Local solutions to manage the effects of global climate change on a marine ecosystem: a process guide for marine resource managers

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The marine environment plays an important role in controlling the amount of CO_2 that remains within the earth's atmosphere, but it has not received as much attention as the terrestrial environment regarding climate-change effects, mitigation programmes, and action plans. Potential physical effects of climate change within the marine environment, including ocean acidification, changes in winds that drive upwelling and ocean circulation patterns, increasing global sea surface temperatures, and sea level rise, can result in dramatic changes within marine and coastal ecosystems. Often, marine resource managers feel overwhelmed by the magnitude of this issue and are therefore uncertain how to begin to take action. It may seem that they do not have the time, funding, or staff to take on a challenge as large as climate change, and fail to act as a result. Using NOAA's Gulf of the Farallones National Marine Sanctuary as a case study, this paper outlines the need to act now and presents an easy-to-use process guide, providing managers options to incorporate effectively the influences of climate change into management strategies, as well as mitigate these influences through community outreach and a reduction in workplace emissions.

Keywords: action plan, adaptive, climate change, marine, ocean, resource managers, strategies.

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Introduction

The marine environment plays a critical role in controlling the amount of carbon dioxide (CO_2) that remains within the earth's atmosphere, but it has not received as much attention as the terrestrial environment regarding climate-change effects, mitigation programmes, and action plans. The world's oceans, covering 71% of the earth's total surface, have served as a sink for up to 30% of all anthropogenic CO_2 produced since the Industrial Revolution (Raven and Falkowski, 1999). Without the ocean's uptake of carbon, atmospheric CO_2 would be $\sim$55 ppm higher than what it was at the start of the 21st century (Sabine *et al.*, 2004). It is estimated that in the future, the amount of anthropogenic CO_2 emissions produced will far exceed the amount of CO_2 the oceans can absorb because of the inherent slow mixing time of the oceans. On a decadal time-scale, the oceans may become a less efficient sink for CO_2 (Sabine *et al.*, 2004), which means that the amount of CO_2 taken up by the ocean will proportionally continue to decline if atmospheric CO_2 continues to increase.

The increasing amount of CO_2 present in the oceans and the atmosphere has an effect on climate and a cascading effect on the marine environment. Anticipated effects of climate change on temperate ocean systems include rising sea level, higher ocean temperatures, changes in wind and wave activity, altered ocean chemistry, and changes in ocean circulation. In turn, these changes will affect upwelling, salinity, sedimentation, shoreline erosion, and inundation, as well as stratification of the water column. These physical effects could result in dramatic basic changes in marine and coastal ecosystems, such as expansion and contraction of species ranges, changes in local distribution, changes in predator–prey balance, changes in the timing of breeding and migration, alteration of foodwebs, and increases in the type and number of non-native species. Altered ecosystems could result in changing coastal economies through a reduction in marine ecosystem services, such as commercial fish stocks and coastal tourism.

Effects brought on by climate change should be of paramount importance for marine resource managers because climate change poses an overarching cumulative threat to coastal environments already compromised by a variety of other stressors, such as overharvesting, pollution, and habitat fragmentation. For many managers though, it may seem that they do not have the time, funding, or staff to take on a challenge as large as climate change and fail to act as a result. This paper highlights ways marine resource managers can work to provide protection and build ecosystem resilience using a "process guide" (Figure 1) that promotes extensive partnerships and collaborations, the development of a climate-change action plan, the use of adaptive management, managing for multiple stressors, and greenhouse gas emission

