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Short Communication

Securing ocean benefits for society in the face of climate change

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ABSTRACT

Benefits humans rely on from the ocean – marine ecosystem services – are increasingly vulnerable under future climate. This paper reviews how three valued services have, and will continue to, shift under climate change: (1) capture fisheries, (2) food from aquaculture, and (3) protection from coastal hazards such as storms and sea-level rise. Climate adaptation planning is just beginning for fisheries, aquaculture production, and risk mitigation for coastal erosion and inundation. A few examples are highlighted, showing the promise of considering multiple ecosystem services in developing approaches to adapt to sea-level rise, ocean acidification, and rising sea temperatures.

Ecosystem-based adaptation in fisheries and along coastlines and changes in aquaculture practices can improve resilience of species and habitats to future environmental challenges. Opportunities to use market incentives – such as compensation for services or nutrient trading schemes – are relatively untested in marine systems. Relocation of communities in response to rising sea levels illustrates the urgent need to manage human activities and investments in ecosystems to provide a sustainable flow of benefits in the face of future climate change.

1. Problem statement

Recent disasters such as the tsunami in Japan, the Gulf of Mexico oil spill, and Hurricane Sandy reinforce understanding of human dependence on the ocean, and how the delivery of ocean services could be affected by multiple environmental stressors, including climate change, contaminants, and increasing coastal development (e.g., [1–4]). Although society receives many natural benefits from ocean ecosystems, from seafood production to shoreline protection to recreational opportunities [5–8], many of these benefits are not valued through markets and thus are not explicitly accounted for in decisions. Consequences of further degradation of marine ecosystems include more expensive and less available seafood, declines in ocean-based livelihoods and cascading social and economic impacts, increases in coastal property damage and risk to human life, and reduced recreation.

Climate change affects the biophysical background upon which other human impacts are measured, but because its impacts are perceived to be distant, it is typically ignored in developing day-to-day ocean management strategies. In reality,

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climate change impacts on the ocean are already evident and likely to worsen with time [9,10]. Atmospheric CO_2 concentration has increased by 40% over the last century, and is projected to continue growing into the future under all realistic emission scenarios [11], further increasing pressures on marine systems through ocean acidification and warming. Observed and projected anomalies in global temperature and sea level are increasing at an accelerating rate [11], which portend challenges for species' environmental tolerances and ocean productivity, the ecological interactions that determine ecosystem function, and the stability of coastal human communities [9]. Greenhouse gas emissions from the past have committed the planet to a certain amount of future climate change, regardless of mitigation measures put into place in the near to mid-term future [11].

In the face of these dramatic changes to ocean environments, society is beginning to respond by altering individual behaviors, innovating technologically, and adjusting policies and management [10,12–15]. Evaluating the cumulative effects of potential climate solutions for society as a whole remains a challenge, especially because marine climate impacts cut across several sectors of existing management and regulation, such as fisheries, transportation, recreational activities, and coastal and energy development. Expressing objectives for climate adaptation in terms of multiple ecosystem services would allow us to: (1) understand the breadth of climate change impacts more clearly by focusing on changes to those ocean services society values most (e.g., food security, shoreline protection, recreation), and (2) consider and prioritize potential adaptation and mitigation solutions to account for cumulative impacts on people through changes in these highly valued ecosystem services.

2. Climate change and marine ecosystem services

Climate change will impose significant challenges to food security for both capture fisheries and aquaculture. Seafood currently provides ~15% of the animal protein intake for the world's population, along with essential nutrients and livelihoods [16–21]. Range shifts in fish and shellfish populations attributed to climate [4,19,21–24] have altered the magnitude and distribution of capture fisheries taken across the globe [25,26]. Small-scale commercial and recreational fisheries are especially vulnerable, since it is difficult for small boats to venture far from harbors and traditional fishing grounds [27–30], and less capital is available to switch gear or develop new markets [28,31]. Thus, even though the total value of fishery landings may have risen in some areas, the distributional effects for fishers are likely to be stark, as some fisheries fail and others emerge [3,25,27,32].

