Ambio
https://doi.org/10.1007/s13280-019-01156-3

KUNGL. VETENSKAPS- AKADEMIEN
THE ROYAL SWEDISH ACADEMY OF SCIENCES

CrossMark

RESEARCH ARTICLE

Views from the dock: Warming waters, adaptation, and the future of Maine's lobster fishery

Loren McClenachan, Steven Scyphers, Jonathan H. Grabowski

Received: 12 September 2018 / Revised: 4 January 2019 / Accepted: 30 January 2019

Abstract The ability of resource-dependent communities to adapt to climate change depends in part on their perceptions and prioritization of specific climate-related threats. In the Maine lobster fishery, which is highly vulnerable to warming water associated with climate change, we found a strong majority (84%) of fishers viewed warming water as a threat, but rank its impacts lower than other drivers of change (e.g., pollution). Two-thirds believed they will be personally affected by warming waters, but only half had plans to adapt. Those with adaptation plans demonstrated fundamentally different views of human agency in this system, observing greater anthropogenic threats, but also a greater ability to control the fishery through their own actions on the water and fisheries management processes. Lack of adaptation planning was linked to the view that warming waters result from natural cycles, and the expectation that technological advancements will help buffer the industry from warming waters.

Keywords Adaptive capacity · Climate vulnerability · Fisheries · Gulf of Maine · Mental models · Social-ecological system

INTRODUCTION

Adaptive capacity in fishing communities

The effects of anthropogenic climate change in marine ecosystems are unprecedented in human history, raising concerns about how coastal communities will respond and adapt (Marshall and Marshall 2007; McClanahan and Cinner 2011). Adaptive capacity is the ability to enact strategies that mitigate immediate risk and strengthen responses to future risks, and has its roots in both vulnerability and resilience frameworks (Adger and Vincent 2005; Gallopín 2006; Engle 2011). Vulnerability literature focuses on the characteristics of both biophysical and social systems (Engle 2011). For example, vulnerability to climate change is influenced by physical exposure to hazards like severe weather and sea level rise, as well as social factors such as social capital, planning skills, and economic dependence on natural resources (Adger 2009; Smit and Wandel 2006; Marshall et al. 2007). The concept of resilience is rooted in the natural sciences (Holling 1973), and has more recently been adapted to understand social–ecological systems (SES), with social and cultural characteristics recognized as important in achieving desirable environmental outcomes in the face of change (Folke 2006, Engle 2011). For example, a community's resilience can be decreased by environmental degradation that reduces the availability of resources, or increased by adaptive capacity, which includes recognition and agreement about the degree and causes of ecological change (Adger and Vincent 2005; Nelson et al. 2007).

Adaptive capacity is widely recognized as a critical element of social resilience to environmental change (e.g., Marshall and Marshall 2007; Folke et al. 2002; Smit and Wandel. 2006). For instance, Marshall and Marshall (2007) describe and measure adaptive capacity as having four key components: risk perceptions, planning skills, coping ability, and interest in adapting. Mortreux and Barnett (2017) identify five types of capital—natural, physical, financial, social, and human—access to which has been assumed to predict an ability to adapt to climate change. However, they note that these attributes do not always align with adaptation outcomes, as groups with access to capital often fail to deploy it effectively in times of crisis. For example, households with more financial assets may

Published online: 09 March 2019

lack flexibility to shift income streams, and nations with high GDP may lack political will to invest in effective adaptation outcomes (Mortreux and Barnett 2017). Therefore, flexibility and agency are also key characteristics of social systems that will adapt to climate change (Cinner et al. 2018). Likewise, psychosocial attributes are emerging as key to understand adaptation outcomes. For example, an individual may fail to adapt due to a low perception of personal risk despite an understanding of generic risk (Mortreux and Barnett 2017). Trust in institutions is another characteristic that affects adaptation (Stern and Coleman 2015), with lack of adaptation at both ends of the trust spectrum in some contexts; high levels of trust can lead to complacency and lack of personal initiative in the face of disaster, while low levels of trust can result in lack of compliance with the advice of authorities (Mortreux and Barnett 2017).

Fishing communities are vulnerable to climate change due to their proximity to coastal hazards and their natural resource dependence (Stedman et al. 2004; Adger et al. 2005; Barange et al. 2014). Adaptive capacity in fishing communities is highly linked to flexibility, with the relative reliance on fisheries, degree of diversification within the fishery, and the ability to change fishing strategy a strong predictor of a community's ability to adapt (Finkbeiner 2015; Belhabib et al. 2016). Personal traits, including ability to engage with decision making and knowledge of climate change also can improve the ability to adapt to in times of crisis (Cinner et al. 2015; Finkbeiner 2015). However, the role of psychosocial factors—such as risk perception and trust in institutions—in climate adaptation in fishing communities is only beginning to be understood. Here, we use the lobster fishery of Maine to examine the ways in which adaptation is linked to risk perception, views of human agency in the SES, and trust in institutions. Our work builds on previous research that strives to understand the relationship between adaptive capacity and adaptation outcomes at the individual and community level (e.g., Marshall and Marshall 2007; Mortreux and Barnett 2017).

Maine's lobster fishery

Lobster fishing communities in coastal Maine have a high degree of exposure to climate change due to rapid warming in the Gulf of Maine (GoM) (Mills et al. 2013; Le Bris et al. 2018). Lobster populations are susceptible to warmer water temperatures. In particular, increased water temperature is associated with northward and offshore migration of lobster (Wahle et al. 2013; Wahle et al. 2015). Increased incidence of episodic shell disease, a bacterial infection that weakens lobsters' immune systems, may also be associated with warming waters (Tlusty and Metzler 2012; Shields 2013). Warming waters have also been shown to decrease survival and size at maturity of developing lobsters, which ultimately may decease overall fecundity (Waller et al. 2017).

The vulnerability of the lobster fishery to climate change is compounded by a low degree of diversity within GoM fisheries. Historically, Atlantic cod (*Gadus morhua*) and other large predatory groundfish diversified the region's fishing economy (Rosenberg et al. 2005), but lobster (*Homarus americanus*) comprises 80% of the value of modern Maine fisheries (Steneck et al. 2011). Lobster populations in the GoM are considered stable and well managed, with steady increases in landings since the late 1980s. However, the lack of diversity in Maine's fisheries and high investment in the lobster fishery leaves coastal fishing communities highly vulnerable to perturbations (Steneck et al. 2011). With vulnerability due to warming waters and single resource dependence, and reduced resilience as a consequence of degradation to the GoM marine ecosystem, understanding the factors that affect adaptive capacity of Maine's lobster fishery will be critical.

