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How do human actions affect fisheries? Differences in perceptions between fishers and scientists in the Maine lobster fishery

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Abstract

The degree to which human actions affect marine fisheries has been a fundamental question shaping people's relationship with the sea. Today, divergences in stakeholder views about the impacts of human activities such as fishing, climate change, pollution, and resource management can hinder effective co-management and adaptation. Here, we used surveys to construct mental models of the Maine lobster fishery, identifying divergent views held by two key stakeholder groups: lobster fishers and marine scientists. The two groups were differentiated by their perceptions of the relative impact of pollution, water temperature, and fishing. Notably, many fishers perceive the process of fishing to have a positive effect on fisheries through the input of bait. Scientists exhibited a statistically significantly stronger concern for climate change and identified CO_2 as one of the dominant pollutants in the Gulf of Maine. However, fishers and scientists agreed that management has a positive impact, which appeared to be a change over the past two decades, possibly due to increased collaboration between the two groups. This work contributes to the goal of decreasing the distance between stakeholder perspectives in the context of a co-managed fishery as well as understanding broader perceptions of impacts of human activities on marine ecosystems.

Key words: fisheries, lobster, Gulf of Maine, mental models, stakeholder engagement

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1. Introduction

1.1. Perceptions of drivers of change in marine fisheries

Historically, the ocean was viewed as too vast and marine fish too prolific for either to be impacted by humans (Roberts and Hawkins 1999). However, during the 20th century, the evidence that overfishing can cause declines in target fish populations grew (Steneck and Pauly 2019), and acknowledging the primacy of overfishing as a driver of change in marine systems became common among fisheries scientists and ecologists (Jackson et al. 2001). The ecosystem effects of selective fishing were also identified; in particular, scientists described the removal of top predators as resulting in ecological simplification and release from predation for lower trophic level species, which acted to increase the relative importance of invertebrate fisheries (Pauly et al. 1998; Howarth et al. 2014). While the scientific community increasingly discussed the impacts of overfishing, there was also growing attention paid to the ability of humans to manage fisheries successfully to recovery, and the relative importance of different management measures in reversing declines (Worm et al. 2009). At the same time, discerning the relative importance of local actions like overfishing and management as compared with global climate drivers have been the subject of extensive discussion for fisheries around the world (Rose 2004; Holt and Punt 2009).

Within the context of managing particular fisheries, stakeholder perceptions about the ways in which humans influence marine ecosystems and fish populations can vary substantially (Daw et al. 2011; Mackinson and Wilson 2014; Verweij et al. 2010). For example, fishers, scientists, and other stakeholders diverged in their views of the status of target fish populations in the North Sea, which heightened tensions in the management process (Verweij et al. 2010). When considering drivers of change of populations, stakeholder views can diverge even further. For example, in the English Channel, fishers' perceptions of change matched those of scientific data sources, but diverged with respect to the reasons for this change (Rochet et al. 2008). Verweij et al. (2010) described three sets of mechanisms that help explain observed differences in perceptions among stakeholder groups: differences in information environments, differences in processing and evaluating available information, and differences in cognitive resonance, which resulted in certain information being discarded if it did not fit within a frame of current beliefs. These differences have been shown to exist among stakeholder groups in fisheries around the world. For example, in Seychelles artisanal trap fisheries, cognitive conflicts were identified among stakeholders who did not rely on the same data sources to make judgements about the status of targeted marine fish populations (Daw et al. 2011).

Understanding divergent views among stakeholder groups is important within the context of adaptation and decision-making in fisheries management. Alongside differences in perceptions of drivers of change, different stakeholder groups can have different potential adaptation tools at their disposal, and in the absence of knowledge co-production, separate stakeholder groups can come to different conclusions about which tools and actions are important (Cooke et al. 2020). In the context of climate adaptation for example, a range of possible tools exist including adapting management controls (Grafton 2010) and diversifying fisheries (McClenachan et al. 2020). Understanding the views of fishers is particularly important in the context of co-managed fisheries where power and responsibility are shared between the government and local resource users (Berkes 2009).

1.2. Perceptions of drivers in the Maine lobster fishery

The American lobster (*Homarus americanus*) fishery in the Gulf of Maine is a clear example of a fishery for which a range of locally and globally derived human and natural drivers are known to influence abundance and decline (Steneck and Wahle 2013). The lobster fishery is consistently among the most valuable in the United States (Le Bris et al. 2018), with increasing landings since the early 1990s (Acheson and Steneck 1997; Maine Department of Marine Resources 2021) and with strong stakeholder investment in its continued success (Steneck et al. 2011). However, it is unclear whether the primary forces responsible for recent sustained high lobster abundance and landings are human or natural, derive from top-down or bottom-up forcing, or are short-term or long-term in their impact.

Effective management actions have been commonly cited as a reason for high abundance (Acheson and Gardner 2014), with the Maine lobster fishery globally recognized as an example of co-management success (Dietz et al. 2003). This co-management exists officially in the form of Zone Councils comprised of appointed and elected lobster fishers who work with the Maine Department of Marine Resources and state legislators to define lobster management policy (Maine Statute 6447). Additionally, informal social networks among lobster fishers effectively help to support management goals, which include limiting effort and protecting breeding female lobsters. At the same time, the simplification of the Gulf of Maine ecosystem due to overfishing of cod and other groundfish predators has been credited as a driver of high lobster abundances (Acheson and Steneck 1997; Boudreau and Worm 2010). Related to this predator depletion hypothesis is the idea that the entire Gulf of Maine is a pseudo-farmed or aquaculture system, as lobsters feed on traps baited by humans, which have been shown to subsidize juvenile lobster diets and enhance lobster growth and overall fisheries yield (Grabowski et al. 2010). Finally, the evidence of warming waters as a key driver of lobster abundance has existed for more than two decades (Drinkwater et al. 1996), with data showing that warming waters have benefited Gulf of Maine lobster while driving declines in southern populations (Wahle et al. 2015; Goode et al. 2019). Various approaches have been used to discern the relative impact of these drivers, but the system is complex. For example, substantial variation exists in drivers of lobster abundance across a thermal gradient (Boudreau et al. 2015).

The relative importance of key drivers in lobster abundance has implications for designing effective and adaptive management, and differences in views among key stakeholders in this co-managed fishery can lead to conflict about the most important future action (Acheson and Steneck 1997). In the Gulf of Maine lobster fishery, stakeholder perceptions of drivers of change have been documented alongside the development and evolution of the State's co-management system, with key advancements occurring in the 1990s (Acheson and Steneck 1997). Stakeholder interviews among Maine lobster fishers and scientists in the 1990s demonstrated differences in views about these drivers in the Gulf of Maine, with biologists emphasizing water temperature and fishing effort and fishers focusing on ecological factors like groundfish predation (Acheson and Steneck 1997). However, alongside the evolution of co-management structures in the last two decades, climate impacts have accelerated (Oppenheim et al. 2019), the use of bait has increased (Grabowski et al. 2010; McClenachan et al. 2020), lobster landings have continued to increase (Maine Department of Marine Resources 2021), and groundfish populations have further declined (Pershing et al. 2015). Additionally, rapid declines in populations of lobster in the Long Island Sound and Narragansett Bay have led to local fisheries crashes (Wahle et al. 2015), and disruptions of markets due to stochasticity in temperature have occurred (Mills et al. 2013; Henry and Johnson 2015). These events have amplified the belief that climate adaptation is needed in the Maine lobster fishery (Mills et al. 2013). However, the approach to adaptation will depend on what is believed to be the primary direct or proximal driver(s) of change. Here, we ask two related questions: How do two key stakeholder groups perceive the relative importance of drivers in the lobster fishery? How have these perceptions changed over the past two decades?