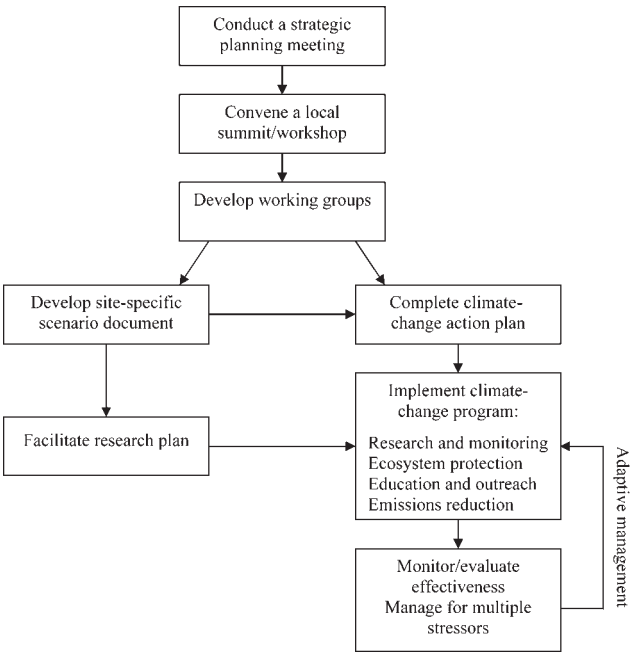

Figure 1. Process guide to manage the effects of global climate change on a local ecosystem.

reduction. The Gulf of the Farallones National Marine Sanctuary (Farallones Sanctuary), one sanctuary within the National Oceanic and Atmospheric Administration's (NOAA) National Marine Sanctuary System, is highlighted as a case study, providing examples of how marine resource managers can effectively incorporate the influences of climate change into management strategies, as well as mitigate these influences through both community outreach and options available to reduce workplace emissions.

Addressing localized effects of global climate change

Resource management choices providing indirect ecosystem benefits

Indirect ecosystem benefits help build resilience within a biological community by providing increased protection from the effects of climate change. This protection is deemed "indirect" as it focuses on engaging humans, ranging from decision-makers to stakeholders and individuals in resource stewardship. Such activities include building a regional constituency of key community members, convening a local summit and/or workshop, establishing topic-based working groups, producing an action plan, facilitating well-communicated science, changing individual behaviour through public outreach, and reducing greenhouse gas emissions at the workplace.

Conduct a strategic planning meeting

One of the most important steps a resource manager could take to prepare for local effects of global climate change is to build a regional constituency to support climate-change solutions. Critical components of this step are first to define the goals, objectives, and mission in addressing the effects of climate change on, e.g. a protected area, then to involve key community members in the clarification of the goals, objectives, and mission. A strategic planning meeting should be convened that includes key federal, state, and local agencies, non-governmental organizations, academia, and other potential partners, funders, or stakeholders, such as foundations and the business community.

Once a mission statement has been clearly defined, broad strategies to address this statement should also be discussed as a part of the strategic planning meeting. Next steps should include: (i) convening a local summit or workshop to create a climate-change site-specific scenario document and explore potential science, outreach, and policy actions; (ii) establishing topic-based working groups to develop and implement more specifically defined strategies; (iii) identifying what agencies or organizations will take the lead in addressing specific issues; and ultimately (iv) producing an action plan containing these strategies. The process can stop at producing an action plan specific to the area of management or, additionally, seek regional collaboration from groups addressing climate change in other areas that will have indirect effects on the area of management. The group may choose to meet periodically as a "regional team" and ultimately combine separate plans into a regional action plan covering, for example, terrestrial, estuarine, and coastal and open-ocean environments.

Convene a local summit and/or workshop

Three options are available that will permit further involvement of local expertise in the development of a climate-change site-specific scenario document and action plan: convening a local summit, holding a workshop, or doing both. Convening a larger summit can provide input from multiple disciplines, including scientists, social scientists, educators, other resource managers, and policy-makers. A summit can serve as an arena to begin developing partnerships that will benefit an ecosystem through shared responsibility and resources (e.g. staff, materials, vessel time). Topics of focus could include potential climate-change effects, current public perception of the influence of climate change on their lives, and existing climate policies for the region. Breakout groups should then be utilized to help further define issues and begin discussing solutions over a broad range of themes, such as community engagement, behavioural change, priority protection and restoration sites, well-communicated science, and the effects of multiple stressors. Organizing a summit would be a more costly option, but funding partners could be sought to alleviate the expenses.