The strong history of co-management and informal social organization within the lobster fishery would suggest that this fishery has a number of key attributes important to adaptation. In particular, strong social networks exist at the state, regional, and local level (Waring and Acheson 2018). The inshore fishery is managed by the Maine Department of Marine Resources, which shares management responsibility with seven spatially defined Zone Councils that have democratic structure and limited autonomy. These councils are credited for improving conservation, for example, by setting trap limits and limited entry rules that are more restrictive than those mandated by the state (Waring and Acheson 2018). Successful co-management relies on trust, institutional structures for conflict resolution, the existence of bridging organizations, and strong leadership (Berkes 2009); these same traits are important in building adaptive capacity (Cinner et al. 2018). The lobster fishery has been identified as a global example of co-management success (Dietz et al. 2003), though its resilience to perturbations such as price shocks has been recently questioned (Henry and Johnson 2015). In addition, strong social structure exists at the local level in the forms of lobster "gangs," or informal groupings of 8–50 boats that collectively defend a territory defined by geographic features, such as a bay (Acheson 2003). Both the competition among and the collective decision-making within groups indicate strong social organization at the local level (Wilson et al. 2007; Waring and Acheson 2018). Social networks such as these that promote information exchange can help fisheries adapt to changing conditions (Cinner et al. 2018).

MATERIALS AND METHODS

We investigated the adaptive capacity of fisheries threatened by rapid climate change, using the Maine lobster fishery as a case study. Specifically, we conducted in-depth interviews with Maine lobster fishers to determine their views on the effects of warming on lobsters and whether they perceive the need to adapt to changes brought by warming oceans. To contextualize climate change among other drivers of change in the lobster fishery, we couple our in-depth, qualitative interviews with semi-quantitative "mental models." Mental models are personal, internal representations of external reality, and are used to describe and quantitate perceived relationships within complex systems (Gray et al. 2013; Gray et al. 2015). The results of these in-depth interviews and mental models provide insight into the overall adaptive capacity of GoM lobster fisheries.

In-depth interviews

Our research focused on active Maine lobster fishers, with the goal of interviewing across a broad range of backgrounds and experiences. Interviewees were identified through organizations involved in the Maine lobster industry such as the Maine Lobstermen's Association. We then used the chain referral or "snowball sampling" method where each participant was asked to identify additional potential interviewees (Biernacki and Waldorf 1981). Interviews were conducted in person and were audio recorded for later transcription and analysis.

The semistructured interviews focused on observations and adaptive capacity to changes in the lobster fishery. We asked specifically if interviewees had observed changes throughout their careers in water temperatures, lobster populations or dynamics, or other species within the GoM. For any change identified, we asked why they thought observed changes were happening and if they perceived changes as having a current or future impact on lobster fisheries. To understand better if fishers plan to adapt to future climate-driven disturbances, we asked if they thought that water temperature would impact the lobster industry or their personal fishing practices, and if they had plans to alter their practices in response to these changes. Finally, we asked about long-term future changes to the GoM lobster industry, including how lobster fishers thought the industry would change in the next century and what they thought would be the main drivers of change to the industry.

All of the questions described above were open-ended and aimed at allowing interviewees to describe change in their own words. In addition, we asked respondents to rank their agreements with the statements "I am concerned about climate change," and "I feel that I can influence the fisheries management process," "I trust fisheries managers," and "I trust other commercial fishermen." Finally, we collected demographic data on fishers including their age, reliance on the fishery, and years of experience.

Mental models

In addition to these interview questions, we used fuzzy-logic cognitive mapping (FCM) to construct mental models on how lobster fishers perceive relationships among lobster populations, human drivers, and other components of the environment. Following the methodology of Özesmi and Özesmi (2004), our multistep mental model approach aimed to draw individual cognitive maps of causative relationships in the lobster fishery. Mental models were presented prior to questions about climate change to avoid biasing results.

All 43 interviewees were asked questions related to our mental modeling approach. The first 20 of these interviewees were asked to identify or "freely associate" concepts that related to the lobster fishery SES (Fig. 1) (Gray et al. 2013). When the rate of new concept identification plateaued (Fig. 2), we then condensed the identified key concepts, and conducted a second set of 23 interviews using standardized concepts. During this second set of interviews, participants were asked a series of pairwise questions to identify potential positive or negative causal relationships between all concepts and ascribe semiquantitative edge weights ("low" = ± .33, "medium" = ± .66, "high" = ± 1). Maps were considered finalized after the full set of pairwise questions were completed and the participant was satisfied with the resulting map.

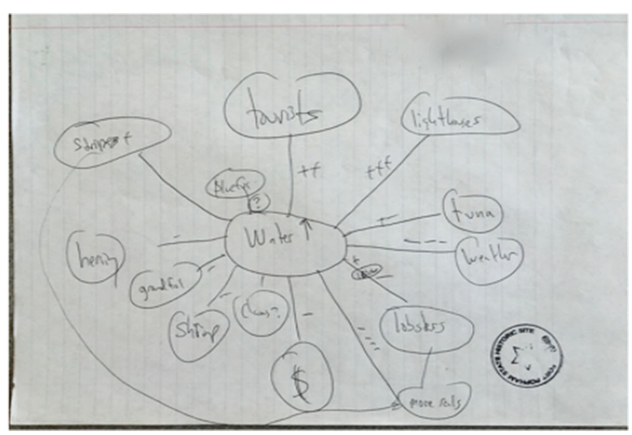

Fig. 1 Example of a hand-drawn individual mental model. In the first phase of our interviews, lobster fishers were asked to free associate important components of the lobster fishery, the relationship among those components, and the strength of each relationship. These concepts were then used to standardize the mental modeler interview questions

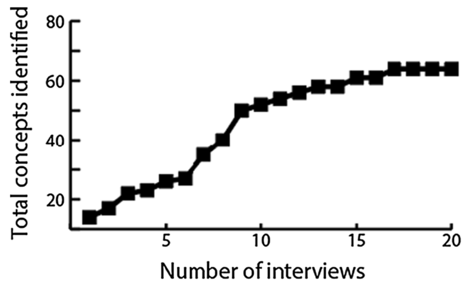

Fig. 2 Concept accumulation curve of key concepts. The eight most frequently cited concepts were used in the structured mental model interviews

To visualize and analyze the mental models, we used the online program Mental Modeler (www.mentalmodeler.org; Gray et al. 2013). We limited our structural analyses to 23 interviews involving standardized concepts. We conducted these analyses on both individual models and a "community model" produced by averaging individual models (Özesmi and Özesmi 2004). One structural metric useful in interpreting mental models is centrality, which represents the relative importance of an individual concept to the overall system. For individual concepts, centrality can be separated into "indegree" and "outdegree" components. Both types are calculated by adding the absolute values of edge weights; indegree therefore represents the relative number and strength of factors that affect a given variable, while outdegree represents the relative effect of one variable on all the others. Centrality can be used to evaluate how important a given variable is within a mental model, and therefore, within the greater system that is being depicted.