2. Methods

2.1. Mental models

Mental models are personal, internal representations of external reality and are used to describe and quantify perceived relationships within complex systems (Gray et al. 2015). We followed the two-step methodology described by Özesmi and Özesmi (2004) with the goal of constructing individual cognitive maps of causative relationships in the Maine lobster fishery. Specifically, our mental models are aimed at demonstrating how stakeholders perceive relationships among lobster populations, human drivers, and other components of the environment.

To identify the key concepts to include in our mental models, we first asked 20 active lobster fishers to identify or "freely associate" concepts that related to the lobster fishery. These open-ended interviews were all conducted in person. When the rate of new concept identification plateaued, we condensed responses into the eight most identified concepts: lobster populations, predator populations, prey populations, habitat, warming coastal waters, pollution, commercial fisheries, and management actions.

To quantify perceived relationships among key concepts, the second step of our mental model construction consisted of standardized surveys, which we built using these eight concepts. The standardized survey asked all participants a series of pairwise questions to identify perceptions of causal relationships among concepts. For example, respondents were asked, "How would you expect an increase in pollution to influence lobster populations?" Each possible response corresponded a numerical value: −1 = large decrease, −0.67 = moderate decrease, −0.33 = small decrease, 0 = no effect, +0.33 = small increase, +0.67 = moderate increase, +1.0 = large increase. In all cases respondents were asked to consider the interaction of these concepts in the Gulf of Maine.

To provide more depth and understanding of how individuals perceived these concepts, we asked respondents additional questions about several concepts. Prior to completing the mental model survey, respondents were asked to identify the most important predator, prey, and habitat for lobster. We also asked respondents to identify the most important management actions with respect to Gulf of Maine ecosystems, the most substantial source of pollution in the Gulf of Maine, and the most important commercial fisheries in the Gulf of Maine. We used these responses to inform our interpretation of the mental models.

Finally, we asked respondents to rank their concern about climate change on a scale of 0–3 (0 = not at all concerned, 1 = not very concerned, 2 = somewhat concerned, 3 = very concerned), and collected data on several demographic variables, including years of experience, age, gender, and percent of income derived from lobster.

2.2. Stakeholder surveys

The first stakeholder group invited to participate in the standardized survey was active Maine lobster fishers. 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). We conducted fisher interviews in person to avoid biasing the sample toward fishers more likely to complete an online or paper survey. Fisher interviews took place between October 2016 and October 2018. Results of this mental modeling exercise in the context of climate vulnerability and ecosystem change are described in McClenachan et al. (2020).

The second stakeholder group invited to participate in the standardized survey was natural and social scientists, fishery managers, and students involved with lobster research in Maine. This group was collectively the Maine Department of Marine Resources (DMR) Lobster Research Collaborative (LRC). The LRC began in 2018 and provided funding from the Maine Lobster Research, Education and Development Board for six research projects centered around a shared goal of providing improved science to support the management of Maine's lobster fishery. The researchers were awarded two-year research grants. In accepting the grants, the researchers also agreed to participate in quarterly meetings to share results and build collaboration between researchers and different stakeholder groups. The LRC was broadly inclusive with more than 80 members and was representative of the Gulf of Maine scientific community. The majority of LRC participants were faculty or students at academic institutions in Maine, science and policy staff at DMR, and researchers at nonprofit research institutions. The LRC held quarterly meetings from 2018 to 2020 to share updates on funded research, discuss issues of the day, and connect researchers across the State. The LRC concluded in November 2020 with its eighth meeting. In the second half of the two-year LRC, we constructed an online, standardized mental model and invited participants to complete the survey. Scientist interviews were conducted online because this stakeholder group was already connected via an online forum, and it was assumed group members had equal likelihood of completing an online survey or an in-person survey. Survey responses were collected from February 2020 to May 2020. We closed the survey at this time when the responses collected were equivalent to those for lobster fishers.

The same standardized mental modeling survey was administered, in person and online, to allow for comparison. These interviews were deemed exempt from IRB review by Colby College under category 45 CFR 46.101(b)(2)(ii).

2.3. Analysis

We compared mental models in terms of 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. Indegree centrality represents the relative number and strength of factors that affect a given variable, while outdegree centrality represents the relative effect of one variable on all the others. Both types are calculated by adding the absolute values of the strength of each relationship (range 0–1), also termed "edge weights". Because our survey included eight concepts and it was not possible for a concept to affect itself, the maximum value for indegree and outdegree centrality for any concept is seven. Mean centrality is calculated as the absolute value of both indegree and outdegree components; the maximum value for mean centrality in our survey is therefore 14. 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. We also compared the average reported concern about climate change between the two groups using a t-test.

We sought to understand differences in perception of the system as a pseudo-farmed aquaculture system (Grabowski et al. 2010; McClenachan et al. 2020) by categorizing respondents based on their responses to two questions: What is the most important lobster predator? What is the most important lobster prey? From these responses, we identified four different "views" of the lobster fishery. Those with a "natural" view identified both a naturally occurring predator and prey. Those with a "full aquaculture" view identified humans as the most important predator and bait as the most important prey. Those with a "partial aquaculture (bait driven)" view identified a naturally occurring predator, but identified bait supplied by lobster fishers as the most important prey. Finally, those with a "partial aquaculture (fishing driven)" view identified a naturally occurring prey, but perceived that humans were the most important predator via their extraction through the lobster fishery.

Finally, we compared our results to those reported in Acheson and Steneck's (1997) analysis of perspectives on "boom and bust" in the Maine lobster fishery. Acheson and Steneck (1997) interviewed lobster fishers, scientists, and managers who collectively identify 10 perceived key drivers of lobster landings during a period of bust or low landings in the 1920s and 1930s and a subsequent period of boom or high landings in the 1990s. The interviews were structured differently from those of the present study and do not provide a direct one-to-one mapping, but there was enough detail to provide a semi-quantitative comparison. We summarized their results as a near analog to ours by dividing the drivers into negative (i.e., those associated with bust in the 1920s and 1930s) and positive (i.e., those associated with boom in the 1990s). In one instance, we reversed this directionality, as bait was associated with bust because of a reduction in bait, rather than an increase. We quantified Acheson and Steneck's (1997) interview data by totaling the number of lobster life stages that scientists and fishers described as affected by each driver, arriving at relative weights for each of these drivers. For comparison, we grouped the drivers described in Acheson and Steneck (1997) into categories that approximately matched those used in the current study (**Table 1**). One key difference between our approach is that in our mental models, each set of interactions could only be positive,

Table 1. Comparison of drivers in the Maine lobster fishery in Acheson and Steneck (1997) and this study.