At the same time, sea-level rise and potential increases in storm frequency and severity will threaten coastal communities. Coastal habitats – such as seagrasses, kelp forests, coral reefs, mangroves, wetlands, and dunes – can provide protection from erosion and inundation due to storm surge (e.g., [33–43]). Loss of these nearshore habitats can have dire implications, including damage to coastal infrastructure, private property, and loss of human life [39,44–49]. For example, coastal wetlands in the United States are estimated currently to provide $23.2 billion/year in storm protection services [50]. Marshes and mangroves are especially vulnerable to sea-level rise, particularly in developed areas where "coastal squeeze" allows no room for inland migration [51]. The shielding benefits of coastal habitats may become more acute in the future as the coastal human population expands [2,47,52]. Many of these same coastal habitats also function as nurseries for recreationally and commercially important marine and estuarine species [53].

Fishing opportunities and coastal protection directly impact recreation and tourism, which are among the world's most profitable industries (e.g., [54,55]). Several studies of climate change have quantified resulting economic loss in recreational diving, fishing, tourism, and property values [1,28,56–62]. For example, Brander et al. [1] noted that recreation and tourism in coral reef systems often constitute the most important use values. On Australia's Great Barrier Reef, surveys suggested that reef trips by divers and snorkelers could fall by up to 80% under reasonable scenarios of climate-induced coral and fish decline, resulting in lost tourism expenditures in the Cairns area of ~A$103 million per year [63]. Unfortunately, both corals [64] and temperate seagrasses [65] are highly sensitive to warming; and the occurrence of coral bleaching from thermal stress may be exacerbated by ocean acidification [9,66].

3. Opportunities and challenges of climate adaptation strategies

Governments, NGOs, development banks, and private sector innovators at the cutting edge of climate policy are actively seeking adaptation strategies that address multiple, interacting effects of climate change on marine systems [67–71]. Fig. 1 illustrates how evaluations of climate adaptation strategies could change when considering the consequences for multiple ecosystem service benefits. For example, a strategy such as coastal armoring can look like a good idea when property protection is the only goal; but look very different when trade-offs in impacts on fisheries and recreation also are considered. One obvious solution – drawing from the toolbox of existing management measures to address pollution, over-fishing, coastal hazard risks, or poor infrastructure – can increase resiliency of marine ecosystems and services [14,15]. For example, existing coastal habitat protection laws aimed at reducing eutrophication of receiving waters also keeps in check those same biophysical processes that exacerbate ocean acidification [13].

An ecosystem services framework for climate adaptation informs questions like: should we focus on adaptation strategies

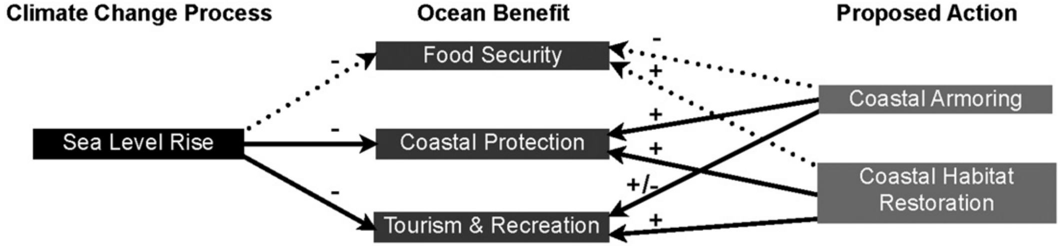

Fig. 1. An illustrative example of how two potential adaptation strategies (coastal armoring and habitat restoration) to a climate change process (in this case sea level rise) affect three types of ocean benefits (food security, coastal protection, tourism and recreation). Type of impact indicated as either primarily positive (+), primarily negative (−), or mixed (±). Solid lines indicate stronger interactions than dotted lines. Although this represents a simplified view of these interactions and does not include other aspects such as cost-effectiveness over time, it illustrates the value of evaluating tradeoffs among policy options.

that maximize benefits for critical services (e.g., food provision), or those that benefit the greatest number of services, or the most vulnerable groups of people? Also, how can services provided by ecosystems reduce risks to people from climate change? This paper examines how the following proposed solutions to marine climate change impacts could be evaluated through the lens of ecosystem services.

3.1. Ecosystem-based adaptation

Ecosystem-based adaptation takes advantage of natural habitats and processes to avoid or ameliorate climate impacts [67,72–74]. Assessments show that where ecological resilience is high (e.g., often where local stressors are minimized and habitat heterogeneity and connectivity among marine habitats is maintained), coastal systems will be better equipped to respond to climate-related changes in storms, freshwater runoff, fishing pressures, and other potential stressors [2,75–79].

