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Making Marine Zoning Climate-Change Adaptable

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MAKING MARINE ZONING CLIMATE-CHANGE ADAPTABLE

by Robin Kundis Craig[*]

ABSTRACT

Marine spatial planning, including the increased use of marine protected areas and marine reserves, has become the new goal for marine protection law and policy, both in the United States and world-wide. However, as a concept, marine spatial planning arose without reference to climate change and hence does not automatically account for the dynamic impacts that climate change is imposing on the marine environment or the special importance of preserving marine resilience in the face of those impacts.

This Article attempts to adapt marine spatial planning to climate change adaptation. In so doing, it explores three main topics. First, it examines how established marine protected areas such as the Papahānaumokuākea Marine National Monument can play a role in climate change adaptation and responses. Second, the Article takes a quick glance at how nations have otherwise incorporated climate change into marine spatial planning (or vice-versa), focusing on the international leader in marine spatial planning: Australia. Finally, the Article explores means of incorporating much needed flexibility into marine spatial planning to address existing stressors that reduce marine ecosystems' resilience, potential movement of ocean currents, potential shifting of marine ecosystems because of increasing temperatures and ocean acidification, and the eventual transformation, if climate change remains unchecked, of vast swaths of coastal life. Specifically, drawing on work by Josh Eagle, Barton H. Thompson, and James Sanchirico, this Article argues that, through the assignment of use rights, governments could encourage users to make bets about the future productivity and use value of different parts of the ocean. Such a system would have the added benefit of encouraging the private sector to pursue climate change adaptation research, increasing the knowledge base for all parties trying to adjust to the impacts that climate change is having and will have on the oceans.

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INTRODUCTION

Marine spatial planning, including the increased use of marine protected areas and marine reserves, has become the new goal for marine protection law and policy. In the United States, for example, in summer 2010, President Obama included marine spatial planning in his oceans executive order.[1] More internationally, the United Nations Educational, Scientific and Cultural Organization (UNESCO) has been promoting marine spatial planning for decades.[2]

At heart, marine spatial planning is the equivalent of marine zoning: government agencies and officials delineate areas of the ocean and designate them for different uses, such as fishing (commercial and/or recreational), diving, shipping lanes, and so forth. In the most protective designations, generally known as marine reserves, the government forbids all extractive or damaging uses of the area.

As a concept, marine spatial planning arose without reference to climate change and hence—like land use zoning and other forms of terrestrial spatial planning—does not automatically account for the dynamic impacts of climate change on the marine environment or the special importance of preserving marine resilience in the face of those impacts. This Article attempts to adapt marine spatial planning to climate change adaptation.

This Article begins by providing an overview of marine spatial planning. In Part II, it then looks at the need for adaptability in ocean governance as a result of climate change, detailing the impacts and ecosystem changes that climate change is bringing to the world's seas. In Part III, the Article examines in more detail three ways in which marine spatial planning could be made more climate-change adaptable. First, Part III looks at how established marine protected areas such as the Papahānaumokuākea Marine National Monument can play a role in climate change adaptation and responses. Second, Part III examines how nations such Australia, one of the earliest leaders in marine spatial planning, have incorporated climate change into marine spatial planning (or vice-versa). Finally, Part III explores other means through which much needed flexibility can be incorporated into marine spatial planning to address existing stressors that reduce marine ecosystems' resilience, potential movement of ocean currents, potential shifting of marine ecosystems because of increasing temperatures and ocean acidification, and the eventual transformation, if climate change remains unchecked, of vast swaths of coastal life.

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[1] Exec. Order No. 13547, *Stewardship of the Ocean, Our Coasts, and the Great Lakes*, 75 Fed. Reg. 43,023 (July 19, 2010).

[2] *See*, *e.g.*, INTERGOVERNMENTAL OCEANOGRAPHIC COMMISSION & MAN AND THE BIOSPHERE PROGRAMME, UNESCO, MARINE SPATIAL PLANNING: A STEP-BY-STEP APPROACH TOWARD ECOSYSTEM-BASED MANAGEMENT (2009) [hereinafter 2009 UNESCO MSP GUIDE].

I. MARINE SPATIAL PLANNING AND OCEAN GOVERNANCE

It always helps, when discussing legal regimes, to figure out what you're trying to accomplish -- at least generally. One oft-stated goal of marine governance regimes is to restore and maintain health marine ecosystems, or sometimes to protect and preserve representative marine ecosystems. However, that really just begs the question: What do we mean when we say that the governance goal is healthy ocean ecosystems?

In a climate change era, the governance goal of healthy ocean ecosystems should encompass four components. First, the governance regime should seek to protect, restore, and maintain multiple kinds of marine ecosystems—that is, to promote marine biodiversity at the ecosystem level. Most coastal nations benefit from the existence of different kinds of marine ecosystems—coral reefs, kelp forests, rocky intertidal zones, cold-water ecosystems dependent on nutrient upwelling, and so forth. Moreover, many coastal nations already structure their ocean governance regimes to protect representative marine ecosystems. GET CANADA EXAMPLE.

Second, each of those ecosystems should have an appropriate level of species-level biodiversity, as judged against a baseline status that reflects minimal human exploitation. Establishing the appropriate baseline by which to judge to the health of marine ecosystems, and hence the effectiveness of marine governance, is one of the most difficult aspects of creating and implementing a marine governance regime, because most marine ecosystems have been heavily exploited and changed by fishing and as a result of development. Moreover, climate change impacts, as discussed in Part II, are likely to alter the appropriateness of any historical baseline actually chosen. Nevertheless, historical states of the ecosystem, when known, still provide relevant points for assessment, just as the current state of the ecosystem provides an important reference point for both the current state of degradation and the measurable impacts of climate change.

Third, especially in a climate change era, ocean governance regimes should seek to make marine ecosystems—and the socio-ecological systems of which they are a part—as resilient as possible for as long as possible. Resilience is the capacity of a system to absorb disturbance without shifting to another systematic state or regime. In a climate change era, disturbances of various kinds, detailed more extensively in Part II, will be continual stressors to marine ecosystems. As a result, ocean governance regimes should be seeking to reduce other stressors on marine ecosystems and to enhance marine ecosystem resilience so that, for as long as possible, existing ecosystems will have the capacity to change as the world changes while still maintaining their current functionality.

Finally, however, in a climate change era, ocean governance must acknowledge that marine ecosystems will change over time, and many of them will shift to new ecological states of being. When climate change makes such ecological regime shift inevitable, governance regimes should help to ensure, to the extent possible, that marine ecosystems and the socio-ecological systems of which they are a part will transition to new states of being that are productive and adaptive, rather than collapsing into the equivalent of decimated marine deserts.

Marine spatial planning is a widely-promoted method for achieving at least the first three of these goals, although its integration with climate change adaptation is less than complete. Marine spatial planning seeks to achieve ecosystem-based management of the oceans, balancing biodiversity protection with human use. For example, in 2009, at the international level, the United Nations Educational, Scientific and Cultural Organization's (UNESCO's) Intergovernmental Oceanographic Commission and its Man and the Biosphere Programme published a "step-by-step approach" to marine spatial planning, noting that:

> During recent years, marine spatial planning (MSP) has been the focus of considerable interest throughout the world, particularly in heavily used marine areas. MSP offers countries an operational framework to maintain the value of their marine biodiversity while at the same time allowing sustainable use of the economic potential of their oceans. Essentially, MSP is an approach that can make key components of ecosystem-based management of marine areas a reality.[3]

In plainer terms, marine spatial planning is essentially marine zoning—that is, the spatial separation of incompatible uses of the ocean through legal fiat. However, unlike much land use zoning, marine spatial planning takes care to include the needs of the ecosystem itself in the zoning plan. For example, marine spatial planning will provide special protections for, and perhaps even forbid all human use of, those areas of the relevant marine ecosystem that are particularly critical to maintaining the ecosystem's function, productivity, and biodiversity, such as spawning grounds and critical habitat areas. These specially protected areas are generally referred to as marine protected areas, and the areas where all human extractive uses are forbidden are generally referred to as marine reserves.

Australia's zoning of the Great Barrier Reef over three decades ago is generally deemed to be the first use of marine spatial planning.[4] Since then, marine spatial planning has been used in several countries to protect critical marine ecosystems—often coral reefs—from overuse and to separate competing uses, such as fishing and diving. Two examples can illustrate the range of complexity that already exists in marine spatial planning.

Figure 1 presents the zoning plan for the Soufrière Marine Management Area (SMMA) on St. Lucia in the Caribbean. In the late 1980s and early 1990s, the southwestern coastal area of St. Lucia began to experience notable degradation as a result

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[3] 2009 UNESCO MSP Guide, *supra* note XX, at 10.
[4] 2009 UNESCO MSP GUIDE, *supra* note XX, at 7.

of overuse of the area—and competition for use of the area—by fishers and a growing tourist industry based on diving and snorkeling in the coral reefs.[5] Measurable impacts and problems included degradation of water quality, depletion of local fish stocks, loss of tourism revenue, decreasing quality of beach recreation, pollution, and increasing conflicts among the various types of users.[6] St. Lucia used a public process to establish a zoning system to help resolve these growing problems.

Figure 1: SMMA Marine Spatial Planning, St. Lucia

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5 Soufrière Marine Management Area, *Conflict Resolution and Participatory Planning: The Case of the Soufrière Marine Management Area* 2 (1999), *available at* http://www.smma.org.lc/Public/Case%20Studies/SMMA%20Case%20Study.pdf.

6 *Id.*

The result, as shown in Figure 1, is a rather simple zoning plan, designed primarily to separate commercial fishers from recreational divers and boaters. Thus, for example, in the fishing priority areas (dark pink in Figure 1), divers, snorkelers, and recreational boaters are cautioned that "commercial fishing has precedence over all other activities. Access by other users is allowed only to the extent that it does not interfere with any fishing activities."[7]

However, the system's assortment of marine reserves (green in Figure 1) also protect the coral reef ecosystem itself. Specifically, the primary purpose of these marine reserves "is to allow fish stocks to regenerate in order to ensure healthy fish populations in the future. These areas of high ecological value have been set aside for the protection of all marine flora and fauna, scientific research, and the enjoyment of divers and snorkelers."[8] A permit is necessary for divers to use these zones, although licensed dive operators and dive leaders can take care of the permitting as well as the management authority.[9]

A much more complex—and not entirely effective—system of marine zoning has arisen in the United States waters of the Gulf of Maine, between the U.S. and Canada off the United States's northeastern coast, as is shown in Figure 2. Like the Soufrière area of St. Lucia, both the ecosystem of the Gulf of Maine suffer and its human users suffer as a result of multiple, competing, and at times irreconcilable uses. As one writer has described this area:

> On any given day, the Gulf of Maine supports hundreds of different uses, ranging from a quick, quiet kayak trip along a protected shore to the passage of an enormous tanker bearing hundreds of thousands of gallons of oil. Fishermen work the waters of the Gulf's banks and shoals, whale watch boats track down its largest inhabitants, and scientists tow and tether the latest in ocean monitoring technology to track currents, winds and oceanographic conditions. Dredge spoils are dumped, yachts races are contested while fish, shellfish and seaweed are farmed—the list goes on and on.[10]

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[7] Soufrière Marine Management Association, *About Our Zones*, http://www.smma.org.lc/index.php?title=About%20our%20Zones&page=zoning (last visited March 5, 2011).

