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Managing for cumulative impacts in ecosystem-based management through ocean zoning

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Abstract

Multiple activities affect the marine environment in concert, yet current management primarily considers activities in isolation. A shift towards a more comprehensive management of these activities, as with recent emphasis on ecosystem-based approaches to management, requires a means for evaluating their interactive and cumulative impacts. Here we develop a framework for this evaluation, focusing on five core concepts: (1) activities have interactive and cumulative impacts, (2) management decisions require consideration of, and tradeoffs among, all ecosystem services, (3) not all stressors are equal or have impacts that increase linearly, (4) management must account for the different scales of activities and impacts, and (5) some externalities cannot be controlled locally but must be accounted for in marine spatial planning. Comprehensive ocean zoning provides a powerful tool with which these key concepts are collectively addressed.

1. Introduction

The management of ocean resources is presently characterized by a sector-by-sector approach, with a few exceptions (e.g., Ref. [1]), where each human activity, such as coastal development, water management, and fisheries or energy production, is managed separately. The anthropogenic threats that result from these activities—including climate change, biodiversity loss, eutrophication, habitat damage and fragmentation, and invasive species—are numerous and particularly harmful to coastal ecosystems, which are influenced by activities on land (terrestrial and freshwater), along the coasts, and in the ocean. Furthermore, our understanding of the consequences of human activities on marine systems has focused on declines in endangered species or resources, communities (e.g., Refs. [2,3]), habitats [4], or some combination of these [5], but these efforts generally assume additive effects of these activities.

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When management planning and implementation within a sector does consider the effects of an activity on habitat or other ecosystem components, it is only with respect to the overall goals for that sector. For example, U.S. fishery management plans are required to consider habitat impacts of fishing and other activities, but only insofar as they affect Essential Fish Habitat, defined by Congress as ‘‘those waters and substrate necessary to fish for spawning, breeding, feeding or growth to maturity’’ [6]. Other sectors such as coastal wetlands protection under the U.S. Clean Water Act or the *Environmental Protection and Biodiversity Conservation Act 1999* in Australia may have requirements to reduce, minimize or mitigate impacts of particular activities, yet these typically do not incorporate specific goals and objectives to maintain ecosystem properties or functions.

It is a focus on ecosystem function and services within management that allows for a full appreciation of how human activities interact. Restoration and maintenance of the suite of benefits that ecosystems provide—ecosystem services—is a core goal of ecosystem-based management [7,8]. These services are diverse and are influenced by a suite of ecological and social factors. For example, provisioning services such as the production of local, healthy seafood depend upon, among other factors: (1) fish and shellfish populations that are robust to fishing pressure, (2) availability of suitable habitat, (3) the presence of other ecosystem components such as prey or nursery habitat, (4) suitable water quality, (5) local fleet access, including accessible harbors, and (6) local markets. Clearly, all of these factors are influenced by anthropogenic activities other than the direct effects of fishing, but current fisheries management tends to focus disproportionately on population metrics for particular target species rather than the many other factors that affect population size.

Cumulative and interactive consequences of different human activities are largely ignored in management plans because of the piece-wise nature of current management. In simple terms, the cumulative impact across all of the sectors may be much greater, or in rare cases less, than the sum of individual impacts because of interactive or multiplicative effects. These different scenarios of how activities can interact are illustrated in Fig. 1 and described in greater

