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30 April 2009

Dr. Jane Lubchenco
Under Secretary of Commerce for Oceans and Atmosphere, and
NOAA Administrator
Department of Commerce
1401 Constitution Avenue, NW, Rm 5810
Washington, DC 20230

Mr. Will Shafroth
Principal Deputy Assistant Secretary of the Interior
for Fish and Wildlife and Parks
Department of the Interior
1849 C Street, NW
Washington, DC 20240

re: recommendations by **Marine Protected Areas Federal Advisory Committee**

Dear Under Secretary Lubchenco and Deputy Assistant Secretary Shafroth:

On behalf of the Marine Protected Areas Federal Advisory Committee (MPA FAC), it is my pleasure to submit for your consideration two related sets of recommendations from our recent meeting in Annapolis, Maryland, on 21-23 April 2009. Both documents are relevant for effectively evaluating and improving the National System of Marine Protected Areas, the first providing a foundation for the second. I am honored to report that, as has become the norm for this distinguished and highly engaged panel of 30 ocean experts, both documents passed unanimously.

The first set of recommendations, "**Ecological Resilience and Gap Analysis of the National System of Marine Protected Areas**," explains the importance of resilience as a theme for meeting the natural heritage and sustainable production goals and objectives of the National System. We offer a practical definition of resilience, review specific examples, and provide general guidelines applying resilience thinking to a gap analysis of the National System.

The second set of recommendations, "**Guiding Principles for Ecological Gap Analysis of the National System of Marine Protected Areas**," elaborates on the theme developed in the first document, and more specifically applies the concepts of gap analysis to the National System. Here, we focus on major principles and general approaches for assessing the different types of gaps that may occur.

Thanks again for meeting with the MPA FAC and helping us celebrate the launch of the National System of MPAs. In close cooperation with the National MPA Center, the FAC has been working diligently toward this goal since 2003. It is especially gratifying for the FAC to see that a genuine partnership has developed between Commerce and Interior to support the National MPA Center.

Through the years, an excellent partnership has also developed among members of the MPA FAC, our ex officio federal representatives, and the staff of the National MPA Center. Such engaged partnerships are certainly essential for the success of new National System of MPAs.

The MPA FAC looks forward to your response to our recommendations, and to continuing our work with the Departments of Commerce and the Interior to help ensure that the National System of MPAs effectively serves both present and future generations of Americans. Thank you for your consideration.

Sincerely,

Mark Hixon
Helen Thompson Professor of Marine Conservation Biology and
Chair, Marine Protected Areas Federal Advisory Committee

attachments
cc: Lauren Wenzel, Designated Federal Official, National Marine Protected Areas Center, NOAA

Marine Protected Areas Federal Advisory Committee
23 April 2009

ECOLOGICAL RESILIENCE AND GAP ANALYSIS OF THE NATIONAL SYSTEM OF MARINE PROTECTED AREAS

Executive Summary*: 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. *Examples of the causes and losses of resilience in marine ecosystems include the important roles of herbivores in tropical coral reefs, of urchin predators in temperate kelp forests, and of top predators in cold-temperate continental shelf ecosystems. Protecting these ecologically important species in marine protected areas (MPAs) can foster resilience. Resilience is also applicable to individual marine populations, where MPAs can 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. Ecological networks of MPAs can foster resilience by mechanisms originally described in the "Framework for the National System of Marine Protected Areas of the United States of America" (National MPA Center, November 2008): (1)* ***representation*** *– protecting refuges for high-priority ecosystems and populations; (2)* ***replication*** *– protecting multiple refuges for insurance against catastrophic loss; (3)* ***viability*** *– protecting sufficiently large areas of habitat and numbers organisms to ensure persistence; and (4)* ***connectivity*** *– locating and spacing MPAs to allow ecologically important linkages among sites. Relative to the gap analysis of the National System, each of these components could be assessed as follows: (1)* ***representation*** *– by comparing the full suite of high-priority marine ecosystems and major habitats within a region with those protected by the existing system; (2)* ***replication*** *– by comparing the desired number of MPAs of a given type in a given region with the existing system; (3)* ***viability*** *– by comparing the desired location and size of MPAs of a given type in a given region with the existing system; and (4)* ***connectivity*** *– either by comparing known patterns of linkages with the existing system or by ensuring no large spatial gaps between MPAs within the same regional network.*