Driver category—this study	Driver phrasing—Acheson and Steneck (1997)
Temperature	Water temperature (settlement) Water temperature (settlement, trapability)
Bait	Culturing
Predation/habitat	Postsettlement survival Predation (groundfish) Increased early benthic survival
Management actions	Poverty gauge Venting, v-notching Conservation ethic
Commercial fishing	Illegal activity Excess fishing effort

Note: We used a semi-quantitative comparison to identify changes in perceptions among fishers and scientists over the past two decades, during a period characterized by changes including increased landings, developments in the co-management system, and increases in water temperatures.

negative, or neutral, whereas Acheson and Steneck's (1997) focus on effects across lobster life stages allowed for interactions to be both positive and negative.

3. Results

We conducted structured mental model interviews with 23 fishers in 18 different towns along the coast of Maine. The rate of positive response to our request for interviews was approximately 50%. The age of interviewees ranged from 19 to 83 years old with a mean age of 42 and a median of 46. The number of years of fishing experience ranged from 1 to 61 with a mean of 22. Both male (n = 17) and female (n = 6) fishers were interviewed. Most interviewees received 100% of their personal income from the lobster fishery, with a mean of 84% of income derived from the lobster fishery.

We obtained 24 completed responses of a possible 85 (28%) to the online survey from the LRC group. Additionally, we received nine partially completed surveys, in which respondents answered the first set of questions about the most important predator, prey, and habitat for lobster but did not complete questions related to the mental model exercise. We omitted these responses from the mental model analysis but included them in our reporting of the most important predator, prey, and habitat. Of those who completed the survey, 67% self-identified as natural science researchers, 29% as "other" or multiple categories (social science researcher, manager, policy maker), and 4% as students. degree of experience varied; 46% of respondents had studied lobster for 5 years or less, 33% had studied lobster for 6–15 years, and 21% had studied lobster for more than 15 years.

The two stakeholder groups placed differing importance on particular components of the lobster fishery (Fig. 1; Table 2). Lobster fishers viewed commercial fisheries, lobster populations, and pollution as the most important concepts in the lobster fishery. Both commercial fisheries and lobster population had a mean centrality >4 for the lobster fisher mental model. In contrast, scientists viewed concepts as more equivalent in importance, with commercial fisheries, lobster population, and predator and prey populations holding equal weight, and with no concept having a mean centrality of >4. As noted above, the maximum value for mean centrality in our mental models is 14.

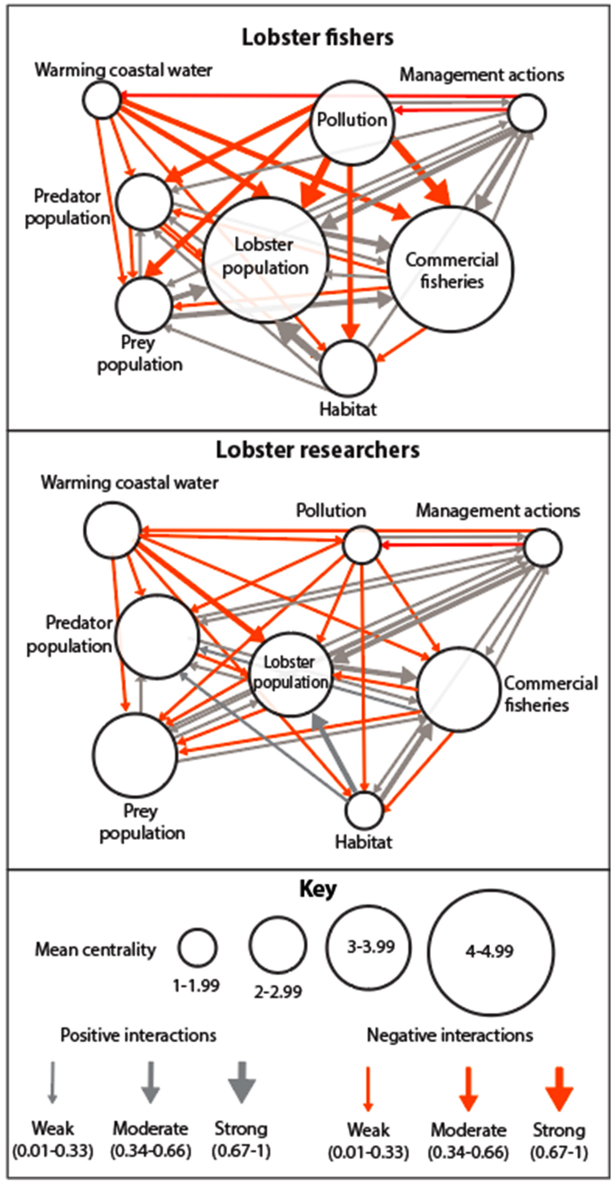

Fig. 1. Comparative mental models. Mean centrality for each concept is indicated by circle size, directionality of relationships is indicated by arrow color, and strength of relationships is indicated by arrow weights.

3.1. Drivers of change: management, pollution, and warming coastal waters

Both groups had a similar and positive view of management actions in the Gulf of Maine lobster fishery. Specifically, outdegree values were similar between groups, with slightly higher values for lobster fishers (1.69) than for scientists (1.60). Both groups viewed management as having a positive impact on lobster populations and commercial fisheries, with lobster fishers holding slightly more positive views of management's impact; on average, fishers viewed management actions as having a moderately positive impact on commercial fisheries (0.45) as compared with scientists who viewed

Table 2. Outdegree, indegree and mean centrality values for lobster fishers and scientists.

Concepts	Fishers			Scientists		
	Outdegree	Indegree	Mean	Outdegree	Indegree	Mean
Lobster	1.29	3.08	4.36	1.34	2.63	3.97
Predator	0.85	1.98	2.83	1.22	1.95	3.17
Prey	1.33	1.50	2.83	1.08	2.55	3.63
Habitat	1.10	1.55	2.65	1.29	0.50	1.79
Warming coastal water	1.45	0.03	1.48	2.11	0.10	2.21
Pollution	3.44	0.06	3.50	1.74	0.21	1.95
Commercial fisheries	1.20	2.99	4.19	1.18	2.42	3.60
Management actions	1.69	0.00	1.69	1.60	0.00	1.60

Note: Centrality is indicative of the relative importance of given variable is within a mental model. Indegree centrality represents the relative number and strength of factors that affect a given variable, while outdegree centrality represents the relative effect of one variable on all the others. Both types are calculated by adding the absolute values of the strength of each relationship (range 0–1). The maximum value for indegree and outdegree centrality for any concept is 7; the maximum value for mean centrality in our survey is therefore 14.

Table 3. Views of pollution.

Type of pollution	Scientists
Nutrient loading and runoff	54%
CO_2 and climate impacts	29%
Debris and plastic	17%

Note: Scientists identified CO_2 and climate impacts among the top three pollutants in the Gulf of Maine.

the impact as weakly positive (0.12). Both groups viewed management's impacts on lobster populations as moderately positive, but again lobster fishers viewed this relationship as stronger than did scientists (0.51 vs. 0.34). Particular management measures mentioned as effective by both groups were restrictions on individual lobster sizes, V-notching (a practice aimed at protecting breeding female lobsters), and management of the amount of gear in the water. Similarly, respondents agreed that management measures aimed at addressing warming waters and pollution are effective at mitigating or decreasing these impacts, but respondents did not specify particular management measures they supported in the same way that they did for lobster fisheries management. In this case, views were strikingly similar, with both groups viewing management measures as having a weakly negative impact on warming coastal waters (−0.03 for fishermen; −0.07 for scientists) and a slightly stronger, though still weak impact on pollution (−0.23 for fishers; −0.21 for scientists).

