Adaptive Capacity of the Maine Lobster Fishery: Insights from the Maine Fishermen's Climate Roundtables

Ellie Mason

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Committee:

Anne H. Beaudreau

Phillip S. Levin

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University of Washington

Abstract

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Ellie Mason

Chair of the Supervisory Committee:

Anne H. Beaudreau

School of Marine and Environmental Affairs

Climate change is altering the abundance and distribution of fish stocks globally, resulting in changes in catchability and availability to commercial fisheries. The Gulf of Maine in the northwestern Atlantic Ocean is considered one of the world's fastest warming marine regions and supports major commercial groundfish and shellfish fisheries in the U.S. Concomitant changes in ocean conditions affect growth, survival, distribution, and health of marine organisms; these include American lobster (*Homarus americanus*), which supports important fisheries in Maine. Lobster licenses are held in every coastal and island town in Maine and the lobster fishery contributed $391 million to Maine's economy in 2022. Beyond economic value, lobster fishing holds cultural significance to coastal Maine communities. In this study, we examined the social-ecological domains of adaptive capacity in the Maine lobster fishery using

insights from the Maine Fishermen's Climate Roundtables. We examined these records to address the following questions: (1) What oceanographic and ecological changes have fishermen observed over the last 15 years? (2) How are fishermen responding to these observed changes, as well as other pressures the fishery is experiencing? Fishermen reported an overall shift in lobster biomass further east and offshore, resulting in strategic expansion of fishing seasons and geographic locations as a response. Shifts in biomass were thought to be connected to increases in sea surface and bottom temperature, decreases in salinity, a shift in the Eastern Maine Coastal Current, and a loss of historic lobster predator species. Fisheries learning exchanges, such as the Climate Roundtables, create social networks that foster continued knowledge sharing beyond the event as well as an opportunity to build more effective participatory conservation strategies that in turn support the continued viability of local livelihoods.

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Climate change is altering the abundance and distribution of fish stocks globally, resulting in changes in catchability and availability to commercial fisheries. The Gulf of Maine in the northwestern Atlantic Ocean is considered one of the world's fastest warming marine regions and supports major commercial groundfish and shellfish fisheries in the U.S. Concomitant changes in ocean conditions affect growth, survival, distribution, and health of marine organisms; these include American lobster (*Homarus americanus*), which supports important fisheries in Maine. Lobster licenses are held in every coastal and island town in Maine and the lobster fishery contributed $391 million to Maine's economy in 2022. Beyond economic value, lobster fishing holds cultural significance to coastal Maine communities. In this study, we examined the social-ecological domains of adaptive capacity in the Maine lobster fishery using insights from the Maine Fishermen's Climate Roundtables. We examined these records to address the following questions: (1) What oceanographic and ecological changes have fishermen observed over the last 15 years? (2) How are fishermen responding to these observed changes, as well as other pressures the fishery is experiencing? Fishermen reported an overall shift in lobster biomass further east and offshore, resulting in strategic expansion of fishing seasons and geographic locations as a response. Shifts in biomass were thought to be connected to increases in sea surface and bottom temperature, decreases in salinity, a shift in the Eastern Maine Coastal Current, and a loss of historic lobster predator species. Fisheries learning exchanges, such as the Climate Roundtables, create social networks that foster continued knowledge sharing beyond the

event as well as an opportunity to build more effective participatory conservation strategies that in turn support the continued viability of local livelihoods.

Introduction

Climate change is altering the abundance and distribution of fish stocks globally (Bell et al. 2020), resulting in changes in catchability and availability to commercial fisheries (Maltby et al. 2021, Barange et al. 2019, Sainsbury et al. 2018). The Gulf of Maine in the northwestern Atlantic Ocean is considered one of the world's fastest warming marine regions (Saba et al. 2016, Pershing et al. 2015) and supports major commercial groundfish and shellfish fisheries in the U.S. (Corre et al. 2020, Johnson et al. 2014, Brewer 2011). The last ten years have shown an increase in the rate of warming in the Gulf of Maine compared to previous decades (Seidov et al 2021, Shearman and Lentz 2010). Additionally, future projections of sea surface temperature indicate the Gulf of Maine as a continued hotspot of warming that could experience temperature increases two to three times greater than the global mean ocean temperature (Saba et al. 2016). Coastal Maine, USA, is also experiencing more intense and frequent rainfall and storm events, an overall increase in summer through fall precipitation, a decrease in river ice and ice thickness, a shift earlier in the spring freshet (snowmelt), and an increase in dry spells in the summer months (Staundinger et al 2019). Concomitant changes in ocean conditions affect growth, survival, distribution, and health of marine organisms (Staundinger et al 2019, Henderson et al. 2017); these include American lobster (*Homarus americanus*), which supports important fisheries in Maine (Staudinger et al. 2019, Mills et al. 2013).

Changes in ocean conditions have affected lobster population dynamics and health along the coast of the northeastern U.S. Shifts in lobster phenology have been linked to increases in sea surface temperature (Heimann et al. 2017). Warming waters have the potential to produce a

higher abundance of smaller, fecund lobsters through effects on molting probability and size at maturity (Hodgdon et al. 2022) and can impact the settlement of lobster larvae (Lopez-Anido et al. 2021, Staudinger et al. 2019). Temperature threshold studies for lobster larvae settlement found that increased temperature and simulated heat "shock" events led to observed stress responses in the larvae (Lopez-Anido et al. 2021, Chiasson et al. 2015). Associations between warming water and Epizootic Shell Disease (ESD) have also been observed, particularly in Southern New England (Reardon et al. 2018). Increased temperatures have led to a stock collapse of Southern New England lobster while expanding suitable habitat for lobsters in the Gulf of Maine (Goode et al. 2019, Reardon et al. 2018, LeBris 2017, ASMFC 2020). Warming events have also extended fishing seasons, with a lengthening of the summer season associated with a larger stock biomass in Gulf of Maine waters during the fall (Henderson et al. 2017). A 2012 marine heatwave in the Gulf of Maine warmed waters three weeks earlier than historical temperatures, yielding higher lobster fishery landings in June and July than in previous seasons (Mills et al. 2013). Fall landings also were markedly higher in 2012, resulting from a delayed onset of seasonal cooling (Mills et al. 2013). Mills et al. (2013) also found that abnormally high water temperatures in 2012 were associated with lobster molting, inshore migration, and higher activity levels, which led to a more active inshore fishery that year.

In addition to climate change, the Maine lobster fishery is facing environmental, economic, and regulatory pressures that have the potential to impact fishery resiliency and adaptive capacity. These include, but are not limited to, bait shortages and increased cost of bait (Brewer 2012, McClenachan et al. 2020, Stoll et al. 2022), barriers to diversification into other fisheries (Brewer 2013, Brewer 2012, McClenachan et al. 2020, Stoll et al. 2017, Pershing et al. 2015, Hall-Arber et al. 2001, Johnson et al. 2014), interactions between right whales and the

lobster fleet (Myers and Moore 2020, Willse et al. 2022), trap and entry limits to the fishery (McChlenachan et al. 2019, Brewer 2012), and gear saturation in inshore waters resulting in tangles (Brewer 2013). These changes have implications for coastal communities with strong reliance on lobster fisheries.

