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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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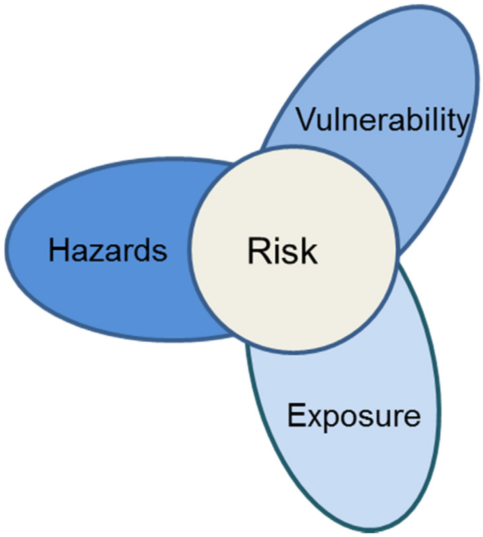

Fig. 1. Risk model from IPCC, 2014.

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

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et al. [44] that we integrate with the CSVIs to inform our understanding of the impact of changing climate conditions on fishing communities. These indicators can be used in combination with ecosystem based indices to improve forecasting of potential impacts of climate change.

2. Methods

Because the climate vulnerability indicators were developed using the same methodology, a brief overview of the CSVIs and their progress is given below first. See Jepson and Colburn [6] and Jacob et al. [8–9] for a detailed description of the methodology. Then the methodology for developing each of the new climate indices is described in turn.

2.1. Community social vulnerability indices

NOAA Fisheries' CSVIs were developed with readily available secondary data using factor analysis that included social, demographic and fisheries variables. A principal component analysis with a single factor solution was used to empirically test the latent structure for each index. Indices were constructed to meet the following criteria: a minimum variance explained of 45%; Kasier-Meyer-Olkin measure of sampling adequacy above .500; factor loadings above .350; Bartlett's test of sphericity significance above .05; and an Armor's Theta reliability coefficient above .500. Factor scores for each community were ranked based on standard deviations into the following categories: High (≥ 1.00 SD), Moderate .500–.999 SD) and Low (< .500 SD).

The initial CSVIs were refined to include indices for 2659 communities in coastal counties[1] for 19 states from Maine to Texas, of which 1130 showed evidence of commercial and/or recreational fishing activity. The twelve indices represent a range of issues or pre-existing conditions that could affect an individual's, and thus a community's, ability to cope with and respond to disruptive events such as changing fishery management regulations or climatic conditions. Of these, four fishing dependence indices captured the relative importance of commercial and recreational fisheries both within and across communities [6–7]. Table 1 shows the sub-set of six indices selected specifically for this analysis of commercially dependent fishing communities.

The variables included in each of the social vulnerability indices have been identified through the literature as being important components contributing to a community's vulnerability [6,9]. Indicators such as increased poverty rates, higher separation rates, higher crime rates and unemployment are all signs of vulnerable populations. These vulnerabilities will also play an important role in a community's ability to adapt to climate change.

Commercial engagement and reliance are two different aspects of the concept of fishing dependence. The variables included in the commercial fishing engagement and reliance indices are all variables that help locate critical infrastructure and people who are involved in fishing within a community. The commercial engagement fishing index is an absolute measure of commercial fishing in the community while the commercial fishing reliance index is a relative measure of commercial fishing within a community based on its population size.

Some communities demonstrate high engagement in commercial fishing but not reliance, while others may show low engagement but high reliance. For those communities that demonstrate both, it may be assumed that they are highly dependent on commercial fishing and that its support industries play a significant role in the local economy. These indices can be compared with other social vulnerability indices, both within a community and across communities.

[1] Coastal counties were selected based upon their proximity to the ocean through some connection either through shoreline, river, bay or estuary. See Ache et al. [45] for the definition of shoreline community. All communities within a coastal county for which data were available were included for the purposes of comparison.

Table 1
Select community social vulnerability and fishing dependence indices (from Jepson and Colburn, 2013).

Personal disruption index	**Poverty index**
Percent unemployed Percent in poverty Crime index Percent females separated Percent with no diploma	Percent receiving assistance Percent of families below poverty level Percentage over 65 in poverty Percentage under 18 in poverty
Labor force structure index	**Housing characteristics index**
Percent females employed Percent population in the labor force Percent self employed Percent people receiving social security	Median rent in dollars Median mortgage in dollars Median number of rooms Percent mobile homes
Commercial fishing engagement index	**Commercial fishing reliance index**
Value of landings Number of commercial fishing permits Number of dealers with landings Pounds of landings	Value of landings by population Number of commercial fishing permits by population Dealers with landings by population Percent in forestry, farming and fishing occupation

2.2. Community climate change indices

2.2.1. Sea level rise risk

To assess the potential impacts of sea level rise and develop new measures of climate change vulnerability for coastal communities of the U.S. Eastern and Gulf coasts, land area at elevations from one to six feet above mean higher high water (MHHW) within community boundaries was computed based on methodology from Weiss et al. [43]. Coastal elevation data developed by the NOAA Office for Coastal Management were used. NOAA reproduces high-resolution digital elevation models (DEMs; 5- to 10-meter horizontal resolution) from the National Elevation Dataset (ned.usgs.gov) for coastal areas of the U. S., adjusting them for variations in local tide levels (coast.noaa.gov/slr). NOAA additionally provides subsets of the adjusted DEMs as polygon shapefiles that delineate areas by one-foot increments from one to six feet in elevation. NOAA shapefiles of elevational increments were chosen based on analyses of DEMs that incorporate hydrological connectivity, a 'bathtub' approach that estimates the inland spread of water as sea level rises by comparing elevation values of the eight neighboring cells to the value of a particular cell in a DEM raster. NOAA elevation shapefiles were acquired for all states along U.S. Eastern and Gulf coasts except for Louisiana.

