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Climate-Driven Stock Shifts And Expansions In The U.S. Northeast Shelf: Identifying Challenges, Opportunities, And Barriers Through Fishermen And Manager Perspectives

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Climate-driven stock shifts and expansions in the U.S. Northeast Shelf: identifying challenges, opportunities, and barriers through fishermen and manager perspectives

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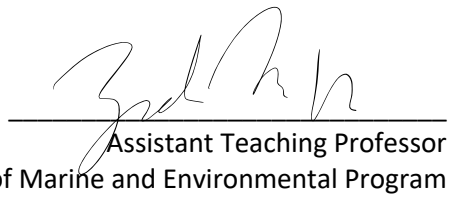

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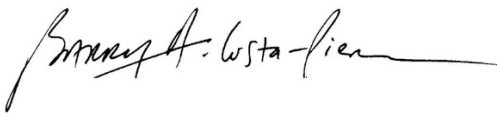

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Abstract

Climate-driven warming in the U.S. Northeast Shelf (NES) has led to changes in the spatial distributions of many marine resources. Shifts and expansions of commercially important fish stocks pose major challenges to fishermen and fisheries managers in this region. American lobster (*Homarus americanus*) in the Gulf of Maine (GOM) is one of these impacted stocks and is projected to continue its shift towards more northern and offshore areas. Continued ocean warming could potentially reduce the GOM lobster stock by up to 60% over the next several decades. Given Maine's reliance on its lobster fishery—which contributes over 80% of the value of Maine's commercially harvested marine resources—building climate resilience into the fisheries social-ecological system is critical. Southern New England (SNE) serves as an example of a region that has already experienced much of the changes posed to impact the GOM. Through semi-structured interviews with SNE and GOM fishermen and a focus group of NES fisheries managers, black sea bass (*Centropristis striata*) was identified as a potential opportunity for fishermen to adapt to climate-driven changes. However, existing barriers—such as permitting, quota allocations, and bycatch regulations—prohibit the region's fishermen from actualizing emerging opportunities. Results indicated that these barriers are not insurmountable and implementing "social-ecological management" approaches could provide viable pathways to facilitate opportunities and bolster climate resilience in the GOM.

1. Introduction

1.1 Climate change along the U.S. Northeast Shelf region

Anthropogenic climate change has caused global ocean temperatures to shift, in many cases rising above the range of natural variability (Dahlman & Lindsey, 2011; Hoegh-Guldberg & Bruno, 2010). The literature makes it evident that the U.S. Northeast Shelf (NES; Figure 1) is one of the fastest warming marine environments in the world (McHenry et al., 2019; Papaioannou et al., 2021; Saba et al., 2016). Ocean temperatures in this region have warmed faster than most of the world's oceans over the past several decades and are expected to continue warming through the 21st century (Brickman et al., 2021; Kleisner et al., 2017; McHenry et al., 2019; Pershing et al., 2015). The Gulf of Maine, in particular, stands out as a body of water undergoing dramatic increases in ocean temperatures in this century (Brickman et al., 2021; Mills et al., 2013; Pershing et al., 2015, 2021; Slesinger et al., 2021). Sea surface temperatures (SST) in the Gulf of Maine have continued to rise in the past several decades, with sharper increases in more recent years (Figure 2; Pershing et al., 2015). Figures 2b and 2c illustrate the degree to which SST trends in the Gulf of Maine differ from those of the global ocean. The NES region more broadly has seen surface and bottom temperatures warm by approximately 2 ˚C between 1960 and 2014 (Kleisner et al., 2016).