Lobster licenses are held in every coastal and island town in Maine (Island Institute 2018) and the lobster fishery contributed $391 million to Maine's economy in 2022 (DMR 2023). Beyond economic value, lobster fishing holds cultural significance to coastal Maine communities. Many fishermen consider fishing to be a part of their individual social identity (Johnson et al. 2014) as well as an integral part of community identity and function (Brewer 2013). In a 2013 study that highlighted voices of Maine fishermen, many felt that a fishery was only successful if it could support the broader community (Brewer 2013), especially in Downeast Maine, the easternmost region of the coast where communities are relatively rural, remote, and rely primarily on fishing and fishing-related businesses (Johnson et al. 2014). In these small communities, relationships are often interdependent and mutual support systems exist without formal organization (Brewer 2012, Brewer 2013, Johnson et al. 2014). However, governments have recognized the need for policies to support resilience of fisheries and fishing communities and helping marine resources and resource users increase adaptive capacity to changing ocean conditions (NOAA 2021). Definitions of adaptive capacity in fisheries social-ecological systems vary; a useful way to conceptualize it in the context of lobster fisheries is the capacity of an individual, household, or community to respond to social or environmental changes within their local system (Green et al. 2021, ICPCC 2014), such that key elements of the structure, function, and identity of the fishery are retained (Cinner and Barnes 2019). The capacity for a fishery to adapt depends on a range of attributes (i.e., domains of adaptive capacity), such as diversity and

flexibility, access to assets, learning and knowledge, governance and institutions, and natural capital (Green et al. 2021).

In this study, we examined the social-ecological domains of adaptive capacity (Green et al. 2020) in the Maine lobster fishery through the lens of fifteen years of fishermen's knowledge and shared experiences. Although many other studies have explored the changing social-ecological landscape of the Maine lobster fishery (McClenachan et al. 2020, Brewer 2012, Brewer 2013, Johnson et al. 2014, Stoll et al. 2017, Stoll et al. 2022), this research makes a novel contribution by using a unique dataset: oral records obtained from the Maine Fishermen's Climate Roundtable. Hosted by the Island Institute, a nonprofit organization focused on Maine coastal and unabridged island community development, the Maine Fishermen's Climate Roundtable is an annual event that has taken place since 2007. This event brings together lobstermen and Maine lobster and climate scientists to informally discuss observations of long-term ecological and fishery-related changes in the Gulf of Maine. We examined these records to address the following questions:

1. What oceanographic and ecological changes have fishermen observed over the last 15 years?
2. How are fishermen responding to these observed changes and other pressures to the fishery and what fishing strategies are they employing as a result?

We then used a framework developed by Green et al. (2021) for small-scale fisheries to evaluate domains of adaptive capacity and implications for resilience of the Maine lobster fishery.

Methods

Maine Fishermen's Climate Roundtable records

In 2007, the Island Institute, a non-profit organization based in Rockland, ME, hosted the first Maine Fishermen's Climate Roundtable (hereafter, Climate Roundtable). Continuing annually, the Climate Roundtable is an informal gathering of Maine fishermen and scientists to discuss observed long-term ecological changes occurring in the Gulf of Maine as well as new and relevant lobster and climate research. All fishermen participants hold state lobster fishery licenses and fish lobster, but many participants have also fished other Gulf of Maine species throughout their careers and hold federal lobster permits. Each Climate Roundtable hosted 10 fishermen on average. Between 2007-2021, one fisherman attended more than 10 years, eight attended between 5-9 years, eighteen attended between 2-4 years, and 23 fishermen participated in only one year. Between the years 2007-2021, 50 individual fishermen attended the Climate Roundtables. Non-fishing participants include scientists from the Maine Department of Marine Resources (DMR) as well as local nonprofits and academic institutions. Occasionally, participants included other fishermen from outside Maine (e.g., Prince Edward Island, Southern California).

The Climate Roundtable is an all-day event that includes multiple sessions. A typical structure includes a morning session (1-3 hours) in which fishermen recount the previous year's fishing season. Conversations range from offshore observations to ex-vessel prices and any other pressing topics of importance. This is usually followed by a lunch break before reconvening for an afternoon session that consists of multiple, shorter presentations on relevant research in the Gulf of Maine. Audio recordings of Climate Roundtable discussions are maintained and archived by the Island Institute. We were granted permission by the Island Institute, with assent from Climate Roundtable participants, to use the recordings for this study with the understanding that we would maintain files in a secure drive shared only with the research team and remove

identifying information about participants from data summaries. The lead author shared preliminary results with Island Institute staff and incorporated their feedback into further analysis and revision. The use of Climate Roundtable records was also reviewed and approved by the University of Washington's Institutional Review Board (IRB ID: 00017196).

For the purpose of this study, content analysis of Climate Roundtable recorded sessions focused on the informal morning conversations and did not include afternoon research presentations. Morning sessions in all years from 2007 to 2021 were transcribed for analysis except 2010 and 2012 for which there were no audio recordings available. Starting conversation topics varied from year to year, depending on who was facilitating the Climate Roundtable, and the open-ended discussions were generally led by the fishermen themselves once started.

Within the results section, the term "fishermen" is used to describe Climate Roundtable participants who currently participate in the lobster fishery. This choice reflects the language that the men and women from the Climate Roundtables used to describe themselves.

Thematic analysis and domains of adaptive capacity

Transcripts were read closely and initially coded inductively by the lead author based on emerging themes (Braun and Clarke 2006). The codebook was revised iteratively through discussions with other authors. Basic themes of ecological changes and oceanographic changes were grouped into a broader organizing theme of changing ocean conditions (Attride-Stirling 2001). Ecological changes included codes for observations of species emerging or disappearing, and lobster-specific changes in biomass, health, size, and sex. A separate set of inductive codes was generated to track stressors and pressures identified by fishermen, as well as their concerns and responses.

We then used deductive coding based on an existing framework of adaptive capacity domains in small-scale fisheries to assess fishermen responses and strategies to stressors and pressures and their ability to adapt, react, or cope to changing ocean conditions (Green et al. 2021). Green et al. (2021) identified five domains of adaptive capacity: diversity and flexibility, access to assets, learning and knowledge, governance and institutions, and natural capital. Ability to respond to stressors in a social-ecological system can then be tracked as either adding capacity to one of the domains or taking away capacity from a domain. For example, if a fisherman has the ability to fish in a new location as species shift due to warming waters, that response would be categorized as adding to the diversity and flexibility domain of adaptive capacity. Subsequently, higher capacity across the five domains would facilitate an easier pathway towards an "adapt" response, or "proactive planning of individual or collective actions based on knowledge of past or anticipated future environmental change" (Green et al. 2021, Bennett et al. 2014). Lower capacity across the domains might necessitate a "react" ("an unplanned response to a stressor or change") or "cope" ("to passively accept the consequence of an environmental stressor") response (Green et al. 2021).