RESULTS

We interviewed 43 fishers in 23 different towns along the coast of Maine between October 2015 and October 2018. The age of interviewees ranged from 17 to 85 years old with a mean age of 47. The number of years of fishing experience ranged from 1 to 78 with a mean of 27. Both male ($n = 35$) and female ($n = 8$) fishers were interviewed. The majority of interviewees received 100% of their personal income from the lobster fishery, with a mean of 83% of income derived from the lobster fishery. The mean age of Maine lobster fishers is 50 years old (Johnson and Mazur 2018), with an average of 31 years of experience (Singer and Holland 2008), both similar to our interviewee pool. One recognized difference in our sample was reflected by the 19% of female fishers in our sample compared to the estimated 4% statewide (Waring and Acheson 2018). There were no demographic differences between the initial 20 interviews (used to generate key concepts) and second set of 23 structured interviews that applied those key concepts in a structured mental modeling framework.

Lobster fishers perceive warming waters, but many do not plan to adapt

Our results indicate that the majority of lobster fishers are aware of the effects of temperature-driven changes to Maine's lobster fishery. Of our 43 respondents, 84% reported having observed temperature changes in the GoM, and 84% believed that warming waters will affect the industry. However, only 67% thought that warming waters would affect them personally, and 51% had plans to adapt (Fig. 3). Stated adaptation plans included diversifying fishing and increasing the numbers of licenses for different fisheries, supplementing income with non-fishing activities, changing gear use (e.g., boats, traps), location, or timing, and becoming more involved in fisheries management and local politics.

Age was a significant factor in fishers' perceptions of the personal threat of warming waters and plans to adapt. While fishers of all ages largely agreed that waters were warming, those who reported that warming waters would affect them personally were significantly younger (mean 42 years) than those who did not (mean 56 years; ($t(40)2.19$, $p = 0.02$). Fishers with stated plans to adapt were also younger (mean 43 years) than those who did not (mean 54 years; ($t(37)2.00$, $p = 0.03$).

An ecosystem view: Displaced effort and the potential for emergent fisheries

Lobster fishers viewed changes to the fishery within the context of ecosystem change, perceiving both positive and negative effects of this change on the lobster fishery. Collectively, lobster fishers identified 39 species as declining in abundance over their fishing careers, with eight identified as declining due to warming waters (Table 1). The majority of species' declines were linked to increased fishing effort, and the effects of ecosystem-wide overfishing were viewed as having a spillover effect into the lobster fishery. Specifically, declines in other species

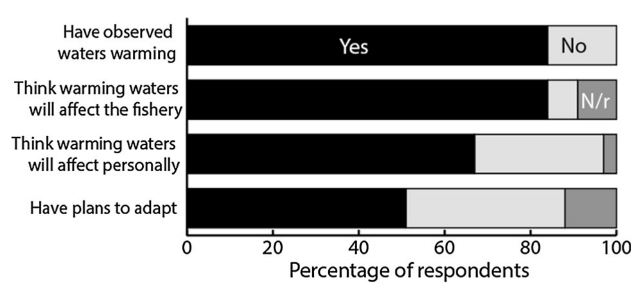

Fig. 3 Warming waters' perceived effects on the lobster fishery. Percentage of respondents who report having observed temperature-driven changes in the Gulf of Maine; that warming waters will affect the lobster fishery; that warming waters will affect them personally; and that they have plans to adapt to these changes. N/r = 'no response'

Table 1 An ecosystem view: A subset of the species fishers observed to increase or decrease. The percentage of respondents indicating that the species has been depleted or had increased over the course of their careers; indication that depletions or increases were linked to warming waters; that depletions have negatively impacted lobster fishery; and that increases had the potential to benefit local fisheries. Table is limited to species either noted by three or more respondents, or that at least one respondent noted as linked to warm water or impact on lobster fishery

Species	Decrease noted (%)	Linked to warm water	Impacts lobster fishery
Atlantic cod	2	Yes	
Green urchin	2		Yes
Atlantic wolffish	2	Yes	Yes
Northern shrimp	2	Yes	Yes
Haddock	5	Yes	
Atlantic menhaden	5		Yes
Silver hake	5	Yes	Yes
Bluefish	5		Yes
Atlantic mackerel	7		
Pollock	7		
Atlantic herring	7		Yes
Rock crab	7		Yes
Striped bass	7	Yes	
Sculpin	7	Yes	
Dogfish	9		Yes
American plaice	9		Yes
Atlantic salmon	14		Yes
Lamprey eels	21	Yes	
Winter flounder	23		Yes
Species	**Increase noted (%)**	**Linked to warm water**	**Potential to benefit fisheries**
Black sea bass	30	Yes	Yes
Green crabs	30	Yes	
American lobster	28	Yes	Yes
Seaweed/Kelp	16	Yes	
Barnacles	7	Yes	Yes
Bluefish	7		
Gray seals	7		
American plaice	5	Yes	Yes
Jellyfish	5	Yes	Yes
Asian shorecrabs	5		Yes
Atlantic menhaden	5		Yes
Atlantic cod	5		Yes
Gray triggerfish	5	Yes	
Blue crab	2	Yes	Yes
Squid	2	Yes	Yes
Seahorse	2	Yes	
Octopus	2	Yes	

(e.g., northern shrimp (*Pandalus borealis*), menhaden (*Brevoortia tyrannus*), and haddock (*Melanogrammus aeglefinus*) were described as increasing pressure in the lobster fishery, as displaced fishers attempted to enter the lobster fishery. Lobster fishers described the effects of increased fishing pressure in terms of declines in their personal profit and individual lobster catches. One fisher stated, "the piece of the pie has gotten smaller," and another described the effort as doubling or tripling in their zone. Respondents were keenly aware of the lack of diversity in Maine's fisheries, with one respondent describing lobstering as "the only thing left to do."

Lobster fishers also reported increases in abundance of certain species in the GoM. Collectively, 35 species were identified as increasing in abundance; 12 of these increases were linked to warming waters, including lobster and black sea bass (*Centropristis striata*). Interviewees expressed cautious optimism about the potential for emergent fisheries as the ranges of more southerly species shift north. Fishers viewed increases in species like squid (*Doryteuthis pealeii*), green crabs (*Carcinus maenas*), and black sea bass as having the potential to be developed into commercial fisheries locally, augmenting or replacing fisheries in decline. However, lobster fishers were reserved in their enthusiasm about emergent fisheries offering opportunities for diversification. One stated that he believed that the current conditions in the GoM are not yet suitable for warmer-water species. Another thought it might be possible to switch species but expressed concern about whether the population size of new species could support a commercial fishery. In addition, population increases in species such as black sea bass were viewed as potential threats to native species, with some lobstermen concerned that sea bass would increase predation pressure on juvenile lobsters. One interviewee stated, "The black sea bass are now going to come in and take the place of the codfish …I don't think it's a good thing."

Mental models of the Maine lobster fishery

In total, respondents identified 64 key concepts associated with the lobster fishery (Fig. 2), with the number of new concepts diminishing over time. Of the 64 identified concepts, we selected the eight most frequently cited to use in the structured interviews. These were lobster populations, predator populations, prey populations, habitat, warming coastal waters, pollution, commercial fisheries, and management actions. For three of these (predator, prey, and habitat), respondents were asked to identify the most important predator, prey and habitat for lobster, which allowed for some variation in responses.