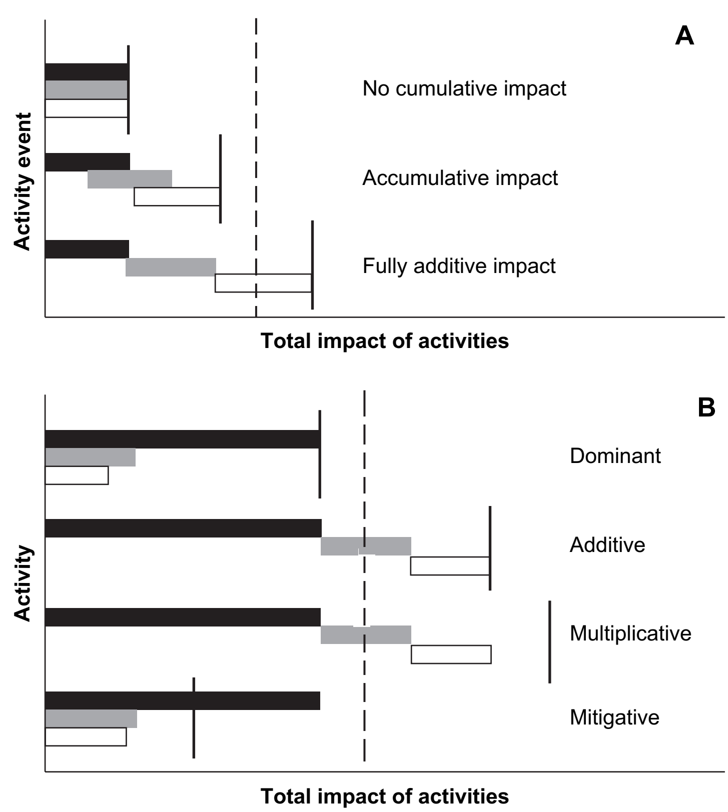

Fig. 1. Schematic of the different types of cumulative impacts. Color bars represent different activities, solid lines indicate the total impact of the activities, and dashed lines represent a hypothetical threshold of ecosystem function. (A) Individual events of a particular activity can interact in a variety of ways to create a cumulative within-activity impact. (B) Multiple activities can interact with each other in four ways: the impact of one activity is dominant and overrides other activities, the impacts of activities are purely additive, activities have a total impact that is multiplicative and therefore larger than the sum of the parts, or one activity actually mitigates the impact of another activity.

detail below. If most activities do interact, and there is good evidence supporting this (e.g., Ref. [9]), then managing each activity largely in isolation will be insufficient to conserve marine ecosystems, or even to meet individual sector goals. Furthermore, some of these threats have direct effects on ecosystem components, as with fishing overharvest or damage to habitat caused by bottom trawling or anchors from recreational boats, while others have more indirect consequences, for example introduced species that compete with or prey on native species. These indirect effects in particular make detection and assessment of interactions more complex than simple cause–effect mechanisms. Importantly, these activities may also interact with natural temporal or spatial variability in environmental conditions, such as El Nino, multi-decadal oscillations, or the location of upwelling zones. Acting in concert, natural variability and anthropogenic perturbations (through both direct and indirect mechanisms) decrease the ability and predictability of marine ecosystems to deliver vital services to humankind, such as abundant seafood, clean water, recreational opportunities, and the protection of coastal areas from storm surge and waves [7,10].

These issues can make it seem daunting if not impossible to manage for cumulative and interactive impacts. However, ecosystem-based management, of recent interest both nationally (e.g., U.S. Commission on Ocean Policy, Pew Oceans Commission) and internationally (e.g., Millennium Ecosystem Assessment, United Nations Environment Programme), provides a framework for addressing these issues through a more integrated approach to maintaining the ecosystem services that support human well-being rather than just sector-by-sector goals. Furthermore, active discussions about the use of marine spatial planning, and possibly the specific approach of ocean zoning, throughout the world seek to determine whether management could be made more spatially coherent across broad areas (e.g., Ref. [11]). Putting these approaches into practice requires clarity on several key issues. Conventional sector-by-sector management is largely ill-equipped to handle the full range of human activities that affect the ocean because it does a poor job of accounting for: (1) interactions among activities, (2) cumulative impacts of these activities over space and time, (3) the process by which activities (both singly and cumulatively) ultimately affect the delivery of ecosystem services, and (4) explicit tradeoffs among activities. Ecosystem-based management that includes marine spatial planning, in particular the specific application of spatial planning that is comprehensive ocean zoning, can explicitly deal with each of these issues.

Here, we are concerned with the cumulative impacts of human activities on the potential of marine ecosystems to provide the suite of services that we need and want. To address this issue we describe the key concepts concerning cumulative impacts of human activities in marine environments, the interactions between activities that compromise the ability of marine ecosystems to provide ecosystem services, the role of dominant stressors in degrading ecosystems, and how scaling of these effects must be carefully considered. We illustrate these concepts with examples from a variety of marine ecosystems, and offer general guidelines for how to incorporate the ideas into marine spatial planning, or where necessary comprehensive ocean zoning.