Coastal communities were identified using the 2007 U. S. Census Bureau's municipal boundaries for Census Designated Places (CDPs) and County Subdivisions (MCDs), and the same 2659 coastal communities were used as in the development of the initial CSVIs. Before calculating area within communities at or below one-foot increments from one to six feet in elevation, we removed parts from within municipal boundaries that either were below MHHW as

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defined by the NOAA elevation shapefiles or defined as estuarine or marine wetlands in GIS shapefiles from the U.S. Fish and Wildlife Service [46]. The area of potential sea level rise impacts in communities was computed by overlapping the remaining, or land, areas of municipalities with NOAA elevation shapefiles from one to six feet. All geospatial data analysis was performed using Environmental Systems Research Institute (Esri) ArcGIS Desktop™ software.

The variables of land area potentially affected by one to six feet of sea level rise served as input for a factor analysis, using the same statistical tests and criteria as the CSVIs, to create an index factor score for each community that represents its overall sea-level-rise risk. While there is substantial correlation between these variables over broad regions, coastal elevations can vary considerably within communities. For example, some locales may have a relatively small proportion of their land area at the six foot level of elevation, whereas for others this proportion may be relatively large. For some communities, the amount of land area lost at one foot level may not change as sea level rises while other communities may experience a substantial increase in area lost at each subsequent foot level. The resulting factor score for a community represents an overall risk of impacts from rises in sea level of one to six feet, such that a higher score represents a higher risk of impacts.

2.2.2. Sea level rise and businesses affected

To understand the impact of sea level rise on fishing businesses within these communities, a similar measure was calculated for the same six elevations by community using recently acquired business location data. Business location data used in this analysis was obtained from ESRI and consists of a database compiled by Dun and Bradstreet [47]. The data (current as of 2012) includes the business name, location (latitude-longitude coordinates and address), industry classification code, number of employees, and sales volume for over 18 million U.S. businesses. These are available via the six-digit North American Industry Classification System Codes (NAICS) [48]. The specific codes used in this present analysis were labeled “Seafood Commerce” sector and are listed in Table 2. They correspond to the ocean economy sector “Living Resources” created by the NOAA's Office of Coastal Management.[2]

Businesses assigned to the seafood commerce sector were placed into ArcMap™ and overlaid onto the municipal boundary files. The six different levels of area lost projections, calculated earlier for each community, were also overlaid and an “intersect” with the business location points was performed. An “intersect” is an analytical operation where only those items that “intersect” with another layer are retained within each polygon of ‘area lost’ for a municipal boundary, thereby joining two types of data. In this instance, the business location points within each polygon of area lost were retained. The results for each polygon include the total number of seafood commerce businesses and total revenue that would be affected at each projected foot of sea level rise. The total revenue affected at each foot of sea level rise was placed into a principal component analysis with a single solution factor as described above using the same criteria to create an index.

2.2.3. Species vulnerability and catch composition diversity

Based on a methodology developed by Morrison et al. [44], Hare et al. [42] reported the results of a climate vulnerability assessment for 82 fish and invertebrate species from the Northeast U.S. Shelf. All of the federally managed and many of the state managed fisheries species were included. The assessment estimated the vulnerability of each species to a change in productivity or abundance resulting from climate change. The species list and vulnerability rankings are provided in Appendix 1; see Hare et al. [42] for more details. Because species climate vulnerability measures have so far been created for Northeast (New England and Mid-Atlantic) species only (not the Southeast or Gulf coasts), this index was calculated only for fishing communities in the Northeast.

Northeast fishing communities were classified into four categories of climate change vulnerability (low, moderate, high and very high) based on the percent contribution of vulnerable species to total value landed in 2013 for each community. Communities were classified as: *High*, if the sum of value landed for species classified as having high or very high climate change vulnerability represented 50% or more of the total value landed; *Moderate*, if the sum of value landed for species characterized by moderate vulnerability represented 50% or more of the total value landed; *Low*, if the sum of species characterized by low vulnerability represented 50% or more of the total value landed; and *Mixed*, if the percent contribution to total value landed of the sum of species belonging to any one of the climate change vulnerability categories did not surpass 50%.

Further, communities where fishermen land a diverse array of species are considered potentially less vulnerable to climate change than those that are dependent on only one or a few species [49]. Because the flexibility to harvest a diverse array of species may buffer the effects of climate change, the Simpson's Reciprocal Index,[3] a measure of biodiversity, was used to develop an indicator of community-level catch composition diversity. This index is not currently available for the other regions outside the Northeast, but may be developed in the future for other regions.