Both lobster fishers and scientists agreed that pollution is a negative driver in the lobster fishery, with impacts on lobster populations, commercial fisheries, predator, prey, and habitat (Fig. 1). However, views diverge on the relative importance of pollution and what the most important pollutants are in the Gulf of Maine. Lobster fishers viewed pollution as the most important driver, with an outdegree value of 3.44, more than double the next most highly ranked driver (Table 2). In contrast, the average outdegree value for pollution in scientists' mental models was 1.74. The two groups also diverged on

Table 4. Average concern for climate change expressed by lobster fishers and scientists.

Concern level	Lobster fishers (n = 22), no. (%)	Scientists (n = 24), no. (%)
Very concerned (3)	36%	86%
Somewhat concerned (2)	23%	8%
Not very concerned (1)	27%	4%
Not at all concerned (0)	14%	0 (0)

the most important pollutants in the Gulf of Maine. Scientists defined pollution narrowly; more than half defined pollution as nutrient loading and runoff. Interestingly the second most common source of pollution was linked directly to climate change, with 29% of scientists listing CO_2 as the most important pollutant in the Gulf of Maine (Table 3). Debris/plastic was the third category of pollutants identified by scientists. Like scientists, fishers most frequently defined pollution in terms of nutrient loading and runoff. However, lobster fishers collectively defined the term pollution into more diverse categories, and when discussing the potential effects of pollution in Maine, fishers also frequently referenced shell disease and other areas where shell disease is more prevalent and lobster populations have recently crashed, such as Narragansett Bay and Long Island Sound. In these cases, fishers perceived the effects of insecticides used to control mosquitos as linked to effects on lobster larvae.

Finally, both stakeholder groups agreed that warming coastal waters represent a negative driver in the lobster fishery, with impacts on lobster populations, commercial fisheries, predator, prey, and habitat (Fig. 1). However, views diverged on the relative importance of warming coastal waters, with scientists ranking it as the most important driver (outdegree value = 2.11), and lobster fishers ranking it as less impactful than pollution and management actions (outdegree value = 1.45; Table 2). Scientists also reported a greater concern for climate change, with 86% indicating that they are very concerned about climate change, as compared with only 36% of lobster fishers (Table 4). On a scale of 0–3, scientists average concern was 2.83 and lobster fishers was 1.82, representing a highly significant difference between the two groups ($t(44) = 4.12$, $p < 0.0001$).

3.2. Is the lobster fishery an aquaculture system?

Our results demonstrate that neither group sees the lobster fishery as a wholly "natural" system, with only 22% of lobster fishers and 30% of lobster researchers expressing the view that both the most important predator and prey are naturally occurring (Fig. 2). Naturally occurring predators included cod and other groundfish, crabs, and zooplankton predators, while naturally occurring prey included zooplankton prey, bivalves (mussels, clams, oysters), and detritus (Table 5). However, the way in which human influence is seen to drive the system differed between these groups. Fishers expressed a belief that the human influence on the fishery was primarily bottom up, through the use of bait, with 44% of respondents expressing this view, compared with only 3% of researchers. In contrast researchers expressed a belief that the largest human influence is top down through fishing, with 33% expressing this view, compared to only 9% of fishers. Both groups expressed the full aquaculture view at similar proportions (26% and 33%).

3.3. Change over the past two decades

When comparing our results to a similar analysis conducted two decades earlier (Fig. 3), we found that several key perceptions have remained the same. First, fishers have consistently viewed bait as an important driver of lobster abundance and landings. Acheson and Steneck (1997) reported the

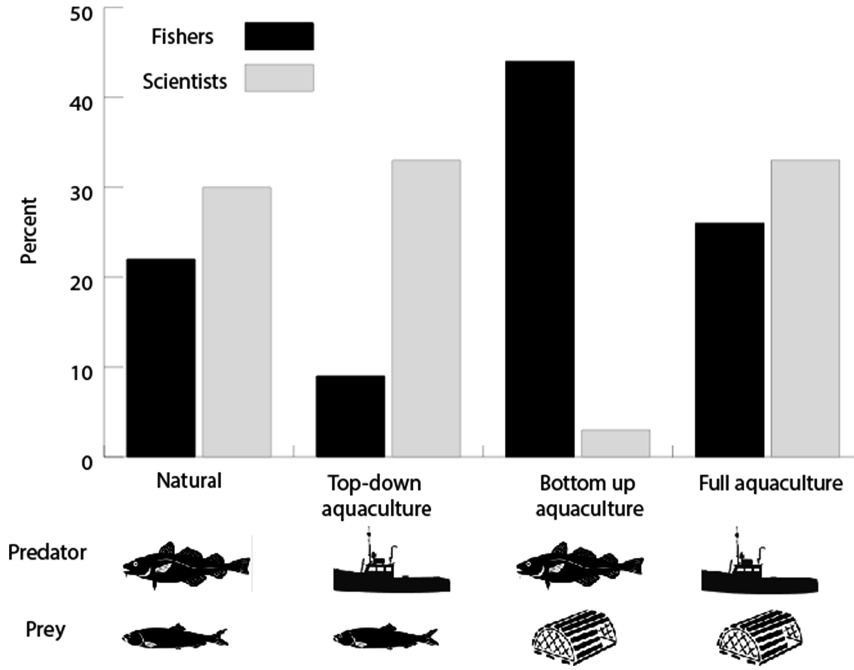

Fig. 2. Views of the Maine lobster fishery as an "aquaculture" system. Percentages of respondents categorized by their selection of the most important lobster predator and prey. Those with a "natural" view identified a naturally occurring predator and prey. Those with a "bottom-up aquaculture" view identified naturally occurring predator and bait. Those with a "top-down aquaculture view" identified humans as the most important predatory and a naturally occurring prey. Those with a full aquaculture view identified humans and bait as the most important predator and prey.

perception among fishers of an impact of bait on lobster landings. This was expressed as the effect of "culturing" (Table 1); a decrease in culturing (i.e., less baiting) was blamed for a bust period in the fishery. In contrast, scientists did not connect bait to lobster landings at all. Second, scientists emphasized the important of top-down human impacts in the form of fishing. Finally, both then and now, scientists placed greater emphasis on temperature as a driver of lobster landings and abundance, while fishers did not. Of the five key drivers identified, temperature was the only one that fishers did not connect to lobster abundance.

Despite these consistencies, several things seem to have changed in the last two decades. First, scientists in our study had a more positive view of management than those in 1997. Scientists did not connect management actions to lobster landings in the 1990s, but we found that they largely had a positive view of management today. Second, while they still do not rank it as a top priority, fishers seem to have increased their view that temperature has an impact.