2. The nature of human activities

2.1. Cumulative impacts and tradeoffs among ecosystem services

The generic concept of cumulative impacts has been part of environmental policy for many years under the U.S. National Environmental Policy Act [12] and other authorities, as well as in scientific literature (e.g., Refs. [13–15]). According to the U.S. EPA (1999) "the cumulative impacts of an action can be viewed as the total effects on a resource, ecosystem, or human community of that action and all other activities affecting that resource no matter what entity (federal, non-federal, or private) is taking the actions." These cumulative impacts can emerge from activities occurring at a spatial or temporal frequency high enough to make the individual events of an activity no longer independent [14], or they can emerge from multiple activities acting in synergy (Fig. 1). Unfortunately, few management plans move beyond recognizing that there are cumulative consequences of different activities, and instead focus primarily on the consequences of each individual activity [16]. This situation is much like recognizing that many different factors can lead to a human illness (e.g., diet, exercise, exposure to pathogens, lack of adequate sanitation) but only treating one factor.

In order to implement an ecosystem-based approach, clear measures of the environmental impacts of activities on ecosystem services—loss of seafood production, water filtration capacity, sediment capture, storm barriers, etc.—must be made and the cumulative consequences of different activities on these services assessed. Such a shift in focus, however, will require explicit consideration of tradeoffs among the services supplied by an ecosystem. Policy actions within various sectors will necessarily alter the mix of available services supplied, and the cumulative effects of those policy actions may further alter this mix. For example, coastal development policies may provide more marina space for vessels, particularly for recreation. Fishery management or aquaculture activities may initially benefit from port development and increases in local economic activity derived from the recreational sector (e.g., supplying local restaurants). However, the cumulative effect of increasing recreational vessel access may reduce access for commercial vessels, make fishery or aquaculture operations less viable because of higher costs and competition for coastal space, or have greater ecological impacts through increased boat strikes, groundings, anchor damage or pollution. In an extreme case, some services will be effectively precluded by the cumulative actions across various sectors within a specific area. For example, coral reef loss due to climate change, water quality degradation, sedimentation, disease, and overfishing may result in complete loss of the suite of services that these systems formerly provided, such as fish production for recreational, artisanal, and aquarium purposes; pharmaceutical products; building materials; and tourism and recreational opportunities.

In other cases, the cumulative effects of various activities may substantially affect major ecosystem services not directly tied to market-based valuations, and in many cases those services are not accounted for in the usual sector-by-sector analysis. For example, activities associated with provisioning services such as seafood (either wild caught or farmed) or offshore energy necessarily affect supporting services such as coastal wetlands that provide habitat for wildlife and buffers from natural disasters. Fishing and energy production depend upon access to coastal waters by vessels, port and infrastructure development, and coastal communities, all of which can alter the shape and nature of the coast. In these cases, the issue of how much supporting services can be sacrificed in order to obtain the provisioning services is critical for policy-making. These tradeoffs are not well-articulated or handled in the current sectoral policy process. For example, coastal wetlands loss through dredging, channeling, and changing sediment flows for transportation, development, pipelines, or other purposes may result in large reductions in protection from natural disasters related to storm surges and flooding as was graphically illustrated on the Gulf of Mexico coast during the 2005 hurricane season and the Tsunami impacts in Southeast Asia in 2004. Such impacts accumulate over both time and space. The wetland habitats that provide coastal protection have become fragmented (a spatial effect) and experienced dramatic losses over time (0.5–1.5% loss of area globally per year [17]). The services of transportation and coastal development were in this case implicitly weighted much higher than the potential storm protection provided by these habitats. A management analysis based on an ecosystem approach should make this tradeoff in services explicit.

Within an ecosystem-based management framework, the goals for maintaining a set of ecosystem services would be established within the management process that would in turn require evaluation of how different activities affected each service (for better or worse). Using a zoning approach, explicit decisions could then be made as to which objectives will take precedence within particular zones to ensure all services are maintained. For example, some areas may be zoned with coastal access and transportation as a priority, while others would prioritize storm protection. Without setting ecosystem-based goals or objectives, it is difficult to evaluate how ecosystem services will be affected by human activities, and it is unlikely that conscious decisions will be made regarding tradeoffs in services. And without explicit zones, it will become increasingly difficult to resolve conflicts between different sectors.