When used to calculate biodiversity, the Simpson's Reciprocal Index starts with 1 as the lowest possible value and ranges to a maximum value that represents the total number of species in the sample. The index accounts for the relative abundance of each species found in the sample and attributes more weight to more abundant species. A higher index value indicates greater diversity. In the context of this study, the index was calculated using the relative contribution of each species landed to total value landed in a given community. The species that contributed more to total value landed have more weight in the index calculation than species with less substantial contributions.

Table 2
NAICS codes selected for analysis of businesses affected by sea level rise[*].

Sector	Industry	NAICS code	NAICS industry (2012 NAICS)
Seafood Commerce	Fishing hatcheries and aquaculture	112511	Finfish farming and fish hatcheries
		112512	Shellfish farming
		112519	Other aquaculture
	Fishing	114111	Finfish Fishing
		114112	Shellfish Fishing
		114119	Other Marine Fishing
	Seafood processing	311710	Seafood Product Preparation and Packaging
	Seafood markets	445220	Fish and Seafood Markets

[*] Codes selected from “2012 North American Industry Classification System” published by United States Census Bureau, 2012.

[2] The Economics: National Ocean Watch (ENOW) data from NOAA's Office for Coastal Management is derived from the U. S. Bureau of Labor Statistics and the Bureau of Economic Analysis.

[3] The index is calculated as 1/D, where: $D=\sum (n / N)^2$, n=value landed for a given species, and N=total value landed.

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3. Results

The results demonstrate how a select set of social vulnerability and fishing dependent indices are integrated with indices of climate change vulnerability. First, the commercial fishing engagement and reliance indices are used to identify those communities most dependent on commercial fishing, comparing their social vulnerability for the first time to all coastal communities. Next, the climate change indices results for these fishing communities, where available, are presented to identify those communities with additional vulnerabilities that may affect their overall well-being.

3.1. Community social vulnerability indices

Based on standard deviation using the same thresholds described earlier in Section 2.1, the four social vulnerability indices were ranked for all coastal communities. Of the 2659 communities analyzed, 174 (6.5%) scored in the high range for commercial fishing engagement and/or reliance. When compared to other communities in coastal counties, the 174 highly engaged and/or reliant commercial fishing communities show distinct differences with regard to social vulnerabilities (Fig. 2).

When considering only highly engaged and/or reliant commercial fishing communities, the percent of communities that scored in the high range for the social vulnerability indices were between 8% and 28% higher than the other coastal communities. A nonparametric test of significance, Mann-Whitney *U* Test, was performed to compare the differences in categorical scores for each of the four indices between communities dependent on commercial fishing and all other coastal communities. The results in Table 3 show that the differences were statistically significant for all four indices verifying that highly engaged and or reliant commercial fishing communities are more socially vulnerable. This difference will become even more important when the effects of climate change are evaluated.

3.2. Community climate change vulnerability

3.2.1. Sea level rise risk

As discussed earlier, sea level rise will likely have local and disproportionate impacts on many coastal communities as emphasized by Weiss et al. [43] and Sallenger et al. [50]. These localized impacts are critical for individual communities to prepare for, but regional and national management requires a comprehensive assessment. In order to assess all communities, an overall index of sea level rise vulnerability was calculated. This new sea-level-rise risk index is a measure of the potential impact from sea level rise for coastal communities based on area of community land lost (Fig. 3). The index consists of 6 variables for area lost due to sea level rise from 1 through 6 feet and was calculated using the methods described above. The variance explained was 92% and the criteria for other tests were met. The factor scores were then ranked based upon standard deviation according to the thresholds described above to create a single unified index.

Coastal communities are differentially affected by sea level rise (Fig. 3). Mid-Atlantic communities in the low lying Coastal Plain, especially those clustered around the Chesapeake Bay area and the New Jersey shore were ranked high with regard to expected vulnerability to sea level rise. This is not surprising given that the Mid-Atlantic region is experiencing sea level rise rates 3∼4 times higher than the global average [50]. New England communities in the Gulf of Maine and southern parts of the region were not projected to be as vulnerable. This is due largely to the bedrock coastline that is interestingly missing from the coastal landforms of Long Island (NY) and Cape Cod (MA), where distinct features related

Table 3
Mann-Whitney *U* test for significance of social vulnerability for highly engaged and/or reliant commercial fishing communities versus all other communities.