Introduction

Once the National System of Marine Protected Areas is established from existing sites, a formal gap analysis will identify where meeting the established goals and objectives of the system is most difficult because of shortfalls in the National System. The document entitled "Framework for the National System of Marine Protected Areas of the United States of America" (hereafter, the 'Framework'; National MPA Center, November 2008) lists multiple goals and objectives regarding natural heritage and sustainable production. A foundational concept for unifying these goals and objectives under a central theme for which an effective gap analysis can be designed is 'ecological resilience'. This document clarifies the practical meaning of this concept and uses resilience to develop operational criteria for an effective gap analysis of the National System.

Ecological resilience has emerged as a unifying concept in the science of conservation biology. The MPA Federal Advisory Committee sees the value of resilience as an important theme for meeting the natural heritage and sustainable production goals and objectives of the National System of MPAs. Therefore, our intention is to ensure that ecological resilience as a concept is translated from conservation biology to marine policy. Here, we clarify the meaning of ecological resilience and make practical use of resilience thinking to develop operational criteria for an effective gap analysis of the National System.

Practical Definition of Ecological Resilience

The Framework defines 'resilience' in terms of MPA implementation as "***designed to maintain ecosystems' natural states and to absorb shocks, particularly in the face of large-scale and long-term changes (such as climate change)***" (p.16). This definition must be clarified for practical application. The concept of resilience has a long history in the science of ecology. Unfortunately, its meaning and use has changed through time, consequently causing confusion and sometimes threatening its utility. During earlier times, when there was a mistaken belief that individual populations and entire ecosystems tended toward fixed states (stable point equilibria), resilience was seen as the speed at which an ecosystem or population returned to its original state after suffering some natural disturbance (e.g., a large storm) or human impact (e.g., dredging the seafloor). High resilience was seen as a rapid return to the original state. Subsequently, it was recognized that change at all scales of space and time is ever present in natural ecosystems and populations. Instead of each ecological system remaining in or returning to a single fixed state, each system actually exists in a variable yet identifiable range or suite of states (a **regime**[1]) driven by fluctuations in the environment, including both nonlethal changes in living conditions and an assortment of lethal disturbances. In this more realistic context, ecological resilience is now seen as the capacity of an ecological system to remain in the same regime without crossing a threshold to another regime (a **regime shift**), from which return to the original regime is difficult or even impossible.

The human perspective is also essential in practical applications of ecological resilience because humans value some regimes more than others. For example, we value tropical reefs dominated by living coral more than reefs dominated by dead coral rubble covered with slimy seaweeds. Therefore, management is seen as successful to the extent that it fosters tropical reefs remaining in the 'live-coral regime'. It is important to note that, although human actions can foster ecological resilience (see below), some natural changes are so great, such as the current warming of the Arctic Ocean, that regime shifts are inevitable. Nonetheless, because human value judgments are essential for practical applications of the concept of resilience, especially in the context of assessing the National System of MPAs, we define ecological resilience as follows:

[1] Key supplemental terms are in bold text where they are first used and defined.

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.***

This definition becomes more tangible when considering specific examples from the marine realm relevant to MPAs.

Ecological Resilience in Marine Systems and the Role of MPAs

Resilience is most commonly examined at the level of entire ecosystems (the perspective of many natural heritage MPAs). However, the concept can also be applied to single populations (the perspective of many sustainable production MPAs). The following examples clarify resilience in specific practical terms, and also illustrate the value of MPAs in fostering resilience. Note that not all of these well documented case studies were conducted in U.S waters, but are nonetheless illustrative of issues relevant to the United States.