2.2. Interactions between and among activities

One of the greatest challenges in understanding how various human activities affect ecosystems is that consequences of these activities often interact in a manner that is not simply additive [9] (Fig. 1). For example, even minimal amounts of coastal engineering that removes nursery habitat for a fished species or decreases recruitment into an estuary, as with a protective channel jetty that inhibits an inlet passage of larvae, combined with low catch rates that fall below the maximum sustainable yield (MSY) for that species may seem to be sustainable when considered in isolation, or even if considered together, because they are assumed to have additive effects. However, in combination, these can lead to a local stock crash if the poor recruitment or lost nursery habitat creates a population bottleneck not considered in the MSY calculations. Furthermore, these interactions may be nonlinear and difficult to predict (Fig. 2), or in some cases may actually cancel each other out (Fig. 1). For example, nutrient loading can benefit fisheries when nutrient input is relatively low, due to increased productivity, but can also lead to fisheries collapses (even with equivalent levels of fishing effort) if nutrient loading leads to excess production and hypoxia.

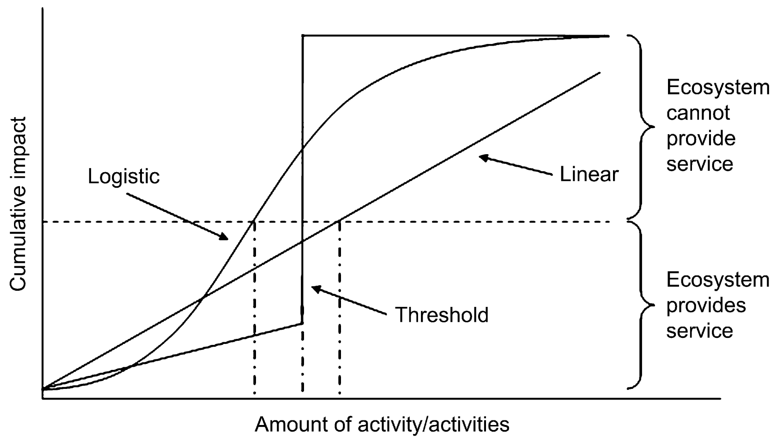

Fig. 2. Potential shapes of the cumulative impact of an activity or activities on an ecosystem. Most often activities are assumed to affect ecosystems in a linear manner, such that increases in the amount of an activity result in a linear increase in the impact of that activity. Other possibilities include threshold relationships where the impact only emerges at particular levels of an activity, and logistic relationships where the impact of an activity initially increases exponentially relative to the increase in the activity level itself and then eventually levels-off (or combinations of these; possibilities not shown). The area below the horizontal dashed line indicates the level of cumulative impacts under which a hypothetical ecosystem can continue to provide a function or service; the vertical dash-dotted lines indicate the maximum amount of activity that would be allowable given the different shapes, assuming perfect knowledge and system predictability, before the ecosystem could no longer provide the function or service.

These interactions need not all be biological in nature. Coastal development for tourism may negatively interact with development for fisheries, shipping or energy production because of a ‘‘not in my backyard’’ attitude. A port that supports a vibrant commercial industry will be quite different from one that supports a strong recreational sector. Development that increases water, sewer, and energy requirements may also want to exclude facilities that deal with those increased demands from that same coastal zone. The result may concentrate the industrial activities in narrower and narrower zones, exacerbating the environmental impacts of those activities. At the same time, areas that lack industrial development may attract more and more residential and tourism development, exacerbating those problems.

Resilience theory [18–20] provides some insight into why and how these interactions are so important. The resilience perspective emphasizes that ecosystems (as well as related social systems) are characterized by complex dynamics, multiple thresholds, uncertainty, and surprise. Systems affected by a single activity may be able to absorb a disturbance by an additional activity, but be vulnerable to that same level of additional activity if the system was initially affected by multiple threats. For example, coral reefs in Australia have been shown to recover from the physical damage caused by recurrent cyclones, while Jamaican reefs subject to similar physical damage from repeated hurricanes have not yet recovered, in part because of the additional stresses posed by overfishing of herbivores and outbreaks of disease [21]. Essentially, thresholds exist beyond which ecosystems cease to maintain their original functions, and these thresholds can be exceeded either through interactive effects or the cumulative impacts of multiple stressors (Fig. 1). A convergence of natural disturbances can push systems past such thresholds, but it is much more likely to occur with the addition of stress brought on by human activities. Well-known examples of such thresholds include shifts from coral to algal dominance on tropical reefs, shifts from canopy-dominated kelp forests to urchin barrens, and the rise in jellyfishes in coastal pelagic systems once dominated by fishes [22].