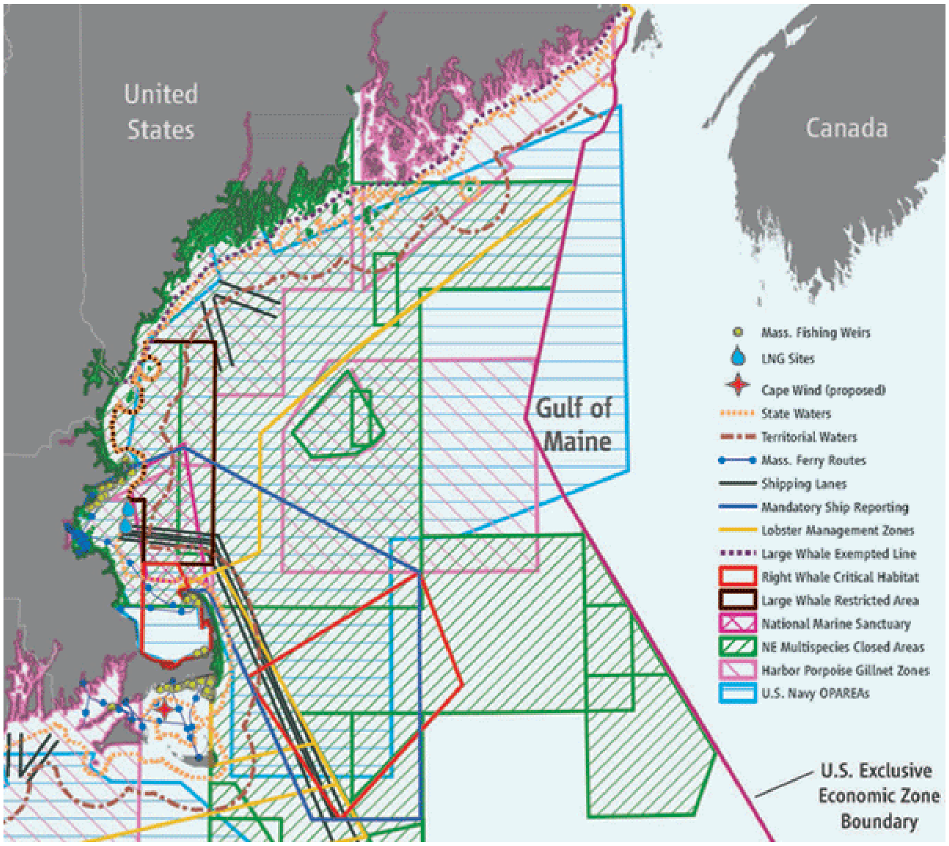
[8] *Id.*

[9] *Id.*

[10] Anne Hayden, "National Ocean Policy Means Changes for Gulf of Maine," *Gulf of Maine Times*, http://www.gulfofmaine.org/gomt/?p=545 (Oct. 27, 2010).

In addition, the area provides habitat that is important to the critically endangered Northern right whale. Two of the major threats to the whale are: (1) collisions with various kinds of ships; and (2) entanglement in various kinds of fishing gear.

Figure 2: Marine Spatial Planning in the Gulf of Maine



Thus, resolution of conflicts in the Gulf of Maine is already complex from the perspective of the multiplicity of users and the needs of the ecosystem itself. However, the current marine zoning in the Gulf of Maine also reflects the complexity of the United States's legal system (or lack of system) for marine governance. Instead of pursuing uniform priorities in marine management, governance of U.S. waters proceeds through a mishmash of regulatory programs and objectives. Moreover, regulatory authority is fragmented, both between the federal and state governments and among various agencies at both levels, but especially within the federal government.

As a result, there is not yet a "plan" for the Gulf of Maine, as full adoption of marine spatial planning would suggest there should be. Instead, there are a variety of overlapping and sometimes contradictory zones in the Gulf of Maine that reflect the different authorities of government agencies. These include a National Marine Sanctuary established under federal law (the dark pink hatched area in Figure 2); Northern right whale critical habitat areas established pursuant to the federal Endangered Species Act (bright red outline in Figure 2); lobster management areas (yellow outline in Figure 2), Massachusetts ferry routes (dotted bright blue lines in Figure 2), U.S. Navy operational areas (bright blue lined areas in Figure 2), and commercial shipping lanes (dark gray parallel lines in Figure 2).

The Gulf of Maine thus represents an area badly in need of improved marine zoning and real marine spatial planning. In the United States, the current driving force toward increased use of marine spatial planning is President Obama's July 2010 Ocean Stewardship Executive Order.[11]

In this Executive Order, President Obama first recognized the pervasive importance of the oceans to Americans. Specifically, "The ocean, our coasts, and the Great Lakes provide jobs, food, energy resources, ecological services, recreation, and tourism opportunities, and play critical roles in our Nation's transportation, economy, and trade, as well as the global mobility of our Armed Forces and the maintenance of international peace and security."[12] It then set out ten goals in protecting the United States's ocean ecosystems, including to: "protect, maintain, and restore the health and biological diversity of ocean, coastal, and Great Lakes ecosystems and resources;" "improve the resiliency of ocean, coastal, and Great Lakes ecosystems, communities, and economies;" and "improve our understanding and awareness of changing environmental conditions, trends, and their causes, and of human activities taking place in ocean, coastal, and Great Lakes waters[.]"[13] The Ocean Stewardship Executive Order thus incorporates both climate change and improved resilience into its goals, a fact made clear as well in the order's purposes, which include "providing for adaptive management to enhance our understanding of and capacity to respond to climate change and ocean acidification . . . ."[14]

In terms of implementing these goals, the Executive Order provides little by way of specifics. However, it does create a National Ocean Council with representatives from a wide variety of federal agencies and departments.[15] Most relevantly for this Article, the National Ocean Council is charged with approving and implementing marine spatial planning in U.S. waters, and:

[11] Exec. Order No. 13547, *Stewardship of the Ocean, Our Coasts, and the Great Lakes*, 75 Fed. Reg. 43,023 (July 19, 2010).
[12] *Id.* § 1, 75 Fed. Reg. at 43,023.
[13] *Id.* § 2(a)(i), (ii), (ix), 75 Fed. Reg. at 43,023-24.
[14] *Id.* § 1, 75 Fed. Reg. at 43,023.
[15] *Id.* § 4, 75 Fed. Reg. at 43,024-25.

> All executive departments, agencies, and offices that are members of the Council and any other executive department, agency, or office whose actions affect the ocean, our coasts, and the Great Lakes shall, to the fullest extent consistent with applicable law[,] . . . participate in the process for coastal and marine spatial planning and comply with Council certified coastal and marine spatial plans, as described in the Final Recommendations and subsequent guidance from the Council.[16]

Finally, the Executive Order defines "coastal and marine spatial planning" to mean:

> a comprehensive, adaptive, integrated, ecosystem-based, and transparent spatial planning process, based on sound science, for analyzing current and anticipated uses of ocean, coastal, and Great Lakes areas. Coastal and marine spatial planning identifies areas most suitable for various types or classes of activities in order to reduce conflicts among uses, reduce environmental impacts, facilitate compatible uses, and preserve critical ecosystem services to meet economic, environmental, security, and social objectives. In practical terms, coastal and marine spatial planning provides a public policy process for society to better determine how the ocean, our coasts, and Great Lakes are sustainably used and protected_now and for future generations.[17]

The referenced "Final Recommendations" in the Executive Order are the July 2010 final recommendations of the Interagency Ocean Policy Task Force,[18] which President Obama had established in July 2009.[19] Two of the Task Force's four main recommendations included "a strengthened governance structure to provide sustained, high-level, and coordinated attention to ocean, coastal, and Great Lakes issues" and "a framework for effective coastal and marine spatial planning (CMSP) that establishes a comprehensive, integrated, ecosystem-based approach to address conservation, economic activity, user conflict, and sustainable use of ocean, coastal, and Great Lakes resources."[20] Thus, improved governance and marine spatial planning play prominent roles in the federal government's attempts to improve ocean management.

More specifically, the Task Force identified nine priority implementation

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[16] *Id*. § 6(a)(ii), 75 Fed. Reg. at 43,026.
[17] *Id.* § 3(b), 75 Fed. Reg. at 43,024.
[18] *Id.* § 1, 75 Fed. Reg. at 43,023. *See also generally* WHITE HOUSE COUNCIL ON ENVIRONMENTAL QUALITY, FINAL REPORT OF THE OCEAN POLICY TASK FORCE (July 19, 2010), *available at* http://www.whitehouse.gov/files/documents/OPTF_FinalRecs.pdf [hereinafter 2010 OCEAN POLICY RECOMMENDATIONS] (presenting the Task Force's recommendations to the President).
[19] 2010 OCEAN POLICY RECOMMENDATIONS, *supra* note XX, at 1.
[20] *Id.* at 2-3.

objectives for the United States. Relevant to this Article, these include: the adoption of "ecosystem-based management as a foundational principle for the comprehensive management of the ocean, our coasts, and the Great Lakes" (#1); implementation of "comprehensive, integrated, ecosystem-based coastal and marine spatial planning and management in the United States" (#2); and strengthening of "resiliency of coastal communities and marine and Great Lakes environments and their abilities to adapt to climate change impacts and ocean acidification" (#5).[21] The Task Force considered the first two of these objectives—ecosystem-based management and marine spatial planning—as much changes in the way the United States implements ocean management, its most fundamental ways of "doing business."[22] Thus:

> The implementation of ecosystem-based management embodies a fundamental shift in how the United States manages these resources, and provides a foundation for how the remaining objectives would be implemented. Within that construct, the implementation of coastal and marine spatial planning and management would mark the beginning of a new era of comprehensive, integrated techniques to address conservation, economic activity, user conflict, and sustainable use of ocean, coastal, and Great Lakes resources.[23]

In contrast, climate change is one of five "Areas of Special Interest"[24]—that is, "priority areas of work [that] seek to address some of the most pressing challenges facing the ocean, our coasts, and the Great Lakes."[25]

With respect to Coastal and Marine Spatial Planning (CMSP) in particular, the Task Force recommended seven national goals:

> 1. Support sustainable, safe, secure, efficient, and productive uses of the ocean, our coasts, and the Great Lakes, including those that contribute to the economy, commerce, recreation, conservation, homeland and national security, human health, safety, and welfare;
>
> 2. Protect, maintain, and restore the Nation's ocean, coastal, and Great

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[21] *Id.* at 6. The other recommended priorities are to better inform decisions and to improve understanding of the ocean and its services (#3); to better coordinate across the federal government and among federal agencies, the states, Tribes, and local governments (#4); to implement regional marine ecosystem protection and restoration (#6); to improve water quality and sustainable practices on land (#7); to address changing conditions in the Arctic (#8); and to strengthen and integrate basic ocean observation, measuring, and monitoring (#9). *Id.*

[22] *Id.* at 28.