A workshop is a good choice should a more intimate setting be desired, which will first focus on synthesizing observed and predicted physical and biological effects from climate change into a scenario document, before moving forward with outreach, management, and policy strategies. Local experts could be brought together to downscale current global climate-change information through a collaborative effort that would serve as a baseline for management response and prioritization. Such a workshop could be scheduled in conjunction with a summit, held either before or after the summit, to provide greater focus on the physical and biological climate-change effects that will help shape future action-plan strategies.

Develop working groups

One product of the summit and/or workshop should be the creation of topic-specific working groups. Such groups provide expert advice and ensure the participation and support of other agencies and local stakeholders in the design, development, and implementation of a climate-change action plan. Specific needs

for working groups, such as the oversight of, and contribution to, the climate-change site-scenario document, should be identified, along with working groups specific to developing action-plan strategies.

Develop a site-specific scenario and facilitate a research plan

For policy-makers and the public they serve, the issue of climate change is often still met with uncertainty regarding its exact causes, severity, and long-term implications (Arvai *et al*., 2006). The first step a resource manager should take is to facilitate the creation of a climate-change site-specific scenario document, which can then be used to identify information gaps regarding the implications of climate change on the mandated resource. The second is to use this document to facilitate the development of a cohesive research plan to fill these gaps and to identify local research partnerships that can be utilized to divide the production and implementation of this plan into specific areas of expertise. The plan should determine what new monitoring protocols will need to be incorporated into future projects and what existing protocols could be modified to fill information gaps, as well as identify leads for plan implementation.

Because climate change is a complex and multifaceted global issue, the need for well-communicated science is urgent to educate the public, to ensure community support, and to facilitate political reform. As data are generated, it is important to make the information available to the public through reports and peer-reviewed literature. If trends are not reported, policy-makers have no justification for new climate-change regulations. Complex science should also be translated into accessible viewing formats, such as podcasts, websites, and short films. These are the media that resonate with the public, who in turn comprise a policy-maker's constituency. Researchers and educators need to work together to translate climate science into easily understood materials that include an inherent call for public action. The best available science regarding climate drivers, potential ecosystem effects, and subsequent links to human effects must be communicated actively and consistently. Engaging local media is an important step in linking science to policy-makers as well. Interviews of scientists by reporters from local newspapers, magazines, and news stations should be encouraged, as these serve to describe the potential climate-change challenges society will face.

Complete a climate-change action plan

The culminating product of community engagement is the action plan. This plan will represent countless hours of collaboration, discussion, and partnership building, and will serve as a blueprint to respond to and reduce climate-change effects at a site. The action plan should not only include the issues on which an agency will focus, but also the issues and topics that will be led by each partner. The plan can either be divided into programme areas, such as ecosystem protection, research and monitoring, and education and outreach, or issue areas, such as sea level rise, increasing extreme weather events, public perception, and behavioural change, or both. Issue areas will need to first identify the target issue and thereafter indicate through strategies how research, education, policy, etc. will be used to address this target. Conversely, programme areas would include strategies that are discipline-specific, but which address a range of issues. This action plan will be the guiding document for the implementation of a long-term, climate-change programme; for each strategy, it should include a detailed timeline, performance measures to be evaluated annually, the partners involved, the budget requirements, and potential funding sources.

Reduce carbon emissions

Resource managers have a range of strategic choices at their disposal that can indirectly protect a place-based natural resource by reducing greenhouse gas emissions at the workplace. Because federal legislation to reduce greenhouse gas emissions is not currently in place, resource management agencies should serve as examples in their community and provide leadership on individual actions that can help mitigate the negative effects of climate change. Mitigation strategies should be all encompassing and include sustainable operations (e.g. on-site recycling, minimizing paper consumption/maximizing recycled content, and purchasing only environmentally friendly office supplies), green facilities (e.g. performing an energy emissions audit, reducing building emissions based on this audit, utilizing only sustainable and recycled building materials, decreasing water usage, avoiding the use of harsh chemicals, and providing hazardous waste disposal options), employee incentives to reduce individual emissions, the development of an employee green team, and responsible transportation choices. A communication plan, including outreach to the public and to the media, and facility tours/presentations (if feasible) should also be included to help influence a community-wide change in lifestyle to more sustainable livelihood practices, thereby providing additional indirect natural resource protection.