2.3. Dominant and nonlinear stressors

Nearly all human activities have at least some effect on the ecosystem in which they occur. These effects can be positive, as with protection or restoration activities, or more typically negative, as with most extractive activities and many non-extractive ones as well. Clearly no two activities are alike in their effect on marine ecosystems, and importantly each activity affects particular ecosystems (or ecosystem components) differently. For example, changes in sediment input regimes due to damming rivers or overdevelopment of agricultural lands have had large consequences for salt marsh accretion rates (e.g., Refs. [23,24]), but probably have much smaller effects on kelp forest and pelagic ecosystems [25]. In coral reef systems, changes in sea surface temperature, nutrient input, and sediment runoff have all been implicated as key drivers of reef degradation [26], while invasive species, so far, have relatively smaller consequences for reef structure and stability. Habitat destruction of any kind is often viewed as a dominant stressor, especially for biogenic habitats, because it completely removes foundation species that support entire biological communities (e.g., with no kelp, there are no kelp forests and fewer kelp forest animals), but this same stressor may have a much smaller impact on soft-sediment habitats. For example, trawling devastates soft corals, but has less impact on sandy/muddy benthic habitat [27]. The frequency of an activity will also influence how dominant a stressor it is, and this may in turn be modified by how naturally disturbed an ecosystem is—high disturbance ecosystems should be more resistant or resilient to high-frequency or high-intensity threats [28]. In short, not all activities are equally important in how they affect various marine ecosystems; some act as dominant stressors, while others have relatively minor effects (Fig. 1).

To date, the identification of such dominant threats has been largely anecdotal. We know that changes in average and extreme values of sea surface temperature are critical for coral reef systems because the corals bleach—often dramatically—in response to this change in temperature. In contrast, pollutant input into coastal systems tends to be chronic and at low to medium levels that often do not produce immediate and pronounced responses by the ecosystem. However, few, if any, studies have experimentally tested the relative importance of multiple activities on any given ecosystem, and many threats that act at low but sustained levels may not attract the attention of scientists or managers [9]. For example, substantial attention has been drawn to fish kills in estuaries that correlate with periods of hypoxia or anoxia, since this is an obvious and acute effect, but chronic nutrient loading, enhanced productivity, and intermittent hypoxia common in estuaries cause sub-lethal reductions in fish growth in nursery habitats. This chronic effect, though less obvious, has a much larger effect at the population level than does the occasional, but dramatic, fish kill (e.g., Ref. [29]). It is of course difficult, if not impossible, to experimentally control for all possible ecosystem drivers, and so we are left to make inferences from studies that examine one to at most a few threats [30].

Halpern et al. [5] have developed a method for quantitatively identifying which threats act as dominant stressors that parses out the ecological basis for their dominance. The impact of an activity on an ecosystem depends on five attributes: the spatial scale, taxonomic scale (species to entire community) and frequency of the activity, and the resistance and recovery time of the ecosystem to the activity. Threats that rank high in several or all of these five vulnerability measures emerge as dominant stressors to an ecosystem, while threats that rank high in few or none of the vulnerability measures are less important stressors. Indeed, the anecdotes above hint at these vulnerability measures as the ‘‘cues’’ we use to describe a threat as major. Coral bleaching is a major problem because it can ultimately remove the corals and all of the other species dependent on the reef structure—the entire community is affected—and the system has low resistance and slow recovery time to this threat.

Understanding the landscape of dominant and weak stressors allows for a better ‘‘mapping’’ of the cumulative and interactive effects of different human activities. It is much more important to assess the cumulative impacts of two dominant stressors than the impacts of a weak and dominant stressor, and it is also more likely that two dominant stressors will have interactive effects compared to a dominant and weak stressor. Marine spatial planning, and its key component comprehensive ocean zoning, is well-equipped to account for these differential impacts of stressors by isolating the dominant stressors into unique areas while allowing multiple weak stressors to co-occur.