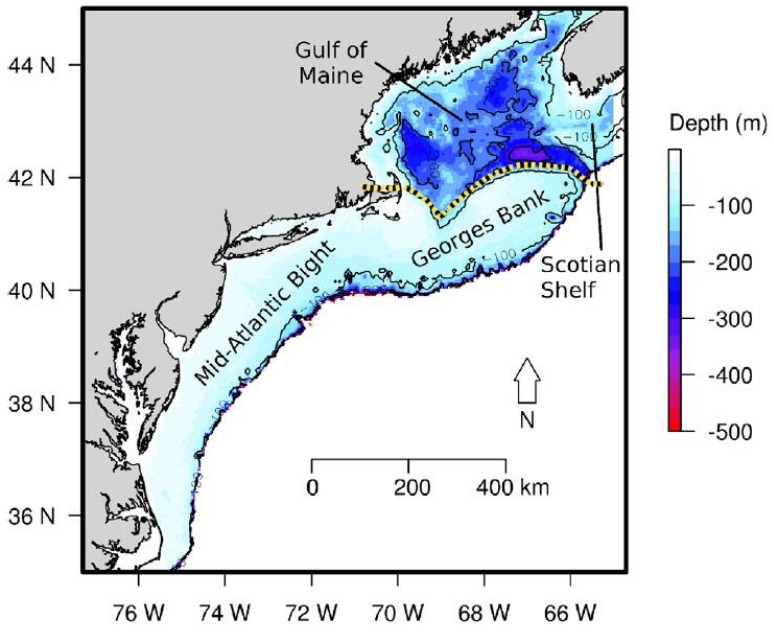

Figure 1. The Northeast U.S. Shelf (NES), showing the southern region (Mid-Atlantic Bight and George's Bank) and northern region (Gulf of Maine; from Kleisner et al., 2017).