4. Discussion

Our results suggest different views of the relative impact of humans on the Maine lobster fishery among lobster fishers and marine scientists. In particular, the two groups were differentiated by their perceptions of the relative impact of water temperature and fishing, and whether the effect of fishing is positive or negative. However, they agreed that the impact of management was positive, which appeared to be a change over the past two decades. We describe differential perceptions of each of

Table 5. The most important predator, prey, and habitat as identified by scientists. (n = 33)

Order of importance	No. (%)
Predator	
Humans	67%
Cod and other groundfish	15%
Crabs	6%
Zooplankton predators	6%
Striped bass	3%
Black sea bass	3%
Prey	
Bait	36%
Zooplankton prey	21%
Bivalves (mussels, clams, oysters)	18%
Detritus/Waste material	12%
Habitat	
Rocky or cobbly bottom	88%
Intertidal	6%
Mud	3%
Ledge	3%

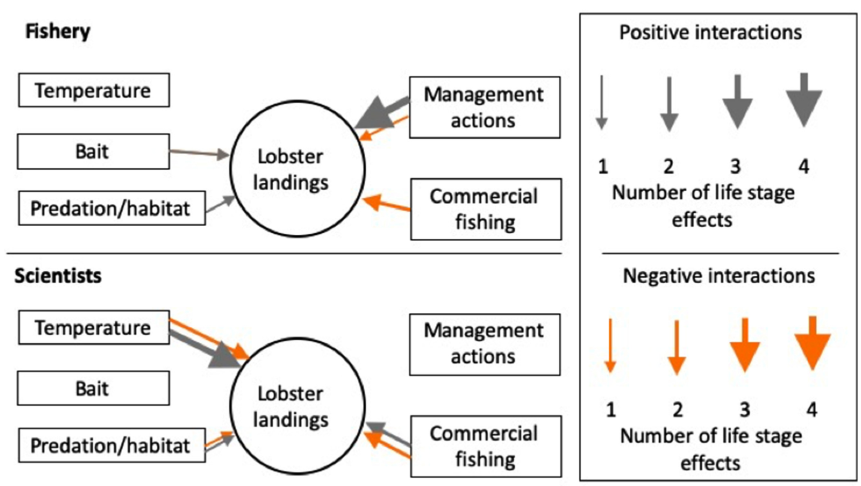

Fig. 3. Mental model created from Acheson and Steneck (1997). We quantified their interview data by totaling the number of lobster life stages that scientists and fishers described as affected by each driver, arriving at relative weights for each of these drivers. For comparison, we grouped the drivers described in Acheson and Steneck (1997) into categories that approximately matched those used in the current study (Table 1).

these three drivers in more detail, as well as mechanisms driving these differences, and the implications for adaptation within this co-managed fishery.

4.1. Does water temperature have an impact on lobster populations?

The largest difference that we identified between lobster fishers and marine scientists was the perception of the effect of warming coastal waters in the Gulf of Maine on lobster populations. Scientists ranked warming coastal waters as the most important driver and had an associated higher concern for global climate change. Notably, they also indicated that CO_2 was the most important pollutant in the Gulf of Maine, underscoring the primacy of climate change as a driver in this system. In contrast, fishers viewed warming coastal waters as less important than other drivers and had a significantly lower concern for global climate change. These results are consistent with those from Acheson and Steneck (1997), as well as more recent work. For example in Nova Scotia, only 19% of lobster fishers identified changes in climate or water temperature as the cause of the changes in lobster landings (Boudreau and Worm 2010). The decoupling of observations of warming coastal water from global climate change has also been shown; lobster fishers frequently view water temperature as cyclical, which it has approximately been over the past century, subtracting out the long-term trend (McClenachan et al. 2019; McClenachan et al. 2020).

The difference between scientists' views of climate change and fishers' views of climate change is similar to other divides, and this may be due to either directional motivated reasoning, when individuals preferentially believe information that is consistent with previously held beliefs, or accuracy motivated reasoning, which is when individuals try to form the most accurate conclusion, but vary on which evidence is considered credible (Druckman and McGrath 2019). These biases are closely related to those described by Verweij et al. (2010), who further described mechanisms for differences in information processing across groups (see section 4.4 for a more in-depth discussion of these mechanisms as they relate to our results). For example, the belief that warming coastal water is temporary may be linked to collective cultural memories of warming and cooling periods in 1940–1960 (McClenachan et al. 2019).

Despite these equivocal views, there is strong evidence for the effect of climate change on lobster fisheries (Boudreau et al. 2015; Le Bris et al. 2018; Goode et al. 2019). However, the effects are complex across time and space and therefore greatly simplified in our mental models. For example, Goode et al. (2019) demonstrated the geographic differential impact of warming waters, with warming waters supporting increased recruitment in northern waters and recruitment failure and fisheries collapses in southern waters. Both scientists' and fishers' perceptions are likely influenced to some degree by the belief that lobster increases in the past two decades are partially due to increasing water temperatures, but also perceptions that temperature was in important driver in the decline of the lobster populations in southern New England and subsequent concern about the future of the Gulf of Maine.

4.2. Does fishing have an impact on lobster populations?

We also identified fundamentally different views between lobster fishers and scientists with respect to the impact of fishing on lobster populations. Both groups viewed fishing as impactful but in different ways. The fishing community viewed human influence as primarily bottom up, viewing humans as most impactful through feeding lobsters, therefore decoupling fishing from depletion and supporting the idea that fishing benefits lobster populations. In contrast lobster researchers held the belief that humans were most impactful through fishing lobsters, a more classic view of effort-based depletion.

Around the world, research has shown that fishers are unlikely to indicate that fishing is responsible for declines to target species. In the English Channel, for example, fishers perceived declines in cod to be due to environmental factors that caused cod populations to migrate (Prigent et al. 2008; Rochet et al. 2008), and in California, fishers indicated that natural cycles and pollution were more important for resource health than fishing pressure (Scholz et al. 2004). Vested interest in fisheries can consciously or unconsciously shape fishers' perception of their own impacts (Harmon-Jones and Harmon-Jones 2007), and Rochet et al. (2008) suggested that a lack of acknowledgement of the impact of commercial fisheries extraction on declines in fish populations could be due to a difficulty for an individual to see themself as both the cause and consequence of change. Our results demonstrating fishers' lack of attribution of extraction as impactful to lobster populations fits within this global literature.

Unlike research on other global fisheries, however, lobster fishers perceive the process of fishing to have a positive effect on fisheries, which to our knowledge is unique among the literature on fishers' perceptions of fisheries impacts on capture fisheries. This finding is consistent with those from the 1990s that suggested fishers connected decreases in the use of bait to the earlier busts in the lobster fisheries (Acheson and Steneck 1997) and to some degree with other studies on the perceived and measured effects of the top-down and bottom-up forcing on lobster populations. For example, 40% of Nova Scotian lobster fishers believe that they were to some extent feeding the lobsters with bait during the fishing season, but most did not view this as the cause for increased landings (Boudreau and Worm 2010). Conversely, 74% of respondents were concerned that the lobster population may eventually decline due to increased fishing effort and movement into offshore fishing grounds as well as the targeting of large lobsters and depletion of the brood stock. However, Boudreau et al. (2015) also showed little empirical support that fisheries have a strong impact on lobster populations, either positively or negatively. Their analysis of effort and landings data suggested that fishing effort is not influencing lobster abundance, either through lobster mortality or bait use. Instead, increases in fishery efforts followed increases in lobster abundance, such that as lobster abundances increase, fishing effort then increases (Boudreau et al. 2015).