[23] *Id.* at 29.

[24] *Id.* at 28.

[25] *Id*. at 29.

> Lakes resources and ensure resilient ecosystems and their ability to provide sustained delivery of ecosystem services;
>
> 3. Provide for and maintain public access to the ocean, coasts, and Great Lakes;
>
> 4. Promote compatibility among uses and reduce user conflicts and environmental impacts;
>
> 5. Improve the rigor, coherence, and consistency of decision-making and regulatory processes;
>
> 6. Increase certainty and predictability in planning for and implementing new investments for ocean, coastal, and Great Lakes uses; and
>
> 7. Enhance interagency, intergovernmental, and international communication and collaboration.[26]

Like all proponents of marine spatial planning, it viewed CMSP as a way of rationally dealing with the multiple and conflicting users of the United States's marine ecosystems.[27] However, the Task Force also viewed CMSP as a means of reducing existing stresses on these marine ecosystems, thereby increasing their resilience. As it emphasized, CMSP "allow[s] for the reduction of cumulative impacts from human uses on marine ecosystems . . . and reduce[s] conflicts . . .between using and preserving the environment to sustain critical ecological, economic, recreational, and cultural services for this and future generations."[28]

Nevertheless, marine spatial planning imports a static quality into marine management. Like terrestrial zoning, and as suggested in the Soufrière Marine Management Area's plan, marine spatial planning establishes boundaries on areas of use that, while not necessarily set in legal stone, may be more or less difficult to alter, both legally and practically. Indeed, some such stability is desirable. For example, the U.S. Ocean Policy Task Force, while emphasizing that CMSP in the United States needs to be "adaptive"[29] and "flexible,"[30] also stressed that CMSP would increase predictability for users, underscoring the static element of marine spatial planning:

> CMSP is intended to facilitate sustainable economic growth in coastal communities by providing transparency and predictability for economic investments in coastal, marine, and Great Lakes industries, transportation,

[26] *Id*. at 7.
[27] *Id.* at 32-33, 41.
[28] *Id.* at 33.
[29] 2010 OCEAN POLICY RECOMMENDATIONS, *supra* note XX, at 41.
[30] *Id.* at 42.

> public infrastructure, and related businesses. CMSP could promote national objectives such as enhanced national energy security and trade and provide specific economic incentives (e.g., cost savings and more predictable and faster project implementation) for commercial users.[31]

Therefore, as in terrestrial zoning, one of the tensions in promoting marine spatial planning is how to balance the desire for predictability and stability with the knowledge that human needs and desires will change over time. To these anthropocentric concerns, however, the oceans add a backdrop of physical, chemical, and biological dynamism with which terrestrial planners—especially those working with traditional urban and suburban zoning—rarely have to contend. For example, one phenomenon of importance to both global currents and global weather patterns is the El Niño/Southern Oscillation (ENSO), in which sea surface temperatures in the eastern Southern Pacific Ocean vary over cycles lasting from two to seven years.[32] The oscillation between warm El Niño and cold La Niña patterns changes relative sea level in the Pacific Ocean basin, alters current patterns, changes fishing grounds and species' ranges, and affects rainfall partterns throughout the world.[33] More local variations of a variety of durations also occur in ocean ecosystems, potentially limiting the value of static ocean zones for certain kinds of marine uses, such as fishing.

And that's even *before* climate change impacts on the oceans are considered. As the next Part discusses, these impacts call the long-term viability of static marine spatial planning into sharp question, suggesting that conventional marine spatial planning (as new as it is as a marine management tool) needs to better incorporate climate change adaptation in order to remain an improvement in marine governance over the longer term.

II. The Need for Climate Change Adaptability in Ocean Management

As the Ocean Policy Task Force recognized in July 2010, "The importance of ocean, coastal, and Great Lakes ecosystems cannot be overstated; simply put, we need them to survive."[34] Climate change, however, both compounds existing threats to ocean resources and adds its own. As the Task Force summarized:

> Climate change is impacting the ocean, our coasts, and the Great Lakes. Increasing water temperatures are altering habitats, migratory patterns, and ecosystem structure and function. Coastal communities are facing sea-

[31] *Id.* at 44.
[32] National Weather Service, National Oceanic & Atmospheric Administration (NOAA), *Frequently Asked Questions About El Niño and La Niña*, http://www.cpc.ncep.noaa.gov/products/analysis_monitoring/ensostuff/ensofaq.shtml (last updated Dec. 19, 2005).
[33] *Id.*
[34] 2010 Ocean Policy Recommendations, *supra* note XX, at 12.

> level rise, inundation, increased threats from storms, erosion, and significant loss of coastal wetlands. The ocean's ability to absorb carbon dioxide from the atmosphere buffers the impacts of climate change, but also causes the ocean to become more acidic, threatening not only the survival of individual species of marine life, but also entire marine ecosystems. The ocean buffers increased global temperatures by absorbing heat, but increasing temperatures are causing sea levels to rise by expanding seawater volume and melting land-based ice. Increased temperatures may eventually reduce the ocean's ability to absorb carbon dioxide. Conversely, climate change is predicted to lower the water levels of the Great Lakes, thereby altering water cycles, habitats, and economic uses of the lakes.[35]

This Part will examine each of these impacts in turn, making to the overall general point that climate change is already altering, and will continue to alter, ocean ecosystems in ways that not only exacerbate the "normal" dynamism of the seas but also threaten to push marine ecosystems over resilience thresholds.

A. The Oceans' Role in Climate Change

The oceans play a significant role in climate change impacts, and understanding the interactions between the atmosphere and the oceans is widely acknowledged to be critical to understanding and modeling climate change impacts on land. A recent NOAA report explains:

> Most of incoming solar energy absorbed by Earth is absorbed at the top ocean layer, but not all the absorbed heat is stored and transported by the oceans. Over 80% of the heat is released back to the atmosphere by two heat exchange processes at the air-sea interface: evaporation that releases latent heat and conduction, and convection that releases sensible heat. The amount of heat being exchanged is called heat flux. Latent and sensible heat fluxes from the oceans are significant energy sources for global atmospheric circulation, and their changes on short- and long-term timescales have important implications for global weather and climate patterns.[36]

Thus, the interactions of the oceans and the atmosphere create the heat circulation and the wind and weather patterns that in turn express the realities of climate change and determine its impacts on all terrestrial life.[37]

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[35] *Id.*

[36] Joel M. Levy ed., *Global Oceans*, *in* STATE OF THE CLIMATE IN 2009*,* 91(7) BULL. OF THE AM. METEOROLOGICAL ASS'N. S53, S59, S61 (July 2010) [hereinafter Levy] (citations omitted).

[37] MEA 2005: CURRENT STATE AND TRENDS, *supra* note XX, at 498.

B. Climate Change's Exacerbation of Existing Ocean Stresses

One way that climate change will increase the dynamism of the ocean is by exacerbating current stresses to the seas. For example, about eighty percent of ocean pollution, perhaps more, comes from land.[38] Mercury, for example, frequently reaches the oceans through atmospheric deposition: land-based sources emit the mercury into the air, which falls back into waters or onto land, where runoff carries it to sea.[39] Methyl mercury, the organic form of mercury, bioaccumulates in marine organisms, becoming more concentrated the further up the food web a species resides.[40] High-level predators such as tuna, swordfish, shark, and mackerel can end up with mercury concentrations in their bodies that are 10,000 times the ambient concentration of mercury in the water.[41] Mercury contamination is already prevalent in food fish, and in 2003, seventy percent of the coastal waters in the contiguous forty-eight states—including ninety-two percent of the Atlantic coast and one hundred percent of the Gulf coast—were under fish consumption advisories for mercury; the State of Hawai'i also issued such advisories.[42] In March 2004, the U.S. Food and Drug Administration (FDA) and the U.S. EPA jointly advised pregnant women and children not to eat shark, swordfish, tilefish, or king mackerel because of the likely mercury content in those fish.[43] Other studies suggest that the population in general is at risk from mercury-contaminated fish. For example, the EPA's safety guidelines suggest that a 120-pound person ingest 38.5 micrograms per week or less of mercury.[44] A random test conducted by the *San Francisco Chronicle* of fish in Bay Area markets in 2003 found 23.2 micrograms of mercury in one six-ounce

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[38] Li Daoji & Dag Daler, *Ocean Pollution from Land-based Sources: East China Sea, China*, 33 AMBIO 107, 108 (2004); *Problems: Ocean Pollution*, WORLD WILDLIFE FUND, http://wwf.panda.org/about_our_earth/blue_planet/problems/pollution/ (last visited ~~Oct. 1~~Dec. 2, 2010).

[39] *Mercury Contamination in Fish: Know Where It's Coming From*, NAT. RESOURCES DEFENSE COUNCIL, http://www.nrdc.org/health/effects/mercury/sources.asp (last visited Dec. 2, 2010).

[40] *Mercury Contamination in Fish: Learn About Mercury and Its Effects*, NAT. RESOURCES DEFENSE COUNCIL, http://www.nrdc.org/health/effects/mercury/effects.asp (last visited Dec. 2, 2010).

[41] *Id*.

[42] ZACHARY CORRIGAN, ENVIRONMENT COLORADO RESEARCH & POLICY CENTER, FISHING FOR TROUBLE: HOW TOXIC MERCURY CONTAMINATES FISH IN U.S. WATERWAYS 5 (Oct. 2004), *available at* http://cdn.publicinterestnetwork.org/assets/70I4xouqei5JOkGAMODHLA/Fishing_for_Trouble_2004.pdf.

[43] FDA & EPA, WHAT YOU NEED TO KNOW ABOUT MERCURY IN FISH AND SHELLFISH 2 (Mar. 2004), *available at* http://www.fda.gov/downloads/Food/ResourcesForYou/Consumers/UCM182158.pdf.