Table 2 Mean centrality values. Outward centrality indicates driving concepts, while inward centrality indicates receiving concepts

Concept	Mean centrality	Outdegree	Indegree
Lobster populations	4.36	1.29	3.08
Commercial fisheries	4.19	1.20	2.99
Pollution	3.50	3.44	0.06
Predator	2.83	0.85	1.98
Prey	2.83	1.33	1.50
Habitat	2.65	1.10	1.55
Management actions	2.50	1.51	0.98
Warming coastal water	1.48	1.45	0.03

Drivers of change

Centrality values in the averaged community model revealed the components of the system, which were perceived to be the most common and significant drivers of change (Table 2, Fig. 4). Overall, centrality demonstrates the prevalence and relative importance of each variable. Of the eight concepts, lobster populations unsurprisingly ranked the highest (4.36); warming coastal waters ranked the lowest (1.48), due to the fact that the indegree value was almost always 0. The concepts with the highest indegree values were lobster (3.08), commercial fisheries (2.99), and predator populations (1.98), meaning that these components of the system are perceived to be the most affected by cumulative impact of the other concepts. In contrast, fishers perceive pollution to be the most significant driving concept (3.44), followed by management actions (1.51), and warming waters (1.45). For each of the top three identified drivers, we use information from the in-depth interviews to further explore perceived relationships.

Pollution

Pollution was identified as the most significant driver in the lobster fishery, with the highest overall outgoing centrality value. Pollution was perceived as having negative impacts on lobster populations, predator populations, prey populations, habitat, and commercial fisheries (Fig. 4). The perceived effect of pollution on lobster populations was strongly negative (− 0.65); several respondents ranked it as having the highest possible impact (− 1.0). However, our in-depth interviews revealed that fishers defined the term "pollution" broadly. For example, one lobster fisher

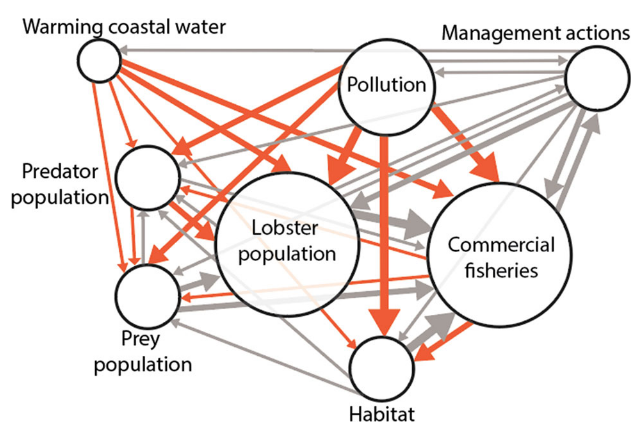

Fig. 4 The community model. A mental model showing the eight key concepts and their average relationships as expressed by lobster fishers. The size of the circle represents the overall centrality of that concept (See Table 2 for specific values); the width of each line indicates the relative strength. Positive relationships are indicated with a gray line arrow, while negative ones are indicated with a red line arrow

cited the potential for a decommissioned nuclear power plant near his home to leak, while others linked epizootic shell disease to local wastewater treatment plants. When discussing the potential effects of pollution in Maine, fishers frequently referenced other areas where lobster populations have recently crashed, such as Narragansett Bay and Long Island Sound. One said, "I think that [the population crash] had a lot to do with spray and runoff. I bet it could happen here." The effects of insecticides were commonly mentioned. Another fisher said, "They sprayed pesticides on the mosquitoes and the pesticides directly affected the lobster larvae [in Narragansett Bay]." Declines in southern lobster populations were also linked to "trash barge pollution" and a general view of degraded waters. However, some respondents pointed out key differences between Maine's oceanographic conditions and those farther south, such as one who said, "Long Island had a problem with fertilizer and its very contained so it's not comparable to the big open water we have here. There is just more water moving around." Therefore, despite the high outgoing centrality value for pollution in the mental models, the in-depth interviews indicate that respondents may consider pollution as a potential impact based on their perceptions of drivers in other locations.

Management

Management was identified as the second greatest perceived driver of change in the lobster fishery, with positive impacts on all other components of the system (Fig. 4). The mean effect of management on lobster populations was 0.51, or moderately positive; the majority (78%) of interviewees indicated that management had a positive impact on lobster populations. In the in-depth interviewees, one fisher said, "Maine's always managed their lobster fishery in a way that watched out for the resource." Maintaining limited entry laws was cited as key to success: "If I had my way it wouldn't change one bit… Licenses should never be able to be sold. Maintain a steady number of traps. Catch laws, and all the conservation laws are all paying off today, which is why we're seeing the lobster fishery doing what it's doing." Notably, fishers perceived a positive interaction between management actions and commercial fisheries, with each perceived as having a positive effect on the other (Fig. 4).

Despite these positive results, some fishers indicated frustration with the management process: 13% indicated that management had a negative impact on lobster populations, and 9% indicated the relationship was neutral. In the in-depth interviews, fishers confirmed these disparate views. Negative descriptions often focused on management failures in other fisheries, including groundfish and shrimp, blaming policy decisions for overfishing, with subsequent increased pressures on the lobster fishery. Respondents with a negative view of management consistently stated that management agencies were to blame for encouraging more effort in the lobster fishery. As one respondent said, "The lobstering field cannot take any more effort, but they're still encouraging too many students to go through the courses." Corresponding to this mixed view of management, two-thirds (66%) agreed that they were able to influence decisions made by fisheries managers, but the majority (62%) also stated that they did not trust managers. Levels of trust for fisheries managers were significantly lower than trust for other commercial fishers, with only 14% of fishers stating that they did not trust fellow commercial fishers. However, on the whole, our interviews reveal largely positive views of management among Maine lobster fishers.

Warming waters

Warming coastal waters were identified as the third most important driver in the lobster fishery. The average coefficient for the effect of warming waters on lobster populations was − 0.36, but like management actions, respondents were split on whether warming waters had a positive or negative impact on lobster populations. While the majority (61%) indicated a negative interaction, 22% viewed warming waters as having a positive effect and 17% indicated neutral effect on lobsters. In addition to the effect on lobsters, on average, fishers viewed warming waters as detrimental for commercial fisheries (− 0.39), predators (− 0.28), prey (− 0.19), and habitat (− 0.23) (Fig. 4).

The in-depth interviews confirmed the majority view that warming waters would be detrimental to lobsters, but expressed the opinion that warming waters to date have been favorable. According to one respondent, "If the water continues to warm at the rate, it will go from a very positive impact to a very negative one." These impacts include geographic shifts and increased disease. As one respondent said, "[increased ocean temperature] would probably be negative. That's what makes us unique—our cold water. Too warm and whole ecosystem's going to move north." Another said, "If it gets warm enough then the lobsters are going to leave. They will seek much deeper water or head north." The same respondent highlighted the potential impact of shell disease at warmer temperatures: "Warmer water is a more favorable environment for bacteria. There's generally more stress on the animal." Another respondent expressed concern with how warming waters might allow more new species to take hold in the GoM: "[Other species moving in] would be a negative in my book. I don't want invasives. I want to keep [the GoM] the way it has been for years." Despite these concerns, some respondents expressed an equivocal view: “There may be losers and there may be winners. Maybe we’ll all be jellyfishing.”