Ecosystem Level

Tropical Coral Reefs: Tropical reefs exist in two primary regimes: one dominated by living coral, and the other dominated by seaweeds. The live-coral regime is preferred by humans because of the many ecological goods and services living reefs provide, including fisheries, coastal protection, recreation, tourism, and aesthetics. In the live-coral regime, natural disturbance (e.g., hurricanes) and human impacts (e.g., coastal pollution) occasionally kill large swaths of coral, but the system normally has high resilience and eventually recovers. Resilience is fostered by a diverse suite of herbivores that keep reef surfaces clean, allowing coral larvae to settle and grow unimpeded by seaweeds. The high diversity of herbivores further enhances resilience because loss of some herbivore species can be compensated by other ecologically similar species (**ecological redundancy**). Such compensation within groups of species that provide the same ecological services demonstrates the value of conserving species diversity. For example, reefs in the Caribbean region remained highly resilient, even after intensive overfishing of herbivorous fishes, because long-spined sea urchins assumed the role of primary herbivores. After a pandemic almost eliminated urchins from the system in 1983, resilience was severely reduced. A combination of human impacts, including siltation from coastal development, eutrophication from agricultural and sewage effluent, and coral bleaching due to a warming ocean, killed corals and pushed the reefs to domination by seaweeds. This degraded regime is itself highly resilient because seaweeds thrive in very warm, silty, eutrophic waters. Seaweeds inhibit coral settlement and growth, and there are now few herbivores to control the seaweeds. Recovery of degraded reefs to the live-coral regime is very difficult, which underscores the value of pre-emptive management for resilience to prevent regime change. Managing for resilience of coral reefs includes (1) fostering natural abundances and diversity of herbivores and (2) providing a favorable environment for corals. MPAs can help foster resilience by allowing herbivores to flourish and by prohibiting local human impacts that degrade coastal seawater quality.

Temperate Kelp Forests: Rocky reefs along the Pacific coast of the United States occur in two regimes: one dominated by large brown seaweeds called kelp, and the other dominated by a layer of living crusts (low-lying plants and sessile animals) covering otherwise bare rock. Humans prefer the kelp-forest regime because of the many ecological goods and services provided, including recreational and commercial fisheries, kelp harvest, high biodiversity, coastal protection, recreation, tourism, and aesthetics. The kelp-forest regime is naturally disturbed by large storms and warm-water periods (El Niño) that kill kelp, but under normal conditions, the kelp eventually recovers. Resilience in this case is fostered by natural controls of invertebrate herbivores (especially sea urchins) by their predators (especially sea otters to the north, and certain fish and spiny lobster to the south). Where these predators have been eradicated by hunting or overfishing, urchins have proliferated and inhibited the recovery of kelp following natural disturbances. Urchins can become so abundant and graze the seafloor so intensely that only a thin layer of encrusting algae and invertebrates can survive; newly settled kelps are soon consumed. This 'urchin-barrens' regime is itself resilient until the urchins are greatly reduced in abundance, typically by storms, disease outbreaks, or the recovery of their predators. MPAs that protect urchin predators have been demonstrated to enhance the resilience of kelp forests.

Cold-Temperate Continental Shelf Ecosystems: Stocks of northern cod (*Gadus morhua*) and other top predators of continental shelves of the northwest Atlantic collapsed in the 1990s and have failed to recover, at least partly because the regional ecosystem shifted to an undesirable regime as a result of its relatively low resilience compared to other areas. As cod stocks collapsed off Nova Scotia, Canada, due to intensive overfishing, prey fishes increased in abundance. In turn, herbivorous zooplankton (prey of the prey fish) decreased, and phytoplankton (prey of the zooplankton) increased, a classic 'trophic cascade'. This new regime has not reversed, despite a virtual ban on fishing cod in this region since 1993, apparently because (1) there are no top predators available to replace cod (all potential candidates were also overfished, causing low ecological redundancy), (2) the now abundant prey fishes consume and/or compete with juvenile cod, and (3) cold water delays population growth and recovery. In this case, MPAs protecting cod and other top predators before the collapse of the fishery could have fostered resilience. Following the regime shift, MPAs for cod that also left prey fishes vulnerable to exploitation could have possibly fostered recovery, yet the entire food web is now fundamentally altered. Similar ecosystems to the south of Nova Scotia in U.S. waters have shown greater resilience to fishing, apparently because, first, non-target predatory species have compensated for overfished cod (ecological redundancy), and second, warmer water has enhanced population growth and recovery.

