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Prioritizing coastal ecosystem stressors in the Northeast United States under increasing climate change

Sarah L. Smith[a,*], Shannon E. Cunniff[b], Natalie S. Peyronnin[b], Jacob P. Kritzer[a]

[a] Environmental Defense Fund, Oceans Program, Boston, MA, USA
[b] Environmental Defense Fund, Ecosystems Program, Washington, DC, USA

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ABSTRACT

Coastal and marine ecosystems around the world are under threat from a growing number of anthropogenic impacts, including climate change. Resource managers, researchers, policy makers, and coastal community planners are tasked with identifying, developing, and monitoring strategies to reduce or reverse the ecological, economic and social impact of environmental stressors. These individuals must make decisions about how to prioritize and allocate finite resources to address these issues, all under conditions of significant uncertainty about which of these stressors to address. This paper presents the results of a survey and workshop designed to rank the impact of a series of stressors on four components of the marine and coastal ecosystems of the Northeast United States. The methodology described here – expert elicitation supplemented by workshop deliberations – proved to be relatively cost-effective, time-efficient, and informative for identifying priority stressors for the ecosystem components under consideration, both now and in the future.

1. Introduction

Coastal and marine ecosystems around the world are under threat from a growing number of anthropogenic impacts. Many of these systems have been altered for centuries and continue to change due to the complex interactions between anthropogenic and natural stressors. Many of these stressors are well documented and have been subject to ongoing research and mitigation efforts for the last few decades, including nutrient pollution (Vitousek et al., 1997; Howarth and Marino, 2006), coastal habitat degradation and loss (Lotze et al., 2006; Airoldi et al., 2008), and fishing impacts such as overfishing (e.g. Jackson et al., 2001; Hutchings and Reynolds, 2004) and marine habitat damage (Dayton et al., 1995). Others are relatively recent phenomena and are less well-studied, particularly those caused by increasing emission of greenhouse gases, and include impacts such as ocean acidification (Harley et al., 2006; Doney et al., 2012), increasing ocean and air temperatures (IPCC, 2014; Levitus et al., 2009), sea level rise (Cazenave and Llovel, 2010; IPCC, 2014), changes in storm intensity and frequency (Bender et al., 2010; Knutson et al., 2010), and changes in precipitation rates (IPCC, 2014).

As one of the first regions of North America to be settled by Europeans, the Northeast U.S. has experienced substantial anthropogenic impacts on ecosystem structure and function for centuries, with transformation of its coastal watersheds, and alteration or loss of coastal habitats, underway since the time of colonization (Roman et al., 2000). New England has lost an estimated 37% of its salt marshes since the early 1800s, and losses may exceed 50% in some areas (Bromberg and Bertness, 2005). Commercial fishing was a major economic driver in the region as far back as the 1600s, and some fish stocks were overfished by the early to mid-20th century (Murawski, 2005). Both nutrient and inorganic pollution have impacted rivers, estuaries, and nearshore coastal waters since the industrial revolution (Gedan et al., 2011; Roman et al., 2000).

While these stressors and others continue to impact the region's coastal and marine ecosystems, the landscape of stressors is also changing. The region is experiencing the effects of climate change, and these effects may be experienced most acutely by coastal and marine ecosystems. In the Gulf of Maine, sea surface temperatures have increased between 2004 and 2012 at a rate of 0.26 °C/year (Mills et al., 2013), faster than almost anywhere else on Earth. Likewise, the Mid-Atlantic Bight is also experiencing rapidly accelerating warming over the last decade (Forsyth et al., 2015). The Gulf of Maine region has experienced record high precipitation levels in the last two decades (NOAA Ecosystem Assessment Program, 2012). Some climate model predictions of precipitation suggest the Northeast region will experience an increase in annual precipitation of about 5–10%, with much of that increase along the coast (Fernandez et al., 2015). Climate change will also bring about an increase in extreme precipitation events. The

* Corresponding author.
E-mail address: ssmith@edf.org (S.L. Smith).

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region has already experienced a 70% increase in the heaviest precipitation events from 1958 to 2010, and this trend is expected to continue (Horton et al., 2014), along with increasing variability in precipitation, leading to both more flooding and more droughts (Balch et al., 2012).

The stressors driven by climate change, including sea level rise and increased storm intensity, as well as the related issue of increasing ocean acidification, not only have direct impacts but can also amplify existing stressors. For instance, sea level rise and increasing storm intensity and frequency can exacerbate existing shoreline erosion problems driven by development and shoreline hardening (Scavia et al., 2002; Nicholls and Cazenave, 2010). Storms and sea level rise can also cause additional loss of wetland habitats by submerging salt marshes or converting brackish marsh to salt marshes (Scavia et al., 2002; Gedan et al., 2011; Barbosa and Silva, 2009). Increasing precipitation can cause salinity changes in estuarine and marine systems (Scavia et al., 2002), and melting of the Arctic ice cap can further alter salinity of marine systems (Nummelin et al., 2016). Increasing sea surface temperatures, estuarine habitat loss, and ocean acidification are all likely to make many marine fish populations more vulnerable to severe depletion (Hare et al., 2016; Klein et al., 2016). Heavier precipitation combined with excessive fertilizer use and poorly designed stormwater systems can increase nutrient loading, while rising temperatures will decrease solubility of coastal waters. Together, these effects could increase the frequency and severity of hypoxic events (Rabalais et al., 2009; Doney et al., 2012). Finally, cities and towns built in coastal areas are already experiencing many climate-related impacts, such as sea level rise and greater storm surge, which will only grow in severity as climate change progresses (e.g. Horton et al., 2014; Moser et al., 2014).

