Climate Change Impacts on Coastal and Marine Ecosystems and the Potential Role of the National System of MPAs

A Primer and Guide for Members of the
Marine Protected Areas Federal Advisory Committee
[Produced by the MPA FAC Scientific and Technical Subcommittee]

I. Introduction

The Marine Protected Areas Federal Advisory Committee (MPA FAC) has been asked to address how climate change[1] may affect the marine ecosystems[2] of the U.S. and what role the National System of Marine Protected Areas (MPAs) may play in protecting the marine resources of our nation from the impacts of climate change.

This paper is intended to serve as 1) a climate change primer for members of the MPA FAC, and 2) an examination of the relationship between climate change and the National System of MPAs. It is primarily a literature review of published peer-reviewed scientific papers on the topic of how climate change is affecting, and will continue to affect, marine ecosystems with cited references included for substantiation. The intent of this paper is to help inform the MPA FAC of the pertinent climate change issues as they relate to the design and implementation of the National System of MPAs. The ultimate objective of this work is to produce a set of recommendations regarding these issues that will be delivered to the Secretaries of the Departments of Interior and Commerce for their due consideration.

From an investigation of peer-reviewed scientific literature on the impacts of climate change on our nation's marine environments and resources, as well as the April 2009 MPA FAC recommendations entitled *Ecological Resilience and Gap Analysis of the National System of Marine Protected Areas*,[3] we conclude that:

1. Climate change is a serious threat to the marine environment and its resources.
2. The impacts of climate change are increasing in intensity and are predicted to have profound effects on our marine resources and ecosystems in the near-, mid- and long-term future.
3. Marine ecosystems have already been degraded by a wide range of stressors induced or caused by human activities.
4. Degraded ecosystems are less likely to be resilient to the effects of climate change than healthy, fully-functional ecosystems.

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[1] Throughout this document the term 'climate change' when used alone is intended to refer to all of the primary, secondary and tertiary effects of climate change in and on the ocean (e.g. warming, melting ice, sea-level rise, altered upwelling and currents, coastal erosion, changing weather patterns, salinity changes) and ocean acidification.

[2] The use here of the term 'marine ecosystems' is intended to refer to ocean, marine and coastal ecosystems and their constituents (e.g. habitats, species, populations, and living resources such as fish stocks).

[3] "Ecological resilience is the capacity of an ecosystem or natural population to resist or recover from major changes in structure and function following natural and human-caused disturbances, without undergoing a shift to a vastly different regime that is undesirable and very difficult to reverse from a human perspective." (MPA FAC 2009).

5. Eliminating or ameliorating human-caused stressors (under management control) on marine ecosystems potentially will improve their resilience thereby increasing the capacity for ecosystems to resist and recover from the impacts of climate change.
6. MPAs have the potential to play an important role in maintaining and restoring ecosystem resilience, protecting biodiversity and creating refugia from climate change impacts.
7. Climate change is altering the physical dynamics of the ocean and the marine ecosystems of the U.S. MPA management should strive to anticipate these physical changes and adaptively manage MPA systems to effectively cope with predicted changes.

II. Climate Change Impacts on Marine Ecosystems: An Overview

Marine ecosystems have been exposed to long-term human impacts, in some cases for centuries. In recent decades, the impacts of climate change have become additional sources of stress on the ocean. These impacts are projected to become more severe during the 21st Century (IPCC 2007a). Since the onset of the industrial revolution, the amount of carbon dioxide (CO_2) in the atmosphere has risen steadily. Over one-half of all human-caused carbon emissions over the past 200 years have been absorbed by the ocean, which, through basic chemistry, has caused a 30% increase in the acidity (decrease in pH) of sea water (IPCC 2007b). Further, the rise in atmospheric CO_2 has amplified the atmosphere's greenhouse effect and led to substantial warming of the planet in the last few decades. That warming has resulted in numerous secondary and tertiary physical manifestations, such as melting sea ice and glaciers, sea-level rise, altered rainfall patterns, increased storm intensity, and changes in ocean currents.

Long-standing human-caused stressors on marine ecosystems have been widely demonstrated to cause numerous undesirable changes in living systems (IUCN-WCPA 2008), including:

- loss of biodiversity,
- decreased abundance of key species,
- structural damage to living and nonliving habitats, and
- loss of ecological functions, resulting in reduced resilience to additional stresses.