Population Level

Although ecological resilience is usually considered in terms of entire ecosystems, the concept can also be applied to populations of single species. This extension of the concept is important because it addresses the fact that overexploited populations may undergo internal 'regime shifts' that compromise the viability of a fishery. In such cases, sustainable production MPAs may be useful tools for stock restoration and sustainability in at least four ways:

(1) MPAs can protect specific critical habitats, such as spawning and nursery areas, that enhance stock viability and productivity.

(2) MPAs can protect species that regulate the abundance of target species. Population sizes of fish and other marine organisms vary through time, sometimes tremendously, because the birth rate and the death rate can vary independently of each other; births sometimes exceed deaths, and vice versa at other times. A population is resilient, that is, it persists indefinitely and at levels that can support a sustainable fishery, when regulating factors keep the population size at sustainable levels. (In the parlance of resilience, fishery populations can be thought of as existing in two 'regimes': economically viable and economically extinct.) Natural regulating mechanisms include competition, predation and disease, which push populations down when they are too large (births < deaths), while also easing-off and allowing growth when populations are too small (births > deaths). Therefore, managing for population resilience includes conservation of competitors and other species that naturally regulate population size. MPAs can help ensure that regulating species maintain this ecological service by prohibiting their overexploitation

(3) MPAs can maintain old-growth age structure. Among marine fishes, natural selection has favored life-history characteristics, such as high fecundity (egg production), that ensure sufficient birth rates to at least balance the extremely high death rates of larvae and juveniles typical in the sea. In a broad variety of fishery species, including cods, rockfishes, and tunas, it has long been known that older, larger females produce far more eggs than younger, smaller females, and that they have longer spawning seasons. These and other adaptations make big, old, female fish extremely valuable, not only for replenishing populations, but also for fostering population resilience. For example, in black rockfish (*Sebastes melanops*) off the coast of Oregon, a highly variable marine environment, there are years when big, old females produce almost all of the young fish, younger females having spawned too late in the season for their young to survive. Because fishing almost always depletes the abundance of older, larger fish, MPAs can help ensure that a reasonable number of big, old females survive.

(4) MPAs can protect genetic diversity that enhances stock adaptability, viability and productivity.

In all the above examples, it is important to keep in mind that ongoing directional changes in the ocean environment, especially ocean warming and acidification, may lead to regime shifts in marine ecosystems independent of local human activities and management, including MPAs. Nonetheless, what we know of marine ecosystems indicates that relatively intact systems are more resilient to regime shifts than relatively degraded systems. Therefore, MPAs are clearly useful tools for fostering ecological resilience.

Applied Ecological Resilience: MPA Networks

The above examples illustrate how individual MPAs that protect key ecosystem components can foster ecological resilience in particular locations. However, a system of MPAs functioning as an ecological network can enhance resilience at far broader spatial scales. In this context, an

ecological network is a regional system of MPAs ecologically linked by dispersal of larvae and/or movement of juvenile and adult organisms. There are four components of networks that enhance resilience at large scales:

(1) ***Representation***: The Framework includes geographical, ecological, cultural, and governmental 'representativeness' as fundamental principles for implementing the National System (p.16). For natural heritage goals, it is, of course, essential to protect refuges for high-priority marine ecosystems for which MPAs are likely to be effective. In a practical sense, such protection comes from focusing on a variety of marine habitats; habitat complexity and variety have been shown to be accurate surrogate measures of marine biodiversity. In the context of networks, many marine species occupy different habitats as they grow from larvae to juveniles to adults (ontogenetic habitat shifts), so protecting entire life cycles demands including refuges for all relevant habitats in the network. This fact is applicable to both sustainable production and natural heritage goals.

(2) ***Replication***: The Framework includes 'replication' as a National System design principle in terms of "multiple sites to ensure continued representation in the face of harmful impacts" (p.16). Just as multiple species within the same ecologically functional group provide redundancy that enhances resilience locally (see examples above), multiple MPAs that protect the same ecosystem and habitat types ensure that the catastrophic loss of any particular site does not jeopardize the entire system. Such catastrophic loss could be due to the formation of a large hypoxic (low-oxygen) zone, coral bleaching over a broad area, a catastrophic hurricane, etc. Representation combined with replication provides both taxonomic and spatial redundancy because different sites can support different species with the same general ecological roles.