Resource managers, researchers, policy makers, and coastal community planners are tasked with identifying, developing, and monitoring strategies to reduce or reverse the ecological, economic and social impact of environmental stressors. These individuals must make decisions about how to prioritize and allocate finite, and often inadequate, resources to address these issues. At the same time, our understanding of the current and future impacts of climate change on coastal and marine ecosystems, along with our understanding of effective solutions, is still relatively limited, in part because of the difficulty of studying marine systems as compared with terrestrial systems (Hoegh-Guldberg and Bruno, 2010).

A high degree of uncertainty, sometimes referred to as 'deep uncertainty', is embedded in understanding current and future stressors and their relationships to each other and the environment (e.g. Kandlikar et al., 2005). It is difficult to predict how environmental conditions will change in the future as a result of these stressors, particularly considering the rapid, non-linear growth predicted for climate change variables, such as sea level rise, and the interactions among new and existing environmental stressors. New methods and strategies must be developed to both understand and manage coastal and marine resources and communities under conditions of deep uncertainty.

One way of addressing this deep uncertainty, especially in the face of limited resource for empirical investigations and synthesis, is through eliciting expert judgment. Expert elicitation is one means of reducing uncertainty and risk in a policy context (Morgan and Henrion, 1990), particularly when there are gaps in our scientific understanding. Previous studies have employed expert elicitation to rank the impact of various ecosystem threats at different scales (e.g. Halpern et al., 2007; Kappel et al., 2012; Wilcox et al., 2016). Some of these studies have moved beyond qualitative evaluation by quantitatively estimating the magnitude of different impacts and associated levels of uncertainty. Importantly, the nature of the question posed can yield different responses and insights. For example, asking experts to score and rank impacts on habitats produces different results than simply asking experts to list the top stressors (Halpern et al., 2007).

For the most part, previous expert elicitation studies addressing ecological stressors have focused primarily on current impacts (e.g. Halpern et al., 2007; Teck et al., 2010; Kappel et al., 2012), without explicitly considering how climate change might alter the severity of and interactions among of stressors in the future. Climate change magnifies uncertainty, making expert elicitation an even more useful tool for evaluating potential impacts. Therefore, we used an expert survey to rank the severity of a variety of environmental stressors for coastal and marine ecosystems in the Northeastern United States in the present as well as under a future climate change scenario. We then reviewed and modified the survey results during an expert workshop that enabled us to capture more detail and nuance than is possible through a survey. The goal of this paper is to describe a novel methodology of evaluating and comparing the relative impacts of a large variety of environmental stressors on different habitat and resource types, and to describe the results of the application of this methodology to the Northeast U.S. Our study considered major components of coastal and marine ecosystems separately, and therefore reveals differences in the severity of stressors among the individual components as well as how the relative impacts are expected to change through time.

2. Methods

To rank stressors on different components of the coastal ecosystem, we created a survey and distributed it to a group of 615 experts identified from across the Northeast U.S. (Maine, New Hampshire, Massachusetts, Rhode Island, Connecticut, New York, and New Jersey). The experts were drawn from academic institutions, federal and state environmental, coastal resource management, and fish and wildlife agencies, and prominent environmental NGOs. We sought expertise in marine and coastal ecology, fisheries science, habitat, climate change, human dimensions of natural resource management, coastal zone management, coastal geology, hydrology, and natural resource economics, among others. We used the online platform Survey Monkey to develop and distribute the survey. This work builds upon the study by Kappel et al. (2012) that used expert elicitation to develop impact scores for a variety of environmental stressors on several coastal and marine habitats in Massachusetts. Kappel et al. (2012) focused on different types of ecosystems in the region, but did not evaluate how climate change might alter the importance of those stressors.

We asked survey respondents to rank the impact of a series of stressors on four components of the ecosystem:

- *Marine Fish Populations*: Ecologically and economically important species found in state and federal waters of the Gulf of Maine, Georges Bank, and Southern New England regions.
- *Marine Habitats*: Offshore (to the continental shelf) and nearshore marine habitats seaward of the intertidal zone, including pelagic and demersal habitats. Marine habitats encompass the sediment, sessile organisms, submerged aquatic vegetation, prey species, and oceanographic processes necessary to sustain fisheries and other large marine species.
- *Wetland/estuarine habitats*: Salt- and brackish-water habitats that connect marine and freshwater systems, including vegetation and sessile shellfish, as well as the water, nutrients, sediment, and other abiotic elements.
- *Coastal cities and towns*: The built infrastructure of cities, towns, and other coastal development, as well as ecological infrastructure necessary to maintain clean water, storm protection, recreational activities, and other ecosystem services.

We identified a series of ecosystem stressors based on a literature review of current and future impacts to the ecosystem components under consideration, as well as the expert elicitation survey by Kappel et al. (2012) (Table 1). This list is not exhaustive, and many impacts are not independent of one another. For example, habitat degradation and loss can occur by direct action on habitats, as well as due to shoreline erosion and sea level rise. However, our list reflects many of the priority