Adaptive management choices providing direct ecosystem benefits

Climate-change variables acting upon an ecosystem are complex and often uncertain. Resource managers must often make management decisions although faced with uncertainty. Moreover, they may have to accept possible failures, and learn from "mistakes" by taking an adaptive approach to future decisions. The issue of climate change should be approached from an ecosystem management perspective, that is to say, a holistic approach that incorporates a larger spatial context and focuses on multiple species and habitats within an ecosystem, as opposed to a focus on an individual species and habitat. Such an approach recognizes our uncertain knowledge of natural ecosystem structure and function, with the understanding that humans cannot necessarily control such systems. Ecosystem management involves broad stakeholder groups in the decision-making process and considers ecological, socio-economic, and institutional perspectives in maintaining or restoring the composition, structure, and function of natural and modified ecosystems. A broad sharing of decision-making is required, and stakeholders must often decide how to both include and manage human behaviour for the long-term benefit of the ecosystem (Meefe *et al*., 2002).

The success of an ecosystem management team is based on the use of adaptive management (Holling, 1978; Walters, 1986) principles. Adaptive management essentially means that natural resource management and policy are treated as experiments that should teach lessons. Resource managers must realize that failures are important learning opportunities. Ultimately, the goal of adaptive management is learning, and a feedback mechanism must exist between identifying policy options, gathering scientific information, designing management actions, measuring performance, and identifying the best policy options.

Adaptive management strives to develop an optimal management capacity, not necessarily maintain an optimal condition of the resource. Essentially, management should occur within a "... range of acceptable outcomes while avoiding catastrophes and irreversible negative effects" (Johnson, 1999). Adaptive management considers managed systems as "moving targets" that are largely influenced by human drivers and, therefore, factors human activities into management decisions (Arvai *et al.*, 2006). Because the biological effects of climate change are now only becoming more apparent, the urgency to take action is upon us now, so management must proceed even if complete information is not available or if there is uncertainty of the effects the management decision will have (Johnson, 1999).

Ecological resilience that allows the system to respond to stress must be maintained, and flexibility must be established that allows managers to react to changing conditions. Johnson (1999) emphasizes the notion that agencies should use an adaptive management approach that organizes workshops for stakeholder input, develops models, policy assessments, and a management plan, and monitors the effects of the management decisions. Agencies should also work together to share monitoring costs and continue to search for more efficient ways of collecting data. Adaptive management calls for cooperation across disciplines within an agency, and often across jurisdictions among agencies and stakeholders (Johnson, 1999).

Managing for multiple stressors

At present, there is no area of the earth that is unaffected by human influences. In fact, 41% is affected by multiple influences (Halpern *et al.*, 2008) or "stressors". Abiotic and biotic stressors do not normally act independently of each other; instead, they interact with each other to produce cumulative effects on biodiversity and ecosystem function. Primarily, since the Industrial Revolution, anthropogenic top-down (e.g. overexploitation of top predators) and bottom-up (e.g. excess nutrient influx) effects have resulted in the degradation of ecosystem resilience (Folke *et al.*, 2004). Climate change is not the only stress ecosystems face. To enhance ecosystem resilience and resistance to the effects of climate change, other human-induced stressors must be recognized and actions must be taken to reduce their influence.

Resource managers should identify priority stressors for the region through a local and collaborative effort. All human uses of the resource (e.g. fishing, agriculture, recreation) should be compiled, then evaluated for the severity (or lack thereof) of ecosystem effects. This would often come in the form of a socio-economic effect report that can be made possible by funds solicited from a local foundation or industry interested in its outcome. A list of priority stressors should then be decided upon, based on the assessment, and should include accompanying strategies developed to reduce the effect of each stressor. Human-induced stressors apart from climate change will vary, for example, among marine protected areas, but can include introduced species, habitat fragmentation, degraded water quality, wildlife disturbance, overharvesting, and pollution. Examples of strategies to address such stressors include designating special closure zones to protect sensitive habitat and working with local industry to utilize best management practices.