Restoration of oysters and seagrasses in the Chesapeake [80,81], oyster reefs in the Gulf of Mexico [82,83], mangroves around the Indian Ocean [84], and coral in the Great Barrier Reef [85] have all been motivated in part by desires to protect shorelines from erosion or inundation. If such shoreline restoration strategies also considered climate impacts on future sea level and storms, the benefits to surrounding communities could multiply quickly [39,45,81,86]. Estimates of multiple ecosystem service benefits from restored marine ecosystems are rare, but decision support tools for their accounting, applications, and potential tradeoffs with other uses are emerging [87,88]. Several estimates for restored mangroves show that the benefit-to-cost ratio of planting and maintenance is greater than 4, even accounting solely for timber, fishery support, carbon sequestration, and coastal protection [89–91]. If additional services were included (e.g., other foods, construction materials, household items, medicines, tourism, and spiritual and cultural values) the net benefits would be even greater.

The location of restoration projects has a strong effect on tradeoffs in installation and maintenance costs, longevity, and the full suite of ecosystem services that could be provided [46,84,92–96]. The science is still evolving for how best to site, design, and evaluate such restoration projects, and the scale of implementation is just now increasing beyond that of small-scale research sites (e.g., [83]). On an optimistic note, the rate of recovery of many marine benthic and pelagic ecosystems is on the order of 10 years or less; and there is recent hope for restoration of even coral reefs—thought to be much slower to recover than either mangroves or seagrasses [80,97–100].

3.2. Fisheries management

Simulation models suggest that adjustments to harvest regimes (especially lowering catch of over-exploited species and allowing higher catch of under-exploited, typically offshore species) could have a greater effect on productivity and economic performance in fisheries than impacts due to warming over the next 25 years [3,101–103]. Observed lags in Northeastern United States fisheries over the past 40 years relative to range shifts of fished species suggest that economic or management constraints are limiting adjustments of fishers to climate change [104]. Similarly, a global production-consumption model for fishmeal fisheries found that harvest management and market behavior (e.g., fishmeal demand from aquaculture and agriculture) affected fishery yields more than climate impacts [105]. Thus fisheries management should be a significant tool for bolstering fishery resilience to climate change. In some regions, fishery scientists are developing ecosystem models that incorporate climate impacts on harvested species and their landings and market values [4,25,102,105–107]; and this information could be used to set catch levels that can be sustained under climate futures. For data-limited fisheries and in places where technical capacity is low, simpler methods are needed that incorporate basic ecological principles into stock assessments and management decisions (e.g., [108–110]).

Additional fisheries management strategies to bolster resilience to climate change include integrating marine protected areas (MPAs) into spatial management approaches to support livelihoods through multiple ecosystem services, and identifying multiple livelihood options for fishers and others whose livelihoods depend on the ocean [29,87,111,112]. Assessment of these strategies can help identify conditions under which fishing or aquaculture-based communities should be encouraged to diversify livelihood options, shift the location of their fishing grounds or gear types, or get out of a fishery altogether. For example, destructive fishing in coral reefs was found to have high initial economic value, but the combined sustainable fishing, tourism and coastal protection benefits of more protected reefs have higher estimated value over time [67]. The ecosystem services framework accounted for these multiple benefits of the reefs and illuminated the significant net cost to those communities from the single sector of fishing.

3.3. Aquaculture practices

Aquaculture is on the rise as demand for seafood increases and wild harvests saturate globally and even decline in some regions [18,23,113,114]. It is unclear how much additional food production can be sustained from mariculture [18,23,24,113,114]. The fraction of seafood consumption by humans from aquaculture reached nearly 46% worldwide in 2008 and is projected to rise [16,115]. In the United States, where 80% of seafood consumed is imported, more than half of the imported seafood comes from aquaculture [116]. Increased ocean acidification, low oxygen events, and rising temperatures are already affecting shellfish aquaculture operations [18,21,117]; and resulting vulnerability tends to be concentrated in the tropics (e.g., [21]). The underlying causes of vulnerabilities include biophysical factors (e.g., time scales over which acidification is likely to reach critical thresholds) and socio-economic factors (e.g., nutritional dependency, economic importance of revenues from sales, and societal adaptive capacity).

