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Indicators of climate change and social vulnerability in fishing dependent communities along the Eastern and Gulf Coasts of the United States

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ABSTRACT

Changing climatic conditions are affecting the relationship between fishing communities and the marine resources they depend on. This shift will require an adaptive response on the part of policy makers and fishery managers. In the U.S., the National Oceanic and Atmospheric Administration (NOAA) established, in its fisheries agency (NOAA Fisheries), a set of social indicators of fishing community vulnerability and resilience to evaluate the impacts of changes in fishery management regimes. These indicators enhance the analytical capabilities within NOAA Fisheries for conducting fisheries social impact assessments and informing ecosystem-based fishery management. Building on the existing Community Social Vulnerability Indicators (CSVIs), new measures of climate change vulnerability are defined for the U.S. Eastern and Gulf coasts. These new indicators are used to assess the impact of sea level rise on critical commercial fishing infrastructure and the dependence of communities on species identified as vulnerable to the effects of climate change. Examples are provided in this article to demonstrate the utility of these new indicators to policy makers and the NOAA strategic goal for building resilient coastal communities that are environmentally and economically sustainable. Integration of CSVIs and the new climate change vulnerability indices highlight community needs for unique solutions in order to adapt to environmental and social changes and maintain their well-being.

1. Introduction

Developing effective strategies and policy frameworks for managing adaptation of coastal communities to climate change has increasing urgency for all coastal states. Methods for rapidly evaluating hazard, exposure and vulnerability to climate change impacts can support assessment of key risks (Fig. 1). Aspects of climate change most critical to fishing dependent communities include direct impacts from storms, weather and sea level rise and indirect impacts tied to changes in availability of fish stocks as a result of changes in ocean temperature and acidification [1].

Understanding climate stressors can provide policy makers with knowledge to develop adaptive management strategies that will improve the resiliency of coastal fishing communities [2]. For example, shifts in species range may cause trip lengths to increase for some harvesters or force a shift to other species, which can increase costs due to increased travel or required gear change. On the other hand, it may create the opportunity to harvest new species with minimal change to gear or harvesting patterns, which could result in a windfall for resident fishermen. Species quotas may have been established prior to species range shifts, so gear types and fishing practices may need to be modified. Such changes in species distribution can force changes to geographically bounded fishery management regimes that were predicated upon a set group of species and their assessment based upon historical harvest patterns [3–4].

Developing useful and practical social indicators is challenging [5] particularly on a large scale. In 2012, the National Oceanic and

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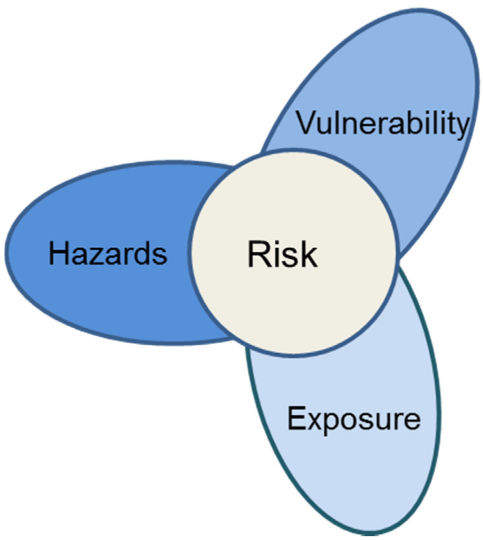

Fig. 1. Risk model from IPCC, 2014.

Atmospheric Administration's agency for Fisheries (NOAA Fisheries) developed an initial set of Community Social Vulnerability Indicators (CSVIs) for coastal communities along the U.S. Eastern and Gulf coasts [6–7]. This was the first time quantitative indicators of social vulnerability and fishing dependence had been developed and operationalized at the community level for such a large geographic area and for application within U.S. fisheries policy. Groundtruthing of the indicators has established their internal and external validity [8–11].

Concentrating on measures of vulnerability and resilience, including fishing dependence, the CSVIs are grounded in a broader effort to gauge the ability of social groups to adapt to change and the contribution to overall community well-being from such adaptation. A key factor currently affecting well-being for many coastal communities is climate change [12–13]. The impacts of a changing climate have important implications for management and policy regarding not only fishing communities, but coastal communities of all types. The need to develop indicators of climate change has also become an important part of a global strategy by the U.S. government to address the impacts of climate-induced fluctuations in temperature and sea levels [14]. In this article, the potential impacts of climate change to coastal communities are discussed and new indicators are incorporated into the CSVI toolbox to assess how fishing dependent and other coastal communities may be affected by a rising sea level and fish species' vulnerability to a changing climate.