Applying the framework: Gulf of the Farallones National Marine Sanctuary case study

NOAA's Office of National Marine Sanctuaries (ONMS) is an example of federal natural resource management within the United States. With 13 national marine sanctuaries and 1 national marine monument, the mission of this agency is "... to serve as the trustee for the nation's system of marine protected areas, to conserve, protect, and enhance their biodiversity, ecological integrity and cultural legacy" (NOAA/ONMS, 2008). Since 1972, the ONMS has worked cooperatively with the public and federal, state, and local officials to promote marine conservation, although allowing compatible commercial and recreational activities within these protected areas (NOAA/ONMS, 2008).

Farallones Sanctuary is part of the National Marine Sanctuary System and includes nearshore waters up to the mean high tide line from Bodega Head to Rocky Point in Marin County, CA, USA, and offshore waters extending out to and around the Farallon Islands (SIMoN, 2008). Its boundaries are located within the California Current System (CCS), a large marine ecosystem that extends along the west coast of North America, from British Columbia, Canada, to Baja California, Mexico. Because of coastal upwelling, and the high degree of nutrient mixing that takes place within these waters, the CCS is one of the most biologically productive regions in the world. It supports more than 150 species of breeding and migrating seabirds, at least 29 species of whales and dolphins, and a variety of sea turtles, seals, sea lions, and fish (Mills *et al.*, 2005).

Several types of habitat are located within the Farallones Sanctuary, including inland estuaries, rocky intertidal areas, sandy beaches, and pelagic and deep-ocean environments. A large variety of marine mammals, fish, plant, algal, and benthic resources, as well as the largest breeding seabird population in the contiguous United States, is all supported within its boundaries (SIMoN, 2008). The goals and objectives set forth by the National Marine Sanctuaries Act direct each of the sanctuaries to take an ecosystem approach to management. The Farallones Sanctuary's role in natural resource management is to protect the area's resource and ecosystem values by protecting the biodiversity, productivity, and aesthetic qualities of the marine environment through ecosystem-based management. The Farallones Sanctuary strives to maintain, and when necessary restore, the natural biological and ecological processes within sanctuary waters, by evaluating and addressing adverse effects of human activities on sanctuary resources and qualities.

Recognizing the urgency to act now as natural resource managers, Farallones Sanctuary has begun the necessary steps to develop and implement a climate-change action plan for the San Francisco Bay Area's (Bay Area) coast and ocean environment. An ecosystem-based, adaptive management approach is being implemented, which contains the following components: conducting a strategic planning meeting, developing a regional climate action team, convening a local summit, developing a climate-change site-specific scenario document, organizing working groups, developing a climate-change action plan, organizing an employee green team, and adopting sustainable and green practices in the workplace.

Strategic planning meeting

The first step taken by the Farallones Sanctuary to address climate change within the Bay Area's marine environment was to identify

key federal, state, and local agencies, as well as non-profit organizations, to invite to a half-day planning meeting, held in September 2007. The purpose of this meeting was to discuss the sanctuary's goals, objectives, and draft mission statement for the development of a climate-change initiative, as well as a summit that would provide input on strategies for the initiative's action plan. The planning meeting included discussions on the goals, objectives, and mission statements for the sanctuary's proposed climate-change summit and initiative, the audience and desired products and outcomes for the proposed summit, the summit agenda, and potential summit speakers and sponsors. New partnerships were built, existing partnerships were strengthened for both the near and long term, and funding for the summit was secured through participating parties. Recommendations were made for the Farallones Sanctuary to take the lead on climate-change issues within the Bay Area's coast and ocean environment, as well as to participate in a regional climate action team.

Regional climate action team

In 2003, the San Francisco Bay Joint Policy Committee was formed to coordinate the regional planning efforts of the Association of Bay Area Governments, Bay Area Air Quality Management District, Bay Conservation and Development Commission, and Metropolitan Transportation Commission. Current initiatives include "... focused growth, climate protection, and development of a sustainable communities strategy" (Joint Policy Committee, 2009). At the September 2007 strategic planning meeting, a need was established for further coordination of the efforts of the Joint Policy Committee, the Farallones Sanctuary, and the San Francisco Bay National Estuarine Research Reserve (NERR), because they pertain to climate-changes issues. The Joint Policy Committee would focus on land-based actions, the Farallones Sanctuary on coast and ocean actions, and the San Francisco Bay NERR on actions within the San Francisco Bay estuarine environment.