Results

Overview

Fishermen residing in Maine's three coastal regions—Southern (Kittery to Boothbay Harbor), Midcoast (South Bristol to Stonington), and Downeast (Mount Desert Island to Lubec)—participated in the Climate Roundtables, with most coming from Midcoast regions. All fishermen in the Climate Roundtables were lobster fishermen, but many had held or continue to hold other fishery permits such as scallop, groundfish, shrimp, and alewife. Many fishermen come from a multi-generational fishing family and grew up in the areas in which they currently

live and fish. The results that follow are structured in three main sections: 1) fishermen's observations of environmental change from 2007-2021, separated into three primary categories of oceanography, lobster biology, and other ecological changes; 2) pressures identified by fishermen that are impacting the lobster fishery; and 3) a synthesis of fishermen's responses to these changes within the domains of adaptive capacity.

1. Observations of environmental change

Oceanographic changes— Observed oceanographic changes included higher sea surface and bottom temperatures, a decrease in salinity attributed to freshwater lenses that form on the ocean's surface after rain events, unusual and increased storm events, and a shifting of the Eastern Maine Coastal Current. Discussion centering around ocean temperatures occurred in 11 out of the 13 years that were analyzed and was one of the core themes that emerged from the Climate Roundtables. During the first three years of the Climate Roundtables, fishermen indicated reluctance to attribute any ecological changes in the Gulf of Maine to warming waters or a changing climate. For example, one fisherman commented that "I haven't seen any changes that I contribute to climate" (CRT 2007), while another fisherman attributed changes to direct human impacts on the ocean, explaining, "…any changes I've seen, I think it's been man's impact on the resource and the environment, not so much the environment's impact" (CRT 2007). That mindset gradually shifted to a deeper understanding of changing water temperatures and its impact on the fishery. The Northwest Atlantic also experienced a heat wave in 2012 (Mills et al. 2013) which shaped much of the conversations in the Climate Roundtables in the years thereafter. There were many instances in years after 2012, of fishermen directly referencing specific water temperatures that they had observed while fishing, either by referencing Gulf of Maine Ocean Observing System (GoMOOS;

https://tidesandcurrents.noaa.gov/gomoos.html) buoy data or through temperature probes they set themselves as part of the Environmental Monitors on Lobster Traps (eMOLT; https://www.emolt.org) study. eMOLT facilitates research through a collaboration between lobstermen and the Gulf of Maine Lobster Foundation in partnership with the Northeast Fisheries Science Center. This is exemplified in a 2019 exchange among Climate Roundtable participants about their findings resulting from original data collection:

> Speaker 1: And it's cold right now, but I've been keeping track of the water temperature for 40 years. And we didn't see, back in the early '80s, hardly any days it was 60-degree Fahrenheit in this area. I mean, you'd see one or two in the summertime. And in 2012 we had water temperature where I was, from the Fourth of July 'til the 20th of October, over 60 degrees Fahrenheit. That is a huge, huge difference!
> Speaker 2: I see it on bottom. I've been doing that eMOLT down off [place name] and I see it isn't—this is out in 43 fathom—and it isn't just that the peak is going up. The width of the graph is getting a lot bigger. It's getting warmer earlier and it's staying warmer later. That peak isn't going up more than a degree or degree and a half. But that length of time that it's staying warmer is going up dramatically. So I've been doing it for 12 or 14 years down there now.
> Speaker 3: The top or the top and the bottom?
> Speaker 2: Down at the bottom, is where I've got– 43 fathom, I've had one there now for 12 or 14 years.

Another prominent oceanographic theme related to shifts in the eastern Maine coastal current (EMCC). In 2016, Climate Roundtable participants discussed the directional change of the EMCC, with one Midcoast fisherman noting, "I think current around where you are and where we are is changed, at least from what I've seen. It's changed in the last 10 or 15 years. And now it's coming more like, comes out of the East almost all day long. It never used to do that… And I don't know if that's coastwide or just there. But I think that the eastern Maine coastal current changed." Multiple fishermen contributed to the conversation, sharing their own observations about the shifting EMCC.

Notably, conversations about ocean acidification and its potential impact on lobsters, did not become a topic of discussion until 2015 (Figure 1). Ocean acidification was not directly observed by fishermen, but it became an issue of concern in 2015-2017 and garnered interest from fishermen as a topic for further research. Increased interest in these years could be attributed to the formation of an Ocean Acidification Commission by the State of Maine Legislature in 2015, which specifically included Maine fishermen as a part of the commission. As one fisherman explained, "I think one of the parts of this equation that always has intrigued me is, I mean, it's easy to look at the amount of lobsters and female V-notches we have and on egg production we have, but it's with ocean acidification, freshening of the Gulf of Maine, the critical plankton levels that it takes for a small lobster to be able to live on through its first couple of stages. You know, I'd like to understand a little bit more about that side of the research." V-notches refer to the conservation measure where fishermen must notch a small V in the tail of a female lobster with visible eggs if she is caught. This individual must then be thrown back overboard and subsequently cannot be harvested by any other fisherman if the V-notch is still visible. Discussions about ocean acidification often focused on the lack of data and research available on the impact of ocean acidification on lobster populations and the desire amongst fishermen to generate that research for their own knowledge and understanding of future impacts.

Lobster biology and population changes— Changes specific to lobster biology and population dynamics fell into three main categories: body size changes, shell disease prevalence, and shifts in biomass and distribution. Nearly all the Climate Roundtable years included conversations centering observations around an increase in "shorts", or lobsters that were caught in traps that fell below the minimum size requirement (Figure 1). In 2018, one fisherman noted

that they had seen “a lot more little, tiny damned lobsters. I normally get 2 or 3 a year that get caught in the bridge and I had one in damn near every string this year over the course of the year.” Observations of shorts were made in earlier years of the Climate Roundtable as well, as noted by a participant in 2011: “I’d say we threw overboard—even though we had a phenomenal year—as many lobsters as we caught every day, if not double that. We had shorts that we’ve never seen, never seen so many shorts before. Just half a dozen every trap, no matter what, for every two keepers we're at least throwing half a dozen shorts.”

Changes in size were often connected with observations about undersized female “eggers” (i.e., egg-bearing females that were caught at a size below the minimum size requirement). This was a stand-out observation for many fishermen due to the historical understanding that a female lobster needed to have grown to at least the minimum size requirement before she could become a reproducing individual, as illustrated in a 2017 discussion. Here, a “measure” refers to the size gauge used by lobstermen to measure each caught lobster. Lobsters must be longer than the minimum gauge measurement and shorter than the maximum gauge measurement to be kept in the Maine lobster fishery.

> Speaker 1: And how about small egg lobsters? I've caught a lot, but the measure would go down over beyond the first section of the tail.
> Speaker 2: Just ask the scientists, he'll tell you that's impossible!
> Speaker 3: Around here they used to say that was impossible. You couldn't have a sexually mature lobster that was smaller than the old small measure.
> Speaker 4: It's amazing. How many there are.

This observed increase in undersized females raised unanswered questions about the potential correlation between warming waters and size at maturity, as well as the patterns of settlement and how those have been changing over the years. Hypotheses were made that a potential change in the EMCC could influence where lobster larvae were settling, which would be associated with the increase in undersized lobsters being caught in lobster traps.