Reduced ecosystem resilience is of particular concern because of the anticipated impacts of climate change in the ocean, which are predicted to be potentially catastrophic for particular ocean ecosystems, habitats and species. The resilience of ecosystems – the capacity to withstand stress and recover from such impacts – is believed to be crucial to their functioning, persistence and viability (Walker and Salt 2006). Degraded ecosystems (i.e., those that have lost biodiversity, ecological functions or structural integrity) are expected to be less resilient, and, therefore, to have less capacity to withstand the additional stresses of climate change (Hughes *et al.* 2005). Conversely, those ecosystems most likely to withstand and recover from the stresses of climate change are those that have been least degraded or have been restored.

Theory suggests that reducing the stressors acting on an area can help maintain ecosystem integrity, population viability, and the health of organisms, and foster recovery from adverse impacts. Removing some stressors (e.g., through establishment and management of MPAs) is considered to be an important tool to build the resilience of ecosystems and populations in the face of climate change. So far, some empirical research has confirmed this relationship, and some has not (Sandin *et al*. 2008). Regardless, it is important to note that MPAs are only part of a broad suite of tools that are needed to fully maintain and restore the resilience of marine ecosystems to a variety of stressors.

The efficacy of designing and managing MPAs, networks of MPAs and the National System of MPAs, as tools that may enhance resilience, must be carefully examined through attention to general ecological criteria, such as connectivity or representativeness, that improve the effectiveness of MPAs, as well as criteria that specifically address the expected effects of climate change. However, while MPAs may have a key role to play in assisting the adaptation of marine ecosystems to climate change, it is important to realize that they are not a tool that can assist in mitigating greenhouse gasses.

III. Current and Anticipated Climate Change Impacts on the Marine Ecosystems of the United States

The 2007 report of the Intergovernmental Panel on Climate Change (IPCC) found that global concentrations of CO_2, methane and nitrous oxide have increased as a result of human activities since 1750, and, today, levels exceed those measured from ice-core samples reaching back hundreds of thousands of years. According to the IPCC, “warming of the climate system is unequivocal, as is now evident from observations of increases in global average air and ocean temperatures, widespread melting of snow and ice, and rising global average sea level.” The U.S. Global Change Research Program (www.globalchange.gov) also concluded that global warming is occurring, resulting in widespread climate-related impacts in the U.S., and that global climate change imposes specific stresses on coastal and ocean environments. At the national level, some of the effects of climate change include (verbatim from Karl *et al.* 2009):

- U.S. average temperature has risen more than 2ºF over the past 50 years and is projected to rise more in the future.
- The amount of rain falling in the heaviest downpours has increased approximately 20% on average in the past century, and this trend is very likely to continue, with the largest increases in the wettest places.
- The destructive energy of Atlantic hurricanes has increased in recent decades. The intensity of these storms is likely to increase in this century.
- In the eastern Pacific, the strongest hurricanes have become stronger since the 1980s, even while the total number of storms per year has decreased.
- Sea level has risen along most of the U.S. coast over the last 50 years, and will rise more.
- Cold-season storm tracks are shifting northward and the strongest storms are likely to become stronger and more frequent.
- Arctic sea ice is declining rapidly and this is very likely to continue.

Oceans play a major role in regulating climate conditions, and changes in atmospheric conditions can have profound effects on the functioning of ocean ecosystems. Ocean warming and ocean acidification can result in lasting change which may be difficult, and in some cases impossible, to reverse. ***Both natural and human-caused climate change impacts should be considered in the design and implementation of the National System of MPAs, so that we may prepare to address these threats and respond through an adaptive ecosystem-based approach.*** By understanding these challenges we may be better able to adapt to changing habitat conditions, maintain the integrity of marine ecosystems, and increase the resilience of the oceans and coasts of the U.S.

Physical Changes in the Oceans Resulting from Climate Change

Physical changes manifesting from climate change have the potential to dramatically reshape ocean dynamics, affecting the function and structure of marine ecosystems and resources. The following is a brief overview of some of the major physical changes occurring or expected in our oceans as a consequence of climate change.

Ocean Temperature Changes

The oceans have absorbed over 80% of the heat added to the climate system (IPCC 2007a). Rising temperatures in the atmosphere and oceans is resulting in a number of broad-scale effects, including: melting polar sea ice; increased sea level rise due to the thermal expansion of water and glacial and ice sheet melt; shifting species distribution and abundance; shifting weather patterns; coral bleaching and mortality; an increase in the frequency and intensity of tropical storms; and may potentially release large quantities of carbon in the form of methane hydrates from the sea floor (longer-term) (WBGU 2006).