2.4. Considering scales

Human activities operate over various spatial and temporal scales, as do the biophysical processes and ecosystems that these activities interact with and affect. To understand how a particular activity may influence an ecosystem service, then, one needs to know not just the intensity of the activity, but also its spatial extent relative to the size of the ecosystem providing the service and the frequency of the activity relative to the ecosystem's temporal dynamics. For example, a commercially important fish species may recruit in the spring, while an activity that disturbs the species' nursery habitat may not occur until the summer—in this case, the temporal mismatch in the activity and the ecosystem process would suggest little consequence for this ecosystem service. High-intensity activities (i.e. with large impacts), such as urban pollution from large cities or benthic habitat destruction resulting from submerged pipelines, can have dramatically different impacts on the ecosystems they affect—and therefore the ecosystem services provided—because the activities act at very different spatial scales relative to the ecosystem being disturbed. Pollution can smother large estuarine ecosystems (e.g., Chesapeake Bay) while pipelines leave a relatively small footprint on deep sea ecosystems. Conversely, low intensity, infrequent activities such as sonar testing by the Navy have a vast spatial reach and intensity of sound that can harm marine species, particularly certain species of cetaceans [31].

Acknowledging the importance of these scale issues in turn requires one to define meaningful boundaries of the system to be managed. Jurisdictional boundaries set obvious spatial scales within which regulatory agencies can enact management measures, but these often do not match the scales at which ecosystems function [11]. Such mismatches in scale are exemplified by wide-ranging species such as salmon that are managed at local and regional levels but are often affected by activities that occur at global scales, or by federal agencies tasked with setting uniform regulations for species or ecosystems that function at very local and spatially heterogeneous scales (e.g., demographically distinct subpopulations of Pacific black rockfish managed as a single unit throughout their range [32]). Matching the scale of management to the scale of desired ecosystem services should make for more efficient (and hopefully more effective) management [33]. Indeed, one of the greatest management challenges is how to ensure the sustainable provision and delivery of ecosystem services in the face of threats whose sources are outside the jurisdictional boundaries of a particular management entity.

2.5. The role of externalities

Ecosystem boundaries are necessarily porous, particularly in the marine environment, no matter how large the ecosystem or how relatively discrete the boundary. Processes from outside the defined area will inevitably affect the proximate ecosystem under management. This is because there are key factors operating on very large scales, climate change being the most obvious example. In effect, management of any particular marine location will only have a very small effect on the drivers of climate change, but climate change may dramatically effect the provision of ecosystem services for that location. This is not to say that within an ecosystem-based management plan it is inappropriate to try to reduce net greenhouse gas emissions. However, it is also crucial to factor in the effects of climate on ecosystem stressors, human activities, and cumulative effects on the system. Even if an external stressor also happens to be the dominant stressor for a system, local and regional management can have important consequences by reducing the cumulative and interactive impacts of local activities with this dominant, external threat. For example, climate change may increase the frequency and occurrence of severe storms external to the ecosystem. The cumulative effect of the loss of natural barriers regionally may greatly exacerbate the problem of increasing storm events and result in even greater loss of coastal habitat and barrier protection.

Not all external factors are on the scale of climate effects. For example, migratory populations of fish, cetaceans, birds or other important components of the ecosystem may spend a significant amount of time outside the defined ecosystem boundaries and may be affected elsewhere [34]. At an even smaller scale, runoff from land links land-based activities to coastal marine management in bays, estuaries, and nearshore zones. These external stressors still need to be considered within a particular local ecosystem, but may not play a dominant role in affecting management goals.