4.3. Does management have an impact on lobster populations?

Finally, our results suggest that lobster fishers and scientists are largely in agreement that management has a positive impact on lobster populations, with striking similarity in our mental model's outdegree values for this variable. These results are stronger than those found in other studies. For example, in Nova Scotia, only 21% of lobster fishers attributed increased landings to conservation measures such as gear restrictions and the protection of egg-bearing females (Boudreau and Worm 2010). These results also appear to represent a change since the 1990s, with scientists expressing a more positive view of management's impact on lobster populations. This change over time could be due to several factors. First, the Maine lobster fishery's strong co-management system was formalized in 1995 and has been well reported in the primary literature over the past two decades (Dietz et al. 2003; Steneck et al. 2011; Acheson 2013; McClenachan et al. 2020). This increased focus on co-management could help explain why scientists have shifted toward a more positive perception of management impacts since the 1990s. Second, government and academic scientists have become more collaborative in their approach to research in this same time period, which has strengthened the exchange of information between the two groups and could have affected scientists' views of management (K. Reardon, personal communication, 2021). Third, academic research has shown harvest control measures such as V-notching and increases in size limits that were introduced in the 1990s to be effective at dampening the effects of climate change (Le Bris et al. 2018). In contrast, in the 1990s, there was disagreement about the importance and effectiveness of V-notching (a practice of notching the flipper of a gravid female lobster to prevent harvest of reproductive females when eggs are not present, marking the female as a successful breeder), with some state and federal scientists doubting its utility (K. Reardon, personal communication, 2021). Finally, the strong increase in lobster landings since the 1990s may have added to the perception that management is working (Maine Department of Marine Resources 2021). The agreement about the positive role of management suggests that this co-management structure provides a point of agreement and institutional structure on which to further align stakeholder perceptions.

4.4. Mechanisms behind differing mental models

This case study suggests different views of the ways that humans can impact marine ecosystems and fisheries. In the context of the history of science and conservation, which has increasingly emphasized the ways that humans impact marine food webs, these results provide insight into the degree to which these ideas influence different stakeholder groups. Of particular interest are the areas where mental models differ, and there is a range of possible mechanisms to explain the differing mental models of the scientist and fisher groups. Verweij et al. (2010) suggested three discrete reasons for differences in perceptions, all of which are applicable.

First, differences in information environments—or the availability, accessibility, and adequacy of information—exist between the two groups. In other words, for both groups, there is selective exposure to information. In principle, scientists should form mental models based on the scientific literature, which should give them access to a wide range of perspectives on different components of the marine ecosystem and an ability to compare different hypotheses. However, biases exist in the scientific corpus; for example, there is significantly more research published on the most monetarily valuable species (Aksnes and Browman, 2016; Record and Vera 2021), thus filtering an understanding of a complex ecosystem through the somewhat narrow lens of extraction. Likewise, the growing emphasis of climate change as a concern in the scientific literature likely influenced the formation of scientists' mental models (Drinkwater et al. 1996; Wahle et al. 2015; Goode et al. 2019). In contrast, fishers are likely forming mental models based on daily experiences at sea, plus those of other fishers. These observations are spatially limited and fragmented, but have a high resolution in space and time, and can therefore provide a more holistic and nuanced view of change (Verweij et al. 2010). For example, observations of novel warm water species both at sea and caught in lobster traps provide fishers with a knowledge the local ecological effects of warming waters before scientists are aware of these changes (McClenachan et al. 2020). The time scale over which individuals are drawing on in construction of their mental models may also differ. Fishers perceive change within a time window that corresponds with their career, whereas scientists have access to data spanning longer but often focus on small and recent section of this time frame (Verweij et al. 2010). Therefore, fishers may be averaging the effects of warming waters over two or more decades, while scientists focused on recent extreme warming trends.

Second, differences in processing and evaluating available information exist between the two groups. That is, even confronted with the same information, differences in how this information is processed and evaluated can lead to perception differences (Verweij et al. 2010). For example, scientists are more accustomed to graphically displayed data than are fishers. This difference may account for the differential value placed on warming waters, as scientists may be consciously or unconsciously drawing from graphs of increasing CO_2 and temperatures in forming their mental models. Likewise, scientists tend to value aggregated or modeled data, whereas fishers instead highlight differences in local conditions, often discounting aggregated data as not applicable in their location. For example, in North Sea fisheries, fishers indicated that time series were not valuable because they perceived spatial variation to be extremely large and unpredictable (Verweij et al. 2010). In the Maine lobster fishery, devaluation of time series data could be responsible for fishers' discounting warming waters as connected to climate change, as they focus instead on local differentiated and year-to-year fluctuations (McClenachan et al. 2020). On the other hand, a recent review of ecological studies showed a tendency to focus on a single hypothesis, rather than explore multiple hypotheses (Betini et al. 2017), implying a potential cognitive bias among scientists that could reinforce the focus on a single consensus explanation.

Third, differences in cognitive resonance (Verweij et al. 2010), which is closely related to confirmation bias (Hart et al. 2009), exist between the two groups. As noted above, different perceptions of the impact of fisheries on fish populations likely impact the ways in which fishers and scientists construct their mental models. The scientific literature is full of research on overfishing (Pauly et al. 1998; Jackson et al. 2001; Steneck and Pauly 2019; Howarth et al. 2014), and scientists may be drawing on examples from other locations in forming their views of the top-down effects of fishing. In contrast, fishers' lived experience involves daily baiting of lobster traps, which likely shaped their view of bait as important in the overall life history of lobsters.

4.5. Implications of differing mental models

These differences have implications for adaptation and management within this co-managed fishery. Fishing practices, for example, both through use of bait and through harvesting, is an area where differing mental models could lead to different approaches to adaptation. The main tool for scientifically based fishery management is to try to control levels of fishing effort, i.e., top-down. In contrast, the fishery has some degree of control over what quantities and types of bait to use, i.e., bottom-up. If the mental models of the two groups differ, there is potential for the approaches to adaptation to conflict, with fishers focused more on importance of maintaining a consistent supply of bait and scientists prioritizing measures aimed managing extraction, such as size limitations.

This divergence has the potential to undermine the previously successful co-management structure as warming becomes more pronounced and the system enters no-analogue conditions. In this case, knowledge co-production could help to bring these worldviews into alignment. Knowledge co-production is described by Cooke et al. (2020) as "the contribution of multiple knowledge sources and perspectives from different stakeholders with the goal of co-creating knowledge and information to inform fisheries management and conservation," and is being increasingly employed in applications ranging from Arctic fisheries in Nunavut, to recreational catch-and-release fisheries, to managing invasive carp in the Mississippi Basin. Underlying principles such as reciprocity, inclusivity, and the joint ownership of research could help to align mental models, ideally making adaptation strategies more effective.

In the Maine lobster fishery, there are multiple opportunities for scientists and fishers to exchange and co-generate knowledge. For example, the annual Fisherman's Forum provides an avenue for information exchange among various stakeholder groups. The media also plays an important role in information exchange, with frequent coverage of the lobster industry concerns and relevant scientific knowledge. Over the past two decades, there has been an increasing movement toward knowledge co-production, as scientists and policy makers have worked to engage with lobster fishers within the context of the evolving co-management system. Today, scientists involved with the lobster fishery in Maine often rely on interactions with fishers to identify questions and collaborate to execute research. While there are multiple opportunities for fishers to engage in information exchange with scientists, there are many more licensed lobster fishers than there are scientists, and individual levels of engagement among Maine lobster fishers vary substantially (J.W., personal observation, K. Reardon, personal communication, 2021). Therefore, while co-management has laid a solid foundation for information exchange, increasing opportunities for knowledge co-production across multiple aspects of ecological knowledge—from the formation of questions to the collection of data ultimately to the building of mental models—would ideally yield a more coordinated effort for adaptation and sustainability.