[44] Jane Kay, *Toxic Fish Alert: Survey finds mercury in 4 species at markets in Bay Area*, S. F. CHRONICLE, Nov. 23, 2003, at A1, *available at* http://articles.sfgate.com/2003-11-23/news/17519632_1_chilean-sea-bass-mercury-contaminated-fish.

serving of Alaska halibut, 55.8 micrograms in six ounces of fresh tuna, 68.1 micrograms in six ounces of Chilean seabass (Patagonian toothfish), and 222.3 micrograms of mercury in six ounces of swordfish.[45]

Of course, humans are not the only apex predators of seafood. Marine mammals in particular also suffer as a result of bioaccumulating both mercury and other toxic pollutants, such as polychlorinated biphenyls (PCBs).[46] Beluga whales in the St. Lawrence River between Canada and the United States and orcas off the Washington coast in Puget Sound accumulate such a high concentration of toxins in their fatty tissues and blubber that they may qualify as toxic waste.[47] This contamination is thought to increase the cetaceans' mortality: the St. Lawrence belugas, for example, account for forty percent of all cancers found in cetaceans,[48] while mortality rates in the orcas are increasing, with forty-two percent of the calves dying in their first few months.[49]

Mercury methylation and the consequent bioaccumulation of mercury in marine organisms appears to be temperature-dependent. As a result, mercury contamination of

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45 *Id.*

46 _~~–~~*Mercury in Aquatic Habitats*, NAT'L OCEAN AND ATMOSPHERIC ADMIN. OFF. RESPONSE AND RESTORATION http://response.restoration.noaa.gov/type_audience_entry.php?RECORD_KEY(entry_audience_type)=entry_id,audience_id,type_id&entry_id(entry_audience_type)=86&audience_id(entry_audience_type)=6&type_id(entry_audience_type)=2 (last updated Apr. 27, 2005) ("Marine mammal tissues have some of the highest concentrations of mercury found in all marine organisms, with the liver generally having the highest total mercury concentration."); Eric W. Montie et al., *Organohalogen Contaminants and Metabolites in Cerebrospinal Fluid and Cerebellum Gray Matter in Short-beaked Common Dolphins and Atlantic White-sided Dolphins from the Western North Atlantic*, 157 ENVTL. POLLUTION 2345, 2345, 2351-55 (2009) (finding significant concentrations of PCBs in dolphins).

47 *See* Xenia Shih, *Jean-Michel Cousteau's Ocean Adventures: Beluga Whales Under Threat*, PBS (Mar. 23, 2009) http://www.pbs.org/kqed/oceanadventures/episodes/seaghosts/indepth-belugas.html (finding St. Lawrence beluga blubber contains PCB levels ranging from 240 to 800 parts per million (ppm~~);~~) and under Canadian Law a PCB level of 500 ppm is considered toxic waste); *see also* Marla Cone, *A Disturbing Whale Watch in the Northwest*, L.A. TIMES, Feb. 16, 2001, *available at* http://www.orcanetwork.org/habitat/latimespcbs.html (finding Puget Sound orca blubber contains PCB levels as high as 250 ppm).

48 Shih, *supra* note 46. Cetaceans include "[a]pproximately 78 species of whales, dolphins, and porpoises are included in the Order Cetacea." *Cetaceans: Whales, Dolphins, and Porpoises*, NOAA FISHERIES, OFFICE OF PROTECTED RESOURCES, ~~http://www.nmfs.noaa.gov/pr/species/mammals/cetaceans/ (last visited Nov. 3~~http://www.nmfs.noaa.gov/pr/species/mammals/cetaceans/ (last visited Dec. 2, 2010).

49 *See* Cone, *supra* note XX.

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fish and marine mammals is likely to increase as ocean temperatures increase in response to climate change.[50]

The oceans already suffer from another form of land-based pollution: nutrient runoff. Water flowing over and from farms, in the forms of both irrigation return flows and runoff from rain or snowmelt, carries excess fertilizer (mostly nitrogen compounds) to the ocean.[51] Nutrients also reach the waters through atmospheric deposition, such as from the burning of fossil fuels.[52] Once there, the fertilizer induces large blooms of marine plants—phytoplankton and algae. As the blooms then die off, their decomposition consumes all of the oxygen in the water column, leading to hypoxic conditions that make large areas of the ocean uninhabitable by marine animals.[53] In the United States, the largest of these so-called "dead zones" occurs seasonally in the northern Gulf of Mexico at the mouth of the Mississippi River and can reach the size of New Jersey—over 7000 square miles.[54] The Mississippi River drains forty-one percent of the United States and dumps 1.6 million tons of nitrogen per year into the Gulf, three times as much as forty years ago.[55]

Dead zones are now common throughout the world's coastal regions, often impinging on fisheries.[56] The number of dead zones in the world's seas has doubled every decade since 1960 as a result of increasing marine pollution, and a study that appeared in *Science* in 2008 identified more than 400 dead zones throughout the world.[57] The world's biggest dead zone is in the Baltic Sea, where sewage and nitrogen fallout from the burning of fossil fuels combine with fertilizer runoff to over-enrich this small, contained marine environment.[58] More precisely, the Baltic Sea "is now home to seven

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[50] Shawn Booth & Dirk Zeller, *Mercury, Food Webs, and Marine Mammals: Implications of Diet and Climate Change for Human Health*, 113(5) ENVTL HEALTH PERSP. 521, 525 (May 2005).
[51] Robert J. Diaz & Rutger Rosenberg, *Spreading Dead Zones and Consequences for Marine Ecosystems*, 321 SCI. 926, 927 (2008).
[52] *Id*.
[53] *Id*.
[54] *See* Jennifer Vargas, *Gulf Wildlife 'Dead Zone' Keeps Growing*, DISCOVERY NEWS (May 7, 2010), http://news.discovery.com/animals/gulf-dead-zone-oil-spill.html.
[55] National Research Council, *Mississippi River Water Quality and the Clean Water Act: Progress, Challenges, and Opportunities*, THE NAT'L ACAD. PRESS, 21, 38-40 (2008), http://www.nap.edu/catalog/12051.html.
[56] *See* Diaz & Rosenberg, *supra* note XX, at 926 ("[D]ead zones have developed in continental seas, such as the Baltic, Kattegat, Black Sea, Gulf of Mexico, and East China Sea, all of which are major fishery areas.").
[57] *Id*. at 926, 928.
[58] James Owen, *World's Largest Dead Zone Suffocating Sea*, NAT'L GEOGRAPHIC NEWS (Mar. 5, 2010), http://news.nationalgeographic.com/news/2010/02/100305-baltic-sea-algae-dead-zones-water/.

of the world's ten largest marine dead zones."[59] Perhaps most disturbingly, dead zones are missing biomass according to what would be expected, suggesting that the oxygen deprivation can have long-term effects on the region's biodiversity and productivity.[60]

One of the general impacts of climate change will be changes in precipitation patterns, including increased rainfall in some places and more severe rain events in many more—including places where the overall impact of climate change will be to reduce precipitation overall. Increased and more severe storm events, especially when combined with increased hear, which stimulates algae blooms, means that climate change is likely to increase the size and severity of many ocean dead zones.[61]

In addition, climate change will almost certainly increase the frequency and severity of coral bleaching events.[62] Coral bleaching events are a type of disaster that punctuates the cumulative degradation of the oceans. Most surface coral species rely on symbiotic zooxanthellae, a type of algae contained within the coral polyps' tissues, to supplement their nutrition.[63] However, when water temperatures warm, corals expel their zooxanthellae, turning white (hence the term "coral bleaching") and potentially dying, especially if the bleaching event is prolonged or repeated.[64] Mass coral bleaching events occurred in 1982-1983 in Panama and the Galapagos Islands and again in 1997-1998 across the globe; both were associated with strong El Niño currents, which elevated sea surface temperatures in much of the world.[65] In the 1982-1983 event, coral reef mortalities in the Galapagos Islands reached 99 percent;[66] in the 1997-1998 event, "[c]oral reefs suffered mortalities of up to 95% in Kenya, Tanzania, the Maldives, the Seychelles, Sri Lanka, and India."[67]

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59 *Id.*

60 *See* Diaz & Rosenberg, *supra* note XX, at 927.

61 Diaz & Rosenberg, *supra* note XX, at 929. *See also* INTERGOVERNMENTAL PANEL ON CLIMATE CHANGE, CLIMATE CHANGE 2007: SYNTHESIS REPORT 47, 49 fig.3.3 (Nov. 2007) (noting that there will likely be increases in precipitation in the tropics and at the poles, but likely mostly decreases in precipitation at the mid-latitudes of the oceans, with corresponding increases and decreases of runoff into the oceans) [hereinafter 2007 IPCC SYNTHESIS REPORT].

62 MEA 2005: CURRENT STATE AND TRENDS, *supra* note XX, at 523.

63 MEA 2005: CURRENT STATE AND TRENDS, *supra* note XX, at 523.

64 *Id.*

65 *Coral Bleaching,* NOAA'S CORAL HEALTH AND MONITORING PROGRAM, http://www.coral.noaa.gov/~~cleo/coral_bleaching.shtml~~index.php?option=com_content&view=article&id=132&Itemid=166 (last visited ~~Sept. 30~~Dec. 2, 2010).

66 *Id.*

67 *Climate Change and Marine Diseases: The Socio-Economic Impact*, UNITED NATIONS ENVIRONMENT PROGRAMME WORLD CONSERVATION MONITORING CENTER, 5 (2009), http://www.unep-wcmc.org/marine/pdf/Epublication_V3_23092009.pdf (current version as of Sept. 30, 2010) [hereinafter *Climate Change and Marine Diseases*].

The IPCC projected increasing coral bleaching events even at current levels of SST increases.[68] Widespread coral mortality is likely to begin occurring if SSTs increase by approximately 2.5 to 3.0 degrees Celsius.[69]

Finally, climate change is likely to increase outbreaks of marine diseases. Outbreaks of marine disease signal that the world's marine resources are already over-stressed and vulnerable. For example, according to research published in 2004, disease outbreaks are increasing among sea turtles, corals, marine mammals, sea urchins, and marine mollusks.[70] UNEP considers the number of outbreaks of marine disease in the last few decades and the resulting mortalities to be "unprecedented."[71]

Climate change will exacerbate these existing trends by providing better conditions for certain types of diseases. For example, sea-level rise is likely to increase habitat for mosquitoes, contributing to the return and spread of diseases such as malaria and dengue fever. Cholera has a sea phase, and warming seas are associated with cholera outbreaks. Finally, as UNEP reported in 2009, climate change is likely to increase outbreaks of marine diseases:

> Climate change has resulted in rising sea temperatures and levels, changes in ocean circulation, pH and salinity, and has exposed the world's oceans to increasing levels of ultraviolet radiation. These physical and chemical changes influence the prevalence and potency of marine pathogens and biotoxins, with serious ecological and socio-economic ramifications.[72]

Among other things, an increase in marine diseases has direct implications for human health, in the form of shellfish contamination and increased outbreaks of cholera.[73] Marine disease also threatens the sustainability of marine aquaculture and tourism.[74]

C. Climate Change's Additional Stresses on Marine Ecosystems

In addition to exacerbating existing stressors, climate change is already creating new stressors for ocean ecosystems, such as increasing temperature, changing current patterns, and ocean acidification, that also increase the long-term dynamism of these systems.[75] For example, climate change has resulted in rising sea temperatures and levels,