3. Implications for ocean zoning and ecosystem-based management

Since all activities and their associated consequences (threats or benefits) are necessarily spatially explicit, managing the ocean spatially makes intuitive sense. Indeed, this is what individual sectors have been doing for a long time—oil and gas companies are given certain areas of the ocean floor for exploration and development, fisheries are managed regionally and often incorporate spatial and temporal closures, and conservation is enhanced by the use of effective marine protected areas. As we have illustrated above, however, activities rarely occur in isolation, even if they are currently managed that way. The best-known examples of distressed coastal and marine ecosystems (e.g., the Black Sea, Chesapeake Bay, the Gulf of Mexico, San Francisco Bay, Baltic Sea) are subject to multiple stressors (overfishing, nutrient loading, other pollutants, invasive species, habitat damage, climate change) and it is difficult or impossible to relate any one symptom to its cause. One management tool that can explicitly deal with the reality of the cumulative and interactive effects of multiple stressors is comprehensive ocean zoning. Zoning partitions a region into zones that are designed to allow or prohibit certain activities, with the intent to maintain the provision of an overall set of ecosystem services provided by the overall zoned area. Such a zoning process needs to pay particular attention to the consequences of allowing multiple conflicting activities to occur within the same location.

The key to understanding these consequences is to recognize the spatial scale and full range of ecosystem services that are being provided by the area to be managed and zoned. This is one of the foundation principles of ecosystem-based management [8]. If the services desired from a particular region of the ocean are produced and delivered at much larger scales than the management area, then policy decisions for that area will not be able to adequately affect the delivery of those services. There will always be some externalities influencing any managed system, but the goal should be to minimize or at least account for these externalities. Indeed, spatial management through zoning cannot control where ecosystem services are produced, and so ocean zones will always need to be developed based on the spatial scales of ocean habitats and resources. Planning at appropriate scales can help limit the number of externalities affecting ecosystem services since activities would be managed at a scale similar to that of the managed ecosystems.

Furthermore, ecosystem components have heterogeneously distributed capacity to produce various ecosystem services and are also differentially sensitive to various human activities. This spatial heterogeneity, if known and well-mapped, creates opportunities for maximizing both the delivery of services from ecosystems and the extent of human activities allowed in any particular area. When these spatial patterns are poorly known or mapped, however, spatial management will need to be precautionary. A precautionary approach could involve a variety of strategies, depending on the context of the ecosystems and human activities, including (1) protecting representative habitats, (2) allocating larger-than-needed areas for particular goals as an insurance policy, or (3) incrementally allowing activities to occur in zones and monitoring the consequences at each step.

Comprehensive ocean zoning by its very nature is cross-sectoral because the purpose is to allow activities within a zone that are compatible, i.e. do not undermine or interfere with one another. If done coherently and with a clear objective in mind for that particular zone, planning for each zone would require one to acknowledge and manage for the cumulative and interactive consequences of different activities. Activities that interact and lead to multiplicative consequences could be separated into different zones, while awareness of cumulative impacts would help define acceptable levels of activities for each sector permitted to act within a zone. If dominant stressors are identified, zoning plans could prohibit the activities that lead to that stress throughout the management area, or only allow that stressor in areas where no other activities occur. For stressors that are outside jurisdictional boundaries, zoning can at least partially address these threats by acknowledging and accounting for the ways these stressors interact with local and regional stressors. For example, sea level rise may decrease the available sea turtle nesting habitat, such that other stressors to turtles (such as long-line or trawl fishing) should probably have tighter restrictions than would be needed without climate change as a concurrent stressor.

Zoning plans provide an explicit approach to resolving conflicts between activities and determining tradeoffs in the provision of services. Zoning by itself, however, cannot manage all activities or ensure the delivery of ecosystem services. Other spatial management tools (including permits, management plans, site planning, industry Codes of Practice, etc.) when used in conjunction with zoning and temporal management tools such as seasonal closures collectively provide an effective framework for marine spatial planning. Global scale threats such as climate change can only be partially addressed locally and will require national and international policy actions to mitigate. In coastal areas, run-off from land can occur regardless of the type of zoning restrictions created nearshore, and so these land-based threats will require additional management actions.

Considering cumulative impacts of activities, whether or not zoning is used for management purposes, requires a common currency for measuring the effects of different activities. An ecosystem approach to management explicitly acknowledges this need by using changes in ecosystem services (whether measured by function or value) as the currency with which to evaluate consequences and tradeoffs. Significant challenges remain in understanding the specifics of how different combinations of activities interact cumulatively and where nonlinearities in how activities affect ecosystems exist, yet the framework we provide here for considering these issues allows for consideration and incorporation of these issues into management plans. Zoning recommendations can then be refined as more information becomes available through adaptive management.

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