance connectivity and resilience^{26–28}. At least in theory, such a framework is amenable to the incorporation of the impacts of environmental change.

In reality, integration of climate change and ocean acidification is an often-overlooked component of MPA planning processes. Many MPA design and management efforts are still based on the assumption that current climatic conditions will persist into the future. Adaptive management strategies provide an opportunity to improve integration of best-available scientific information into flexible, responsive policy frameworks²⁹. Given that MPA design and management efforts include multiple options for consideration by decision makers, these decisions should be future-proofed as much as possible³⁰ by reflecting potential changing conditions.

While not yet a widespread practice, several long-term planning and management processes are beginning to incorporate climate variability and change. NOAA's Office of National Marine Sanctuaries serves as the trustee for a network of 14 MPAs that encompass more than 170,000 square miles of marine and Great Lakes waters. The Office of National Marine Sanctuaries and the sanctuary sites are advancing initiatives to make these MPAs more climate smart. For example, the Gulf of the Farallones National Marine Sanctuary in California is implementing a Climate-Smart Conservation Program to integrate climate change monitoring, mitigation, preparedness and education into sanctuary management. In 2010, a working group of experts developed a climate change impacts report for the Gulf of the Farallones and Cordell Bank National Marine Sanctuaries³¹. The report identified key issues and vulnerabilities, such as increases in sea level and coastal erosion, reduced runoff of freshwater, increases in surface ocean temperature, range shifts of species (including gray whales and bottlenose dolphins) and other climate-related changes³¹. Informed by the report, the Gulf of the Farallones National Marine Sanctuary is currently in the process of developing a stakeholder-led climate adaptation action plan to respond to, and manage for, the identified climate impacts. These efforts, along with mitigation, monitoring and education initiatives, will form the sanctuary's Climate-Smart Conservation Program, a first of its kind within the National Marine Sanctuary System. The plan will serve as a guiding document for sanctuary managers and partners to ensure long-term viability of the habitats and resources protected by the MPA.

Challenges and opportunities

Large strides have been made in recent years in aligning scientific understanding of climate impacts on oceans with national-scale policies in the United States (Table 1). However, despite progress to date, many challenges to successful coastal and ocean climate adaptation actions still exist¹⁷. Some of these barriers are due to lack of access to usable, policy-relevant information; others are associated with institutional and capacity challenges to implementation, including lack of financial resources, stakeholder awareness, support and engagement^{17,32}. As climate and ocean scientific knowledge grows globally, it will become increasingly overwhelming for ocean resource managers and decision makers to stay abreast of new studies as they emerge and even more difficult to determine what information is the most relevant. Additionally, once usable scientific information is identified, it must be weighed with other decision factors — such as public values, financial considerations, stakeholder needs and feasibility of potential actions³³.

Intensity:

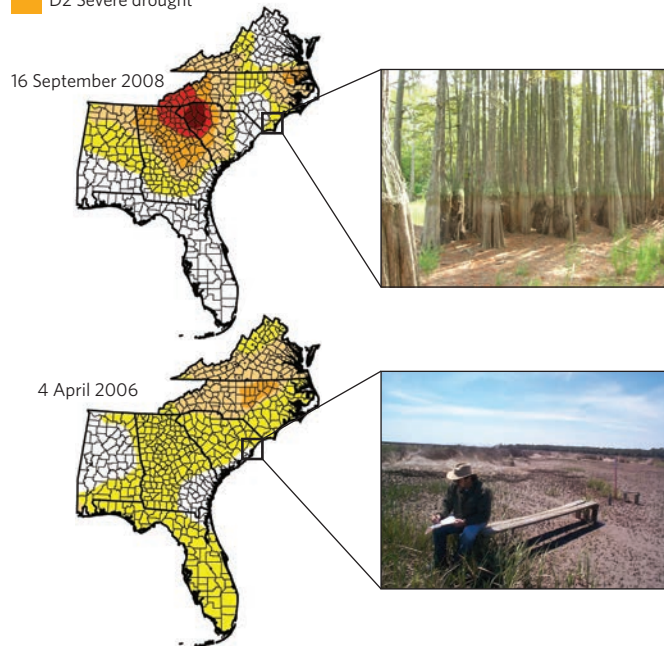


Figure 1 | Images of drought in the US southeast, including the Carolinas.