Alongside observations about undersized and short lobsters were observations about shell disease up and down the coast. Shell disease conversations ranged from discussions on what caused it, how prevalent it was in that fishing season, what it looked like on lobsters, and what size and sex of lobster had more instances of shell disease as illustrated in this exchange from 2013:

> Speaker 1: What time of year? Are you seeing differences in time of year? Or just in the summer?
> Speaker 2: No this is their season, but I bet the water was warmer than it was 10 years ago.
> Speaker 3: When I saw this shell disease was in mostly June and July and early August. And it was mostly pound and quarter, pound and half females. I'd never seen it like that before. Just before they shed.
> Speaker 4: Do you see many, [name]?
> Speaker 5: Almost every big old sized male no matter where you are, they hadn't shed in a long time. It's on all of them.
> Speaker 6: We had a run last spring outside that last July on the hard bottom that you'd just see big beautiful females coming in, not a nick of shell disease on them, just big beautiful female lobsters coming in and didn't have any issue there, but up inside you see quite a bit of shell disease.

Lastly, fishermen often discussed the shifting size and biomass of the lobster population. Fishermen reported a movement seen generally amongst the entire fleet from fishing in state waters for the majority of the year to fishing in offshore, federal waters for longer periods of time than historically observed. Two themes came out of these conversations: a shift in biomass to offshore and a shift in biomass to further Downeast. Fishermen noted that the 2013 season was the first year they had memories of lobstermen setting traps in offshore waters in the spring and then staying offshore all season. Historically, lobstering would begin offshore and move into nearshore state waters at the onset of summer months, when the lobsters shifted inshore. As demonstrated in this 2014 quote from a fisherman with over 40 years of fishing experience, being able to catch large amounts of lobsters offshore has led to conditions where it is now viable to remain offshore year-round: "Last year for the first time I've ever heard of guys that

usually fish [offshore] in the spring, were doing so well they just stayed there…And they would, I mean 2000 pound hauls on a three night set. Unheard of…That's unheard of where we are. I mean, that's totally unheard of." Fishermen expressed uncertainty about the size of the offshore biomass and concern about reliability of the settlement survey for predicting lobster biomass offshore because of its current limited extent in state waters. This issue was raised in 2016, in an exchange among three lobstermen:

> Speaker 1: My bet is if you were able to, when you did the settlement studies in deep water offshore 20 years ago, you probably wouldn't have seen little or none.
> Speaker 2: They did in 2008. They saw some but not much.
> Speaker 1: Whereas now if you were to do those sites, my bet is you'd see a significant amount.
> Speaker 2: It's possible but I mean, even for the sites that we're looking at now it's a difference of one lobster versus…
> Speaker 1: Well they have to be settling out there because little lobsters aren't going to travel from the inshore out 20 or 30 miles offshore.
> Speaker 3: There's something missing.

Again, in 2017, concerns were raised about the lack of data on the offshore component of the lobster population, as well as questions about the overall sustainability of the offshore fishery:

> Speaker 1: Well, that's the other thing. I mean, there's the elephant in the room. How big is the offshore, you know, biomass? I mean obviously, for what we see coming in it's big, but is it sustainable? I mean, as I mean, I know [name], you're starting to put collectors out there. But I'm hearing the guys, I'm seeing my kid, a couple of my kids are out there, their lobsters are this big out there, which that never was before. Obviously, there's not a lot of ground fish, I would say but what's going on? Is that a sustainable population? Or is that…?
> Speaker 2: Yeah, well, that's one of the big questions. So you know, there are two ways of thinking about that. Are those little guys settling out way up there? Or are they settling in shallow and moving out deep, and it's hard to imagine, some of these places are pretty far from shore.
> Speaker 3: Pretty good travelers at that size.
> Speaker 2: So, but the difference between those two scenarios has some really important implications for sustainability.

Fishermen also discussed an eastward shift in the biomass of the lobster population over the last 15 years. This observation was made in the first year of the Climate Roundtables in 2007:

"Of course the water temperature is warmer and the lobsters are coming east. Before long they're going to be by us, they'll be in Nova Scotia. As we warm up the lobsters are gone…Things are changing and it wouldn't surprise me if in 20 years we find out that we as a fishery have made wicked [big] mistakes." This shift in biomass is documented through historical state landings data, which is broken down into landings by county. In recent years, counties further Downeast have been landing the most lobster of all counties in the state compared to a decade ago where Midcoast counties consistently had the highest reported landings (DMR 2023).

Other ecological changes— Conversations about other ecological changes centered mostly on shifts in occurrence of Gulf of Maine species as well as the arrival of new species into the Gulf of Maine. Many fishermen had memories of prevalent species in the 1970s, 1980s, and 1990s that have since disappeared, such as dogfish, sea urchins, striped bass, and seahorses. Many of the species that have since disappeared were important to the lobster fishery, as they denoted seasonal cues for availability of harvestable lobster. This conversation from 2018 illustrates the importance of species such as dogfish, and ocean pout, as indicator species for when the lobsters would begin to show up in fishermen's traps:

> Speaker 1: We're not getting the fish that we used to get. When I was first starting, there used to be ling-eel, ocean pout. Come through in the spring, 2 or 3 every single trap for about 2 or 3 weeks. Every damn trap…we used to get those and all the old timers would say you wouldn't catch a lobster in the spring until they went by. Because they liked water a little bit colder than the lobster did. So when they go by then the lobsters would come in. And July we had the same damn thing with dogfish. Every single trap would have 2 or 3 in it. I haven't seen any in a long time.
> Speaker 2: I haven't seen one in 15 years.
> Speaker 1: But that was food for the lobsters and they're not there, and I'm sure the ocean pout would get eaten.
> Speaker 2: There's no question the ecosystem has changed in the last 30-45 years, and the biomass is now lobsters more than anything else on bottom.

Fishermen also noted when new species started showing up in their fishing grounds, due to increased abundance or range shifts. Of particular note was an increased presence of various species of salps and jellyfish. A noticeable increase in salps and jellyfish presence was first noted in 2014 and was mentioned in multiple, consecutive years after (Figure 1). Salps and jellyfish were of particular concern because they have the ability to inhibit lobster fishing, as discussed in a 2016 exchange:

> Speaker 1: I never saw anything like that. Then we had places out there you look down through the water as far as you can see 20% of the water was salp. We had a couple of guys with strainers on that boat, they'd pull it up just like Jell-O.
> Speaker 2: I had to clean mine a couple of days.
> Speaker 1: Did you see the eggs that they released? Just one of them real glassy slow rolling days and there was the eggs were about that wide, the width of them and they didn't look like they went down very deep but it was just as far as you can see, I followed them over, I don't know, quarter of a mile, and it just went and I guess that's what it was because it was so many little things around.

Other species that fishermen indicated as increasing in presence in the Gulf of Maine included black sea bass and menhaden—two species that are not considered traditional Gulf of Maine species and historically had a center of distribution further south along the eastern seaboard. Fishermen indicated a desire to participate in the black sea bass fishery but noted the complicated regulations for harvest as one of the barriers to fishing. Currently, black sea bass cannot be caught and kept on lobster trips, which means fishermen would have to make separate trips to target black sea bass, should they wish to participate in that fishery.