Finally, it is worth noting, that coastal Maine is a complex ecosystem with rapidly changing human uses. In the two years that separate the two surveys, lobster landings remained high, and there were no major changes in regulations. However, in the short time since these surveys were conducted, a series of major changes have occurred that would likely affect the mental models of both scientists and fishers. For example, climate-driven oceanographic changes have altered the migration routes of the North Atlantic right whale (*Eubalaena glacialis*) population (Record et al. 2019), leading to contentious management decisions that have affected the Maine lobster fishery. Specifically, in December 2020 and January 2021, the National Oceanographic and Atmospheric Administration issued two documents aimed at reducing right whale entanglement risk with lobster fisheries in the Northeast region and across federal fisheries (NOAA 2020; NMFS 2021). Another emerging issue is the development of offshore wind in the Gulf of Maine, with ongoing conversations with stakeholder groups about potential effects of this technology on impacted species, fisheries, and surrounding environment. Similarly, the developments in coastal aquaculture, as well as recent political maneuvering, such as the lobster tariffs of 2018, have the potential to alter perceptions. Finally, COVID-19 has impacted these fisheries. For example, impacts on seafood markets in 2020 provided further points of stress for Maine lobster fishers and the lobster supply chain (Smith et al. 2020). Taken together it is likely that the events of the year following this survey have likely shifted industry and researcher perceptions of the environment, the Maine lobster fishery and managers at the state, regional, and federal levels. Repeating a mental modeling study, coupled with more in-depth interviews, would help to identify the relative importance of these conflicts in shaping the worldviews of key stakeholder groups, as well as to distinguish short-term year-to-year changes in perceptions from persistent shifting baselines. Using the results presented here as a baseline, the "mental model" framework could provide a valuable tool to assess the impact of these large-scale events on both the research and commercial fishing community associated with the most valuable single-species fishery in the country.

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Author contributions

LM, NRR, and JW conceived and designed the study. LM performed the experiments/collected the data. LM and NRR analyzed and interpreted the data. JW contributed resources. LM, NRR, and JW drafted or revised the manuscript.

Competing interests

The authors have declared that no competing interests exist.

Data availability statement

All relevant data are within the paper.

References

Acheson J. 2013. Co-management in the Maine lobster industry: A study in factional politics. Conservation and Society, 11(1): 60–71. DOI: 10.4103/0972-4923.110936

Acheson J, and Gardner R. 2014. Fishing failure and success in the Gulf of Maine: Lobster and groundfish management. Maritime Studies, 13: 1–21. DOI: 10.1186/2212-9790-13-8

Acheson JM, and Steneck RS. 1997. Bust and then boom in the Maine lobster industry: Perspectives of fishers and biologists. North American Journal of Fisheries Management, 17: 826–847. DOI: 10.1577/1548-8675(1997)017<0826:BATBIT>2.3.CO;2

Aksnes DW, and Browman HI. 2016. An overview of global research effort in fisheries science. ICES Journal of Marine Science, 73(4): 1004–1011. DOI: 10.1093/icesjms/fsv248

Berkes F. 2009. Evolution of co-management: role of knowledge generation, bridging organizations and social learning. Journal of Environmental Management, 90(5): 1692–1702. PMID: 19110363 DOI: 10.1016/j.jenvman.2008.12.001

Betini GS, Avgar T, and Fryxell JM. 2017. Why are we not evaluating multiple competing hypotheses in ecology and evolution? Royal Society Open Science, 4(1): 160756. PMID: 28280578 DOI: 10.1098/rsos.160756

Biernacki P, and Waldorf D. 1981. Snowball sampling: problems and techniques of chain referral sampling. Sociological Methods & Research, 10: 141–163. DOI: 10.1177/004912418101000205

Boudreau SA, Anderson SC, and Worm B. 2015. Top-down and bottom-up forces interact at thermal range extremes on American lobster. Journal of Animal Ecology, 84(3): 840–850. DOI: 10.1111/1365-2656.12322

Boudreau SA, and Worm B. 2010. Top-down control of lobster in the Gulf of Maine: Insights from local ecological knowledge and research surveys. Marine Ecology Progress Series, 403: 181–191. DOI: 10.3354/meps08473

Cooke S, Nguyen VM, Chapman JM, Reid AJ, Landsman SJ, Young N, et al. 2020. Knowledge co-production: a pathway to effective fisheries management, conservation, and governance. Fisheries, 46(2): 89–97. DOI: 10.1002/fsh.10512

Daw TM, Robinson J, and Graham NA. 2011. Perceptions of trends in Sechelles artisanal trap fisheries: comparing catch monitoring, underwater visual census, and fishers' knowledge. Environmental Management, 38(1): 75–88.

Dietz T, Ostrom E, and Stern PCP. 2003. The struggle to govern the commons. Science, 302: 1907–1912. PMID: 14671286 DOI: 10.1126/science.1091015

Drinkwater KF, Harding GC, Mann KH, and Tanner N. 1996. Temperature as a possible factor in the increased abundance of American lobster, *Homarus americanus*, during the 1980s and early 1990s. Fisheries Oceanography, 5(3–4): 176–193. DOI: 10.1111/j.1365-2419.1996.tb00116.x

Druckman JN, and McGrath MC. 2019. The evidence for motivated reasoning in climate change preference formation. Nature Climate Change. DOI: 10.1038/s41558-018-0360-1

Goode AG, Brady DC, Steneck RS, and Wahle RA. 2019. The brighter side of climate change: how local oceanography amplified a lobster boom in the Gulf of Maine. Global Change Biology, 25(11): 3906–3917. PMID: 31344307 DOI: 10.1111/gcb.14778

Grabowski JH, Clesceri EJ, Baukus AJ, Gaudette J, Weber M, and Yund PO. 2010. Use of herring bait to farm lobsters in the Gulf of Maine. PLoS ONE, 5(4): e10188. PMID: 20419167 DOI: 10.1371/journal.pone.0010188

Grafton RQ. 2010. Adaptation to climate change in marine capture fisheries. Marine Policy, 34(3): 606–615. DOI: 10.1016/j.marpol.2009.11.011

Gray SA, Gray S., De Kok JL, Helfgott AER, O'Dwyer B, Jordan R, and Nyaki A. 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(2): 11. DOI: 10.5751/ES-07396-200211

Harmon-Jones E, and Harmon-Jones C. 2007. Cognitive dissonance theory after 50 years of development. Zeitschrift für Sozialpsychologie, 38(1): 7–16.