Index	Group	N	Mean rank	U	Z	P
Poverty	Highly engaged	174	1668.56	157,285	−8.362	< .000
	All other	2485	1306.29			
Personal Disruption	Highly engaged	174	1591.63	170,672	−6.117	< .000
	All other	2485	1311.68			
Labor Force Structure	Highly engaged	174	1565.86	175,155	−5.661	< .000
	All other	2485	1313.48			
Housing Characteristics	Highly engaged	174	1852.77	125,233	−11.34	< .000
	All other	2485	1293.4			

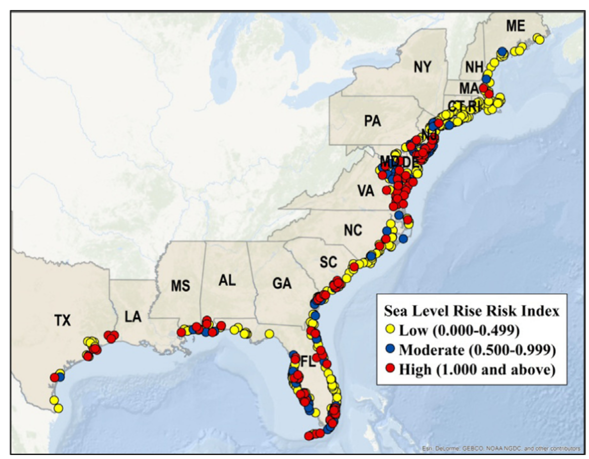

Fig. 3. Community sea level rise risk index for Maine to Texas based on area lost at 1–6 feet. NOAA elevation shapefiles for Louisiana were not available at the time of analysis.

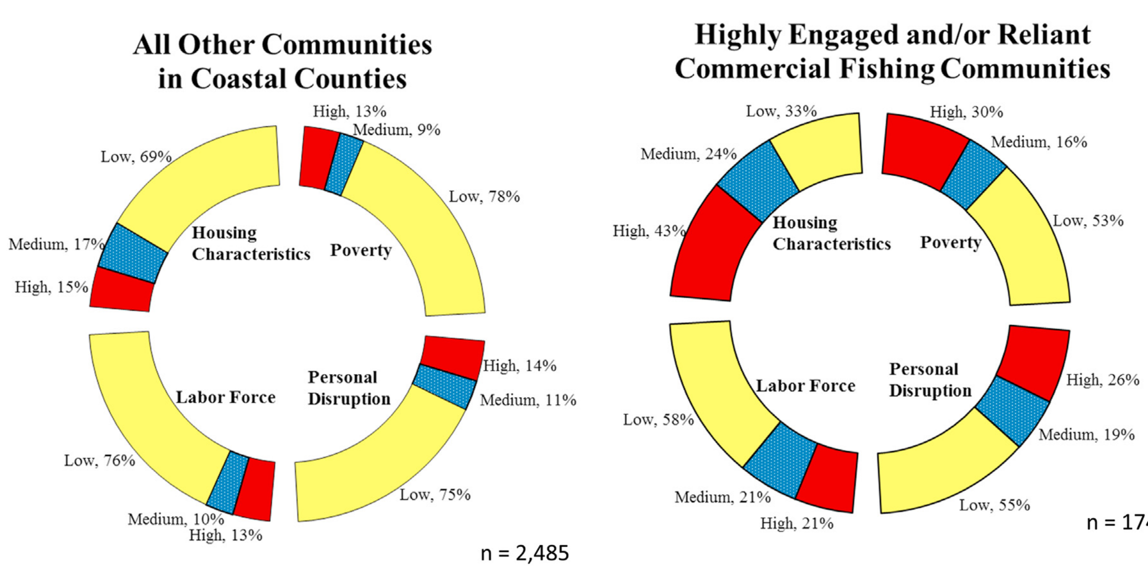

Fig. 2. Social vulnerability in highly engaged and/or reliant commercial fishing communities compared to all other communities in coastal counties.

to glacial processes moderate the area of land lost in coastal communities [51]. South Atlantic communities (North Carolina to Florida's East Coast) had pockets of high vulnerability and those in the southeastern Florida had the highest concentration of vulnerable communities, including the Florida Keys for that region. The western part of Florida and Gulf states were mixed. Once data for Louisiana become available we anticipate that it will have a number of communities at risk.

3.2.2. Sea level rise and business location

A more focused assessment of the potential risk of sea level rise is the differential impacts to the businesses in the seafood commerce sector. Risk was assessed by location and then in terms of revenue. Using the intersect data described earlier, the number of businesses affected within each community were aggregated and mapped. The resulting maps demonstrate that although some areas may not have a high overall risk for sea level rise (Fig. 3), there are seafood commerce businesses that will be affected at the early stages of projected sea level rise (Fig. 4). This is important given that many businesses involved in the seafood commerce sector are likely to be close to the shore, as proximity to fishing vessels and other infrastructure may be critical to acquiring and distributing fresh seafood and other products. That proximity also places them at risk to storms and other hazards and certainly to the early stages of sea level rise. This proximity and the risks are further defined when revenue from the same businesses affected by the early stages of sea level rise are examined.

3.2.3. Sea level rise and business revenue

A revenue affected index was also calculated to measure the potential revenue affected at each foot of sea level rise for businesses found within the seafood commerce sector in coastal communities. The variance explained was 72% and the criteria for other tests were met. The factor scores were categorized based on standard deviations according to the thresholds described above. Communities with high potential revenue loss are concentrated along the New England and Mid-Atlantic coasts (Fig. 5). In the Southeast, the majority of the communities with moderate to high revenue loss are located in Florida. Like the number of businesses affected, revenue lost associated with those businesses can also be high in areas where there may not be a high overall risk for sea level rise. It is likely that the impacts of climate change, especially sea level rise, could be substantial for many coastal fishing communities and although we were unable to include Louisiana in this analysis, the anticipated effects of sea level rise will be substantial for communities located in the Delta area of that state [52].