2. Pressures on the fishery and fishermen concerns

Many of these observed environmental changes have led to pressures on the lobster fishery. Increases in ocean temperature and a shifting in the EMCC have implications on settlement patterns for lobster larvae which are used as a predictor of the future biomass of the

lobster population. Lobster larval settlement is driven by temperature of the water column (Chiasson et al. 2015) and increasing temperatures have the potential to open up new areas of the Gulf of Maine for lobster settlement while also creating "dead zones" of settlement—areas that are too warm and can no longer support larval settlement. With changes in the EMCC, those larvae also have the potential to be distributed in different areas of the Gulf and the coastline. Shell disease has also been linked to an increase in water temperature (Glenn et al. 2006, Groner et al. 2018) and impacts a lobster's ability to shed its shell in predictable intervals. This has led to an unpredictability in timing for lobster "sheds" which have financial implications for the fishery as there is a higher ex-vessel price for lobsters with hard shells compared to lobsters with soft shells. Historically, fishermen could accurately predict the week when a shed would occur; now, the timing and frequency of shedding events are much more unpredictable, which translates to uncertainty and variation in seasonal profits.

Beyond environmental pressures, the fishery is also facing socio-economic and regulatory pressures. Climate Roundtable participants highlighted economic issues, such as an increase in the cost of baitfish and challenges in accessing bait, and social issues, such as a generational divide between older fishermen who remembered periods of historic low lobster abundance and younger fishermen who have only ever experienced a boom in the lobster population. Participants also emphasized the ongoing challenges of working waterfront loss along the coast, which has been well documented elsewhere (e.g., Island Institute 2009). Regulatory pressures, such as an increase in gear restrictions and the implementation of seasonal areas closures from the North Atlantic Large Whale Take Reduction Team in response to an Unusual Mortality Event (UME) the North Atlantic right whale population experienced in 2017 (§ 229.32), generated much concern amongst fishermen about the continued viability of the

fishery and continues to be an issue of deep tension. Other regulatory pressures identified by fishermen include the proposal to develop the Gulf of Maine as a zone for large offshore wind arrays which introduces a competing interest for ocean use in an area that has historically been dominated by fishing (https://www.maineoffshorewind.org/road-map/).

Taken altogether, these combined pressures are resulting in a variety of fishing strategies that fishermen are employing to maintain continued viability of fishing as their livelihood. The following section describes fishing strategies arising from multifaceted fishery pressures as they connect to the five domains of adaptive capacity.

3. Fishing strategies and adaptive capacity domains

Fishing strategies were identified and categorized according to the five domains of adaptive capacity (Green et al. 2021). Strategies were defined as actions taken by fishermen that differed from the ways they had fished historically due to an experienced pressure. For example, using non-traditional bait was classified as a strategy in response to increased costs for traditional bait. Sixteen different strategies were identified, ranging across all five domains of adaptive capacity. The access to assets domain had the highest number of strategies followed by diversity and flexibility. Multiple responses fell into more than one domain (Figure 2).

Access to assets—Green et al. (2021) defined components of the access to assets domain to include: community infrastructure, household material assets, decision-making/regulatory authority, human resources, financial resources, access to credit, access to aid, access to markets, access to information, and fishing gear and technology use. Nine strategies fell into this domain. These strategies included: using non-traditional bait, making bait adjustments based on the cost or availability of bait, using bait saver bags, purchasing a boat suited for offshore fishing, buying and selling federal lobster fishing permits, fishing non-lobster species, diversifying into

aquaculture, entering other revenue streams that are lobster fishery adjacent, and expanding the lobster market internationally (Figure 2). The most frequent strategy in this domain revolved around bait shortages and high costs that frequently occurred on a year-to-year basis.

Bait discussions were a major topic of concern in 2014, due to the combined pressures of high cost and low availability of bait. For example, high costs of rockfish bait in 2014 resulted in fishermen switching to something less expensive but also less preferred, such as pig or cow hide. One fisherman noted how prices of bait were becoming "cost prohibitive" and another fisherman described bait bills as reaching an amount he was no longer able to afford (i.e., $500 to $600 a day for menhaden and redfish, which he had used for the past twenty years). High bait costs and limited bait availability resulted in some fishermen choosing to set fewer traps or simply put less bait in their traps, while others diversified to other non-fish sources of bait, such as pig hide and cow hide, which were less expensive and generally more accessible regardless of the season. There was little consensus on how best to deal with bait shortages and high costs, but multiple fishermen expressed their concern about using pig and cow hide as bait for lobster traps, citing concerns around marketability and image of the fishery, as well as unknowns surrounding the potential to spread pathogens by using alternative bait.

Another strategy that came up in multiple years that fell into the access to assets domain of adaptive capacity was the trend of fishermen purchasing boats upwards of $800,000 dollars to suit the year-round style of fishing that occurs in federal waters. The federal water lobster fishery has emerged in recent years as a deep water, offshore, year-round fishery that typically requires a larger boat that is more suited to longer trips in potentially inclement weather. Many fishermen expressed how younger fishermen were entering into the offshore lobster fishery and had purchased expensive boats generating high monthly boat payments and resulting in a need to fish

harder to meet their overhead costs. On the profits generated by fishing offshore, one fisherman said in 2013, “But offshore was stupid, ridiculous. You know, unbelievable, the best year I've ever had. Most money I’ve ever made.” This financial boost of the offshore fishery was echoed again with one fisherman saying in 2017, “Our co-op was up 10% this year over last. But almost everybody that fished inside 10 miles was down 10%. The ones that were outside [offshore] made the difference up.” Yet in the same year, fishermen expressed concern about how this expansion and the huge overhead costs of offshore fishing would impact the fishery should the offshore biomass of lobsters disappear or collapse. In this quote from an older fisherman in 2017, the uneven access to assets across generations was made clear, indicating that younger fishermen are more likely to purchase large boats, fish offshore year-round and sustain larger bait bills regardless of how older fishermen are faring: “…you got these young guys who don’t care about boat payments, $2,000 a month. They gonna go like we did with 12 or 14 hundred traps before we went to 800. They can afford to pay $100,000 for bait. And they’re gonna say to you, if you can’t afford it, don’t go.”

Diversity and flexibility—The domain of diversity and flexibility captures strategies that connect to livelihood diversity, occupational mobility, geographic flexibility, and room for autonomous change (Green et al. 2021). Twelve responses fell into this domain. These responses included fishermen shifting to new geographic locations to fish (both into federal waters and into new areas in state waters), expanding to fish year-round or set traps in non-historic seasons, diversifying into aquaculture or other fisheries, or expressing frustration with lack of opportunity to diversify, and entering fisheries adjacent revenue streams such as the marketing and seafood side of the fishery (Figure 2).

Of all the strategies in this domain, fishing in new locations and new seasons was mentioned the most often and appeared the easiest option to access while continuing to participate in the lobster fishery. Fishing in new seasons and locations does not require new fishing gear, but it can require purchasing a federal lobster permit if a fisherman is choosing to fish in federal waters as part of the geographic flexibility. These responses seemed to be driven by the shifting of lobster biomass into deeper waters and further Downeast. A conversation from 2018 highlights the growth of the offshore fishery in response to shifting biomass and the uncertainty participants experienced about the underlying mechanisms driving changes in lobster distribution:

> Speaker 1: I think that offshore fishery is a question though. I mean, you know 20, 30 years ago there was a handful of people that went out there in the fall and they did okay for 4 or 5 weeks and then they'd go out in the spring, and they'd do okay. Now there seems to be a body of lobsters that wasn't there 25 years ago that's now there that's big.
> Speaker 2: Do you think that 25 years ago there was no fishermen there so all these lobsters kept gaining and gaining and gaining?
> Speaker 1: Well, I don't think they were settling out there then. I think something's changed. The ones I've talked to that have fished there a long time, they never saw short lobsters out there. They didn't see little lobsters out there. They saw big lobsters out there. When they went out they didn't have to measure lobsters, they were beautiful stuff…what is going on now is there's settlement out there because there's short lobsters out there. In 600 ft of water there's short lobsters where I don't think there was 30 years ago, temperature-wise, something has changed to allow that offshore.