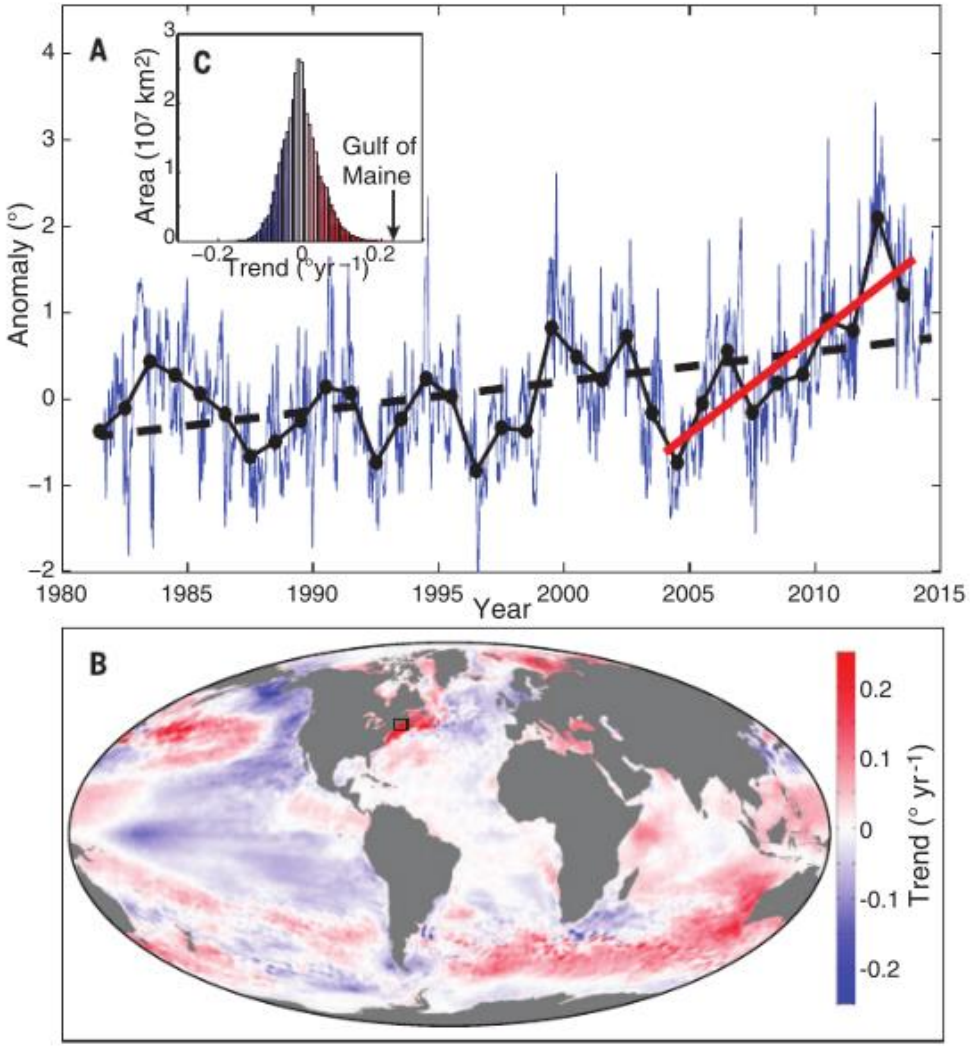

Figure 2. Sea surface temperature trends from the Gulf of Maine and the global ocean: a.) daily (blue, 15-day smoothed) and annual (black dots) SST anomalies from 1982-2013, showing the long-term trend (black dashed line) and trend for the 2004-2013 period (red solid line); b.) global SST trends for 2004-2013 (Gulf of Maine outlined in black); c.) histogram of global SST trends for 2004-2013 with the trend for Gulf of Maine indicated at the right extreme of the distribution (from Pershing et al., 2015).

In addition to temperature shifts, climate-driven impacts to the NES region also include changes in salinity, net primary productivity, pH, and ocean circulation (Brickman et al., 2021; Kleisner et al., 2017; McHenry et al., 2019; Pinsky & Mantua, 2014). In the Gulf of Maine, changes in ocean circulation and other physical aspects are occurring on decadal scales (Brickman et al., 2021). To understand how climate change has impacted ocean condition in the Gulf of Maine and NES as a whole, it is important to contextualize large-scale ocean circulation. In the northern portion of the NES, the Newfoundland/Labrador Shelf, Gulf of St. Lawrence, and Gulf of Maine form an interconnected system (Figure 3). Ocean circulation in this region is dictated by

northeast-southwest flows of water from the Newfoundland/Labrador Shelf areas through the Gulf of Saint Lawrence, Scotian Shelf, and Gulf of Maine to the Mid-Atlantic Bight (Brickman et al., 2021). The NES region represents a confluence of the warm, northeastward-flowing Gulf Stream and the cold, southwestward flowing Labrador current. These currents interact at the tail of the Grand Banks, causing subsurface east-west flows along the shelf break that influence ocean variability downstream of the Scotian Shelf and the Gulf of Maine. In the Gulf of Maine, ocean properties are largely affected by the Nova Scotia current, which brings colder, fresher water from the Gulf of St. Lawrence into the Gulf of Maine coastal current, creating counterclockwise circulation (Brickman et al., 2021). Warmer, saltier subsurface inflows through the Northeast Channel, the main conduit into the Gulf of Maine, are balanced by outflows at the Great South Channel and the western portion of the Northeast Channel.