As shown in Table 4, there is a risk for revenue to be affected with relatively low amounts of sea level rise. Clearly a small number of businesses can account for a substantial amount of potentially affected revenue in a community. Furthermore, only one business sector has been included out of many that may be affected in these areas close to the shore. Future analyses will examine the impacts on other business sectors related to the ocean economy, such as marine transportation, oil and gas, and recreational tourism, as they will undoubtedly experience impacts from rising seas.

It is worth noting that while there may be more Southeast businesses affected; the total revenue affected is higher in the Northeast region. This is likely due to the high value species landed in the Northeast, i.e. scallops. Overall, seafood commerce businesses in the Northeast tend to have higher revenues than those in the Southeast (Table 4). Further, although revenue may be lower, businesses in the Southeast may have just as many employees as their Northern counterparts or be an integral part of the local economy in a small rural community and therefore may represent a significant impact for the community if lost to sea level rise.

3.2.4. Species vulnerability and catch composition diversity

Northeast region fishing communities were mapped based on catch composition diversity (Simpson's Reciprocal Index) and the level of dependence on species highly vulnerable to the effects of a changing climate. Fig. 6 provides a side-by-side comparison of the region based on these two important aspects.

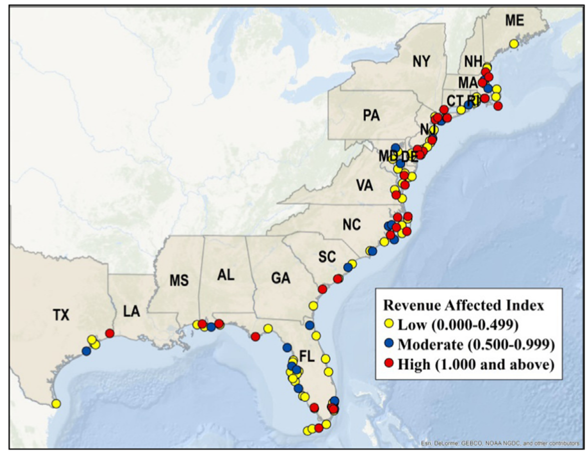

Fig. 5. Seafood commerce revenue affected index.

Table 4
Number of affected seafood commerce businesses and revenue by sea level rise.

Region	# of Business affected			Revenue ($ MM)		
	1ft	**3ft**	**6ft**	**1ft**	**3ft**	**6ft**
Northeast region (ME-VA)	6	54	176	11.8	27.6	241.9
Southeast region (NC-TX[*])	6	71	227	8.3	55.3	153.1
Total	12	125	403	20.1	82.9	395

[*] Does not include Louisiana.

Geographic areas within the region display characteristics that reveal important information concerning their overall vulnerability to climate change. For example, the majority of communities in Maine display moderate dependence on vulnerable species while scoring low on catch diversity, a reflection of the region's high dependence on the lobster fishery. In contrast, communities in Massachusetts and Rhode Island have significant dependence on species such as scallops that are highly vulnerable to climate change, but also have high catch diversity. In southern New Jersey, some communities are significantly dependent on species such as clams that are highly vulnerable to climate change while displaying low overall catch diversity.

For those communities that are highly dependent on more vulnerable species and have low catch diversity, the impacts that come from climate change could be substantial. Switching to substitute species may be limited by external factors such as regulatory constraints or expensive gear modifications to fishing equipment. It is important to note that few communities in the region have low dependency on highly vulnerable species, while at the same time displaying high catch composition diversity, an indication of the region's overall vulnerability to climate change based on the factors analyzed (Fig. 6).

3.3. Summary of fishing community vulnerability indicators

The three new community climate change vulnerability indices are integrated

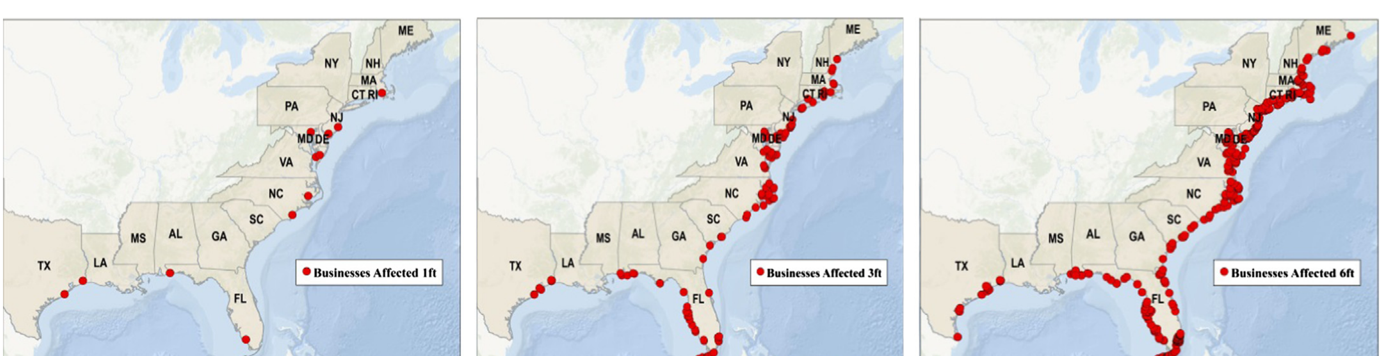

Fig. 4. Seafood commerce businesses affected by sea level rise.