(3) ***Viability***: The Framework includes 'viability' as a National System design principle in terms of "inclusion of self-sustaining, geographically dispersed component sites of sufficient extent to ensure population persistence through natural cycles of variation" (p.16). To some extent, representation combined with replication over the entire geographic range of particular suites of species fosters viability. Viability also includes the notion of an MPA being of sufficient size to ensure the persistence of particular populations. The location of an MPA may also affect ecosystem viability, such as cool-water refugia for tropical coral reefs threatened by ocean warming and coral bleaching.

(4) ***Connectivity***: The Framework includes 'connectivity' as a National System design principle that "maximizes and enhances the linkages among individual MPAs, groups of MPAs within a given eco-region, or MPA networks in the same and/or different regions" (p.16). Movement of organisms among MPAs ensures that protected populations are replenished. Additionally, connectivity between MPAs and unprotected areas can possibly replenish unprotected populations via larval dispersal (**the seeding effect**) and/or movement of juveniles or adults (**the spillover effect**). Measuring population connectivity at sea is currently a major focus of research, with recent advances in methodology documenting both seeding and spillover effects. In a practical sense, because marine ecosystems harbor a diversity of species with a wide range of individual dispersal capabilities, even in the absence of substantial data on the movement of individual species, linkages throughout the ecosystem are fostered where the spacing of MPAs does not inhibit larval connectivity.

Applied Ecological Resilience: Gap Analysis of the National System of MPAs

The components of MPA network design that foster ecological resilience -- representation, replication, viability, and connectivity -- provide a practical foundation for developing an operational and effective gap analysis of the National System.

- For **representation**, the analysis would compare the full suite of marine ecosystems and major habitats within a region with those protected by the existing system. This comparison would require both mapping and categorizing ecosystems and habitats at a resolution that is both affordable and ecologically realistic.

- For **replication**, the desired number of MPAs of a given type in a given region would be compared with the existing system. All else being equal, higher replication fosters greater resilience, yet the resulting ecological benefits must be balanced by socioeconomic considerations.

- For **viability**, the desired size and location of MPAs of a given type in a given region would be compared with the existing system. MPA size and spacing guidelines for network design have already been developed in multiple regions.

- For **connectivity**, ideally, patterns of larval dispersal and juvenile/adult movements would be known for key species to identify gaps in connectivity within the National System. Given incomplete data, because nearly all marine ecosystems contain species that differ greatly in their dispersal capabilities, fostering linkages across the diversity of the ecosystem would be enhanced by networks where the spacing of MPAs does not inhibit larval connectivity. Fortunately, existing regional examples of GIS-based marine gap analysis provide practical models for scaling-up to the National System of MPAs. The ultimate challenge may not be the gap analysis itself, but the process of filling the identified gaps.

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<u>Ecosystem Level</u>

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Marine Protected Areas Federal Advisory Committee
23 April 2009

GUIDING PRINCIPLES FOR ECOLOGICAL GAP ANALYSIS OF THE NATIONAL SYSTEM OF MARINE PROTECTED AREAS

Introduction

Presidential Executive Order 13158 of 26 May 2000 established a National System of Marine Protected Areas (MPAs). The order specified that the national system be scientifically based, comprehensive, and represent the nation's diverse marine ecosystems and natural and cultural resources.

The "Framework for the National System of Marine Protected Areas of the United States of America" (hereafter, the 'Framework') was developed and released in November 2008. [2] The Framework states, "The critical next step toward achieving the national system's conservation objectives is the identification of conservation gaps: areas in the ocean and Great Lakes that meet priority conservation objectives of the national system but that are currently not adequately protected to ensure their long-term viability, as called for in Section 4(a) of the Presidential Executive Order" (p. 30). In accordance with the Framework, the MPA Center will lead a comprehensive collaborative region-by-region process to identify conservation gaps relative to the targeted conservation objectives and national system design criteria (p. 30). Conservation gaps will be used to inform the development of recommendations for new MPAs through regional MPA planning and can also be used by managing entities and stakeholders to guide their efforts to establish new MPAs. The National Oceanic and Atmospheric Administration (NOAA) and the U.S. Department of Interior (DOI) has sought advice from the Marine Protected Areas Federal Advisory Committee (MPA FAC) to assist with the conceptual design of the gap analysis process.