Despite concerns for the effects of future warming, respondents expressed optimism for two reasons. First, they believed that the timeframe of negative impacts is too far in the future to be of consequence. One said, “It’s going to be a long time…” while another said “We’re looking at this in too small scale—it has to be over 500 years to make a difference.” The second, commonly expressed reason for optimism was the view that water temperatures are cyclical and driven by natural cycles, and therefore, would not continue to increase in the future. One respondent explained his hesitancy to attribute changes in water temperature to humans by saying, “it fluctuates every year.” Natural cycles were linked to year-to-year changes in species migration patterns (lobster, bluefish, herring), and population size (lobster, striped bass, eelgrass), ontogenetic changes such as lobster molting (shedding), and shell disease. The perspective that these changes occur primarily through natural cycles was linked to the belief that the GoM is a resilient ecosystem. One respondent said, “The GoM is lucky, it’s resilient, because look at the currents. The Labrador current that comes down we’ve got that natural cold water… We’ve got that little safety net there.” References to natural cycles were often tied to the belief that current changes in GoM ecosystems had the potential to reverse in the future, with one lobsterman saying, “there is a historical peaks and valleys.”

A natural or aquaculture system?

One key pattern that the mental models revealed was the degree to which lobster fishers viewed the abundance of lobsters as primarily controlled by natural ecological interactions, or by the fishers themselves. One quarter (26%) of respondents identified the most important predator and prey of lobster naturally occurring components of the GoM ecosystem. These respondents listed groundfish or seals as the most important predator of lobsters, and mollusks, crustaceans, bottom fish, or dead fish as their most important prey, and believed that changes to other species had impacted lobster populations. For example, according to one, “There’s been a big increase in the number of lobsters caught. It’s got to be something to do with the codfish. There are less predators.” The same respondent also suggested that the overfishing of sea urchins might be helping with lobster success: “Kelp is coming back which is good for the lobsters [as habitat]. [Kelp is coming back] because the urchins are getting overfished.”

In contrast, the majority of fishers believed that the lobster fishery is completely or partially domesticated, with humans dominating the dynamics of the lobster population. Half of respondents (48%) had a “partial aquaculture” view of the fishery, listing a marine animal as the most important predator, but bait from lobster traps as the most important food source of lobster. The remaining quarter of respondents (26%) identified humans as the most important predator and bait as the most important food source of lobster, suggesting that the current lobster fishery functions much like an aquaculture system. Across these respondents, the role of bait in growing the population of lobsters was consistently highlighted. According to one “When I was a kid, we used bait bags the size of my fist. Now my bait bag is the size of a basketball…It’s an aquaculture setting. We’re training them.” These two groups did not differ significantly in terms of demographics, support for management, agreement about the effects of warming, or optimism for the future.

When the average mental models were compared for respondents with a natural-system view and those with an aquaculture or partial aquaculture view, key differences emerged. First, “aquaculture” models indicated that prey was a more significant driver of lobster populations than that of natural-system models (0.62 vs. 0.28). Conversely, the effects of warming waters on lobsters were reduced in the aquaculture model ($-$ 0.29 vs. $-$ 0.61), and management actions were less impactful across all seven other variables than in the natural-system model.

The lobster fishery in 100 years

Lobster fishers diverged on their degree of optimism about the future of the industry. Only 8% of respondents expressed pure optimism for the future, saying that they thought the changes to the GoM would be good for fishers. Notably, these respondents were significantly older than those who expressed neutral or negative views with a mean age of 67 years ($t(35) = -2.03$, $p = 0.03$). More than half (59%) expressed pessimism, saying that they thought changes were bad for fishers, and 32% expressed a neutral view. However, most (66%) said that they thought the lobster industry would exist in some form in 100 years; 14% said they thought it would not exist, and the remainder said they did not know. One of those who said that the fishery would not exist expanded on this view, saying “[We] won’t be doing it at all. I doubt it. And I don’t even know as if it’ll take that long…. There’s no groundfishing fleet here in Maine anymore. Eventually lobster will get taken down.” Another said, “I’d give the [Maine lobster fishery] 7–10 more years in Southern Maine and 20–25 years for until the whole state’s lobster industry crashes.” Those with more optimistic views of the future referred back to their earlier views of natural fluctuations, such as one who said, “as long as there is an ocean there will be lobsters. Like I always say there will be good years and there will be years that aren't as good." Another said, "Barring a natural disaster, you're not going to be able to catch" all the lobsters.

Optimism was due also to views that advancements in technology would alleviate the effects of ecological change. Technological advancements came in two forms. The first was larger and more boats. One respondent said, "I don't think I'd recognize it, I think all the boats will be huge and they'll be fishing offshore." Another said, "I think we'll always fish for lobster. I think you're going to find with equipment, with electronics, it'll be a lot more streamlined." The other form of technology had to do with aquaculture, and a view that the already domesticated GoM would move farther in that direction in the future. One said that in one hundred years, "You wonder if they will all even be doing it at that point. If it will be like a farm type thing." Another said, "Probably by then everything will be farm raised, lobsters included" and a third said, "To a certain degree it has to progress a little bit toward aquaculture." This view of the future echoes the view of the current lobster fishery as partially or completely domesticated.

Differences among fishers with plans to adapt

We identified key differences between the fishers who indicated that they planned to adapt to warming waters compared to those who said they did not. First, those that planned to adapt were more worried about climate change; 77% expressed concern compared to 14% among fishers who did not have plans to adapt. The results of the mental models confirmed that those with plans to adapt viewed warming waters as more of a system-wide threat. Fishers with plans to adapt responded that warming waters negatively impacted the lobster fishery—and all of the other relevant variables (predators, prey, habitat, and commercial fisheries)—to a greater degree than those with no plans to adapt; their additive mean value was -2.33, compared to -0.17 for the fishers with no plans. Those with plans to adapt also expressed greater concern about pollution, expressing greater negative impact of pollution across all relevant variables (lobster, predators, prey, habitat, and commercial fisheries).

There were also differences in how those with plans to adapt viewed the degree of human influence over the lobster fishery and its management. Fishers with plans to adapt more frequently had an artificial "aquaculture" view of the fishery, with half of these fishers listing humans as the most important lobster predator. In contrast, those who did not plan to adapt expressed natural or partial aquaculture views; no member of this group listed humans as key lobster predators. Finally, those with plans to adapt expressed a greater confidence that they were able to influence management decisions, with 85% responding affirmatively to the statement "I feel that I am able to influence decisions made by fisheries managers," compared to 29% of those who were not planning to adapt. Taken together, our results suggest that those with plans to adapt have a fundamentally different view human agency in this system, observing greater anthropogenic threats in the form of climate change and pollution, but also a greater ability to control the lobster fishery through their own actions on the water and through fisheries management decision making.