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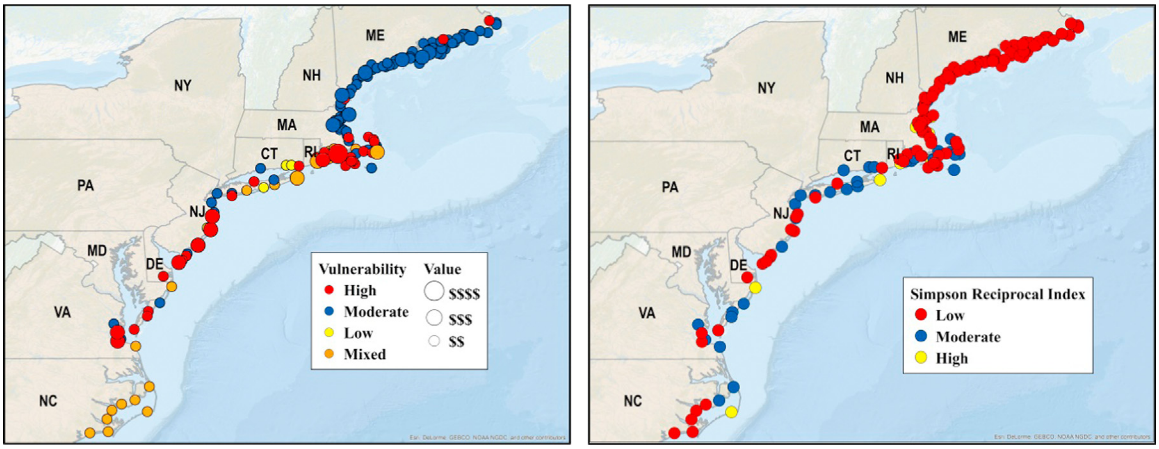

Fig. 6. New England and Mid-Atlantic Fishing communities' climate vulnerability classification based on categories of dependence on vulnerable species (left), and catch diversity scores (Simpson's Reciprocal Index (right)). Only communities with total landings value of 100 thousand dollars or more were mapped.

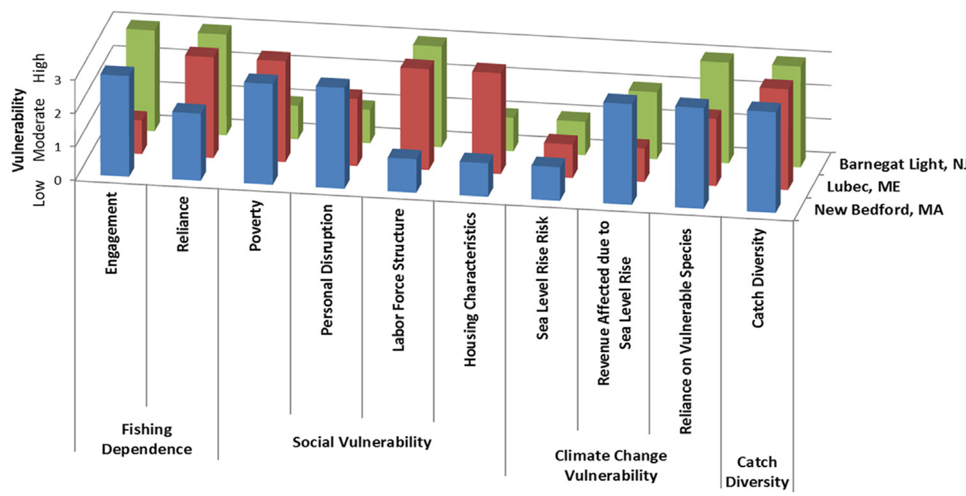

Fig. 7. Combined vulnerability indices for three communities.

with an indicator of catch diversity and a select set of CSVIs to illustrate how the different measures interrelate (Fig. 7). Each community has a unique set of vulnerabilities that will demand a unique set of solutions to address climate change. For example, Barnegat Light, NJ is both highly engaged and reliant on commercial fishing, but has a weak labor force, and shows moderate to high vulnerability on two of the three climate change vulnerability indicators. Lubec, ME is highly reliant on commercial fishing, moderate to highly vulnerable for all four social indicators and scores moderate to highly vulnerable on two of the three climate change vulnerability indicators. New Bedford, MA is highly engaged and moderately reliant on commercial fishing, highly vulnerable on two of the four social vulnerability indicators and highly vulnerable on two of the three climate change vulnerability indicators. All three communities show a high vulnerability in catch diversity.