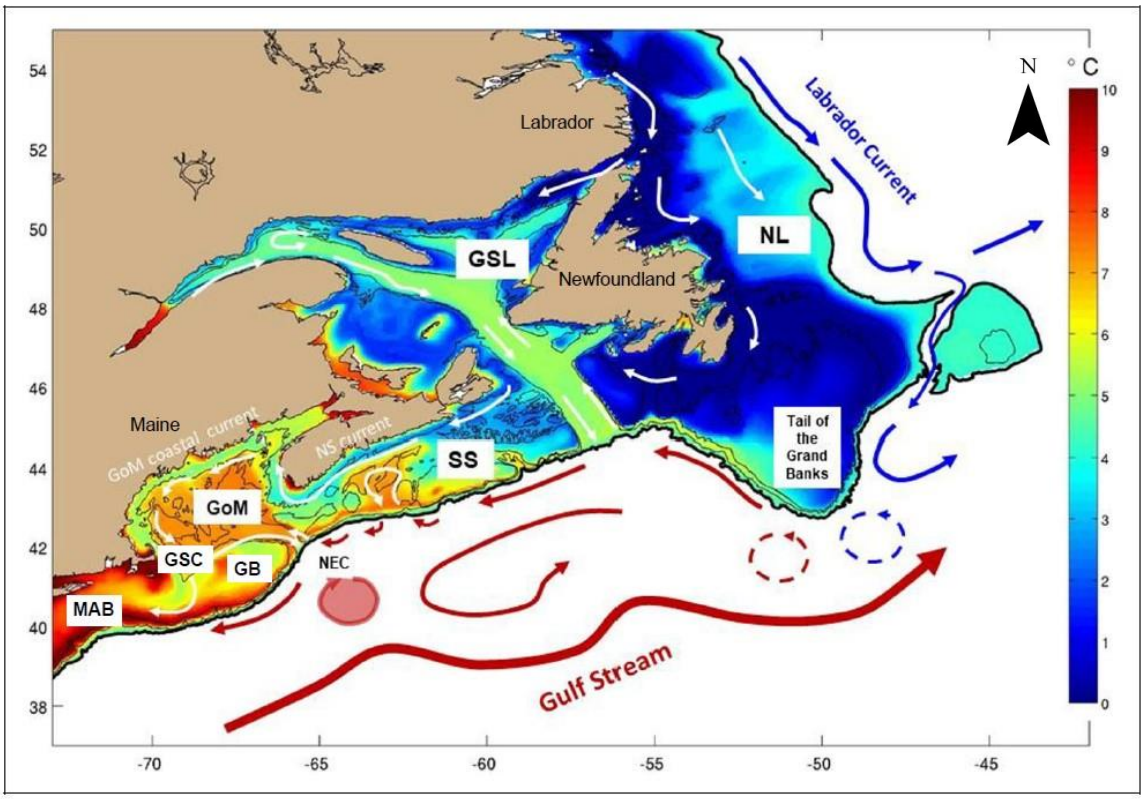

Figure 3. Ocean circulation in the Northwest Atlantic, including the Northeast Shelf, with annual mean bottom temperatures superimposed on the shelf area (bottom temperatures from the Bedford Institute of Oceanography North Atlantic model). Arrows indicate direction of flow, with blue and red indicating relative cold and warm temperature, respectively (onshelf arrows are white for visibility). Dashed circular arrows illustrate subsurface eddies. Solid red circle represents a Gulf Stream ring with surface expression. Abbreviations are as follows: Gulf of Maine (GOM), Scotian Shelf (SS), Gulf of Saint Lawrence (GSL), Newfoundland/Labrador (NL), George's Bank (GB), Northeast Channel (NEC), Great South Channel (GSC), and Mid-Atlantic Bight (MAB; adapted from Brickman et al., 2021).

The variability of deep waters in the Gulf of Maine is controlled by interactions between Gulf Stream and Labrador Current waters at the tail of Grand Banks. In the past 10-15 years, changes in this this process have resulted in a prominence of warmer, saltier Gulf Stream eddies that significantly contribute to warming trends in the NES region's deeper waters (Brickman et al., 2021; Gangopadhyay et al., 2019). The formation of warm Gulf Stream eddies, also known as warm core rings, has increased dramatically in the NES region from 18 eddies per year during the 1980-1999 time period to 33 per year from 2000-2017 (Gangopadhyay et al., 2019). Research by Gangopadhyay et al., (2019) found that, during the first two decades of the 21st century, ocean conditions in the NES may have been strongly influenced by the increase in warm core ring formations and associated intrusions across the shelf. The resulting shifts in temperature caused by the formation of warm core rings have brought a variety of warmer-water species northward along the NES. This results from events referred to as warm- or deep-water intrusions, when warm core rings drift westward and cross the shelf (Gangopadhyay et al., 2019; Leggett, 2022). While surface water temperature swings are not rare, warm core rings can cause deeper water temperatures to rapidly warm by more than 5 ˚C (Leggett, 2022).

Ocean temperature in the NES is further influenced by the relationship between the position of the Gulf Stream and the Atlantic Meridional Overturning Circulation (AMOC; Kleisner et al., 2017). The AMOC is the overarching system of horizontal and vertical flows in the Atlantic Ocean, that result in an "overturning" circulation that is responsible for transporting substantial amounts of heat poleward. A major component of the global climate system, the AMOC is defined by a northward flow of warm, salty water in the top layers of Atlantic Ocean water and a southward flow of colder water in the deep ocean. The overturning nature of the AMOC depends on distributions of temperature and salinity, as well as atmospheric forcings. A weak AMOC corresponds with a more northward Gulf Stream position, leading to warmer ocean temperatures in the NES and more Gulf Stream water entering the Gulf of Maine (Kleisner et al., 2017; Pershing et al., 2015; Saba et al., 2016). In conjunction with changes in regional ocean circulation, a weak AMOC may be exacerbating climate change and associated warming in this region (Pershing et al., 2015; Saba et al., 2016).