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[68] 2007 IPCC SYNTHESIS REPORT, *supra* note XX, at 51 fig.3.6.
[69] *Id*.
[70] Jessica R. Ward & Kevin D. Lafferty, *The Elusive Baseline of Marine Disease: Are Diseases in Ocean Ecosystems Increasing?*, 2(4) PLOS BIOLOGY 542, 542-43 (Apr. 2004).
[71] *Climate Change and Marine Diseases*, *supra* note XX, at 1.
[72] *Climate Change and Marine Diseases*, supra note XX, at 1.
[73] *Id.* at 2.
[74] *Id.* at 4-5.
[75] Levy, *supra* note XX, at S53-~~S~~61.

changes in ocean circulation, pH and salinity, and has exposed the world's oceans to increasing levels of ultraviolet radiation. These physical and chemical changes influence the prevalence and potency of marine pathogens and biotoxins, with serious ecological and socio-economic ramifications. [76] In addition, ocean salinity patterns also appear to be changing in response to changes in global precipitation patterns, but the trend data is too short to be sure of that connection.[77]

One of the most direct impacts of increasing global average atmospheric temperatures is increasing surface sea temperatures (SSTs) and ocean heat content (OHC), both of which contribute significantly to ocean currents and world weather patterns. As NOAA recently noted, "[t]he long-term increase in OHC has an important contribution to sea level rise, reflects a first-order estimate of Earth's radiation balance, and provides a powerful constraint on model projections of future surface temperature rise."[78] Moreover, it reported that "upper-ocean heat content for the last several years have reached values consistently higher than for all prior times in the record, demonstrating the dominant role of the oceans in the Earth's energy budget."[79]

While SSTs in specific oceans can vary noticeably from year to year as a result of changes in current patterns, such as El Niño and La Niña events,[80] the overall trend of SSTs since 1950 is up.[81] Indeed, in 2007, the Intergovernmental Panel on Climate Change (IPCC) indicated that most regions of the ocean have already experienced SST increases of between 0.2 and 1.0 degrees Celsius.[82] It predicted that, under its "business-as-usual" scenario, ocean temperatures would increase by another 0.5 to 1.0 degree Celsius by 2029 and by up to four degrees Celsius by 2099, with warming continuing for at least another century thereafter.[83] However, research by an international team of scientists and reported in June 2008 indicated "that ocean temperature and associated sea level increases between 1961 and 2003 were 50 percent larger than estimated in the 2007 Intergovernmental Panel on Climate Change report."[84] Moreover, scientists have detected temperature increases almost two miles below the ocean's surface.[85]

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[76] *Climate Change and Marine Diseases*, supra note XX, at 1.
[77] *Id*. at S63-S64.
[78] Levy, *supra* note XX, at S59.
[79] *Id.* at S53; *see also id.* at S58 fig.3.7 (graphing upward trend of ocean heat content since 1994).
[80] *Id*. at S53-~~S~~55.
[81] *Id.* at S55 fig.3.3.
[82] *See* 2007 IPCC SYNTHESIS REPORT, *supra* note XX, at 32 fig.1.2.
[83] *Id.* at 46 fig.3.2.
[84] *Ocean Temperatures and Sea Level Increases 50 Percent Higher Than Previously Estimated,* SCIENCE DAILY, (June 19, 2008), http://www.sciencedaily.com/releases/2008/06/080618143301.htm.
[85] *See* Tim P. Barnett, David W. Pierce & Reiner Schnur, *Detection of Anthropogenic Climate Change in the World's Oceans*, 292 SCIENCE 270, 271 & fig.2 (2001) (reporting

Changes in ocean temperatures also cause temperature-sensitive species to migrate poleward,[86] and such migrations have already been detected. In November 2009, for example, researchers at NOAA reported that about half of the commercially important fish stocks in the western North Atlantic Ocean, such as cod and haddock, had been shifting north in response to rising sea temperatures.[87] Unfortunately, temperature-sensitive species at the poles have nowhere to go.[88]

A few marine species may go extinct because of temperature-induced changes in their habitat or food supply.[89] More importantly, climate change will have direct impacts on marine biodiversity[90] and on fishing and fish stocks.[91] As the FAO noted in 2009, "[c]limate change is a compounding threat to the sustainability of capture fisheries and aquaculture development."[92] A study published in *Nature* in late July 2010 suggests that the magnitude of the problem is even greater than suspected, finding ocean temperature

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detection of increases in some oceans' temperatures to depths of at least 3000 meters, when there are 1609.344 meters in a mile).

[86] 2009 FAO FISHERIES REPORT, *supra* note XX, at 87.

[87] Shelley DaWicki, *North Atlantic Fish Populations Shifting as Ocean Temperatures Warm*, NORTHEAST FISHERIES SCI. CENTER, NOAA, (Nov. 2, 2009) http://www.nefsc.noaa.gov/press_release/2009/SciSpot/SS0916/. *See also* B. Planque & T. Frédou, *Temperature and the Recruitment of Atlantic Cod (Gadus morhua)*, 56 CANADIAN J. FISHERIES & AQUATIC SCI. 2069 (1999) (reporting similar results for cod).

[88] *See* Julie M. Roessig et al., *Effects of Global Climate Change on Marine and Estuarine Fishes and Fisheries*, 14 REVIEWS IN FISH BIOLOGY & FISHERIES 251, 262-63 (2004) (explaining the limited options for polar fish species). According to the MEA, "[c]limate change, acting through changes in sea temperature and especially wind patterns, will disturb and displace fisheries. Disruptions in current flow patterns in marine and estuarine systems, including changes to freshwater inputs as predicted under climate change, may cause great variations in reproductive success." MEA 2005: CURRENT STATE AND TRENDS, *supra* note XX, at 498.

[89] The MEA indicated that marine extinctions resulting directly from climate change will probably be rare, although local extirpations are likely. MEA 2005: CURRENT STATE AND TRENDS, *supra* note XX, at 490. Instead, indirect effects are likely to be more important. For example, "[r]ecent results from monitoring sea temperatures in the North Atlantic suggest that the Gulf Stream may be slowing down and affecting abundance and seasonality of plankton that are food for larval fish. Declining larval fish populations and ultimately lower adult stocks of fish will affect the ability of overexploited stocks to recover." *Id*. (citation omitted).

[90] *Id*. at 489.

[91] *See generally* Roessig et al., *supra* note XX (comprehensively reviewing climate change's impacts on fisheries).

[92] 2009 FAO FISHERIES REPORT, *supra* note XX, at 87.

to be a major determinant of marine biodiversity and concluding that changes in ocean temperature "may ultimately rearrange the global distribution of life in the ocean."[93]

Temperature changes also affect ocean currents.[94] The science-fiction movie "The Day After Tomorrow" capitalized on projected changes to one of the largest of the ocean currents, known as the Great Ocean Conveyor. This global "pump" depends on the sinking of cold water in the North Atlantic Ocean, which in turn pulls warm water from the tropics up the coast of the eastern United States and across the Atlantic Ocean to Europe.[95] The Wood Hole Oceanographic Institution has explained the importance of this global conveyor system:

> The phenomenon has far-reaching impacts on climate. It transports tropical heat to the North Atlantic region, keeping winters there much warmer than they would be otherwise. And it draws down the man-made buildup of carbon dioxide from air to surface waters and eventually into the depths, where the greenhouse gas is stored for centuries and offset[s] global warming.[96]

In the 15 years prior to 2009, cold water in the North Atlantic was not sinking at the rates previously experienced, leading to speculation that the Great Ocean Conveyor was shutting down[97]—the basic premise of the overly dramatic "The Day After Tomorrow." However, the sinking of cold water "resumed vigorously" in the winter of 2008-2009, surprising scientists and underscoring just how complex climate change predictions are.[98]

Nevertheless, even if the Great Ocean Conveyor remains intact, more limited changes in ocean current patterns can still disrupt marine ecosystems at the local or regional scale. For example, much of the northwest coast of the United States, Canada, and Alaska benefits from nutrient-rich upwelling currents that support numerous species of fish—and strong fishing industries—in the northern Pacific Ocean. However, at the beginning of the 21st century, a mysterious dead zone began forming, and growing, off the coasts of Oregon and Washington.[99] This dead zone, which occurs in the middle of a commercially important fishery, has been attributed to climate change—specifically, to changing interactions of wind and offshore currents that prevent the normal dissipation of

[93] Derek P. Tittensor et al., *Global Patterns and Predictors of Marine Biodiversity Across Taxa*, 466 NATURE 1098 (Aug. 26, 2010).
[94] MEA 2005: CURRENT STATE AND TRENDS, *supra* note XX, at 490.
[95] *Ocean Conveyor's 'Pump' Switches Back On*, WOODS HOLE OCEANOGRAPHIC INSTITUTION, http://www.whoi.edu/page.do?pid=12455&tid=282&cid=54347 (last ~~visited Sept. 30~~updated Nov. 19, 2010).
[96] *Id*.
[97] *Id*.
[98] *Id*.
[99] *Oregon Dead Zone Blamed on Climate Change*, ENVIRONMENT NEWS SERVICE (Oct. 8, 2009), http://www.ens-newswire.com/ens/oct2009/2009-10-08-092.asp.

oxygen-deprived waters.[100] Three other such climate change-related dead zones have been detected, one off the coast of Chile and Peru in South America and one each off the west and east coasts of Africa.[101]

As climate change impacts become more pronounced, even more dramatic ecosystem impacts as a result of changing ocean currents are also possible. In 2007, for example, the IPCC projected widespread ecosystem changes as a result of changes in major marine currents beginning at about the point when global average temperatures increase by about 2.5 to 3.0 degrees Celsius.[102]

Thermal expansion of ocean waters and melting ice contribute about equally to sea-level rise, another component of global climate change with implications for ocean sustainability. According to NOAA in 2010, "[t]he rate of global mean sea level (GMSL) rise is estimated currently to be 3.1 ± 0.4 mm yr-1 (3.4 mm yr-1 with correction for global isostatic adjustment)."[103] Sea-level rise has multiple impacts on coastal ecosystems, especially with respect to highly productive—but also highly sensitive—estuaries.[104]

Increasing concentrations of carbon dioxide in the atmosphere have led to increasing absorption of carbon dioxide by the oceans, resulting in a phenomenon known as "ocean acidification." The oceans absorb about one-quarter of the anthropogenic emissions of carbon dioxide;[105] NOAA recently confirmed significantly increased rates of ocean uptake and storage of carbon throughout the 1990s and 2000s.[106] Moreover, it appears that the ocean's capacity to absorb atmospheric carbon dioxide may be waning:

> [E]stimates suggest that the annual rate of ocean carbon storage has grown every year since the late 1700s, but the rate increased sharply in the 1950s in response to faster growth in atmospheric CO_2. In recent decades, however, the rate of increase in ocean carbon storage has not been able to

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[100] *Id.*
[101] *Id.*
[102] 2007 IPCC SYNTHESIS REPORT, *supra* note XX, at 51 fig.3.6.
[103] Levy, *supra* note 96, at S70 & fig.3.23 (citations omitted). *See also* 2007 IPCC SYNTHESIS REPORT, *supra* note XX, at 31 fig.1.1 (showing the increase in global average sea level).
[104] *Coastal Zones and Sea-Level Rise*, U.S. ENVT'L PROTECTION AGENCY, http://www.epa.gov/climatechange/effects/coastal/index.html (last updated Aug. 19, 2010).
[105] Richard A. Feeley, Scott C. Doney, & Sarah R. Cooley, *Ocean Acidification: Present Conditions and Future Changes in a High-CO_2 World*, 22 OCEANOGRAPHY 36, 37 (Dec. 2009). A little less than half of the anthropogenic carbon dioxide remains in the atmosphere; the rest is divided between the oceans and terrestrial plants. Scott C. Doney, et al., *Ocean Acidification: A Critical Emerging Problem for the Ocean Sciences*, 22 OCEANOGRAPHY 16, 16 (Dec. 2009).
[106] Levy, *supra* note XX, at S53.