For a community like Lubec, ME, which has moderate to high scores on seven out of ten vulnerability indicators, there may be a multitude of effects that come from any climate change impact. Commercial fishing reliance is not in and of itself a vulnerability. However, depending on its relationship to the other indices, it may become a vulnerability. When considering the potential impacts for any fishing community, one key factor in the capacity to adapt is the ability to replace lost income for the household. That may come from switching to other species for the fishing business, but when that is not available, fishing families often seek temporary or part-time employment in other economic sectors or may leave the fishing industry altogether. This is a concern given evidence that fishermen may have difficulty adjusting to jobs outside of the fishing industry [22–23]. Furthermore, many communities in Northern Maine, like Lubec, may not have other types of employment available as they are highly dependent upon fishing. This may be typical of rural communities in other regions like the Southeast, where shrimp fishing may dominate the local economy. Therefore, to seek other employment may mean long commutes or moving from the community.

4. Discussion

There have been few ecosystem models that are able to couple human behavioral responses to physical and biological environments and accurately frame ecosystem processes such that they capture the interactions between systems. This is due, in part, to a lack of social indicators that are well-matched with current ecosystem models and because few models have been developed to incorporate these types of indicators. Both ecosystems and human behavioral responses are complex, dynamic, and difficult to represent with a fixed set of quantitative indicators but this should not discourage us from attempting to build more comprehensive models. The need to develop effective policies to address potential impacts of climate change on coastal communities outweighs any limitations of integrated models.

This article demonstrates that predicting impacts from climate change at the community level add another layer of complexity to our understanding of fishing community well-being and ability to adapt to change. The effects of climate change are multi-faceted and will have both direct and indirect effects on coastal communities. Therefore, it is vital to begin to develop tools that will assist not only policy makers, but the general public in their understanding of how anticipated changes might impact their

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communities. This research has expanded a set of social vulnerability indicators that have already demonstrated their utility and practicability for social impact assessments [53–54]. These indicators have been used to compare highly dependent fishing communities to all other coastal communities to predict that they are more vulnerable at a statistically significant level. That difference is important because the projected impacts upon coastal communities have been found to be even greater when climate change vulnerability measures are added..

While there have been attempts to create a single indicator of social vulnerability to disruptive events such as natural hazards or changing climatic conditions [36,38,55], the concept of social and ecological well-being is complex and dependent on context. A single indicator may lack sufficient sensitivity to inform the understanding of the specific drivers of vulnerability that affect the overall well-being of communities. The indicator of overall sea level rise risk highlights those areas that may be most exposed to the risk of a rising sea, but as pointed out in this article, the initial phases of sea level rise will have immediate impacts that are not necessarily captured in such a singular measure. Therefore, it is important to assess the unfolding impacts of climate change over time, as well as both direct and indirect immediate effects.

Certain communities are more susceptible to sea level rise and may be at greater overall risk given global projections that range between .26–.82 m (0.85–2.7 feet) by 2100 [17]; however, future risk is not the only consideration. Many parts of the lower Chesapeake Bay are already experiencing more frequent flooding because of sea level rise in conjunction with subsidence, more commonly known as “sinking land” [13]. The city of Miami, Florida is undergoing continued saltwater intrusion into its water supply, while other areas within the state are seeing their beaches retreat [56]. Therefore, it is important to begin to think of how to build baseline data to help assess what impacts may occur and how resilient communities may be in the face of important changes.

For communities with commercial fishing businesses that have infrastructure near the shore, the impacts from sea level rise can be even greater if the local economy is dependent upon a particular ocean-related industry or ocean species and/or is socially vulnerable. Furthermore, reliance on marine species that are vulnerable to the effects of climate change as well as reliance on fisheries with low catch diversity introduce other risks that fishing communities must consider. As ocean characteristics change, fishing patterns may change which will have important implications for individuals, fishing businesses and communities. It is this type of complexity that typifies ecosystems and underscores the importance of developing targeted assessment measures that offer the greatest flexibility for management. The indicators outlined here further the understanding of climate change and its implications for fishing communities, while capturing important nuances that exist within coastal economies. This is certainly important for fisheries management as the disparities that are evident in community vulnerabilities can better inform decision makers when choosing alternatives within fishery management plans to minimize negative impacts.

5. Conclusion

A set of social indicators of fishing community vulnerability and resilience have been established in the U.S. by NOAA Fisheries to evaluate the impacts of changes in fishery management regimes. These indicators have enhanced the analytical capabilities within NOAA Fisheries for conducting fisheries social impact assessments and inform ecosystem-based fishery management. New measures of climate change vulnerability now defined for the U.S. Eastern and Gulf coasts add to the toolbox available to monitor different aspects of community well-being on a broad geographic scale. This is particularly important given that communities that are highly dependent on fishing were found to more likely be socially vulnerable than other coastal communities. These findings emphasize the need for continued examination of the issues of climate change and social vulnerability as subtle differences among all types of coastal communities, their economies and populations may have implications for their ability to adapt to change. Expansion of the social indicators highlights the complexity of the relationship between climate change and social vulnerability and provides a context for more in-depth research that will shed further light on these issues. The use and analysis of these indicators can inform ecosystem models and build a more integrated picture of climate change that will enhance policy decisions. Finally, the development of indicators that are robust and sensitive to significant change will continue to improve the ability to understand how community well-being is affected by vulnerability and contributes to resilience.

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Appendix

List of species included in the Northeast U.S. Fisheries Climate Vulnerability Assessment (Hare et al., 2016; Morrison et al., 2015).