Changes in Ocean Current Patterns

Changes in ocean circulation are predicted to have profound effects on marine ecosystems. At the global level, thermal stratification is expected to increase, which may reduce upwelling and primary productivity (Hoffman *et al*. 2009). In coastal areas and margins, this shift could result in oxygen deficiency, a loss of habitats and biodiversity, and changes in the distribution of species. Such effects have been witnessed along the California Current, where the wind-driven upwelling of deeper, nutrient-rich waters formerly fostered highly productive coastal ecosystems. Variations in this process caused by El Niño events have substantially reduced the productivity of salmon and other fishes (Karl *et al*. 2009). However, there is uncertainly in exactly how ocean currents will be altered by a warming atmosphere and ocean.

Ocean Acidification

Ocean acidification is expected to affect all regions of the U.S., though variations in regional trends are difficult to determine. The pH and carbonate saturation state of the ocean affects the growth and viability of a range of marine organisms by affecting processes including calcification, photosynthesis, respiration, nitrogen fixation, and reproduction (reviewed e.g., in Doney *et al.* 2009, Guinotte and Fabry 2008). Effects on calcification have received the most attention thus far, but the ecological importance of other effects relative to pH level and its impacts on the rates of a broad range of physiological processes has not been determined. In addition to direct effects of ocean acidification, there is the potential for major secondary effects on marine food webs and ecosystems (e.g., Orr *et al*. 2005).

The high CO_2 waters in polar and upwelling regions such as the eastern Pacific and Bering Sea will experience acidification more rapidly than other regions, affecting many cold water corals. Tropical waters will also experience rapid declines in carbonate ions critical for coral reef construction. By 2100, some estimate that 70% of corals will be in waters unfavorable for growth (IAP 2009).

An additional concern relates to potential feedback mechanisms from the added uptake of CO_2 from the atmosphere by the oceans. Feedback mechanisms have the potential to further disrupt the planet's climate and adversely affect marine ecosystems. For example, increased acidification of the oceans could reduce the occurrence of plankton blooms, which extract CO_2 from the atmosphere. With less CO_2 being absorbed by the ocean, more greenhouse gases would be available in the atmosphere and global warming would be accelerated, which would in turn increase the warming of the ocean and further exacerbate climate change impacts.

Sea Level Rise

Specific to the U.S., sea level has risen along most of the coast over the past 50 years. Sea level rise will worsen coastal erosion and storm surge, thereby negatively affecting many low-lying and coastal areas along the Atlantic and Gulf Coasts, the Pacific Islands, and parts of Alaska. According to the recent report of the U.S. Global Change Research Program (Karl *et al*. 2009), "even a 2-foot rise in relative sea level over a century would result in the loss of a large portion of the nation's remaining coastal wetlands, as they are not able to build new soil at a fast enough rate. Accelerated sea-level rise would affect seagrasses, coral reefs, and other important habitats. It would also fragment barrier islands, and place into jeopardy existing homes, businesses, and infrastructure, including roads, ports, and water and sewage systems. Portions of major cities, including Boston and New York, would be subject to inundation by ocean water during storm surges or even during regular high tides."

Shifts in Precipitation Patterns

Overall, rainfall is anticipated to become more concentrated and intense (i.e., heavier downpours), with longer periods of drought between events. Precipitation runoff is an important factor in the functioning of some coastal ecosystems, influencing sediment levels, nutrient content, eutrophication levels and the occurrence of dead zones in the ocean. In some areas, the amount of sediment released through runoff has been so great that it has smothered corals or other sensitive sea life. As precipitation patterns change so too will the quantity, quality and timing of runoff. For example, in areas where snowpack dominates, it is anticipated that runoff will occur earlier in the spring, with lower flows later in the summer (Karl *et al*. 2009).

Changes in Storm Intensity

More intense hurricanes, wind, rain and storm surge events are anticipated in some areas of the U.S. and surrounding coastal waters, with drier conditions expected in the Southwest and Caribbean. Since 1970, the intensity of Atlantic tropical storms has increased with increasing sea surface temperatures, and it is likely that this trend will continue, accompanied by more extreme wind and higher ocean waves. In the eastern Pacific, the intensity of hurricanes has grown even though the frequency of the storms has decreased. Storm tracks are projected to shift toward the poles in both hemispheres (Karl *et al*. 2009). Storm surge is a significant hazard for coastal areas and habitats like coral reefs, seagrass beds, mangrove forests, and salt marshes, and a change in their frequency and/or intensity will affect many coastal ecosystems. Further, particularly for low-lying island areas, tidal inundation due to rising sea levels may intensify.