DISCUSSION

Understanding overall and specific risks of climate change is key to predicting when individuals and groups deploy their resources to adapt to climate change (Marshall and Marshall 2007; Marshall et al. 2007; Mortreux and Barnett 2017). In the Maine lobster fishery, we found consensus among fishers that waters have warmed, and that continued warming waters will negatively affect the industry. However, fewer believed that this warming would affect them personally and even fewer had stated plans to adapt. Some of these differences can be explained by age, but they may also reflect what Mortreux and Barnett (2017) call optimism bias: the cognitive process in which people underestimate the likelihood of negative events affecting them personally, and therefore do not protect themselves. In addition, there was disagreement about the causes of warming water, with many fishers pointing to natural cycles rather than anthropogenic climate change, and indicating a belief that waters would cool again in the future. This viewpoint may be founded on historical events, such as warming and cooling periods that occurred between 1945 and 1960 (McClenachan et al. in review). Our finding that fishers with plans to adapt had a fundamentally different view of human agency in the lobster SES agrees with predictions from previous studies that psychosocial elements are essential to understand adaptation outcomes (Mortreux and Barnett 2017).

Our results suggest that adaptation outcomes may differ widely among individuals in the Maine lobster fishery, with those who view themselves as having agency taking adaptive action while others do not. Those fishers who had stated plans to adapt described adaptation strategies that have been found to be successful in other locations, including diversifying income streams, changing gear use and becoming more involved with fisheries management. Such stated plans demonstrate a flexibility and commitment to building social institutions in a manner that is predictive of successful adaptation (Cinner et al. 2018). It may also be the case that the strong sense of community within and competition among groups of lobster fishers and the social organization that exists at the local and regional level (Acheson 2003; Wilson et al. 2007; Waring and Acheson 2018) will result in information sharing that leads to broader climate adaptation. For example, many lobster fishers have invested in larger boats, which is a way of adapting to temperature-driven movements of lobster offshore.

A lack of prioritization of the effects of warming waters may also be related to the more complex view that fishers expressed about social and ecological change within GoM fisheries. In particular, fishers indicated that the history of mismanagement and overfishing in the GoM had direct impacts on their own industry, with fishing effort from other collapsed fisheries displaced into the lobster fishery. These collapses may have also had had indirect impacts in the lobster fishery, through an erosion of trust in the management process. The relative lack of trust that we found within the lobster fishery in management is surprising given the lobster fishery's reputation as a pinnacle of co-management success (Dietz et al. 2003). Our interview results suggest that this may be a consequence of living in the shadow of the groundfish fishery. The lack of trust in the cod fishery is well known (Kaplan and McCay 2004; Acheson 2011; Acheson and Gardner 2014); respondents indicated that they feared similar processes have been contaminating their own fishery. Thus, these results suggest that the negative outlook on fisheries management in collapsed fisheries may be contagious, such that fishers in neighboring fisheries become negative about the management process because of eroded trust in management more generally.

Lobster fishers may be adapting to this regionwide ecological and social change by embracing a highly domesticated lobster fishery. Our analyses of mental models revealed that the majority of lobster fishers viewed the lobster fishery as an aquaculture system, acknowledging that overfishing had removed lobsters' natural predators, and that fishers fed lobsters with baited traps. In fact, the subsidy provided by baited traps has been shown to be substantial, estimated at up to 15% of fisheries productivity (Grabowski et al. 2010). Notably, the perception of the lobster fishery as an aquaculture system affected fishers' beliefs about other drivers of change. In particular, those who viewed the system as highly domesticated believed that that warming waters had less of an impact on lobster populations. This finding suggests that the domestication of the lobster fishery may in itself be viewed a form of climate change adaptation, as fishers attempt to buffer their industry from change by controlling the production of lobsters. In addition, the interviews revealed that many fishers think the fishery will still exist in 100 years with the help of increased technology and a further movement toward aquaculture. Therefore, embracing and perpetuating the current state may be one way that fishers are adapting to future change. This can also be seen in the lack of buy-in among lobster fishers to promoting the recovery of groundfish. On the other hand, embracing this form of adaptation may be an example of maladaption, or adaptation in a way that acts to erode system resilience (Criddle 2012).

The views expressed by Maine lobster fishers underscore the need to understand fishers' perception and knowledge in fisheries management (Johannes et al. 2000). Fishers' daily first-hand view of change on the water means that their observations are key to perceiving change (Drew 2005; Silvano and Valbo-Jørgensen 2008). Maine lobster fishers have observed warm water species like black sea bass, which have been reported as potential replacements for declining landing in other fisheries (e.g., Trotter 2018). At the same time, we found that lobster fishers' views of long-term change and ecological interactions complicate a potential transition from lobster to new target species like black sea bass, with some considering increases in any predator a threat to the highly simplified ecological system that has allowed lobster to thrive. Understanding such perceptions and values is important in facilitating any transition to a more diverse fishery (Cinner et al. 2018). Finally, our results underscore the need to understand the views of fishers with regard to the management process. While the Maine fishery is looked to as a model of co-management success, we found fishers view the management of the lobster fishery differently, with nearly 70% of respondents lacking trust in fisheries managers. Henry and Johnson (2015) similarly reported dissatisfaction among fishers with the management process, suggesting that the rigidity of the institutional framework inhibits resilience. However, also we found that trust for fellow fishers was high, suggesting that the informal social institutions that have promoted conservation ethic in the fishery are still strong. Any adaptation to change will require understanding the importance of fishers' knowledge and perceptions, from sensing change to sharing knowledge about the best ways to adapt to that change.

Taken as a whole, our results reveal the complexity of adaptive capacity to climate change. We found that agreement over drivers of change is low. In addition, the consequences of ecological degradation and the collapse of other fishery in the GoM have included greater insularity within the lobster fishery, with lobster fishers worried about displaced effort and cynical about the potential for management failure. The view of the lobster fishery as nearly entirely ecologically self-contained, with humans acting as both predator and provider of prey, may ultimately reduce adaptive capacity, with the panacea of technology and further domestication replacing a more holistic view of ecosystem recovery. However, it also appears that fishers with stated plans to adapt have more concern about anthropogenic threats and also describe a greater engagement with the management process, which may be important in instigating community level adaption (Barnes-Mauthe et al. 2013; Cinner et al. 2015). Therefore, community level adaptation may hinge on these individuals with a greater than average engagement with the management process, elevated concern about climate change, and stated plans to adapt, providing some optimism for future adaptation to climate change.

Acknowledgements This research was supported by the NOAA Climate Program Office (Grant #NA15OAR4310135) and the Colby College Environmental Studies Program. The authors would like to thank Colby College students Ryan Clemens, Katie Chicojay, Clea Harrelson, Robin Lewis, Sara LoTemplio, Ella McDonald, Juila Nelson, Barlow Peelle, Tucker Plante, Joshua Reed, Kaya Williams, Emma Wood, and Olivia Wright for their help with data collection and analysis.