Three primary consequences of current and projected climate change on marine ecosystems and coastal communities are: sea level rise; ocean temperature changes; and ocean acidification [3]. However, global assessments are limited in utility at the community level, as these changes are not likely to be distributed evenly nor will they necessarily directly impact fishing communities [2,15]. An effective fisheries management response to climate change will require development of assessment tools at local or regional scales that integrate physical, resource and socio-economic impacts.

The key stressors of climate change with *direct* effects on fishing communities include sea level rise and the resulting impact of increased frequency and intensity of extreme weather events [1]. Sea level rise projections through the 21st century indicate coastal areas will increasingly be affected by submergence, coastal flooding and coastal erosion [16], creating the need to relocate infrastructure [17]. Worldwide, coastal communities will also be disproportionately affected through the socio-economic impacts of climate change. According to Martnich et al., the vast majority of the world's most socially vulnerable coastal populations live in areas that are not likely to be protected from sea level rise [18]. Similarly, given the proximity to the coastline, commercial and recreational fishing infrastructure and businesses are especially vulnerable to impacts. The need for relocation of commercial piers and recreational fishing dockage further compound the profile of affected infrastructure and businesses.

In contrast, some *indirect* effects of climate change (ocean temperature and acidification) will affect the ability of some coastal communities to harvest fish [19], requiring an adaptive response that may include finding new fishing grounds, exploiting different species or seeking non-fishing dependent employment [3,20]. The latter option may be especially hard as many studies have found that fishermen are reluctant to leave the industry even under adverse economic conditions [21–22]. This is of particular concern given their frequent difficulty in adjusting to non-fishing jobs [22–23].

Ocean temperature variation has been linked to changes in species productivity [24–25], physiology [26], distribution [27–28] and interactions between species [29]. Pinsky et al. have examined changes in the distribution of marine species and linked them to long-term changes in ocean temperature utilizing the concept of climate velocity [30]. Climate velocity refers to the speed and direction with which an equal line of temperature moves across the earth. Due to climate velocities that are at least as fast in the ocean as on land [30], coastal communities and fisheries will have to adapt simultaneously to both aquatic and terrestrial changes in regional climate.

Regional changes in ocean temperature are strongly controlled by ocean circulation and climate variability on decadal scales [31]. As a result, prediction of climate change effects on marine ecosystems relies heavily on coupled models of ocean circulation and fish populations [32–33]. Linking the output of these models to stock assessment models and fishing community dependence on species is critical to an effective fisheries management response to climate change [34]. Fishing communities have variable dependence on specific stocks based on historical practices, local availability of resources, markets, and management constraints [35]. Fishing communities will struggle to adapt as fish stocks respond to complex changes in ocean temperature with shifts in species range and productivity [3,19,20].

Ocean acidification, the reduction of pH in the world's ocean from absorption of CO_2, reduces the areas of the ocean that can support the stability of external shells and skeletons made from calcium carbonate [36–37]. The distribution of ocean acidification is likely to vary regionally due to upwelling, coastal eutrophication and discharge of low pH river water [38]. The reduction in pH primarily affects molluscs, especially the larval stages [39–40]. These effects of ocean acidification have indirect effects on fishing communities through changing availability of shellfish and declining harvests and revenue [37–38]. Resource declines can impact not only fishermen, but also shore-based businesses, including fish wholesalers, seafood distributors, restaurants, and markets [41]. For instance, the level of dependence of commercial fisheries on calcifying species in New England is substantial, representing 41.5% of fisheries landed value, and representing more than $482 million in 2013 [41].

Environmental changes within the ocean will have impacts on a multitude of marine species important to coastal fishing communities, both commercially and recreationally [1,42]. Having measures of these climate change impacts that can complement the CSVIs will provide a more complete view of the linkage between social and ecological systems. The focus of this paper is to demonstrate the utility of three new climate change vulnerability indicators based on Weiss et al. [43], Hare et al. [42], and Morrison