In February 2008, leadership and staff from the Joint Policy Committee, the Farallones Sanctuary, and the San Francisco Bay NERR met for the first time to begin to establish a regional relationship and discuss how these groups could better coordinate their activities, develop consistent messaging, and share resources. The parties agreed to continue to meet on a quarterly basis and to discuss further the option of combining each disparate climate-change action plan into one cohesive document to paint a comprehensive regional climate-change picture for the Bay Area.

Ocean climate summit

In April 2008, the "First Biennial Ocean Climate Summit" for the Bay Area's coast and ocean environment was held to discuss potential climate-change drivers and effects, as well as adaptation and mitigation strategies for local coastal and open-ocean ecosystems. The goal of the summit was to address these potential climate-change effects through fostering awareness, advocating solutions, and promoting action among government agencies, public organizations, private corporations, and individuals to build ecosystem resilience and sustainability. To achieve this goal, five objectives were established for the Bay Area's coast and ocean environment: (i) identify key climate-change drivers and potential impacts affecting the area; (ii) discuss the steps in research, outreach, and policy reform needed to address the carbon footprint affecting this area; (iii) determine how existing climate-change programmes can collaborate to help support the needs of this area; (iv) identify the important critical marine habitats within the area that must be managed for resilience and sustainability; and (v) promote partnerships among agencies, non-profit organizations, private businesses, and stakeholders. The desired summit outcomes included developing strategies for an action plan to establish the "Ocean Climate Initiative" for the Bay Area's marine environment, such that the initiative would serve as a pilot programme for implementing localized climate-change initiatives among NOAA's National Marine Sanctuary System. The summit was an invitation-only event to ensure a participant size that would be compatible with the afternoon working session. More than 100 participants from many federal, state, and local agencies, non-profit organizations, foundations, academic institutions, and the business community attended the meeting.

The first half of the day included science, public perception, and policy panel discussions that the Farallones Sanctuary identified as critical background information with panels convened on "Ocean Impacts, Ecosystem Response, and Human Adaptation", "Perceptions, Behaviours, and Economics Within a Changing Ocean Environment", and "Regional Climate Change Actions". The lunchtime keynote address was provided by social scientist Susanne Moser, director and principal researcher, Susanne Moser Research and Consulting, and former National Center for Atmospheric Research scientist; it included information on public perception of climate change and further discussion on communication tactics that could be used to facilitate behavioural change in individuals.

The second half of the day was a working session of the participants, which not only built and strengthened partnerships, but also began to develop strategies on how best to address climate-change issues within the Bay Area's marine environment. Five breakout groups were convened with the following themes: engaging the community, changing human behaviour, prioritizing areas for protection and restoration, communicating science to natural resource managers and policy-makers, and reducing other human-induced stressors.

Climate-change site-specific scenario document

Farallones Sanctuary, in partnership with Cordell Bank National Marine Sanctuary, has brought together local scientists to downsize current climate-change information and develop a climate-change site-specific scenario document for the north-central California offshore and coastal region. Through a collaborative effort spearheaded by Farallones Sanctuary and coordinated by a graduate student, experts are advising the sanctuaries on observed and predicted physical and biological effects of climate change. The document includes drivers of regional responses, regional environmental change, changing habitat structure, biotic responses, community ecosystem response, additional drivers of change, such as agricultural run-off and overfishing, and direct human effects. The goal of the ONMS is for each site within the National Marine Sanctuary System to complete a site-specific scenario document to serve as the foundation for the site's climate-change action plan.