REFERENCES

Acheson, J.M. 2003. *Capturing the commons: Devising institutions to manage the maine lobster industry*. Hanover: University Press of New England.

Acheson, J., and R. Gardner. 2014. Fishing failure and success in the Gulf of Maine: lobster and groundfish management. *Maritime Studies* 13: 8. https://doi.org/10.1186/2212-9790-13-8.

Acheson, J. 2011. Coming up empty: Management failure of the New England groundfishery. *Maritime Studies* 10: 57–86.

Adger, W.N. 2009. Social capital, collective action, and adaptation to climate change. *Economic Geography* 79: 387–404. https://doi.org/10.1111/j.1944-8287.2003.tb00220.x.

Adger, W.N., and K. Vincent. 2005. Uncertainty in adaptive capacity. *Comptes Rendus—Geoscience* 337: 399–410. https://doi.org/10.1016/j.crte.2004.11.004.

Adger, W.N., T.P. Hughes, C. Folke, S.R. Carpenter, and J. Rockström. 2005. Social-ecological resilience to coastal disasters. *Science* 309: 1036–1039. https://doi.org/10.1126/science.1112122.

Barange, M., G. Merino, J.L. Blanchard, J. Scholtens, J. Harle, E.H. Allison, J.I. Allen, J. Holt, et al. 2014. Impacts of climate change on marine ecosystem production in societies dependent on fisheries. *Nature Climate Change* 4: 211–216. https://doi.org/10.1038/nclimate2119.

Barnes-Mauthe, M., S. Arita, S.D. Allen, S.A. Gray, and P.S. Leung. 2013. The influence of ethnic diversity on social network structure in a common-pool resource system: Implications for collaborative management. *Ecology and Society*. https://doi.org/10.5751/ES-05295-180123.

Belhabib, D., V.W.Y. Lam, and W.W.L. Cheung. 2016. Overview of West African fisheries under climate change: Impacts, vulnerabilities and adaptive responses of the artisanal and industrial sectors. *Marine Policy* 71: 15–28. https://doi.org/10.1016/j.marpol.2016.05.009.

Berkes, F. 2009. Evolution of co-management: Role of knowledge generation, bridging organizations and social learning. *Journal of Environmental Management*. https://doi.org/10.1016/j.jenvman.2008.12.001.

Biernacki, P., and D. Waldorf. 1981. Snowball sampling: Problems and techniques of chain referral sampling. *Sociological Methods & Research* 10: 141–163. https://doi.org/10.1177/004912418101000205.

Cinner, J.E., C. Huchery, C.C. Hicks, T.M. Daw, N. Marshall, A. Wamukota, and E.H. Allison. 2015. Changes in adaptive capacity of Kenyan fishing communities. *Nature Climate Change* 5: 872–876. https://doi.org/10.1038/nclimate2690.

Cinner, J.E., W.N. Adger, E.H. Allison, M.L. Barnes, K. Brown, P.J. Cohen, S. Gelcich, C.C. Hicks, et al. 2018. Building adaptive capacity to climate change in tropical coastal communities. *Nature Climate Change* 16: 293–303. https://doi.org/10.1038/s41558-017-0065-x.

Criddle, K.R. 2012. Adaptation and maladaptation: Factors that influence the resilience of four Alaskan fisheries governed by durable entitlements. *ICES Journal of Marine Science* 69: 1168–1179. https://doi.org/10.1093/icesjms/fss085.

Dietz, T., E. Ostrom, and P.C. Stern. 2003. The struggle to govern the commons. *Science* 302: 1907–1912. https://doi.org/10.1007/978-0-387-73412-5_40.

Drew, J.A. 2005. Use of traditional ecological knowledge in marine conservation. *Conservation Biology* 19: 1286–1293. https://doi.org/10.1016/j.joms.2015.09.014.

Engle, N.L. 2011. Adaptive capacity and its assessment. *Global Environmental Change* 21: 647–656. https://doi.org/10.1016/j.gloenvcha.2011.01.019.

Finkbeiner, E.M. 2015. The role of diversification in dynamic small-scale fisheries: Lessons from Baja California Sur, Mexico. *Global Environmental Change* 32: 139–152. https://doi.org/10.1016/j.gloenvcha.2015.03.009.

Folke, C., S. Carpenter, T. Elmqvist, L. Gunderson, C.S. Holling, and B. Walker. 2002. Resilience and sustainable development: Building adaptive capacity in a world of transformations. *Ambio* 31: 437–440. https://doi.org/10.1639/0044-7447(2002)031%5b0437:RASDBA%5d2.0.CO;2.

Folke, C. 2006. Resilience: The emergence of a perspective for social-ecological systems analyses. *Global Environmental Change* 16: 253–267. https://doi.org/10.1016/j.gloenvcha.2006.04.002.

Gallopín, G.C. 2006. Linkages between vulnerability, resilience, and adaptive capacity. *Global Environmental Change* 16: 293–303. https://doi.org/10.1016/j.gloenvcha.2006.02.004.

Grabowski, J.H., E.J. Clesceri, A.J. Baukus, J. Gaudette, M. Weber, and P.O. Yund. 2010. Use of herring bait to farm lobsters in the Gulf of Maine. *PLoS ONE* 5: e10188. https://doi.org/10.1371/journal.pone.0010188.

Gray, S. A., S. Gray, L. J. Cox, and S. Henly-Shepard. 2013. Mental Modeler: A fuzzy-logic cognitive mapping modeling tool for adaptive environmental management. In *Proceedings of the annual Hawaii international conference on system sciences*, 965–973. Wailea, Maui, HI. https://doi.org/10.1109/hicss.2013.399.

Gray, S.A., S. Gray, J.L. de Kok, A.E.R. Helfgott, B. O'Dwyer, R. Jordan, and A. Nyaki. 2015. Using fuzzy cognitive mapping as a participatory approach to analyze change, preferred states, and perceived resilience of social-ecological systems. *Ecology and Society* 20: 11. https://doi.org/10.5751/ES-07396-200211.

Henry, A.M., and T.R. Johnson. 2015. Understanding social resilience in the Maine lobster industry. *Marine and Coastal Fisheries* 1: 33–43. https://doi.org/10.1080/19425120.2014.984086.

Holling, C.S. 1973. Resilience and stability of ecological systems. *Annual Review of Ecology and Systematics* 4: 1–23. https://doi.org/10.1146/annurev.es.04.110173.000245.

Johannes, R.E., M.M.R. Freeman, and R.J. Hamilton. 2000. Ignore fishers' knowledge and miss the boat. *Fish and Fisheries* 1: 257–271. https://doi.org/10.1111/j.1467-2979.2000.00019.x.

Johnson, T.R., and M.D. Mazur. 2018. A mixed method approach to understanding the graying of Maine's lobster fleet. *Bulletin of Marine Science* 94: 1185–1199. https://doi.org/10.5343/bms.2017.1108.