> keep pace with the atmospheric growth rate. The percentage of annual anthropogenic CO_2 emissions stored in the ocean in 2008 was as much as 10% smaller than the percentages of the previous decade, although significant uncertainties remain which preclude a more definitive statement. The rapid growth in emissions over the past 10 years relative to the previous decade is one important factor in the reduction in the ocean's relative uptake of anthropogenic CO_2 emissions. Another key factor is the decreasing ability of the seawater to store the CO_2 as dissolved inorganic carbon. This reduced capacity is a natural and predictable consequence of ocean carbon chemistry that, in the absence of changes in large-scale circulation or ocean biology, will become more significant with time.[107]

Even so, ocean absorption of carbon dioxide is changing the ocean's chemistry and will continue to do so for some time. Average ocean pH, which hovered around 8.2 in preindustrial times, has already decreased 0.1 units.[108] In 2007, the IPCC projected that average ocean pH would drop by 0.14 to 0.35 units by 2100, varying according to the carbon dioxide emissions scenarios.[109] More recently, scientists have predicted that if the world continues to emit carbon dioxide in a "business-as-usual" mode and if atmospheric carbon dioxide concentrations reach 800 parts per million (ppm) (the current concentration is 387 ppm), "surface water pH will drop from a pre-industrial value of about 8.2 to about 7.8 . . . by the end of this century, increasing the ocean's acidity by 150% relative to the beginning of the industrial era"[110] and increasing the concentration of hydrogen ions in the oceans by 250 percent.[111]

While the impact of ocean acidification on marine organisms and ocean ecosystems is not yet fully understood, it is expected to be substantial. Some of the most direct effects will occur in calcifying organisms, such as coral, mussels, clams, and a variety of types of plankton, that rely on calcium carbonate to build their shells. Decreasing ocean pH changes the chemistry of calcium carbonate and its associated nutrients, calcite and aragonite, reducing the availability of these minerals to the organisms that need them.[112] One recent study projects that aragonite undersaturation—a condition in which aragonite becomes largely unavailable to biological processes such as shell formation—could begin to occur in the Arctic Ocean as early as 2020 and in the Southern Ocean around Antarctica by 2050.[113]

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107 *Id*. at S75 (citation omitted).
108 Feeley, Doney & Cooley, *supra* note XX, at 37; 2007 IPCC SYNTHESIS REPORT, *supra* note XX, at 52.
109 2007 IPCC SYNTHESIS REPORT, *supra* note XX, at 52.
110 Feeley, Doney & Cooley, *supra* note XX, at 37.
111 *Id.*
112 *Id*. at 37-41.
113 *Id.* at 42.

Ocean acidification is thus likely to result in "potentially dramatic responses in corals and coral reef communities and planktonic organisms."[114] In particular, corals and their associated calcifying macroalgae are predicted to "calcify 10-50% less relative to pre-industrial rates by the middle of this century," leading to declines in coral reef ecosystems and associated loss of marine habitat and biodiversity.[115]

However, the impacts of ocean acidification on marine ecosystems—and human well-being—are likely to be much broader. At the level of marine biochemistry, "the pH gradient across cell membranes is coupled to numerous critical physiological/biochemical reactions within marine organisms, ranging from such diverse processes as photosynthesis, to nutrient transport, to respiratory metabolism."[116] At the physical level, decreasing pH levels decrease the oceans' ability to absorb sound, and the resulting increased noise in the ocean may impact acoustically sensitive whales and dolphins, while decreasing concentrations of calcium carbonate allow for more light penetration, with unknown impacts.[117] Ecosystem impacts could be tremendous, resulting in loss of commercially important fisheries, locally important fisheries, and coastal protection from storms.[118] As researcher Scott Doney and his colleagues emphasized in 2009, "[u]nless there are dramatic changes in fossil fuel use, projected human-driven ocean acidification over this century will be larger and more rapid than anything affecting sea life for tens of millions of years."[119] The economic and cultural costs for humans, especially those in developing nations or coastal countries, could be enormous.[120]

As a harbinger of things to come, climate change impacts, especially increases in SSTs and ocean acidification, are already interacting synergistically to impair the ocean's primary production for food webs. Phytoplankton—tiny plants that generally float near the surface of the world's oceans—are critical to marine ecosystems.[121] As NOAA recently explained:

> Photosynthesis by the free-floating, single-celled phytoplankton of the upper-sunlit "photic" layer of the global ocean is the overwhelmingly dominant source of organic matter fueling marine ecosystems. Phytoplankton contribute roughly half of the annual biospheric (i.e.,

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[114] Doney et al., *supra* note XX, at 18.
[115] Joan A. Kleypas & Kimberly K. Yates, *Coral Reefs and Ocean Acidification*, 22 OCEANOGRAPHY 108, 109 (Dec. 2009).
[116] Doney et al., *supra* note XX, at 18.
[117] *Id*.
[118] *Id. See also* Sarah R. Cooley, Hauke L. Kite-Powell & Scott C. Doney, *Ocean Acidification's Potential to Alter Global Marine Ecosystem Services*, 22 OCEANOGRAPHY 172, 172-76 (Dec. 2009) (detailing these ecosystem impacts).
[119] Doney et al., *supra* note XX, at 24.
[120] *See generally* Cooley, Kite-Powell & Doney, *supra* note XX, at 172-76 (detailing the value of marine ecosystem services that could be impacted by ocean acidification).
[121] MEA 2005: CURRENT STATE AND TRENDS, *supra* note XX, at 484.

> terrestrial and aquatic) net primary production . . ., and their photosynthetic carbon fixation is the primary conduit through which atmospheric CO_2 is transferred into the ocean's organic carbon pools. These tiny suspended ocean "plants" play a vital role on the Earth's biogeochemical cycles, and are the very base of the oceanic food chain.[122]

Chlorophyll provides a measure of plant life in the ocean.[123] According to NOAA, "[t]he downward trend in global chlorophyll observed since 1999 has continued through 2009, with current chlorophyll stocks in the central stratified oceans now approaching record lows since 1997."[124] Chlorophyll, and hence phytoplankton growth, is inversely correlated temperature changes, meaning that as SSTs increase, phytoplankton growth decreases.[125]

III. MAKING MARINE ZONING ADAPTABLE: THREE THOUGHTS

A. The Role of Existing Marine Protected Areas and Marine Reserves in a Climate Change Era

Existing marine protected areas can assist climate change adaptation in several ways. First, they can act to reduce existing stressors to marine ecosystems, such as by eliminating overfishing and its consequences—by-catch, fishing down the food web, and displacement of trophic level function. Second, they can protect the marine ecosystems most likely to thrive or improve as a result of climate change, such as coral reefs located at the cold-water extremes of coral survival. Third, particularly pristine marine ecosystems that are legally protected can serve as reference sites for similar ecosystems throughout the world, alerting managers as to what kinds of changes are the likely result of climate change impacts—and which aren't.

An example of an existing marine protected area with climate change adaptation potential is the Papahanaumokuakea Marine National Monument (PMNM), which protects the Northwestern Hawaiian Islands. President George W. Bush established the PMNM on June 15, 2006, using his authority under the Antiquities Act, although the Northwestern Hawaiian Islands were already well on their way to becoming a National Marine Sanctuary by that point. The PMNM covers 105,564 square nautical miles (139,797 square miles) and protects the coral reef ecosystem of the Northwestern Hawaiian Islands, the islands themselves, and the historical (World War II) and cultural

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[122] Levy, *supra* note XX, at S75.
[123] *Id.*
[124] *Id*. at S53. *See also Id.* at S78 & fig.3.33 ("From 1999 onward, an overall progressive decrease in chlorophyll is observed and coincident with a general increasing trend in surface-ocean temperature . . . .").
[125] *Id.* at S77-S78.

(Native Hawaiian) values of the system. Moreover, on July 30, 2010, the PMNM was recognized as a World Heritage site for both its ecological and its cultural importance.

The PMNM is an example of marine spatial planning. First, the entire area is a marine protected area, jointly managed by NOAA, the U.S. Fish & Wildlife Service, and the State of Hawaii. All use of the Monument is regulated, and different areas have been recognized within its boundaries. Most prominently, the island of Midway is zoned as a Special Management Area. Second, the PMNM is a marine reserve. The northernmost part of the Monument has been an ecological reserve from the beginning of the Monument's creation, and commercial fishing has been phased out everywhere else since.

The PMNM is thus an example of marine spatial planning used to promote ecosystem-based management. Moreover, several aspects of the PMNM make it relevant to climate change adaptation.

First, while the PMNM protects one of the least-exploited coral reef ecosystems in the world, the area is not pristine, providing room for resilience building—and such resilience building, primarily through the elimination of fishing and the restoration of islands, is fully underway. The island chain sits right in the middle of the Great Pacific Garbage Patch, a collection of plastic from around the world that get caught into the northern Pacific gyre, a swirling of ocean currents in the northern Pacific Ocean. Plastic accumulation in the waters and on the beaches within the PMNM remains an ongoing and difficult-to-correct problem. Other stresses, however, are systematically being reduced. Before it left Midway, for example, the military exterminated all non-native rats on the island, and work continues to eliminate other non-native species. Soil contamination from military fuels has largely been eliminated, and remediation of contamination from lead-based paint began in the summer of 2010. The endemic Laysan duck has been reintroduced to islands from which its was extirpated.