IV. Cumulative Stresses and Ecosystem Resilience

Ecosystems can be characterized by their structure, processes, functions, dynamics and condition, and, like all biological systems, have some emergent capacity for apparent self-regulation, organization, and adaptation. The integrity of an ecosystem is related to its condition - a loss of structure, processes, or functions compared to the 'norm' or historical state implies a degraded condition and compromised integrity. Thus, ecosystem integrity is often defined as a state in which the species composition, community structure, functional relationships, ecological processes and adaptability that are characteristic of natural ecosystems is unaffected or unimpaired by human stresses.

The condition of an ecosystem is a determinant of its capacity to deliver ecosystem goods and services that we rely upon, which can be placed in one of four categories:

1) <u>provisioning</u> of food or other resources,
2) <u>regulating</u> processes such as water filtering, waste decomposition, and carbon sequestration,
3) <u>supporting</u> processes such as larval dispersal that replenishes fish populations, and
4) <u>cultural</u> opportunities such as recreation or aesthetics.

Given that many ecosystems are under stress from multiple human impacts, and therefore are in varying degrees of diminished ecosystem integrity, it is important to understand what determines how stresses individually and cumulatively affect ecosystems and their ability to recover.

Ecological resilience refers to the capacity of an ecosystem to resist stress and recover from fundamental changes in its defining characteristics (Walker and Salt 2006). Specifically, *ecological resilience is the capacity of an ecosystem or natural population to resist or recover from major changes in structure and function following natural and human-caused disturbances, without undergoing a shift to a vastly different regime that is undesirable and very difficult to reverse from a human perspective* (MPA FAC 2009). Regime shifts, such as coral-dominated reefs becoming algal-dominated, or kelp forests becoming urchin barrens, have been repeatedly and widely documented in ecosystems stressed by excessive fishing, nutrient inputs, and other stressors (Hughes *et al*. 2005). An unexpected and unfortunate characteristic of many regime shifts is that they may not spontaneously reverse once the stresses that caused the shift are removed, meaning that the degraded state may persist.

Maintaining and enhancing resilience is critical to maintaining the ecological services we want and need (Levin and Lubchenco 2008). While an ecosystem that has undergone a regime shift will continue to deliver some ecosystem services, those services will most likely not be the ones we need or desire (e.g., the availability of reef fish to consume).

An individual organism whose health has been compromised by disease is less likely to withstand a new stress without its health declining further. Similarly, an ecosystem that has been degraded by human stresses is less resilient in the face of additional or new stresses such as climate change, and may undergo a potentially catastrophic and irreversible shift. It is possible that the severity of climate change will eventually make it impossible for human interventions to prevent most coral reefs from undergoing regime shifts to algal reefs (Hoegh-Guldberg *et al.* 2007), and the same many be true for other ecosystem types. However, because we desire and depend on certain ecosystem goods and services delivered by the oceans, we have a strong interest in keeping those ecosystems in their current state (e.g., tropical reefs dominated by corals and temperate reefs dominated by kelp forests).

Virtually every ocean ecosystem on the planet has been affected by a variety of human stressors (Halpern *et al.* 2008), and, therefore, may have suffered loss of resilience. Where those stressors can be controlled by area-based protections, MPAs have the potential to help restore resilience in the face of climate change. For example:

- The harvesting of wood from mangrove forests can make coastal regions more susceptible to damage from high-intensity storms, which are expected to become more frequent. Healthy mangroves protect coasts from the effects of storm surge and tsunamis (Stanturf *et al*. 2007).
- Excessive fishing of pelagic fishes has been demonstrated to reduce the diversity of pelagic ecosystems, which could render them less resilient. Large pelagic marine reserves have been proposed as a mechanism to restore diversity and resilience in these ecosystems, but have yet to be tested (Game *et al*. 2009).
- Some species of seagrasses form vast mats that are tied together by rhizomes. Breaks in the rhizomes increase the likelihood that high intensity wave action during storms can uproot large portions of the mats (Björk *et al*. 2008). Protecting seagrass ecosystems from damage by dredging, propellers and trawling may enhance their resilience to increased storm intensities.
- In the northwest Atlantic on the Scotian Shelf, overfishing has caused the benthic environment to undergo a regime shift from a system dominated by large predatory fishes (e.g., cod, haddock, and flounders) to one dominated by crustaceans and small fishes (Frank *et al.* 2005). Benthic fish communities elsewhere also may be at risk of such a regime shift. Protecting representative proportions of the benthic environment could contribute to rebuilding resilience and reducing the likelihood of a regime shift.
- Coastal habitats such as salt marshes, mud flats and mangroves, and their substrates are at risk of being ‘flooded’ and eroded as sea levels rise. Those habitats will naturally adapt by migrating landward as water depths change. However, without natural and protected areas behind existing habitats (i.e., ‘set-back’) there will not be any place for those habitats to go, and they will lose area as they are literally squeezed-out. In many places, sea-level projections suggest large areas of such habitats will be lost (Karl *et al*. 2009).