A gap analysis is a common process used in many different disciplines including business, economics, and ecology. In simplest terms, a gap analysis is a decision support process that enables organizations and managers to evaluate actual performance against potential performance. Two basic questions lie at the core of a gap analysis: (1) "Where are we?" and (2) "Where do we want to be?" When an organization or system is under-utilizing its current resources, then typically it is producing or performing at a level below its potential. In general, gap analysis begins with a clear understanding of organization or system goals and objectives, and evaluation of performance measures related to those goals and objectives. Identifying the

[2] Framework for the National System Of Marine Protected Areas of the United States Of America. November 2008. National Marine Protected Areas Center, NOAA's Office of Ocean and Coastal Resource Management, National Oceanic and Atmospheric Administration. 92pp.

performance gaps and subsequently taking action to close those gaps follows from such an analysis.

As it applies to the National System of MPAs, gap analysis should be an assessment of the extent to which a protected area system meets established protection goals within the context of the full mosaic of marine conservation and management measures. The gap analysis should take into account all aspects of spatial resource and environmental management, such as marine managed areas, de facto MPAs, and other management entities that are not part of the national system. It should involve comparing the biodiversity and resource patterns relative to the distribution of protected areas, and finding where species, ecosystems, and ecological processes are unprotected or under-protected. The analysis should seek to identify gaps in the National System of MPAs that may be filled through establishment of new MPAs, modification of existing MPAs, or changes in coastal zone management practices. The gap analysis should consider the diversity and wealth of life that exists within the entire Exclusive Economic Zone (EEZ) of the United States. The desired outcome of a gap analysis process and subsequent implementation of gap analysis recommendations is to strengthen the effectiveness of the National System of Marine Protected Areas.

The gap analysis should consider a range of various gaps which have the potential to undermine effectiveness of a marine protected area network as follows:

(1) **Representation Gaps**: where a particular habitat, ecosystem, or cultural resource type is either unrepresented or underrepresented in the national system.

(2) **Ecological Gaps**: where important species, habitats, ecosystems, or processes are not adequately protected to ensure their lasting conservation and sustainable use.

(3) **Management Gaps**: where the management regimes (management objectives or governance types) of MPAs in the national system do not fully provide for lasting conservation or sustainable production of a particular species, habitat, cultural resource, or ecosystem.

It is important to note that, at the present state of marine science, we do not fully understand marine ecological processes, particularly where they involve complex interactions between species, life-cycles, and ecosystem connectivity. That is why one of the most important principles of the gap analysis will be to employ an iterative, adaptive-management approach.

The Framework (p. 31) provides a view of a comprehensive gap analysis process that will include the following factors:

- "Taking into account existing MPAs and other conservation measures currently in place, … implemented iteratively, relative to targeted specific national system conservation objectives, and on region-by-region bases."

- "Gap identification efforts will be focused at the regional scale, and will be collaborative, involving MPA-related and other entities at various levels of government, Fishery Management Councils, and other organizations and institutions in synthesizing and analyzing existing scientific information, including traditional ecological knowledge, where available, and established conservation priorities. The effort to identify conservation gaps will include opportunities to review and comment on the process and its results by the public, the MPA FAC, relevant federal agencies, state and tribal governments, and other entities, including the National System Management Committee (Management Committee)."

- "Managing entities will need to work with stakeholders under the auspices of appropriate MPA authorities to: (i) evaluate these gaps; (ii) incorporate data on human uses and impacts and related societal and economic considerations; and (iii) assess management priorities to make an informed decision about appropriate next steps in response to an identified conservation gap. These steps might include the establishment of a new MPA, changes to existing MPAs, additional research, or some other alternative. Establishment of new MPAs or changes to the governance of existing MPAs must follow relevant processes under established authorities."