Second, because the coral reef ecosystems of the Northwestern Hawaiian Islands are relatively less exploited than other coral reef ecosystems, they retain a level of biological diversity and hence biological resilience that is almost unequaled anywhere else. For example, apex predators—the tops of the marine food webs, the presence of which is a sign of ecological health—make up 54% of the biomass in the Northwestern Hawaiian Islands, compared to 3% in the Main Hawaiian Islands. Moreover, the reefs are built and maintained by a wide variety of species of coral and coralline algae, providing the ecosystem with resilience in the face of warming waters or new diseases.

Because of this resilience and relative health, moreover, the PMNM provides coral researchers throughout the world with a climate change reference site. If the reef ecosystems of the PMNM experience degradation, the likely causes are the ecological impacts of climate change, not human exploitation or carelessness. As a result, the PMNM provides coral reef managers the world over with a baseline of what impacts to coral reef ecosystems are the largely unavoidable results of climate change. Recognition of such impacts can assist in adaptation planning, particularly in areas of the Pacific where a region or nation's economic and social well-being depends intimately on the health of its reef ecosystems. In contrast, if reefs elsewhere are experience degradation that the PMNM's reefs are not, there is the distinct possibility that more immediate human activities, not climate change, are causing those impacts and hence that improved regulation could improve the health of the coral reef.

Finally, the PMNM may eventually become an important "survivor ecosystem" and biological reservoir for coral reefs in general. The Monument sits at the current northernmost limit of tropical corals' geographic range; the northernmost islands in the chain sit at a higher latitude than either the Florida Keys or the Flower Garden Banks National Marine Sanctuaries in the Gulf of Mexico. Moreover, the PMNM sit—at least on prevailing conditions now—at the receiving end of Pacific currents from Johnson Atoll, Wake Island, and the more distant reefs of the Coral Reef Triangle (Philippines, Indonesia, Malaysia, northern Australia, Papua New Guinea, Solomon Islands, New Caledonia, Fiji). Thus, as climate change progresses, the PMNM is well-positioned both to survive all but the most severe impacts of climate change and to serve as a refuge and reservoir for coral reef species of all types.

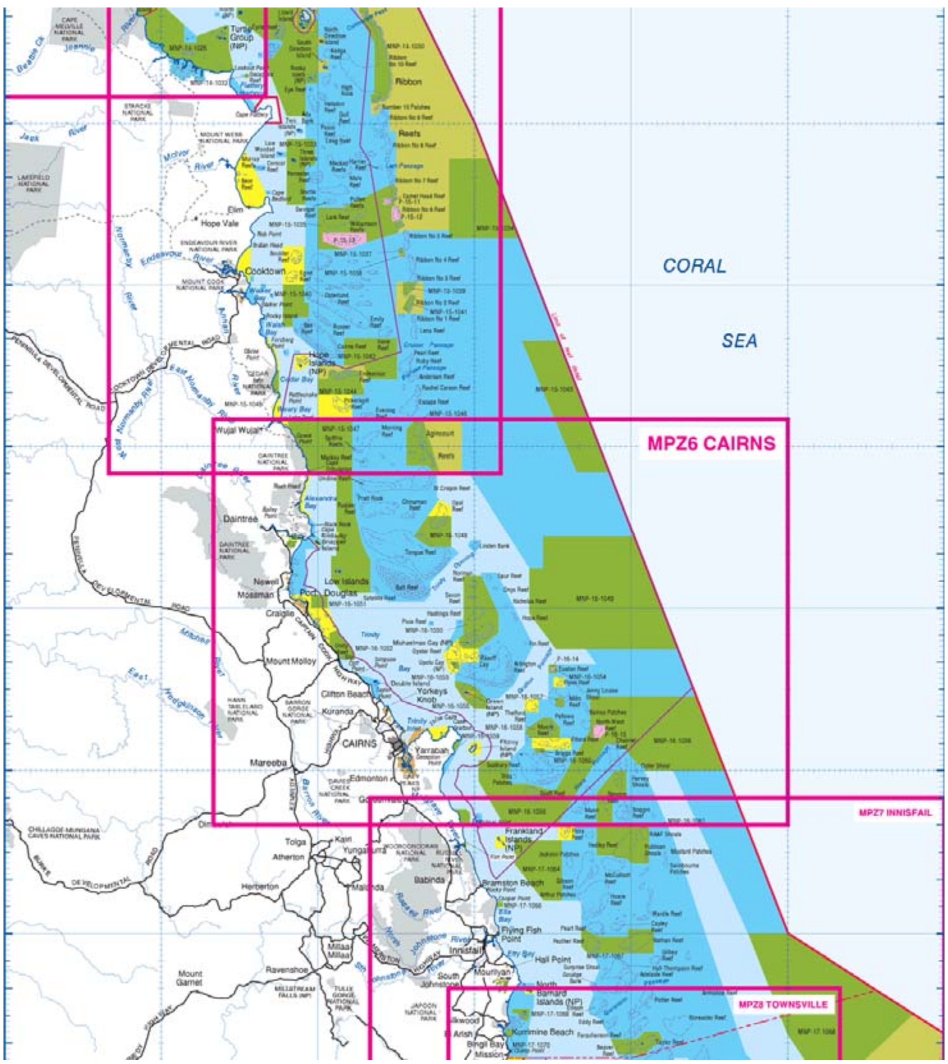
B. Incorporating Climate Change Adaptation into Marine Governance: The Example of Australia

Nations have addressed marine protection and its relationship to climate change in a variety of ways, including not at all. Australia provides a good first case study, because it has been a world leader in both marine spatial planning and climate change adaptation.

At the federal level, Australia's marine spatial planning efforts have centered on the Great Barrier Reef, which lies offshore a large portion of Austalia's eastern coast. Australia first zone the Great Barrier Reef over 30 years ago. However, in 2004 it comprehensively re-zoned the reef to ensure better overall protection of the larger coral reef ecosystem through recognition and protection of representative sub-ecosystems.

The 2004 marine spatial planning system identifies a number of different kinds of use zones for the Great Barrier Reef, as shown in Figure 3. In General Use Zones (light blue in Figure 3), most uses are permitted, but collection of animals and plants is regulated through a permit system. In Conservation Parks (yellow in Figure 3), fishing is restricted by gear to a single hook on a line—in essence, to lower-yield recreational fishing. Habitat Protection Areas (dark blue in Figure 2) cover about 28% of the Great Barrier Reef Marine Park and protect sensitive habitats, primarily be forbidding trawling. Marine National Parks (green in Figure 3) are no-take marine reserves designed to protect biodiversity, which even anchoring is occasionally limited. Even more protective are the Preservation Areas, which the Great Barrier Reef Marine Park Authority describes as "no-go areas": no entry into these zones is allowed without prior written permission. Preservation Areas cover less than one percent of the Park, but they provide high-level protection for special and unique areas that can provide an undisturbed baseline measurement of reef health for use in managing the rest of the ecosystem. Likewise, public access is forbidden in Scientific Research Areas (orange in Figure 3); these zones also cover less than one percent of the Park. Buffer Zones on the outer edge of the reef (olive green in Figure 3) provide protection for these lesser-used areas of the reef in their natural state; trolling for pelagic species is allowed, but no other fishing or collecting. These areas cover about 3% of the Park. Finally, Estuarine Conservation Zones (brown in Figure 3) protect areas where rivers discharge to the ecosystem.

Figure 3: Zoning Plan for the Great Barrier Reef
Map care of Great Barrier Reef Marine Park Authority



Three years after revising its marine spatial plan, the Great Barrier Reef Marine Park Authority published the *Great Barrier Reef Climate Change Action Plan*,[126] detailing measures to improve the reef's resilience in the face of climate change impacts. The Authority emphasized that tourism on the Great Barrier Reef contributes $6.9 billion to the Australian economy each year.[127] Moreover, it recognized that a variety of climate change-related impacts were already affecting the reef: coral bleaching events in 1998 and 2002 affected 50% of the reef each time and killed 5% of the coral affected; a more localized coral bleaching event in 2006 destroyed 40% of the coral in the Keppel Islands; and mass die-offs of seabird chicks have been observed during periods of unusually high temperatures.[128] Future impacts on an assortment of other species, including sea turtles and commercially important fish stocks, are anticipated.[129]

As the Authority recognized,

> Two major factors will dictate the future health of the Reef: the rate and extent of climate change, and the resilience of the Reef ecosystem to climate change. While the bigger issue of climate change mitigation is a matter for international policy, the resilience of the Reef is under the influence of local management strategies.[130]

Thus, the Authority is actively incorporating resilience into its climate change adaptation strategy.

The Authority's Action Plan has four objectives. First, it plans to target its science to address climate change issues on the Great Barrier Reef.[131] Specifically, it seeks to fill in gaps in knowledge about climate change and its impacts on the Great Barrier Reef, including the identification of areas of the Reef with both high and low resilience to change.[132] Another critical aspect of the science objective is "[i]dentify thresholds beyond which climate change causes irreversible damage to vulnerable species (eg sharks, marine turtles, seabirds, corals, fishes and plankton), habitats (eg seagrass, mangroves and pelagic) and processes (eg productivity and connectivity)."[133] Finally, the Authority recognizes the need to translate this new scientific information into workable management responses, and it intends to "[u]se cost-benefit analyses to select management responses that maximise ecological resilience while minimising social and

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[126] GREAT BARRIER REEF MARINE PARK AUTHORITY, GREAT BARRIER REEF CLIMATE CHANGE ACTION PLAN, 2007-2012 (2007), *available at* GET WEBSITE.
[127] *Id* at 4.
[128] *Id.* at 3-4.
[129] *Id.* at 4.
[130] *Id*. at 3.
[131] *Id.* at 6.
[132] *Id*.
[133] *Id.*

economic costs."[134]

The Authority's second objective is to build and maintain a resilient Great Barrier Reef ecosystem.[135] In pursuing this objective, the Authority is focusing on the interaction of climate change and other kinds of stressors to the coral reef ecosystem:

> Significantly, the resilience of reefs is reduced by other stresses such as degraded water quality, fishing and loss of biological diversity. Knowledge of the interactions between climate and other stresses helps identify actions that can restore and maintain resilience, and thereby minimise impacts of climate change on the GBR ecosystem. This objective builds on emerging knowledge of resilience and of the risks posed by climate change and other stresses. The actions in this objective aim to reduce stresses on the ecosystem, facilitate natural adaptation and minimise ecological impacts.[136]

Specific actions in furtherance of this objective include addressing water quality issues, including land-based water pollution; assessing and improving the sustainability of Great Barrier Reef fisheries; protecting the species and habitats most vulnerable to climate change; incorporating expected impacts from climate change into environmental regulation, such as water quality targets and environmental health standards; and "[i]dentify[ing] and protect[ing] transition or alternative habitats that will provide for shifts in distribution and abundance of species and habitats (eg turtle nesting, seabird breeding and productivity zones) affected by climate change."[137] Moreover, in pursuit of this objective, the Authority intends to take steps to reduce climate change impacts as well as impacts from other stressors, such as by investigating management responses to coral bleaching events and taking steps to reduce the vulnerability of seabird and sea turtle nesting sites to climate change impacts.[138]

Pursuant to its third objective, the Authority seeks to improve the adaptability of the communities and industries that depend upon the Great Barrier Reef.[139] Most of the actions in pursuit of this objective revolve around assisting local governments and industries in understanding the risks that they face from climate change and helping them to identify adaptation strategies and other ways of reducing their vulnerabilities.[140]

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134 *Id*.
135 *Id*. at 7.
136 *Id*.
137 *Id*.
138 *Id.*
139 *Id*. at 8.
140 *Id*.