Warming waters that stretch the summer season out into the fall months also created an extension of the summer fishing season into September, October, and November in many years, which resulted in fishermen leaving traps in the water for longer than usual timeframes. In a conversation from 2014, multiple fishermen referenced their own shift in fishing patterns, mentioning that they spent only a few weeks fishing in state waters, choosing to fish the rest of the year in federal waters. This transition to offshore waters was described as "a trend the whole state is seeing," with one fisherman noting that their "area inshore [was] dropping and offshore

[was] producing more than [they'd] ever seen." In a quote from 2015, one fisherman noted that "Whereas you know, 15 years ago we'd get November, December, January into February maybe, when you took your traps up in the spring, they'd be empty. There'd be nothing in them. Now, when it's time to bring them in you're still catching lobsters, there's still little ones in them, you know. The effort, the focus has shifted offshore because that's where the bulk of the lobsters is now."

Learning and knowledge—The learning and knowledge domain includes the components of local ecological knowledge, learning capacity, and risk perception (Green et al. 2021). Two strategies in the Climate Roundtables fell into this domain and included pushing for more research to fill gaps in knowledge about climate processes and lobster biology and using bait saver bags.

The push for more research to answer questions about climate change and lobster populations appeared in conversation every year except 2013 and 2017. While many questions arose over the years, one topic that surfaced year after year circled around patterns and locations of lobster larvae settlement as fishermen started to move into offshore waters to fish year-round. In 2018, one fisherman said, "I don't think they're looking in the right places for them…If the old line, say 10 fathom, it was warm enough for them, if that line is gone out to 15 fathom or 20 fathom the amount of bottom you've opened up for lobsters to settle on is exponentially larger…I think that the lobsters are settling which is why we're seeing so many small ones but they're not being sampled because they're not looking out deep enough." Here, this fisherman is explaining how warming waters could be expanding the potential range of larval settlement into deeper waters noting that the current larval surveys do not cover those deeper benthic environments.

Other calls for more research included the desire to get a better picture of what the offshore lobster biomass actually is, as exemplified in this exchange from 2017:

> Speaker 1: Well, that's the other thing. I mean, there's the elephant in the room. How big is the offshore, you know, biomass? I mean obviously, for what we see coming in it's big, but is it sustainable? A couple of my kids are out there, their lobsters are this big out there, which that never was before. Obviously, there's not a lot of ground fish, I would say but what's going on? Is that a sustainable population? Or is that…?
> Speaker 2: Yeah, well, that's one of the big questions. So you know, there are two ways of thinking about that. Are those little guys settling out way up there? Or are they settling in shallow and moving out deep, and it's hard to imagine, some of these places are pretty far from shore.
> Speaker 3 The difference between those two scenarios has some really important implications for sustainability.

Again, fishermen linked these questions to patterns of settlement, as settlement numbers are what drive future projections of the fishery and are the basis for calculating biomass of Maine lobster. Calls for research arose out of the desire to reduce the uncertainty around lobster biomass and stock size for both long- and short-term planning, as well to ensure continued viability for future generations of lobstermen.

Governance and institutions—The governance and institutions domain of adaptive capacity includes the components of trust, leadership, gender, social capital, regulations, and stakeholder engagement (Green et al. 2021). There were four responses that fell into this domain, which included an interest in the Maine Department of Marine Resources (DMR) and the National Marine Fisheries Service (NMFS) pursuing more lobster and climate specific research to fill knowledge gaps that fishermen identified, the lack of opportunities to meet at Lobster Advisory Councils (LAC), fishermen attending NOAA and NMFS meetings or sitting on panels and committees as fishermen representatives, and a desire to have more input on starting a fishery for new abundant species showing up in the Gulf of Maine (Figure 2).

As species ranges are expanding and shifting along the U.S. Atlantic Coast, fishermen voiced the desire to expand a current fishery or start a new fishery for those new species. One of particular interest was the black sea bass fishery. Black sea bass had been increasingly observed in the later years of the Climate Roundtables and fishermen expressed interest in fishing for them but were frustrated and confused by the small quota. Expanding the longfin squid fishery and black sea bass fishery was also of interest and came up in conversation in 2015. In this instance, both fisheries are managed by the Mid-Atlantic Fishery Management Council rather than the New England Fishery Management Council or the Atlantic States Marine Fisheries Commission, which manages the Maine state lobster fishery. This quote from 2015 illustrates the desire to better align management actions, such as allocation and permitting, with year-to-year predictions of biomass of these new species to support fishermen's ability to diversify as these species arrive:

> So if you're a diversified fisherman, you can look at where to put your effort in what distribution to kind of be the safest. So the reason that these permits might become available is because the Mid Atlantic Council is addressing latent effort in their fishery. So it doesn't do us any good to have to get an allocation and have a permit and then have latent effort in our fishery. So like if you knew, that's my thing, like we had a lot of squid a couple of years ago, we didn't have any last year, maybe we'll have some next year. But if you could kind of look at sort of, some kind of prediction and be like 'well the water's gonna warm up and they like this, you know, environment' then you know that we could go somewhere with that.

Conversations such as these point towards a desire amongst fishermen to have more flexible and responsive management that could pivot with year-to-year variability that is becoming increasingly common in the Gulf of Maine.

Natural capital—The natural capital domain of adaptive capacity covers the umbrella of natural resources generating ecosystem goods and services (Green et al 2021). In the case of the

Climate Roundtables, this domain included strategies in response to stressors and pressures that directly connected to availability and abundance of natural resources needed to fish lobster. Five strategies fell into this domain. These include diversifying to aquaculture, a desire to expand into new fisheries, and access to bait (Figure 2).

Of particular interest in this domain was the emphasis on aquaculture as the "most commercially attractive emerging fishery" (2015 Climate Roundtable participant). Maine has seen an increase in low-impact, small scale aquaculture in recent years which includes mussel, clam, oyster, and kelp farming along the coast. Fishermen in the 2015 Climate Roundtable expressed how they would envision the structure and limited expansion of Maine aquaculture, to reflect similar values and culture of small-scale fisheries:

> Speaker 1: And I think that one of the things that I've been thinking about is how do you, how do you describe the vision for aquaculture in that way that, that is we want.
> Speaker 2: Small scale.
> Speaker 3: We want it to look like the lobster fishery.
> Speaker 4: Small scale fishermen owned.
> Speaker 1: Yeah, and that may not be exactly owner-operator, but that's the set of values and, you know, half a million-dollar investment is a big investment in aquaculture, but that's the scale that we're, we're talking about, you know.