The first step in the comprehensive gap analysis process is an 'ecological gap analysis' which is the focus of this document. Ecological systems must also be considered in context with human interactions with the marine environment. Socio-economic and human use factors must be part of the comprehensive gap analysis.

In summary, the comprehensive gap analysis process will be an ambitious undertaking both in terms of scientific research and implementation of measures required to close the gaps. The gap analysis process must be approached pragmatically with due consideration of available funding and other resources. The MPA FAC cautions against imposing unfunded mandates upon the National MPA Center regarding both expectations of the gap analysis process and implementation actions. Success of the analysis and implementation of resulting recommendations will hinge upon adequate funding for the National MPA Center and MPA managing entities.

Principles of Ecological Gap Analysis

1. **Resilience:** ***Ensure that the National System of MPAs can effectively withstand stresses and changes***. For the purpose of guiding the gap analysis process, the MPA FAC defines *ecological resilience* as "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." For an in-depth discussion about ecological resilience, please refer to the MPA FAC document entitled *Ecological Resilience and Gap Analysis of the National System of Marine Protected Areas*. Recognition of connectivity among ecosystems has created increased interest in MPAs as networks, with core areas joined by complementarily-managed land and water, providing routes or stopping-off places for migratory species, buffering of MPAs against outside pressures, and an opportunity for resident species to interbreed with more distant populations. Protecting and enhancing the resilience of marine ecosystems should be regarded as an overarching principle of the gap analysis with the principles of representation, replication, connectivity, and viability being subsets of resilience as follows:

a. **Representation**: ***Ensure protection of biodiversity across the full range of biological scales (species and ecosystems)***. Representation focuses on ensuring that all ecosystems and habitats that can benefit from spatial management within a region are represented in an MPA network. Although somewhat idealistic, full representation would be achieved when representative samples of all species and ecosystems existed within the protected area network at a sufficient scale to ensure their long term persistence. As a first step in MPA design planning and gap analysis, it is critical to identify both representative and unique habitats. To accomplish this, a multidimensional classification of habitats should be conducted, including but not limited to water depth, exposure, seafloor type, and dominant flora and fauna. Considering that marine protected areas will likely ever cover only a small part of the marine environment, the key to a successful gap analysis is to identify shortfalls in representative protection, and thus to help to ensure that MPAs are located in the most effective places to capture as much biodiversity in need of protection as possible. In general, species diversity increases with habitat complexity, therefore the greater the variety of habitats protected, the greater the biodiversity conserved. MPA networks should advance priority conservation objectives found in each biogeographic region. MPAs that both represent and replicate (see below) all habitat and community types within well-connected networks are more likely to lead to persistence and resilience in ecosystems and ecological processes in a changing world.

b. **Replication**: ***Include replicates of each representative habitat within each biogeographic region to protect against unexpected losses of particular sites, safeguard genetic variation, and ensure ecological redundancy.*** An effective MPA network will include multiple sites to provide some measure of insurance against losses of part of the network. Furthermore, biodiversity elements exhibit genetic and/or compositional variation that ensures evolutionary potential, which is necessary for long-term conservation of species and ecosystems. Where applicable, multiple occurrences of this variation *within* single species or ecosystem types should be conserved. These occurrences should ideally be selected across the ecological distribution of the species or ecosystem type to ensure capture of that genetic and compositional variation. In places where the ecosystem is already degraded, MPA networks should include opportunities for restoration. MPAs should also be considered in places that are currently of low conservation value, if there is a realistic chance of such values being regained through the passive effects of time or more active management interventions. Determining the most effective number of replicates should involve a balance among ensuring adequate representation, minimizing socioeconomic costs, and ensuring effective monitoring and enforcement.