Climate-driven expansions and shifts of fish stocks along the Northeast Shelf

A notable outcome of recorded rising ocean temperatures is the poleward and bathymetric expansion and shift of marine species globally (King et al., 2019; Marzloff et al., 2016; Pinsky et al., 2020). Regionally, shifts and expansions in the spatial distributions of several NES fish stocks in response to climate change have already been observed (Kleisner et al., 2016; Slesinger et al., 2021; Walsh et al., 2015). A shift or expansion of a fish stock's distribution refers to a permanent or multi-decadal (or centennial) movement in the spatial distribution of a species or stock from its traditional region or habitat into a new region or habitat (Karp et al., 2018). Stock expansions occur when the one edge of the traditional stock distribution expands in an outward direction, while the other edge remains stable, to increase the total range of the stock (Figure 4a). In the NES, this has been observed with the northern edge of the stock expanding into waters

previously too cold for certain species to inhabit (Kleisner et al., 2016). When the southern edge of the stock—in the case of NES species—also moves northward along with the northern edge, the change in distribution becomes a stock shift (King et al., 2019; Figure 4b). These changes do not only occur latitudinally, but may occur bathymetrically, as stocks shift or expand to deeper (and often colder) waters (King et al., 2019). In short, a stock expansion constitutes a growth in the stock's traditional distribution, while a shift creates a movement of the stock's distribution without any change in its overall size (Link et al., 2011).

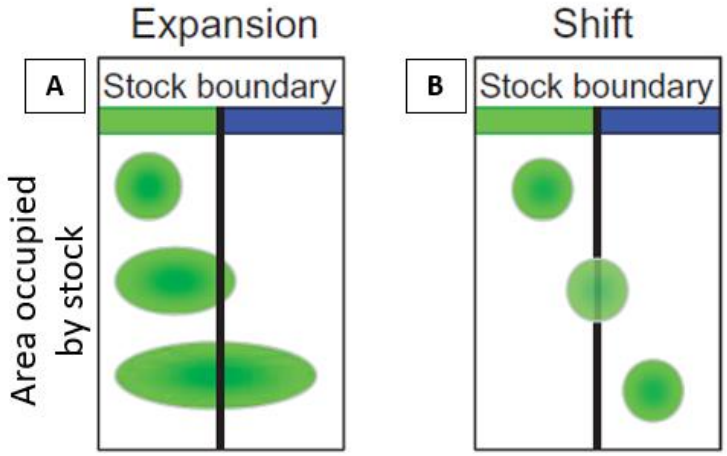

Figure 4. Conceptualization of stock expansions (a) and shifts (b). Traditional/historical stock boundaries are designated by the thick black (vertical) line; actual areas of stock distributions are indicated by the green circles/ovals (adapted from Link et al., (2011)).

Modeling the future: climate change and species distributions

Trends in ocean conditions have led researchers to develop and employ climate models that generate projections of future ocean conditions (Morley et al., 2018). Climate models utilize inputs that characterize future scenarios of greenhouse gas emissions known as representative concentration pathways (RCPs). RCPs represent different global mean atmospheric surface temperature changes based on emission mitigation scenarios and can play a large role in output variables' values (Morley et al., 2018). Saba et al. (2016) employ a high-resolution global climate model to project future ocean conditions in the NES. The results of their study suggest that future warming rates in the NES are likely to exceed that of the global average by two to three times. Brickman et al. (2021) use multiple climate models under different RCPs to predict ocean conditions in the Gulf of Maine in 2050. Results project increases in SST and bottom temperature between 1.5-2.1 ˚C and 1.0-2.75 ˚C, respectively, by 2050. In general, the models predict a decrease in surface salinity in the Gulf of Maine by 2050. Despite model variance in salinity projections, however, results agree that coastal areas and George's Bank are likely to see decreases in salinity by 2050 (Brickman et al., 2021).

With species on the move in response to climate change, the research community has focused modeling efforts on projecting how climate-driven changes in ocean conditions will influence species distributions. Climate models may be combined with habitat suitability and/or species distribution models to generate projections of future suitable habitat or abundance (Kleisner et al., 2017; McHenry et al., 2019; Morley et al., 2018). These models may focus on an individual driver of change, such as sea surface temperature, or a set of variables. Using habitat suitability models allows for projections of the position and extent of species' ranges under future climate scenarios. Factors influencing habitat suitability include ocean temperature, depth, salinity, and sea surface height (McHenry et al., 2019). Depending on the model and RCP employed (which influences projected ocean conditions), outputs of suitable habitat and distributions may differ. Although strong emissions mitigation scenarios are likely to result in significantly smaller shifts in species distributions, research suggests that continued future shifts remain inevitable (Morley et al., 2018).