Fishermen referenced the collapse of the Maine groundfish fishery as both a mechanism for the boom of lobster catches in the past 15 years, but also as contributing to a lack in the ability to diversify to into other fisheries. Urchin diving and the Maine shrimp fishery have also suffered stock collapses in the past twenty years and have been periodically closed on a year-to-year basis or have been opened with low quotas.

Discussion

Management of fisheries so that they are "climate-ready" is gaining traction (e.g., Bell et al. 2020, Bell et al. 2013, Busch et al. 2016, Karp et al. 2019), yet requires a complex and

comprehensive understanding of dynamic, complex social-ecological systems. Other studies have explored the role of co-management and expanding partnerships with the private sector, fishing industries, and academia to offset some of the capacity constraints of current fishery management systems (Lomonico et al. 2021, Holsman et al. 2019, Wilson et al. 2018). This study highlights the important role of holding space for dialogues among fishery practitioners and knowledge holders to share personal and collective strategies to respond to change. In the Climate Roundtable discussions, fishermen highlighted ways they are adopting alternatives to the fishing strategies they may have historically favored to meet the increased uncertainty and unpredictability head on. Additionally, fishermen are engaged in data collection and using local observations of currents, temperatures, and ecological patterns to develop strategic actions to meet the challenges of climate change. Many of the responses and strategies fishermen described fall into the proactive category of "adapt", rather than "react" or more passively "cope" with changes. In their global meta-analysis, Green et al (2020) similarly found that adapt responses were higher at both a household and community level, with relatively low fishing responses falling into the "cope" category.

A dominant narrative that has emerged from the Climate Roundtables has been a trend towards expanding the seasonality of the fishery from a spring, summer, and fall fishery into a year-round fishery while also expanding the geographic range of the fishery into deeper, federal waters. The shift of lobster biomass offshore is driving fishermen into a year-round, offshore fishery, but there remains uncertainty about the ecological mechanisms for the biomass shift. Climate Roundtable participants pointed towards an increase in water temperature nearshore, which may drive settlement of lobster larvae into deeper waters that historically would have been too cold, but are now within a suitable range for settlement. Byrne (2011) found that a

temperature increase of 1-6°C above optimal water temperature impaired developmental success of planktonic larvae in crustaceans. American lobster larvae were found to exhibit stress responses such as irregular heartbeats, reduced respiratory efficiency, and reduced growth at molt to increased water temperatures (Quinn 2017).

Fishermen's observations of range expansion for black sea bass and other species have been well documented in scientific literature (McMahan et al. 2020, Slesinger et al. 2021, Thomas et al. 2023). Dubik et al (2019) found that the Northeast summer flounder biomass has shifted northward, and management structures are grappling with how to account for this geographic shift. Quota reallocation and landings flexibility are two strategies being employed by the flounder fishery but both strategies raise concerns about equity, efficiency, and the impact on local economies (Dubik et al. 2019). In addition, local ecological knowledge can be gained as new species become more prevalent on the fishing grounds and also lost as species move out of the range of the fishery. Climate Roundtable participants discussed no longer being able to predict various important seasonal cues within the lobster fishery, or no longer being able to rely on fishing locations that were once predictable simply because the lobsters were no longer there. Despite this uncertainty, expanding seasonality of the fishery and geographic range have been the dominant strategies fishermen are taking to adapt to lobster biomass shifts. These strategies have been facilitated in large part by the current management structure of the lobster fishery. Size-based management, which is how the lobster fishery operates, restricts the upper and lower size limits of harvestable lobster but does not cap the number of lobsters harvested across the entire fishery or per individual. This creates opportunity for fishermen to fish year-round and make flexible in-season decisions based on their own finances, knowledge, and capacity to fish. Fishing year-round and in federal waters requires little gear innovation, making expansion of the

lobster fishery more accessible than diversifying into other fisheries (e.g., black sea bass). Other studies have found that forced consolidation or hyper-specialization in fisheries, particularly Alaskan fisheries, can be partially attributed to the institutional barriers that exist for entry into new fisheries (Beaudreau et al. 2019, Donkersloot and Carothers 2016, Knapp 2011). Greater cooperation across jurisdictions (e.g., joint management of shifting species between regions) and development of more nimble, proactive, and adaptive governance structures may facilitate opportunities for diversification and participation in emerging fisheries.

With the collapse of most groundfish stocks in Maine as well as the recent closure of the Maine shrimp fishery, lobster fishing has emerged as the dominant fishery in the region (Zhang and Chen 2007). A lack of competing fisheries, coupled with a boom in the lobster biomass, has led to intense specialization for lobster. A parallel situation exists in the drift gillnet sockeye salmon fishery in Bristol Bay, Alaska, which has experienced record catches in recent years even as salmon returns have declined in other populations around the state (ADF&G and NOAA, 2021). Most Bristol Bay drift gillnet fishery participants specialize on sockeye salmon and participate in few other fisheries, leading to higher earnings but also higher potential risk (Beaudreau et al. 2019). In the Gulf of Maine, this is further complicated by the fact that the return of groundfish species would also lead to an increase in predation on lobsters.

Climate Roundtables as a forum for knowledge exchange– The Maine lobster fishery has been a focal point of social science research for decades (Stoll et al. 2022, McClenachan et al. 2020, Stoll et al. 2017, Johnson et al. 2014, Brewer 2013, Hall-Arber et al. 2001). Much of that research has been focused on short-term insights of the fishery through individual interviews. The uniqueness of the Climate Roundtables comes from both the time frame covered by the

dataset as well as in the community that has been built amongst fishermen who have attended the Climate Roundtables since their inception in 2007. Research on "fisheries learning exchanges", such as the Climate Roundtables, shows that social networks created through these exchanges encourages continued knowledge sharing beyond the event, as well as an opportunity to build more effective participatory conservation strategies that support the continued viability of local livelihoods (Cohen et al. 2012, Heyman and Stronza 2011, Stacey et al. 2015, Thompson et al. 2017). In the 2007 Climate Roundtable, many fishermen were reluctant to associate any changes they had been witnessing on the water to climate change (referring to it as global warming at the time), but by the later years fishermen were communicating findings from their own temperature monitors. They were also exchanging ideas about how best to communicate the importance of science to their colleagues and how to share the message of climate change impacts on the future of the lobster fishery. Many of the Climate Roundtable participants have been attending since the start of the forum and have come to rely on the event to share knowledge with other fishermen along the coast.

In James Acheson's now well-known book *The Lobster Gangs of Maine,* he describes a culture of territorial and secretive fishermen, who operate in small 'gangs' that are generally delineated geographically by harbors or towns (Acheson 1988). Other studies have tended to echo this sentiment, emphasizing the individualistic and often isolated nature of the lobster fishery (Acheson 1972, Acheson and Brewer 2000, Brewer 2011). In contrast, the Climate Roundtables push back at that narrative, instead making space for fishermen coastwide to join and share knowledge and experiences. While disagreements do occur in the Climate Roundtables, there is little evidence of a hierarchy amongst fishermen present and each year new fishermen are welcomed into the conversation. In 2007, when fishermen were asked how they

felt about attending their first Climate Roundtable, one fisherman responded by saying: “The beauty of this forum is that it is small enough so there is some give and take. I went to the town meeting and that was so big you didn’t get to burrow into any one subject.”