There are two ways to maintain ecosystems in their desired state in consideration of the coastal and marine impacts of climate change (Salm *et al.* 2006):

1) Reduce the degree of stress they experience, or, in other words, mitigate the cause of climate change and acidification by reducing the concentrations of CO_2 in the atmosphere and ocean. Large-scale climate change mitigation is largely beyond the reach of ocean stewards. However, the oceans do play an important mitigative role. The ocean’s vegetated habitats, particularly mangroves, salt marshes, and seagrasses, account for over

half of all carbon storage in ocean sediments, and carbon captured by these habitats are stored in sediments for millennia. The protection of these coastal habitats, which may be accomplished with the use of MPAs, would increase the capacity of the ocean to store carbon.

2) Maximize the capacity of marine ecosystems to resist, adapt to, and recover from the effects of climate change, or, in other words, to maximize the resilience of coastal and ocean ecosystems to climate change. Here, MPAs serve an important role.

V. Designing MPAs and MPA Networks for Resilience

Marine protected areas are often established to preserve biodiversity, protect habitats, ensure ecosystem integrity, promote sustainability of resources, and/or ensure the ongoing delivery of ecosystem goods and services. A large number of empirical studies have demonstrated that the biodiversity, density, biomass and size of some exploited species are, on average, increased in marine reserves (MPAs that ban take) (Halpern 2003, Lester *et al.* 2009). In fact, there is little question that habitats and ecosystems within MPAs benefit from protection from exploitation and destructive and disruptive activities. It is expected that these benefits translate into a maintenance or restoration of ecosystem condition and integrity. The design criteria that are expected to improve the condition and integrity of MPAs have been well defined in numerous publications and include risk-spreading (representation and replication), viability (siting, size, shape), interaction (connectivity and networking) and ecosystem-based management (Roberts *et al.* 2003, MPA FAC 2009).

Marine Protected Areas are promoted as a key tool for maintaining and restoring the resilience of ecosystems in the face of climate change and increasing CO_2 levels (IUCN-WCPA 2008, MPA FAC 2009). Ideas regarding how resilience can be enhanced and the role of MPAs in that process have been developed primarily with respect to the impacts of coral bleaching due to ocean warming (Graham *et al.* 2008, Keller *et al.* 2008), but the principles developed for coral reefs can be adapted to other ecosystems.

The design of MPAs to protect ocean ecosystems and enhance their resilience to climate change has several elements (adapted from McLeod *et al.* 2009). When MPAs are desired and appropriate, they can be used alone or as one of an integrated suite of measures to achieve one or more of the following objectives:

1. **Reducing non-climate stresses** – Reduce those human-caused stresses on marine ecosystems that exacerbate or interact negatively with climate change to increase ecosystem integrity and resilience, which should improve the capacity of ecosystems to resist and recover from the impacts of climate change in the ocean.

2. **Protecting the least exposed** – Protect those ecosystems that are least exposed to climate change in the ocean by siting MPAs where the effects of climate change are expected to be less severe due to local conditions.

3. **Protecting the most resistant[4] and adaptable** – Protect ecosystems affected by climate change by selectively siting MPAs where organisms are expected to be naturally more resistant or adaptable to climate change impacts.
4. **Protecting the most valuable** – Protect those resources at risk from climate change that are especially valuable by siting MPAs to contain those resources. These include resources that are unique or rare, or those that are ecologically, culturally, historically, socially or economically important.
5. **Protecting resilient populations** – Ensure replenishment, viability and genetic diversity of populations by designing MPAs and MPA networks to protect sufficiently large effective population sizes to achieve these goals and, thereby, increase the chance of population persistence.
6. **Making MPAs dynamic** – Site, design, and modify MPAs and MPA networks to maintain protection of populations in anticipation potential habitat or species range shifts in response to climate change.
7. **Maintaining connectivity – Site and design MPA**s to create ecologically connected and functional networks that facilitate the range shifts of populations and the movements of individuals and genes in response to climate change.
8. **Spreading risk** – Site and design MPA networks to spread the risk of catastrophic loss due to the more extreme impacts of climate change by protecting a range of habitats and replicating sites that include those habitat types.