Finally, the Authority seeks to use the Great Barrier Reef as a means of improving Australia's progress in climate change mitigation—that is, reducing greenhouse gas emissions.[141] As the Authority recognizes:

> The fate of coral reefs will ultimately depend on the rate and extent of climate change. As climate change is driven by global greenhouse gas emissions this issue must be addressed. Therefore, although management responses that build resilience are critically important to minimise the impacts of climate change, they should be pursued in parallel with efforts to reduce human influences on the climate such as greenhouse gas emissions. The high sensitivity of coral reef ecosystems to climate change creates opportunities for linking emission reduction strategies to improvements in the long-term health of the GBR. This objective focuses on activities that raise awareness of climate change and the GBR to motivate individuals, communities, organisations and industries to take action to reduce their greenhouse gas emissions.[142]

Specifically actions in pursuit of this objective include community education, community involvement in coral reef monitoring, and community efforts to identify ways to reduce greenhouse gas emissions.[143]

Many aspects of this Plan, especially the goals of increasing the Great Barrier Reef's resilience and the scientific studies that might illustrate how best to do that, could eventually influence the zoning plan for the Great Barrier Reef. For example, in order to protect areas of low resilience and/or high vulnerability to climate change, the Authority may eventually expand the area of the Great Barrier Reef Marine Park covered my the most protective zones—Preservation Areas and Scientific Research Areas. However, to date, the Authority has focused most of its energy in implementing the Plan on the third and fourth objective, working with local communities and industries to make them aware of their climate change vulnerabilities in connection with impacts to the reefs, beginning to pursue adaptation strategies, and working to reduce greenhouse gas emissions.

For the reef itself, the Authority has begun to implement its Climate Change Adaptation Plan by mapping the entire reef into Google Earth™. This action, while a limited start, nevertheless emphasizes that spatial planning will remain an important tool for the Authority in a climate change era. As the Plan suggests, climate change impacts to particular places within the Great Barrier Reef ecosystem that serve particular functions—seabird nesting, turtle nesting, fish spawning, critical habitat, and so forth—will be the necessary foci of the Authority's resilience thinking. They will also, however, become the critical indicators of when functionality is shifting—and, unfortunately, when resilience begins to fail. Thus, place-based awareness and place-based management

[141] *Id.* at 9.
[142] *Id*.
[143] *Id*.

remain critical to climate change adaptation even though the Great Barrier Reef's marine zoning plan has not yet fully integrated climate change.

C. Making Marine Spatial Planning Adaptable: Negotiable Easements and Bidding for the Future

We know that baseline marine conditions are likely to change in the face of climate change; sea-level rise, temperature increases, ocean acidification, and changing current patterns make fundamental changes in marine ecosystems inevitable at the large scale. What is uncertain, however, is exactly how these impacts will affect particular marine ecosystems in particular locations. As for most issues in climate change, in other words, the problem is one of scaling down. Especially while we are learning exactly how climate change will affect the particular marine resources in specific areas, we should be thinking of ways to make marine spatial planning flexible enough to accommodate those changes.

1. A Starting Point: Negotiable Zone-Based Use Rights for Fisheries

Josh Eagle, James Sanchirico, and Barton H. Thompson have already been working on ways to incorporate flexibility can be built into systems of marine spatial planning.[144] While their work focuses on improving existing fisheries regulation,[145] the suggestions they provide for increasing governance flexibility in that context can also be generalized into increased flexibility to deal with climate change adaptation.

In these authors' view, "[o]cean zoning . . . is not a panacea; rather, zoning creates a framework that can facilitate both the re-alignment of industry incentives as well as the attainment of the broader goal of healthier ocean ecosystems."[146] Zoning the oceans, they note, can be used to create group property rights, which in turn "can change the dynamic of intra-group relations, providing new incentives for group development and participation."[147] As they recognize, "an entirely stable system will not allow for the trades necessary to maximize the overall efficient use of ocean space."[148]

Eagle, Sanchirico, and Thompson advocate first for the establishment of dominant use zones in marine spatial planning—zones that prioritize a single use, such as fishing or diving, but that also "permit non-priority uses where that use can be conducted in a manner consistent with the overall purpose of that zone."[149] Use rights can then be

[144] Josh Eagle, James N. Sanchiro, & Barton H. Thompson, *Ocean Zoning and Spatial Access Privileges: Rewriting the Tragedy of the Regulated Ocean*, 17 N.Y.U. ENVTL. L. REV. 646 (2008).
[145] *Id*. at 646-51.
[146] *Id.* at 651.
[147] *Id.* at 653.
[148] *Id.* at 666.
[149] *Id.* at 654.

assigned to particular entities or groups that engage in the priority use, providing those entities and groups with both stewardship incentives, because they effectively control the area resource of interest, and a basis for bargaining with other potential users and rights holders in other zones, because they hold recognized property rights in a system that allows for multiple uses in the different zones.[150] These property rights and bargaining ability, in particular, would allow the initial marine zoning scheme to accommodate change in fisheries resources over time and space by "[a]llowing the groups the right to negotiate and trade uses over space and time . . . ..."[151] Moreover, the negotiations themselves would also reveal groups' preferences regarding and valuation of particular uses and resources[152]—information that is important to ocean governance generally but traditionally difficult to obtain.

2. Extending Negotiations to Reduce Existing Stressors and Increase Marine Ecosystems' Resilience

The authors' flexible marine zoning system suggests several extensions that could make marine zoning more flexibly adaptable to climate change and its impacts. For example, the assignment of use rights should give the rights holders incentives to bargain not just with each other, but also with people and entities outside the marine zoning system who nevertheless impose externalities on the relevant marine ecosystem. As one fairly straightforward example, a group holding the dive use rights for a particular zone—or a coalition of all the groups holding dive use rights for all the diving priority zones in a particular ecosystem's zoning plan—might well find it worthwhile to bargain with land-based polluters to reduce the amount of pollution, such as runoff from farms or forestry operations or sewage system overflows, that reaches the dive sites. Such bargaining would increase the value of the diving use rights by ensuring divers consistently better dive experiences and cleaner and more healthful water to swim in—the inducement for the rights holders to bargain in the first place. However, it would also more generally increase the resilience of the marine ecosystem, at least potentially increasing that ecosystem's ability to absorb and recover from climate change-induced stresses. As such, this flexible bargaining authority would increase the ability of marine spatial planning to participate in and enhance climate change adaptability.

3. Marine Spatial Planning that Anticipates Climate Change

Even more expansively, marine spatial planners could anticipate future zoning needs and build future use rights into a climate change-minded zoning plan. For example, as climate change progresses coral reefs in Florida may well begin to migrate north up the eastern coast of Florida into waters that historically have been too cold for

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[150] *Id*. at 663-64.
[151] *Id*. at 664. *See also id*. at 664 n.71 (describing how "many species in the ocean environment move over large areas, such as bluefin tuna and sharks, and El Nino and La Nina events shift ocean temperatures and species distributions across space.").
[152] *Id*. at 665.

coral reefs. Indeed, various researchers are already contemplating the possibility of "assisted migration," where humans would actively help these slow-growing ecosystems to take hold is coastal areas that will soon be amenable, temperature-wise, to coral reef growth.

Marine spatial planners who can anticipate the migration of highly productive marine ecosystems such as coral reefs and kelp forests should consider including provisional "climate change zones" in their planning process. Interested user groups could then bid for what is essentially a future interest in the use rights for these climate zones, allowing the zoning/user group system to migrate with climate change impacts.

Such anticipatory zoning is not unprecedented. For example, climate change is opening the Arctic Circle by reducing the sea ice cover, especially in summer. In response,

> In August 2009, the Secretary of Commerce approved the Fishery Management Plan for the Fish Resources of the Arctic Management Area. The plan covers the Arctic waters of the United States in the Chukchi and Beaufort seas. Warming ocean temperatures, migrating fish stocks and shifting sea ice conditions from a changing climate may potentially favor the development of commercial fisheries. The plan establishes a framework for sustainably managing Arctic marine resources. It initially prohibits commercial fishing in the Arctic waters of the region until more information is available to support sustainable fisheries management.[153]

Thus, in anticipation of changes brought on by climate change, NOAA has effectively zoned a large region of the Arctic Ocean "no commercial fishing" even before commercial fishing is a viable option.

Anticipatory marine zoning could have other advantages, as well. As NOAA's Arctic example shows, marine spatial planning that anticipates climate change could help to ensure that newly productive areas are not decimated before effective regulation can be enacted. Commercial fishing, in particular, has a well-documented history of being able to engage in species- and ecosystem-destroying "free-for-alls." For example, Boult Reef in Australia was closed to leopard group fishing for three and a half years to allow the population to recover, but when fishing re-opened, "intensive fishing removed 25% of the stock within only two weeks . . . ."[154] As population increases, systemic world-wide overfishing, and climate change impacts make marine food resources more difficult to come by, marine managers should assume the near-instantaneous overexploitation of new

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[153] Alaska Regional Office, National Marine Fisheries Service, NOAA Fisheries, *Arctic Fisheries*, http://www.fakr.noaa.gov/sustainablefisheries/arctic/ (last viewed March 11, 2011).

[154] CALLUM M. ROBERTS & JULIE P. HAWKINS, FULLY PROTECTED MARINE RESERVES: A GUIDE 59 (2000).

fishing grounds that emerge as a result of climate change and take proactive measures to ensure that those new fishing grounds—and new systems valuable for other uses—will be used sustainably from the beginning or, as in the Arctic, left alone until they and their vulnerabilities are better understood.

Anticipatory marine zoning could also induce increased private investment in basic climate change research. In offshore oil and gas leasing, government auctions of designated plots of submerged lands drive private entities—the oil and gas companies—to invest their own money into basic research to try to anticipate which lease areas are likely to contain commercially profitable oil and gas reserves. In the process, overall understanding of these offshore areas improves dramatically. Similarly, marine spatial planning that anticipates climate change, coupled with auctions of future use rights, could induce private entities to engage in research that would help to fill that most basic of climate change adaptation knowledge gaps: what are the local impacts of climate change likely to be? The accumulation of such private research could help to improve climate change adaptation efforts more generally, at least in coastal regions.

CONCLUSION