The maps are images from the US Drought Monitor, jointly produced by the National Drought Mitigation Center at the University of Nebraska-Lincoln, the United States Department of Agriculture and the National Oceanic and Atmospheric Administration. The photographs depict on-the-ground drought for the corresponding time points. In September 2008 (top), the Carolinas were affected by moderate-to-exceptional drought, with impacts on coastal wetlands, as depicted by the normal waterline on a set of cypress trees in Brunswick County, North Carolina. Photo credit: © Dan Tufford¹⁹. In April 2006 (bottom), even abnormally dry conditions resulted in impacts to wetlands, as shown by a dry, exposed salt marsh at North Inlet, South Carolina. Photo credit: © Jim Morris.

These challenges, opportunities and lessons learned are not unique to the United States. Each of the case studies described here has a globally relevant counterpart. In terms of climate assessments, the Intergovernmental Panel on Climate Change's fifth assessment report is the most comprehensive international effort to date, and the Impacts, Adaptation, and Vulnerability Working Group developed a standalone chapter on ocean systems³⁴. The third NCA and the fifth Intergovernmental Panel on Climate Change assessment report were released within months of each other, providing reinforced knowledge to inform domestic and global decisions. For drought early warning, the North American Drought Monitor has been developed over the past decade to enhance collaboration on, and planning for, drought between the United States, Canada and Mexico³⁵. This international effort leverages the US model of information exchange and engagement with decision makers. Opportunities also exist to learn from other countries that have integrated climate information into long-term planning and MPA design and management (Box 3). International collaboration on ocean conservation and management will become increasingly important over coming decades, as impacts such as ice melt and shifts in the distribution and abundance of highly migratory and threatened and endangered species occur.

Scientists have more opportunities now than ever before to contribute to the implementation of climate-smart policies and practices at national and international scales. Through efforts such as

Box 3 | Managing for climate change in the Verde Island Passage (VIP), Philippines.

The VIP is considered an epicentre for marine biodiversity, housing more than 300 species of corals, 1,775 species of reef fishes and a high diversity of mangroves, algae and seabirds⁴¹. Approximately 830,000 people directly depend on the coastal resources of the VIP for their income, livelihoods and food security.

A vulnerability assessment conducted in 2009 showed that the VIP is predisposed to flooding, erosion, siltation and other storm-related damages associated with climate change⁴². In addition, the area is susceptible to potential climate-related changes in oceanic circulation (for example, upwelling). Climate change also has the ability to exacerbate additional threats, such as unsustainable fishing practices, that impact local fish populations.

Findings from this assessment stimulated immediate and substantial actions to increase the adaptive capacity of coastal marine ecosystems and the people that depend on them. Community-based management practices of marine protected areas were modified to include climate change impacts and flexible catch limits. Ecoparks were implemented to supplement livelihoods, and mangrove restoration and rehabilitation projects were initiated to enhance coastal protection and provide habitat. This work has been conducted with communities, government, the private sector and non-governmental partners, and can provide guidance and lessons learned to other nations interested in protecting ocean health in a changing climate.



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Figure B3 | Conservation International staff, local partners and community members plant mangroves in Silonay, Verde Island Passage, Philippines.

the NCA, key ocean and climate knowledge needs have emerged, including: regional ocean projections and scenarios, holistic understanding of the effects of multiple stressors (climatic and non-climatic) on organisms and ecosystems, prediction of tipping points and thresholds in coupled physical, natural and social systems, and advancing understanding of both human responses and adaptive capacity of marine organisms to ocean change. Improving methods for evaluating the effectiveness of adaptation options also remains a challenge¹⁵. There is also a vital need to develop predictive frameworks to allow estimates of when, where and to what magnitude future changes are most likely to occur; such predictions can be difficult given the novel conditions that climate change presents to natural ecosystems.