c. **Connectivity**: ***Ensure ecological connectivity among MPAs***. Connectivity between MPAs should be of prime consideration in gap analysis. Most marine species produce larvae that disperse, often resulting in demographically "open" local populations that are replenished by distant sources of recruitment. Additionally, many species are dependent upon access to a variety of often spatially separated ecosystems to complete their life cycles. Ensuring protection of spawning sites, proper arrangement and spacing of MPA sites to foster larval connectivity, and adequate linkages of ecosystems to support the completion of life cycles should be at the core of a gap analysis. Additional scientific research to adequately understand these life-cycle linkages should be given high priority. This goal is particularly critical when designing MPAs for marine biodiversity. The need for resilience is increased because major climate changes now seem almost inevitable and will have serious impacts on terrestrial and marine protected areas. Additionally, the effects of climate change on agricultural landscapes means that MPAs will be under increased human pressure and may require active intervention. As agricultural areas migrate due to shifts in climate, new watersheds will be impacted by fertilizer run-off, which will in turn lead to negative impacts on some coastal marine ecosystems. Ecological systems and species will move with changing climates, and therefore foresight and planning for networks will be required to allow this movement over time. In some cases, boundaries may have to be extended; for instance to include a broader range of landscape gradients, or new protected areas may need to be established.

d. **Viability**: ***Ensure MPAs have the ability to sustainably host the natural life forms within.*** In the Framework, viability is a guiding principle of gap analysis, ensuring the "inclusion of self-sustaining, geographically dispersed component sites of sufficient extent to promote population persistence through natural cycles of variation" (p. 16). The goal of this principle is to identify management actions that will promote the marine environment's ability to sustainably host an abundance of life forms. Viability is fostered by representation, replication, and by siting and sizing of MPAs in a manner that ensures the persistence of populations and ecosystems.

2. **Ensure lasting protection:** ***Network design must provide lasting protection to effectively conserve diversity and provide ecosystem benefits. Long-term arrangements for funding, management and enforcement are essential to sustain the National System.*** The use of MPA networks as a key strategy for long-term sustainability of marine ecosystems and the services they provide is dependent on having areas of *lasting protection*, as defined in the Framework (p. 19). The time it takes to accrue social, economic and environmental benefits can vary from a few seasons to decades, depending on the life history of target species, the condition of the ecosystem at the time of implementation, the level of enforcement, and the effectiveness of management within and outside of the MPA. The full effects of an MPA may take decades to be realized. Monitoring and evaluating the effectiveness of MPAs should be implemented as a standard procedure. As with any management intervention, if an MPA is not progressing toward established goals, the management plan must be revised or the MPA itself should be re-evaluated. Therefore, a comprehensive gap analysis must be approached with the objective of creating a network of MPAs that provides lasting protection to effectively and adaptively manage, conserve and replenish resources, and to sustain biodiversity and economic benefits.

3. **Consider various types of gaps**: ***Document representation gaps, ecological gaps, and management gaps in the analysis***. Different types of gaps impinge on the effectiveness of the National System and all should be considered to strengthen the system and close the ecological gaps that remain within it. *Representation gaps* refer to species, ecosystems and ecological processes that are missed entirely or functionally absent within the MPA network. *Ecological gaps* relate to biodiversity and habitats that exist within MPAs, but with insufficient quality or quantity to provide long-term protection. *Management gaps* refer to situations where MPAs exist, but are failing to provide adequate protection, either because they have the wrong management objectives or because they are managed poorly. All three of these gaps should be considered by the gap analysis to strengthen the National System of MPAs.

4. **Employ a participatory approach**: ***Collaborate with stakeholders in conducting an ecological gap analysis.*** A participatory approach, especially including communities adjacent to or affected by potential MPAs, should be pursued. Scientists must work collaboratively with stakeholders in conducting the ecological gap analysis.

5. **Use an iterative process of adaptive management**: ***Review and improve the gap analysis as knowledge grows and environmental conditions change***. In many cases, all the information necessary to make informed choices will simply not be available on management decision timelines. It may take many years of research to develop a comprehensive picture of an area's biological diversity. The gap analysis should therefore not be seen as a once and only exercise, but as an hypothesis that provides a series of maps and guidelines that may have to be revised and improved as time passes and understanding improves. This iterative process should rely on the best science and socio-economic knowledge available, while employing sound value judgments that effectively manage risk.

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