Reducing Non-Climate Stresses

The relationship between human-caused environmental stressors and the condition and integrity of many ocean ecosystems has been well documented. For purposes of illustration we take the example of shallow-water, tropical coral reefs, which are dominated by hard corals and other reef-building organisms and which support a high diversity of algae, invertebrates, fish and other vertebrates. In these systems, algae that have the potential to overgrow corals are regulated by the grazing of herbivorous fishes and invertebrates (e.g., urchins). Numerous studies have documented the ecological extinction of herbivores on coral reefs due to excessive fishing (fishes) and disease (urchins) (Mumby *et al*. 2007). Released from control by grazers, several species of algae overgrow the reef, smothering corals and other sessile organisms, and preventing the reestablishment of corals primarily by occupying recruitment substrates. Theory and experience suggest that an additional factor, such as a hurricane or warming-induced bleaching event, may be needed to trigger a regime shift on such degraded and stressed reefs.

Reducing controllable human stress on a coral reef ecosystem will likely improve its resilience and improve its capacity to recover from episodic stresses (e.g., storms and spikes in temperature) caused by climate change. Better understanding of health-sustaining processes in ecosystems and the human-caused stressors that impede those processes will provide managers the tools and interventions needed to maintain or improve resilience of various ecosystems.

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[4] Ecological resilience represents the ability of an ecosystem to recover from change; resistance in this sense refers to the ability of an ecosystem to withstand change.

Protecting the Least Exposed

The rate and extent of climatic changes will vary temporally and spatially (IPCC 2007b). For any given ecosystem, some areas are likely to experience a lower intensity of climate change impacts than average because: 1) there are large-scale or regional differences in the degree of climate change, or 2) local conditions will ameliorate the regional average.

Climate change is a global process, but there is considerable spatial variation in the strength of changes on a regional and local scale. In other words, there will be some areas in which kelp forests, for example, will experience lower than average warming. Kelp forests, which harbor a rich diversity of fishes, invertebrates and epiphytes, create critical shallow water coastal environment found along of the cool water coasts of the world (Steneck *et al*. 2002). They also can be abundant in deep tropical waters where light penetrates through clear surface waters to cool, nutrient rich waters below (Graham *et al*. 2007). Establishing marine reserves in regions that are anticipated to experience a reduced warming impact would help to maximize the effectiveness of these areas as warming refugia. Likewise, pH is highly variable among space and time, and some areas will retain a higher pH than others, providing potential refugia from the negative impacts of increasing ocean acidification.

Thus, the placement of MPAs can take advantage of areas with low thermal stress or areas where ocean acidification is low. The combination of lower thermal or acidification stress and reduced stress from exploitation and destructive activities is expected to improve the chances that kelp forests in those localities will survive ocean warming. This same approach should work to identify portions of other ecosystems that are less susceptible and, therefore, are candidates for protection. For example, monitoring and modeling will identify areas least likely to experience significant coastal erosion due to the combined effects of sea level rise and increased storm intensity, which could then be evaluated as potential refugia for seagrasses or mangroves.

Protecting the Most Resistant and Adaptable

Living organisms and ecosystems respond and adapt to environmental stresses. Those organisms living in high stress and highly variable environments may display greater resistance to new stresses than those organisms found in relatively constant environments. For example, repeated exposure to high thermal stress appears to be related to some coral species, populations and even particular colonies being more resistant to bleaching and recovering more rapidly afterwards (Hoegh-Guldberg *et al.* 2007). Establishing MPAs in locations that are likely to harbor bleaching-resistant coral species could create refugia and sources of bleaching tolerant phenotypes that will have a higher probability of surviving in the warmer ocean of the future. Similarly, coastal habitats that experience wide ranges of stress from factors such as wave intensity, erosion by currents, or fresh-water runoff, may be better candidates as coastal refugia.

Protecting the Most Valuable

The projections of the impact of climate change suggest that it is likely that we will lose a large number of species. Habitats and ecosystems may be degraded to the point of ecological extinction. Thus, there may be a need to establish MPAs in sites where there are rare, unique, or ecologically, historically, culturally, or economically important resources at serious risk from climate change. Many of these resources will not be part of the 'least exposed' and 'most resistant' groups, and yet may be some of the most valuable ocean resources to afford protection.