Coordination and communication between scientists, natural resource managers and other decision makers ensures that the most urgent and relevant information needs are being addressed with respect to understanding and managing for risks and opportunities associated with climate-related ocean change. For example, the NCA Indicator System (Box 1) and the global Ocean Health Index⁶ are using indices that were identified as being directly applicable to scientists, managers, policy makers and the public. Integrative research and modelling efforts, as well as efforts to enhance communication, translation and utility of scientific information, will be necessary for supporting decisions. As exemplified by these US case studies, collaborative efforts involving diverse participants piecing together needs and response strategies are key to advancing integration of climate information into coastal and ocean policy.

While advancing knowledge gaps is critical, simply having more new scientific information is not enough — and is sometimes not necessary — to advance adaptation efforts. In many cases, relevant scientific knowledge already exists but is not being used by decision makers and managers. This is in part an issue of accessibility and usability of scientific information. For example, many potentially useful scientific studies are only published in peer-reviewed journals that most decision makers do not read. Other sources of scientific information may be publicly available but have not been translated into a format that is understandable and usable by non-scientific audiences. Most importantly, there are not enough

sustained interactions between knowledge producers (that is, scientists) and users (that is, decision makers and managers), leading to the potential for misalignment between what is provided and what is truly needed¹⁴. While not all scientists are interested in engaging directly with decision makers, scientists have an obligation to address today's most urgent societal challenges, as well as to interact with members of civil society¹³.

Many options for interaction between the scientific and policy communities exist. Scientists can provide input during public comment periods for government policies and reports, pursue training and practice in communicating science to the media, policy makers and the public, serve on advisory boards and review panels for local, state, tribal and federal efforts, collaborate with managers on research projects, conduct scientific efforts that are designed to be of high relevance to the policy community, and disseminate scientific findings broadly and in formats that are usable by non-scientists. Decision makers can provide input on scientific projects and reports, attend workshops and briefings on emerging advances and technologies, and approach trusted scientists in their regions to work collaboratively on pressing climate challenges. Because the landscape of potential opportunities related to ocean and climate policy is overwhelming, many scientists and decision makers will find it useful to navigate the landscape by connecting through public affairs officers, professional societies, communities of practice and other networks that regularly track and engage in the science-policy interface.

We now have a window of opportunity to connect science and policy to enhance the resilience of oceans to climate variability and change. The emerging policy landscape (for example, Table 1), which reflects scientific understanding of ocean degradation and change, provides a platform for action. Meaningful and sustained partnerships between scientists and society can help to raise awareness, enhance the effectiveness of preparedness and response efforts, and even reverse trajectories of ocean change in the United States and around the world.

Received 1 December 2013; accepted 9 June 2014; published online 30 July 2014

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Acknowledgements

The authors would like to thank the National Climate Assessment Oceans and Marine Resources technical input team and chapter author team, as well as participants in the workshop on 'Sustaining national climate assessments of oceans and coasts', for providing information and perspectives that were instrumental to the development of this manuscript. We also thank F. Choi for his assistance in conceptualization of figures, as well as K. Lackstrom for input on the drought case study. This is publication number 317 of the Northeastern University Marine Science Center. The article contents are solely the opinions of the authors and do not constitute a statement of policy, decision or position on behalf of NOAA, the US government, Conservation International or the South Carolina Sea Grant Consortium.

Author contributions

L.P. and J.H. contributed equally to conceptualization and writing of this manuscript. B.H. helped to develop the concepts for the paper, B.H. and E.F. contributed to writing, and J.H., E.F., B.H., and L.P. led the development of figures and tables.

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Competing financial interests

The authors declare no competing financial interests.