Choosing a way forward– The Climate Roundtable records reveal a depth of care lobster fishermen have for sustaining the fishery and a way of life for themselves and future generations, for their communities, and for the ocean. Beyond the words spoken there is tension, wry humor, stories of decades long past that may never come again, frustration, and fear. There is hope too: for collaboration and collective action, for positive change and growth. As the waters of the Gulf of Maine change, so too will those who rely on them. That change is not a choice. But the choice that remains is *how* to change: will it be slowly and with resistance? Will it be reactive and unprepared? Will it be with self-agency, or will it be mandated? These are the questions fishermen are asking themselves and their communities. The Climate Roundtables highlight the voices of fishermen as caretakers for the ocean and for their communities, as those whose knowledge of place will be vital as baselines shift and dynamic management is increasingly needed.

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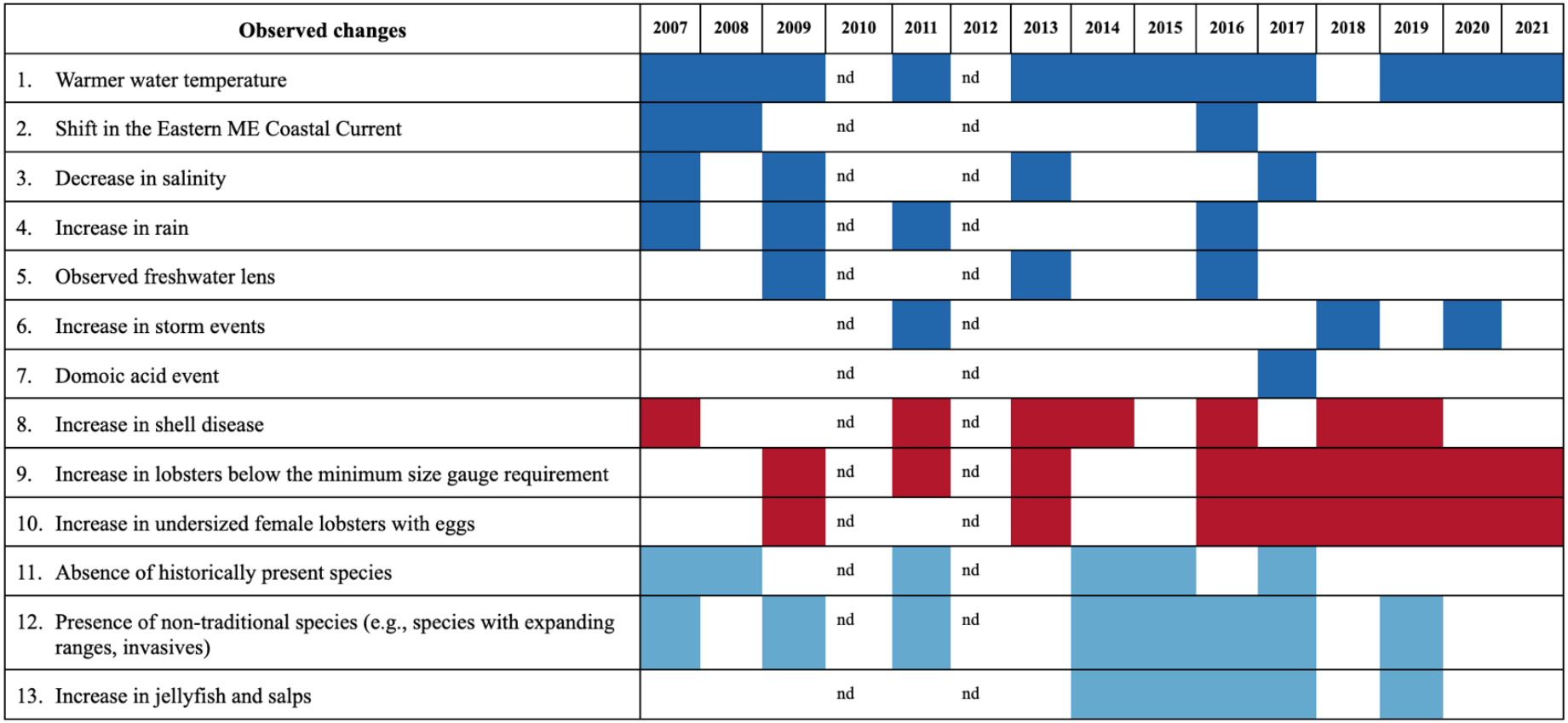

nd=no data

Figure 1. Table of observed changes from 2007-2021. Changes 1-7 are oceanographic changes (dark blue shading), 8-10 are lobster changes (red shading), and 11-13 are other ecological changes (light blue shading). Non-shaded boxes do not indicate that change did not occur, rather it did not come up as a discussion topic in the Climate Roundtable that year.

Response	Domain	2007	2008	2009	2010	2011	2012	2013	2014	2015	2016	2017	2018	2019	2020	2021
Fishing in non-historical, new locations	Diversity and flexibility	■	■	■	nd	■	nd		■	■	■	■	■		■	
Fishing in non-historical, new time of year	Diversity and flexibility	■	■	■	nd	■	nd	■	■			■	■		■	
Increasing traps set in federal waters	Diversity and flexibility	■	■	■	nd		nd		■	■	■	■	■		■	
Use of non-traditional bait (this covers bait shortages and cost mechanisms of change)	Diversity and flexibility, Access to assets, Natural capital	■	■	■	nd	■	nd	■	■			■	■	■	■	
Purchasing gear more suited to federal water fishing	Access to assets	■	■		nd	■	nd		■			■	■			
Call for more research	Learning and knowledge, Governance and institutions	■	■	■	nd	■	nd		■	■	■		■	■	■	■
Interacting with national, regional, state or local fishing management processes	Governance and institutions	■	■	■	nd		nd		■	■			■			
Buying or selling a federal permit	Diversity and flexibility, Access to assets	■		■	nd		nd			■						
Inability to join other fisheries	Diversity and flexibility, Governance and institutions, Natural capital		■		nd		nd		■	■	■		■			
Fishing fewer traps	Diversity and flexibility		■		nd		nd			■						
Entering into other revenue streams	Diversity and flexibility, Access to assets				nd		nd			■						
Fishing other species	Diversity and flexibility, Access to assets, Natural capital			■	nd		nd		■	■	■			■		
Diversifying to aquaculture	Diversity and flexibility, Access to assets, Natural Capital				nd		nd		■	■					■	
Use of bait saver bags	Diversity and flexibility, Access to assets, Learning and knowledge				nd		nd						■	■	■	
Selling lobsters internationally-expanding markets	Access to assets				nd		nd					■			■	
Desire to participate in fisheries for new species appearing in the Gulf of Maine	Diversity and flexibility, Governance and institutions, Natural capital				nd		nd			■	■		■			

nd= no data

Figure 2. Fishermen responses to environmental, regulatory, and social pressures in the Maine lobster fishery from 2007-2021, categorized by domain of adaptive capacity. Non-shaded boxes do not indicate that a response did not occur, rather it did not come up as a discussion topic in the Climate Roundtable that year.