Protecting Resilient Populations

Overexploited populations may undergo internal 'regime shifts' that compromise their viability. Further, climate change, which is already affecting the replenishment, viability and genetic diversity of some populations, will add additional stress to fragile populations. Managing for population resilience includes: protecting specific critical habitats, such as spawning and nursery areas, that enhance stock viability and productivity; providing for conservation of competitors and other species that naturally regulate population size; helping to make certain that a reasonable number of big, old females survive; and protecting genetic diversity that enhances stock adaptability, viability and productivity. To ensure effectively large population sizes over ecological and evolutionary time scales, MPAs can be designed and managed to protect specific critical habitats, protect species that regulate the abundance of target species, maintain the old-growth age structure that enhances population replenishment, and protect genetic diversity that enhances stock adaptability, viability and productivity.

Making MPAs Dynamic

There is already evidence that the geographic ranges of some marine organisms are shifting poleward in response to ocean warming (Perry *et al*. 2005). In addition, some species may shift their depth distributions to deeper water, and others generally may shift to less affected sites or habitats in response to the full range of climate change effects. The rule of thumb for protecting species is to place protected areas in the center of the range, where there is an expectation that populations will have greater viability and individuals will be best adapted to local conditions.

Anticipating range/habitat shifts in response to warming, the dynamic siting of MPAs may have to be shifted toward the poles and/or deeper water as the oceans warm further. Terrestrial managers create corridors of protected habitat to allow species to migrate and habitats to reassemble and reorganize. In the marine environment, because of the fluid nature of larval dispersal, 'stepping stones' rather than corridors might be a better design analogy for the distribution of protected areas. This approach has the potential to work along the west and east coasts, but is not likely to work for species that are 'trapped' in the northern ends of south-facing basins such as the Gulfs of Mexico and Alaska. It will also fail when the necessary substrate is not available. For example, kelp forests may be trapped if there are long expanses to the north without any hard substrates at the right depths. Another example is the coral reefs at the northern end of Northwestern Hawaiian Islands, for which there are only abyssal depths to the north of the chain. With no place to move to the north, their only option may be a depth shift. Further, ecological interactions will strongly influence the potential for successful range expansion.

Because many populations will be moving in response to warming, we will see assemblages, biotic communities, habitats and ultimately ecosystems shifting geographically and reorganizing themselves as they move. The single species model focused on corridors or stepping stones does not capture the complexity of the changes that will occur. A more apt model may be to design the 'stepping stones' as networks of MPAs that anticipate these movements and the dynamic reorganization that will occur over multiple scales.

Maintaining Connectivity

Habitat patches are not typically isolated or completely self-sustaining. Most patches are connected (genetically and demographically) to other patches through the movement of larvae, juveniles and/or adults. Recruitment of marine organisms occurs through a combination of retention (larvae settling in their natal patch) and connectivity (larvae settling on other patches). Some patches are primarily sources, others are sinks, but most both provide and receive recruits to the population. Thus, the viability of most patches is partially dependent on the integrity and productivity of the patch itself (retention), and on the integrity and productivity of other patches (connectivity). Maintaining the integrity and resilience of ecosystems requires that the spatial diversity and connections are maintained (Palumbi *et al.* 2003). This goal can be achieved with the use of larger MPAs that encompass nearly the full complement of habitat types and patches, and other ecosystems, or by effective networks of MPAs. Except in isolated, lightly exploited areas (e.g., the Northwestern Hawaiian Islands) establishing suitably large MPAs has often proven to be politically infeasible. An alternative is to establish a network of MPAs that, in aggregate, provides protection for the full range of habitats, through the placement of individual MPAs that provide the connectivity necessary to maintain ecological integrity.

Because climate change affects ocean structure and ocean circulation that drives larval dispersal, it is highly likely that climate change will alter the connectivity patterns among the different habitats and patches within an ecosystem. This implies that the design of MPA networks will have to anticipate changes in connectivity patterns and dynamics. Given that information about ecological connectivity is available for only a few places, this will be a difficult task.