Common Name	Scientific name	Climate vulnerability
Alewife	*Alosa pseudoharengus*	Very High
American Shad	*Alosa sapidissima*	Very High
Atlantic Salmon	*Salmo salar*	Very High
Atlantic Sturgeon	*Acipenser oxyrhynchus*	Very High
Bay Scallop	*Argopecten irradians*	Very High
Bloodworm	*Glycera dibranchiata*	Very High
Blue Crab	*Callinectes sapidus*	Very High
Blue Mussel	*Mytilus edulis*	Very High
Blueback Herring	*Alosa aestivalis*	Very High
Channeled Whelk	*Busycotypus canaliculatus*	Very High
Eastern Oyster	*Crassostrea virginica*	Very High
Hickory Shad	*Alosa mediocris*	Very High
Horseshoe Crab	*Limulus polyphemus*	Very High
Knobbed Whelk	*Busycon carica*	Very High
Northern Quahog	*Mercenaria mercenaria*	Very High
Ocean Quahog	*Arctica islandica*	Very High
Rainbow Smelt	*Osmerus mordax*	Very High
Shortnose Sturgeon	*Acipenser brevirostrum*	Very High
Soft Clam	*Mya arenaria*	Very High
Striped Bass	*Morone saxatilis*	Very High
Tautog	*Tautoga onitis*	Very High
Winter Flounder	*Pseudopleuronectes americanus*	Very High
American Conger	*Anguilla oceanica*	High
American Eel	*Anguilla rostrata*	High
Atlantic Halibut	*Hippoglossus hippoglossus*	High
Atlantic Sea Scallop	*Placopecten magellanicus*	High
Atlantic Surfclam	*Spisula solidissima*	High
Atlantic Wolffish	*Anarhichas lupus*	High
Black Sea Bass	*Centropristis striata*	High
Cusk	*Brosme brosme*	High
Dusky Shark	*Carcharhinus obscurus*	High
Green Sea Urchin	*Strongylocentrotus droebachiensis*	High
Northern Shrimp	*Pandalus borealis*	High
Ocean Pout	*Zoarces americanus*	High
Porbeagle Shark	*Lamna nasus*	High
Red Drum	*Sciaenops ocellatus*	High
Sand Tiger	*Carcharias taurus*	High
Spotted Seatrout	*Cynoscion nebulosus*	High
Thorny Skate	*Amblyraja radiata*	High
Tilefish	*Lopholatilus chamaeleonticeps*	High
Acadian Redfish	*Sebastes fasciatus*	Moderate
American Lobster	*Homarus americanus*	Moderate
Atlantic Cod	*Gadus morhua*	Moderate
Atlantic Croaker	*Micropogonias undulates*	Moderate
Atlantic Hagfish	*Myxine glutinosa*	Moderate
Atlantic Mackerel	*Scomber scombrus*	Moderate
Atlantic Menhaden	*Brevoortia tyrannus*	Moderate
Barndoor Skate	*Dipturus laevis*	Moderate
Cancer Crabs	*Cancer borealis / Cancer irroratus*	Moderate
Northern Kingfish	*Menticirrhus saxatilis*	Moderate
Pollock	*Pollachius virens*	Moderate
Rosette Skate	*Leucoraja garmani*	Moderate
Sand Lances	*Ammodytes americanus & Ammodytes dubius*	Moderate
Scup	*Stenotomus chrysops*	Moderate
Spanish Mackerel	*Scomberomorus maculatus*	Moderate
Spot	*Leiostomus xanthurus*	Moderate
Summer Flounder	*Paralichthys dentatus*	Moderate

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Weakfish	*Cynoscion regalis*	Moderate
White Hake	*Urophycis tenuis*	Moderate
Witch Flounder	*Glyptocephalus cynoglossus*	Moderate
American Plaice	*Hippoglossoides platessoides*	Low
Anchovies	*Anchoa hepsetus / Anchoa mitchilli*	Low
Atlantic Herring	*Clupea harengus*	Low
Atlantic Saury	*Scomberesox saurus*	Low
Bluefish	*Pomatomus saltatrix*	Low
Butterfish	*Peprilus triacanthus*	Low
Clearnose Skate	*Raja eglanteria*	Low
Deep-sea Red Crab	*Chaceon quinquedens*	Low
Haddock	*Melanogrammus aeglefinus*	Low
Little Skate	*Leucoraja erinacea*	Low
Longfin Inshore Squid	*Doryteuthis pealeii*	Low
Monkfish (Goosefish)	*Lophius americanus*	Low
Northern Shortfin Squid	*Illex illecebrosus*	Low
Offshore Hake	*Merluccius albidus*	Low
Red Hake	*Urophycis chuss*	Low
Silver Hake	*Merluccius bilinearis*	Low
Smooth Dogfish	*Mustelus canis*	Low
Smooth Skate	*Malacoraja senta*	Low
Spiny Dogfish	*Squalus acanthias*	Low
Windowpane Flounder	*Scophthalmus aquosus*	Low
Winter Skate	*Leucoraja ocellata*	Low
Yellowtail Flounder	*Limanda ferruginea*	Low

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