The sustainability and reliability of aquaculture under future climate depends heavily on the location of farms and the type of operation. Climate considerations in risk assessments for aquaculture practices are growing [18,72,118–120]. For example, implementation of the Aquaculture Stewardship Council (ASC) standards for bivalves, abalone, and shrimp are underway; and in some areas, potential climate impacts are being incorporated into the design and siting of facilities [121]. Tradeoffs on multiple ecosystem services will need to be assessed as highly productive coastal and wetland regions are sought for aquaculture facilities, maintenance of biodiversity for wild-caught fisheries [113], sources of coastal protection [15] and draws for tourism [10].

3.4. Market-based incentives

With the notable exception of fishery catch-shares [122–124] and a few nascent investment schemes for coastal wetlands (e.g., [125,126]), market approaches (including Payment for Ecosystem Services, or PES) have been used sparingly in marine management and investment decisions. Nevertheless, PES and other market-based approaches could be developed further to account more fully for the impacts of human activities on marine ecosystem services. For example, nutrient trading schemes designed to reduce eutrophication in Chesapeake Bay are slowly getting underway in Pennsylvania, Virginia, Maryland, and other states; but significant market and regulatory hurdles remain [127,128].

In a growing number of cases around the world, payments through user fees or taxes on commercial enterprises are funding reef and other nearshore habitat protection for the tourism, coastal protection, and fishery habitat benefits they provide [129–131]. Belize charges higher taxes for cruise ship lines to pay for patrolling, research, and stewardship of the coral reef and mangrove keys that are the primary draw for tourists [132]. The Great Barrier Marine Park Authority in Australia was a pioneer in using visitor fees to partially offset maintenance and protection of reefs and islands within the Park boundary [125]. Many other marine parks have since followed suit. There are likely to be limits to environmental market-based approaches for climate adaptation until barriers related to property rights, governance (e.g., local to international jurisdiction) and alignment of providers and beneficiaries in the ocean are lowered [133].

3.5. Relocation

Relocation of human communities is fraught with controversy, but such strategies already are being applied in more vulnerable regions around the world. For example, six Alaskan communities are now planning relocation at a cost of $30–50M per village [95]. Many tropical island nations in the Indo-Pacific are built on low-lying, narrow coral atolls that are especially vulnerable to sea-level rise and leave little room for adaptation strategies such as retreating inland and/or to higher ground. Most of the population of Kiribati, for example, is concentrated in an urban setting on Tarawa, much of which is less than 3 m in elevation and less than half a kilometer wide. Without substantial adaptation, the economic impacts of climate change and sea-level rise on Kiribati are estimated to be equivalent to 17–34% of its 1998 GDP by mid-century [134]. Kiribati and other island nations are pursuing multi-pronged adaptation strategies including efforts to protect coastal infrastructure and limit coastal erosion through, for example, mangrove replanting. On longer time-scales, population resettlement to other countries may need to be implemented as a last resort.

4. Conclusion

In spite of the daunting challenges facing this crowded and warming planet, there are encouraging signs that human interventions can be effective in improving the capacity of marine systems – and the benefits they provide – to adapt to climate change.

Given the precarious state of global and local economies and increasing vulnerability of people living near coastlines, linking market and human wellbeing outcomes to ecosystem protection and restoration offers hope for sustaining and securing services from marine systems. For example, information on the sources of both biophysical and social vulnerabilities of communities to future climate impacts [19,21,135] can be used to target adaptation strategies towards solutions (e.g., increasing adaptive capacity of a community, restoring degraded coastal habitats) that will make a difference.

Promising examples linking ecosystem change to human wellbeing are growing, such as the Coral Triangle Initiative [136], an integrated strategy to increase the resilience of a marine system in the face of future climate change. The Initiative is overseen by six country governments, NGOs, and representatives from the private sector, and encompasses a population of over 200 million people. Its main aims are to support the biodiversity protection of coral reefs, fisheries economies, and food security. A key part of their strategy is to establish multiple MPAs, increasingly coupled to exclusive fishing zones, to help secure benefits for local fishers. These protected areas are designed from the outset to reduce the region's vulnerability to climate change by providing coastal protection, food security, and livelihoods [137–139].

When push comes to shove, policy leaders and individuals will choose actions that meet immediate material needs for their communities or families. When connections between actions affecting marine ecosystems are clearly linked to changes in human health and wellbeing, and multiple objectives (and thus tradeoffs) are included up front, climate adaptation strategies will become management and policy priorities.

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