Hart W, Albarracín D, Eagly AH, Brechan I, Lindberg MJ, and Merrill L. 2009. Feeling validated versus being correct: a meta-analysis of selective exposure to information. Psychological Bulletin, 135(4): 555–588. PMID: 19586162 DOI: 10.1037/a0015701

Henry AM, and Johnson TR. 2015. Understanding social resilience in the Maine lobster industry. Marine and Coastal Fisheries, 7: 33–43. DOI: 10.1080/19425120.2014.984086

Holt CA, and Punt AE. 2009. Incorporating climate information into rebuilding plans for overfished groundfish species of the U.S. west coast. Fisheries Research, 100(1): 57–67. DOI: 10.1016/j.fishres.2009.03.002

Howarth LM, Roberts CM, Thurstan RH, and Stewart BD. 2014. The unintended consequences of simplifying the sea: making the case for complexity. Fish and Fisheries, 15(4): 690–711. DOI: 10.1111/faf.12041

Jackson JBC, Kirby MX, Berger WH, Bjorndal KA, Botsford LW, Bourque BJ, et al. 2001. Historical overfishing and the recent collapse of coastal ecosystems. Science, 293(5530): 629–637. PMID: 11474098 DOI: 10.1126/science.1059199

Jones K, and Seara T. 2020. Integrating stakeholders' perceptions into decision making for ecosystem-based fisheries management. Coastal Management, 48(4). DOI: 10.1080/08920753.2020.1773211

Le Bris A, Mills KE, Wahle RA, Chen Y, Alexander MA, Allyn AJ, et al. 2018. Climate vulnerability and resilience in the most valuable North American fishery. Proceedings of the National Academy of Sciences of the United States of America, 115(8): 1831–1836. DOI: 10.1073/pnas.1711122115

Mackinson S, and Wilson DCK. 2014. Building bridges among scientists and fishermen with participatory action research. *In* Social issues in sustainable fisheries management. Springer. pp. 121–139.

Maine Department of Marine Resources. 2021. Maine Department of Marine Resources, Commercial Landings. Available at: maine.gov/dmr/commercial-fishing/landings/historical-data.html.

McClenachan L, Grabowski JH, Marra M, McKeon CS, Neal BP, Record NR, and Scyphers SB. 2019. Shifting perceptions of rapid temperature changes' effects on marine fisheries, 1945–2017. Fish and Fisheries, 20: 1111–1123. DOI: 10.1111/faf.12400

McClenachan L, Scyphers S, and Grabowski JH. 2020. Views from the dock: warming waters, adaptation, and the future of Maine's lobster fishery. Ambio, 49(1): 144–155. PMID: 30852777 DOI: 10.1007/s13280-019-01156-3

Mills K, Pershing AJ, Brown CJ, Chen Y, Chiang F-S, Holland DS, et al. 2013. Fisheries management in a changing climate: lessons from the 2012 ocean heat wave in the northwest Atlantic. Oceanography, 26(2): 191–195. DOI: 10.5670/oceanog.2013.27

NMFS. 2021. Draft biological opinion on 10 fishery management plans released. Available from fisheries.noaa.gov/bulletin/draft-biological-opinion-10-fishery-management-plans-released.

NOAA. 2020. Draft environmental impact statement: ALWTRP risk reduction rule.

Oppenheim N, Wahle RA, Brady DC, Goode AG, and Pershing AJ. 2019. The cresting wave: larval settlement and ocean temperatures predict change in the American lobster harvest. Ecological Applications, 29(8). DOI: 10.1002/eap.2006

Özesmi U, and Özesmi SL. 2004. Ecological models based on people's knowledge: a multi-step fuzzy cognitive mapping approach. Ecological Modeling, 176(1): 43–64. DOI: 10.1016/j.ecolmodel.2003.10.027

Pauly D, Christensen V, Dalsgaard J, and Froese RM. 1998. Fishing down marine food webs. Science, 279(5352): 860–863. PMID: 9452385 DOI: 10.1126/science.279.5352.860

Pershing AJ, Alexander MA, Hernandez CM, Kerr LA, Le Bris A, Mills KE, et al. 2015. Slow adaptation in the face of rapid warming leads to collapse of the Gulf of Maine cod fishery. Science, 350: 809–812. PMID: 26516197 DOI: 10.1126/science.aac9819

Prigent M, Fontenelle G, Rochet MJ, and Trenkel V. 2008. Using cognitive maps to investigate fishers' ecosystem objectives and knowledge. Ocean and Coastal Management, 51(6): 450–462. DOI: 10.1016/j.ocecoaman.2008.04.005

Record NR, Runge JA, Pendleton DE, Balch WM, Davies KTA, Pershing AJ, et al. 2019. Rapid climate-driven circulation changes threaten conservation of endangered north Atlantic right whales. Oceanography, 32(2): 162–169. DOI: 10.5670/oceanog.2019.201

Record N, and Vera L. 2021. Uncovering big data bias in sustainability science. *In Spire: the Maine journal of conservation and sustainability*. DOI: 10.13140/RG.2.2.28533.65761

Roberts CM, and Hawkins JP. 1999. Extinction risk in the sea. Trends in Ecology and Evolution. DOI: 10.1016/S0169-5347(98)01584-5

Rochet MJ, Prigent M, Bertrand JA, Carpentier A, Coppin F, Delpech JP, *et al*. 2008. Ecosystem trends: evidence for agreement between fishers' perceptions and scientific information. ICES Journal of Marine Science, 65(6): 1057–1068. DOI: 10.1093/icesjms/fsn062

Rose GA. 2004. Reconciling overfishing and climate change with stock dynamics of Atlantic cod (*Gadus morhua*) over 500 years. Canadian Journal of Fisheries and Aquatic Sciences, 46(1): 69–73. DOI: 10.1139/F04-173

Scholz A, Bonzon K, Fujita R, Benjamin N, Woodling N, Black P, and Steinback C. 2004. Participatory socioeconomic analysis: drawing on fishermen's knowledge for marine protected area planning in California. Marine Policy, 28(4): 335–349. DOI: 10.1016/j.marpol.2003.09.003

Smith S, Golden AS, Ramenzoni V, Zemeckis DR, and Jensen OP. 2020. Adaptation and resilience of commercial fishers in the Northeast United States during the early stages of the COVID-19 pandemic. PLoS ONE, 15(12): e0243886. PMID: 33332383 DOI: 10.1371/journal.pone.0243886

Steneck RS, Hughes TP, Cinner JE, Adger WN, Arnold SN, Berkes F, et al. 2011. Creation of a gilded trap by the high economic value of the Maine lobster fishery. Conservation Biology, 25: 904–912. PMID: 21797925 DOI: 10.1111/j.1523-1739.2011.01717.x

Steneck RS, and Pauly D. 2019. Fishing through the Anthropocene. Current Biology. DOI: 10.1016/j.cub.2019.07.081

Steneck RS, and Wahle RA. 2013. American lobster dynamics in a brave new ocean. Canadian Journal of Fisheries and Aquatic Sciences. DOI: 10.1139/cjfas-2013-0094

Verweij MC, Densen WLT, and Mol AJP. 2010. The tower of Babel: Different perceptions and controversies on change and status of North Sea fish stocks in a multi-stakeholder setting. Marine Policy, 34: 522–533. DOI: 10.1016/j.marpol.2009.10.008

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

Worm B, Hilborn R, Baum JK, Branch TA, Collie JS, Costello C, et al. 2009. Rebuilding global fisheries. Science, 325(5940): 578–585. PMID: 19644114 DOI: 10.1126/science.1173146