Working groups

Through recommendations provided at the Ocean Climate Summit, the Farallones Sanctuary will establish multiple working groups, each with specific areas of expertise. These groups will support the development and implementation of the Farallones Sanctuary's climate-change action plan. The groups

will provide expert advice on the development of action-plan strategies; then will collaborate to ensure the successful implementation and monitoring of these strategies. Each group will consist of federal, state, and local agencies, non-profit organizations, academic institutions, and various other stakeholders, including businesses and community members. Attendees of the initial strategic planning meeting will also be invited to join a working group, which will provide a feedback loop from preliminary ideas to executed strategies. To date, "Climate Change Site Scenario" and "Greening" Working Groups have been established under the Gulf of the Farallones National Marine Sanctuary Advisory Council, a stakeholder group representing public interest groups, local industry, commercial and recreational user groups, academia, conservation groups, government agencies, and the public. The stakeholder group provides advice to the sanctuary superintendent on the issues of resource protection.

Ocean climate initiative and action plan

Through initial recommendations from Ocean Climate Summit participants and subsequent refinement of strategies through working groups, an action plan to address climate change within the San Francisco Bay Area's coast and ocean environment will be produced with strategies addressing the following programme areas: research and monitoring, ecosystem resilience and protection, community action, and carbon footprint reduction. The action plan will then drive the Ocean Climate Initiative, a long-term programme that will address climate-change effects within the Farallones Sanctuary region, by fostering awareness, advocating solutions, and promoting action among government agencies, public organizations, private corporations, and individuals, to build ecosystem resilience and sustainability. The initiative's goal is to provide tangible solutions at a local, state, and federal level through partnerships, research collaborations, outreach and education, and policy reform. The initiative's objectives include identifying the physical drivers and addressing the biological effects of climate change on the region's coast and ocean, acting as a climate-change communication centre to facilitate the centralization of ideas and educate the public on personal choices that reduce their carbon footprint, managing local marine ecosystems for resilience, advising the Farallones Sanctuary on how to rehabilitate their facilities and procedures to become a model of sustainability, and promoting inter- and intra-agency, non-profit organization, and business partnerships within the region to form a resource-sharing alliance.

Managing for a changing climate

Farallones Sanctuary now includes the effects of climate change in all site-specific environmental documents, such as National Environmental Policy Act (NEPA) analyses, management plans, and restoration plans. As a result, Farallones Sanctuary and its partners are designing restoration projects with climate change in mind. One example of this is the consideration of sea level rise and increased storm surge in Bolinas Lagoon, CA, USA. Through a collaborative community effort outlined in the Bolinas Lagoon Restoration Plan, a strategy was created recommending that portions of the highway near the lagoon be elevated onto a causeway.

The most effective natural resource policy and management actions that Farallones Sanctuary can take to address climate change are reducing stressors to the marine environment and protecting high-value habitat. Through the site-specific management plan, the sanctuary has identified nearshore water quality, oil spills, invasive species, wildlife disturbance, and fishing effects as the priority issues to deal with in the region. The sanctuary's goal is to reduce human-induced stressors on the ecosystem and to build ecosystem resilience to adapt to climate change.

Concurrently, Farallones Sanctuary is identifying high-value habitat in the region to designate for increased protection and support species resilience. High-value habitat is defined as habitat that supports either high species diversity or abundance, or both. One example of this is the sanctuary's work to enact special closure zones to protect valuable seabird breeding and roosting habitat. This reduces additional stress from human disturbance to seabird colonies. Another example is the development of protection zones for native seagrass beds within the sanctuary, which ensure viable habitat and breeding grounds, as well as serve as a carbon sink.

Leading by example

Farallones Sanctuary is examining the way it does business. The sanctuary is conducting an energy-emission audit through the work of a graduate student, an employee "green" team has been established, and carbon reduction goals will be set. The sanctuary is currently renovating its campus to achieve Leadership in Energy and Environmental Design (LEED) certification, a green building certification programme developed by the US Green Building Council (http://www.usgbc.org). In addition, sanctuary management supports model "green" corporate behaviour, including digital publications, reusable and recyclable materials, employee incentives, and sustainably-held events and meetings. The employee "green" team and the sanctuary's Greening Working Group will evaluate the sanctuary's current transportation portfolio and provide recommendations for emission reductions through teleconferencing, webcast meetings, alternative transportation and carpooling, telecommuting, alternative fuel and hybrid vehicles, and the use of alternative fuel on the sanctuary's research vessel.