Spreading Risk

'Representation' and 'replication' are two general principles of MPA design that act to spread the risk of stresses causing serious and irreparable harm. 'Representation' refers to the design objective of protecting optimal numbers or proportions of various types of a given resource, such as ecosystems, habitats, species or populations. The goal is to preserve the range of biodiversity (genetic, species, habitat, landscape) in the system. Implementing this objective affects the siting, number and size of MPAs. Larger MPAs are likely to have a greater diversity of resources, but are also likely to impose a greater cost on ocean users. Alternatively, the same end often can be achieved by the careful establishment of multiple, smaller MPAs, as is being done in California. 'Replication' refers to a design objective to protect multiple examples of each given type of a resource. The goal is to minimize the chance that large, severe stresses could wipe-out a particular resource type because it occurs primarily in one location.

Faced with significant uncertainty about where, when and which species, habitats and ecosystems are most vulnerable and likely to be lost, the cautious, risk-averse approach would be to protect as much of the diversity as possible – 'representation'. Similarly, because we cannot accurately predict the spatial distribution of vulnerability to climate change, establishing multiple MPAs that protect given species, habitats or ecosystems should be an effective way of reducing the risk of losing everything – 'replication'. As always, trade-offs must be weighed on multiple time scales between the potential benefits of increasing the size or number of protected areas versus the potential costs associated with loss of access.

VI. Ecosystem-Based Management and Coastal and Marine Spatial Planning

Ecological integrity and resilience are ecosystem properties, and, therefore, if the management of resources and environments under stress from climate change is to be effective it will have to be ecosystem-based. The potential severity of impacts and a high degree of uncertainty in predicting the progress of climate change at regional or local scales (i.e., the scales at which MPAs are managed) make it even more important to incorporate the key elements of ecosystem-based management – area-based, precautionary and adaptive management. The benefits of MPAs have been vigorously debated for decades. However, one role that has been widely accepted is the capacity for MPAs to buffer uncertainty. More generally, a precautionary or risk-management approach to management is likely to be called for in the face of climate change. Ecosystems and resources are already changing in ways that we have never experienced, which increases the importance of implementing adaptive management. Management measures will have to be implemented and assessed in an experimental manner, which should include the monitoring of resilience indicators and conducting of research to increase understanding and reduce uncertainty of key processes. For MPAs, this means carefully considering the timeframe of an adaptive management cycle, making boundaries and objectives more flexible, and possibly designing dynamic systems of MPAs. Further, such efforts should be considered in the context of a broader coastal and marine spatial plan.

VII. Conclusion

The oceans and the atmosphere are inextricably linked. Climate change poses a serious threat to our marine ecosystems and resources today and into the future. Many of these same marine ecosystems and resources, now facing new threats from climate change, have been significantly degraded over time by other human stressors, and are less likely to be resilient to the impacts of climate change than healthy ecosystems. The ability of the oceans to maintain life-sustaining processes, threatened in many ways by both the direct effects of increased CO_2 levels and the indirect effects of a changing climate, necessarily affects the sustainability of numerous ecosystems. Compared with terrestrial ecosystems, marine ecosystems are considered highly sensitive to climate change (WBGU 2006). Further, due to geophysical time lags, many of the impacts of climate change, including warming, are likely to persist in the oceans for thousands of years (IPCC 2007b). For MPAs, design and management reforms should be sought and secured as a matter of priority, so that these management tools may better enable us to meet the challenges posed by a changing climate, sustain the vitality of the marine environment, and protect human lives and livelihoods that depend on the ocean. Based on this climate change impacts review, the Scientific and Technical Subcommittee of the MPA FAC recommends that specific recommendations on how to effectively manage the National System of MPAs in consideration of anticipated climate change impacts on our marine resources be developed by the MPA FAC and communicated to the Secretaries of the Departments of Interior and Commerce.

Appendix I

Glossary

Ecosystem Integrity: A state in which the species composition, community structure, functional relationships, ecological processes and adaptability that are characteristic of natural ecosystems unaffected or unimpaired by human stresses.

Ecological Resilience: "The capacity of an ecosystem or natural population to resist or recover from major changes in structure and function following natural and human-caused disturbances, without undergoing a shift to a vastly different regime that is undesirable and very difficult to reverse from a human perspective." (MPA FAC 2009)

Marine Reserves: A type of MPA where extractive uses are prohibited (also referred to as "no-take" reserve) (MPA Center 2008).

Refugia: Areas that have escaped ecological changes occurring elsewhere and so provide suitable habitats for threatened, endangered and relict species.

Regime Shift: A relatively quick, large-scale shift to a drastically different ecosystem state.

Replication: Protecting multiple refuges for insurance against catastrophic loss (MPA Center 2008).

Representation: Protecting refuges for high-priority ecosystems and populations (MPA Center 2008)

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