Kaplan, I.M., and B.J. McCay. 2004. Cooperative research, co-management and the social dimension of fisheries science and management. *Marine Policy* 28: 257–258. https://doi.org/10.1016/j.marpol.2003.08.003.

Le Bris, A., K.E. Mills, R.A. Wahle, Y. Chen, M.A. Alexander, A.J. Allyn, J.G. Schuetz, J.D. Scott, et al. 2018. Climate vulnerability and resilience in the most valuable North American fishery. *Proceedings of the National Academy of Sciences* 115: 1831–1836. https://doi.org/10.1073/pnas.1711122115.

Marshall, N.A., and P.A. Marshall. 2007. Conceptualizing and operationalizing social resilience within commercial fisheries in northern Australia. *Ecology and Society*. https://doi.org/10.5751/es-01940-120101.

Marshall, N.A., D.M. Fenton, P.A. Marshall, and S.G. Sutton. 2007. How resource dependency can influence social resilience within a primary resource industry. *Rural Sociology* 72: 359–390. https://doi.org/10.1526/003601107781799254.

McClanahan, T.R., and J.E. Cinner. 2011. *Adapting to a changing environment: Confronting the consequences of climate change*. Oxford: Oxford University Press.

Mills, K., A. Pershing, C. Brown, Y. Chen, F.-S. Chiang, D.S. Holland, S. Lehuta, J.A. Nye, et al. 2013. Fisheries management in a changing climate: Lessons from the 2012 ocean heat wave in the northwest Atlantic. *Oceanography* 26: 191–195. https://doi.org/10.5670/oceanog.2010.11.COPYRIGHT.

Mortreux, C., and J. Barnett. 2017. Adaptive capacity: Exploring the research frontier. *Wiley Interdisciplinary Reviews: Climate Change* 8: 1–12. https://doi.org/10.1002/wcc.467.

Nelson, D.R., W.N. Adger, and K. Brown. 2007. Adaptation to environmental change: Contributions of a resilience framework. *Annual Review of Environment and Resources* 32: 395–419. https://doi.org/10.1146/annurev.energy.32.051807.090348.

Özesmi, U., and S. Özesmi. 2004. Ecological models based on people's knowledge: A multi-step fuzzy cognitive mapping approach. *Ecological Modeling* 176: 43–64.

Rosenberg, A.A., W.J. Bolster, K.E. Alexander, W.B. Leavenworth, A.B. Cooper, and M.G. McKenzie. 2005. The history of ocean resources: Modeling cod biomass using historical records. *Frontiers in Ecology and the Environment* 3: 78–84. https://doi.org/10.2307/3868514.

Shields, J.D. 2013. Complex etiologies of emerging diseases in lobsters (*Homarus americanus*) from Long Island Sound. *Canadian Journal of Aquatic Science* 70: 1576–1587. https://doi.org/10.1139/cjfas-2013-0050.

Silvano, R.A.M., and J. Valbo-Jørgensen. 2008. Beyond fishermen's tales: Contributions of fishers' local ecological knowledge to fish ecology and fisheries management. *Environment, Development and Sustainability* 10: 657. https://doi.org/10.1007/s10668-008-9149-0.

Singer, L.T., and D.S. Holland. 2008. *Taking the pulse of the lobster industry: A socioeconomic survey of New England lobster fishermen*. Portland, ME: Gulf of Maine Research Institute.

Smit, B., and J. Wandel. 2006. Adaptation, adaptive capacity and vulnerability. *Global Environmental Change* 16: 282–292. https://doi.org/10.1016/j.gloenvcha.2006.03.008.

Stedman, R.C., J.R. Parkins, and T.M. Beckley. 2004. Resource dependence and community well-being in rural Canada. *Rural Sociology* 69: 213–234. https://doi.org/10.1526/003601104323087589.

Steneck, R.S., T.P. Hughes, J.E. Cinner, W.N. Adger, S.N. Arnold, F. Berkes, S.A. Boudreau, K. Brown, et al. 2011. Creation of a gilded trap by the high economic value of the Maine lobster fishery. *Conservation Biology* 25: 904–912. https://doi.org/10.1111/j.1523-1739.2011.01717.x.

Stern, M.J., and K.J. Coleman. 2015. The multidimensionality of trust: Applications in collaborative natural resource management. *Society and Natural Resources* 28: 117–132.

Trotter, B. 2018. Scientists say the Maine lobster boom won't last. Here are the fisheries coming next. *Bangor Daily News*, May 12.

Tlusty, M.F., and A. Metzler. 2012. Relationship between temperature and shell disease in laboratory populations of juvenile American lobsters (*Homarus americanus*). *Journal of Shellfish Research* 31: 533–541. https://doi.org/10.2983/035.031.0213.

Wahle, R.A., C. Bergeron, J. Tremblay, C. Wilson, V. Burdett-Coutts, M. Comeau, R. Rochette, P. Lawton, et al. 2013. The geography and bathymetry of American lobster benthic recruitment as measured by diver-based suction sampling and passive collectors. *Marine Biology Research* 9: 42–58. https://doi.org/10.1080/17451000.2012.727428.

Wahle, R.A., L. Dellinger, S. Olszewski, and P. Jekielek. 2015. American lobster nurseries of southern New England receding in the face of climate change. *ICES Journal of Marine Science* 72: i69–i78. https://doi.org/10.1093/icesjms/fsv093.

Waller, J.D., R.A. Wahle, H. McVeigh, and D.M. Fields. 2017. Linking rising pCO_2 and temperature to the larval development and physiology of the American lobster (*Homarus americanus*). *ICES Journal of Marine Science* 74: 1210–1219. https://doi.org/10.1093/icesjms/fsw154.

Waring, T., and J. Acheson. 2018. Evidence of cultural group selection in territorial lobstering in Maine. *Sustainability Science* 13: 21–34. https://doi.org/10.1007/s11625-017-0501-x.

Wilson, J., L. Yan, and C. Wilson. 2007. The precursors of governance in the Maine lobster fishery. *Proceedings of the National Academy of Sciences* 104: 15212–15217. https://doi.org/10.1073/pnas.0702241104.

Publisher's Note

AUTHOR BIOGRAPHIES

Loren McClenachan (✉) is an Assistant Professor at Colby College. Her research interests include fisheries conservation, historical ecology, and marine extinction risk.
Address: Environmental Studies Program, Colby College, 5351 Mayflower Hill Drive, Waterville, ME 04901, USA.
e-mail: lemcclen@colby.edu

Steven Scyphers is an Assistant Professor at Northeastern University's Marine Science Center. His research interests include coastal development, fisheries management, and climate adaptation.
Address: Marine Science Center, Northeastern University, Nahant, MA 01908, USA.
e-mail: s.scyphers@northeastern.edu

Jonathan H. Grabowski is a Professor and Associate Director at the Northeastern University's Marine Science Center. His research interests include ecological economics, environmental science and policy, and fisheries.
Address: Marine Science Center, Northeastern University, Nahant, MA 01908, USA.
e-mail: j.grabowski@northeastern.edu