Conclusions

To ensure the long-term resilience and survivorship of ecosystems, individual species, and the habitats they rely on, marine resource managers must immediately begin to incorporate a combination of strategies to address the inevitable climate-change effects that natural systems now face. Recent findings of the IPCC (2007) concluded that, "... the resilience of many ecosystems is likely to be exceeded this century by an unprecedented combination of climate change, associated disturbances ... and other global change drivers". Now, more than ever, there is an urgent need to balance the effects of human demands with healthy ecosystems through research and monitoring that incorporates climatic variations, efficient and effective education and outreach on the effects of climate change, and management practices that promote solutions to climate-change impacts through both adaptation and mitigation strategies. Climate change is a unique, multidisciplinary environmental problem that requires extensive collaboration, communication, and life-style changes among agencies, organizations, academia, businesses, and the public. The issue can serve as a unifying force between otherwise often disparate parties, and it should not be viewed as a hopeless failure, but as an opportunity for collaborative success.

References

Arvai, J. L., Bridge, G., Dolsak, N., Franzese, R., Koontz, T., Luginbuhl, A., Robbins, P., *et al.* 2006. Adaptive management of the global climate problem: bridging the gap between climate research and climate policy. Climatic Change, 78: 217–225.

Folke, C., Carpenter, S., Walker, B., Scheffer, M., Elmqvist, T., Gunderson, L., and Holling, C. S. 2004. Regime shifts, resilience, and biodiversity in ecosystem management. Annual Review of Ecology Evolution and Systematics, 35: 557–581.

Halpern, B. S., Walbridge, S., Selkoe, K. A., Kappel, C. V., Micheli, F., D'Agrosa, C., Bruno, J. F., *et al.* 2008. A global map of human impact on marine ecosystems. Science, 319: 948–952.

Holling, C. S. 1978. Adaptive Environmental Assessment and Management. John Wiley and Sons, Chichester, UK.

International Panel on Climate Change (IPCC). 2007. Summary for policymakers. *In* Climate Change 2007: Impacts, Adaptation and Vulnerability. Contribution of Working Group II to the Fourth Assessment Report of the Intergovernmental Panel on Climate Change. Ed. by M. L. Parry, O. F. Canziani, J. P. Palutikof, P. J. van der Linden, and C. E. Hanson. Cambridge University Press, Cambridge, UK.

Johnson, B. L. 1999. The role of adaptive management as an operational approach for resource management agencies. Ecology and Society, 3: 8.

Joint Policy Committee (JPC). 2009. http://www.abag.ca.gov/jointpolicy.

Meefe, G. K., Nielsen, L. A., Knight, R. L., and Schenborn, D. A. 2002. Getting a grip on ecosystem management. *In* Ecosystem Management: Adaptive, Community-based Approach, pp. 57–58. Ed. by G. K. Meefe, L. A. Nielsen, R. L. Knight, and D. A. Schenborn. Island Press, Washington, DC.

Mills, K. L., Sydeman, W. J., and Hodum, P. J. 2005. The California Current Marine Bird Conservation Plan, v. 1. PRBO Conservation Science.

National Oceanic and Atmospheric Administration (NOAA)/Office of National Marine Sanctuaries (ONMS). 2008. http://sanctuaries.noaa.gov/about/welcome.html.

Raven, R., and Falkowski, P. G. 1999. Oceanic sinks for atmospheric CO_2. Plant, Cell and Environment, 22: 741–755.

Sabine, C. L., Feely, R. A., Gruber, N., Key, R. M., Lee, K., Bullister, J. L., Wanninkhof, R., *et al.* 2004. The ocean sink for anthropogenic CO_2. Science, 305: 367–371.

Sanctuary Integrated Monitoring (SIMoN). 2008. http://sanctuarysimon.org/farallones/index.php.

Walters, C. J. 1986. Adaptive Management of Renewable Resources. MacMillan, New York, NY.

doi:10.1093/icesjms/fsp133