In addition to modeling, research on historical changes also shows temporal shifts in species distribution. Across the NES region, Kleisner et al. (2016) conduct an assessment of observed shifts of species assemblages (a group of species that share a common environmental niche) and regional climate velocity (the rate and direction of change of temperature isotherms). Results demonstrate that assemblages inhabiting the southern NES in the fall have exhibited strong northward shifts—in some cases shifting as rapidly as 0.1˚N per year (or, approximately 43.5 nautical miles per decade).

While multiple changes in ocean condition influence the distributions of marine species, the literature has identified ocean warming as a significant driver of changes in those species' distributions (Hare et al., 2016; Kleisner et al., 2017; McHenry et al., 2019; Morley et al., 2018; Nye et al., 2009; Pinsky et al., 2013). In the Gulf of Maine in particular, where colder winter temperatures are a limiting factor for habitat suitability, sea temperature is expected to play a critical role in species distributions in the future (Kleisner et al., 2017; Pershing et al., 2021). The duration of warm summer temperatures in the Gulf of Maine has extended in recent decades due to shifting phenology to earlier spring warming and later fall cooling (Slesinger et al., 2021). As a result, abundances of emerging species have increased in the region. Warming waters and shifting phenology in the NES region has also driven shifts in distribution for a number of fish stocks (Slesinger et al., 2021). This trend is expected to continue into the future. Gangopadhyay et al. (2019) note that the increasing frequency of warm core ring intrusion events across the shelf and associated warming will likely expedite the rate of species' northward shifts and expansions. For example, Kleisner et al. (2017) employ the NOAA Geophysical Fluid Dynamics Laboratory (GFDL) global climate model/general circulation model (GCM), "CM2.6," to project increases of 3.7 ˚C and 3.9 ˚C in surface and bottom temperatures, respectively, over the next 80 years in the Gulf of Maine. Along the Mid-Atlantic Bight and George's Bank, the model projects surface and bottom temperatures increasing by 4.1 ˚C and 5.0 ˚C, respectively, over the 80-year period. Such increases in temperature result in projected northward shifts of thermal habitat for

the majority of species in the region (Kleisner et al., 2017). These findings reflect the ability of more southern NES species to shift northward to maintain suitable thermal conditions, such as into the Gulf of Maine where longer durations of colder temperatures historically restricted survivability (Kleisner et al., 2017).

The Gulf of Maine and Southern New England: regions of rapid change

A climate vulnerability assessment conducted by Hare et al. (2016) further supports modelling efforts and observed historical changes. Their study relies on expert assessments of exposure factors and sensitivity attributes for each species assessed, which are combined to produce a species-specific vulnerability ranking. The majority of the 82 NES species assessed exhibit high or very high potential for change in distribution through 2055 due to projected changes in climate. Significant effects were indicated for species such as black sea bass (*Centropristis striata*), which is expected to continue its ongoing northward expansion and increase in productivity, potentially moving into the Gulf of Maine permanently (Hare et al., 2016). Citing a likely increased availability of black sea bass and other Mid-Atlantic species in the Gulf by 2050, Pershing et al. (2021) further bolsters this assessment.

The literature reveals that the Gulf of Maine will likely experience future increases in abundances of species that currently dominate the Mid-Atlantic Bight and George's Bank (Hare et al., 2016; Kleisner et al., 2017; Pershing et al., 2021). Black sea bass is one of those species—trends in future black sea bass biomass point towards increased abundance in northern regions of the NES, particularly the Gulf of Maine. Because overwintering conditions are an important factor determining juvenile black sea bass survival (Black Sea Bass Working Group, 2017; Miller et al., 2016), climate-driven changes in winter ocean conditions will likely influence black sea bass' future range. Figure 5 illustrates that future centers of biomass for black sea bass will likely shift dramatically northward, though the extent of the shift differs depending on the RCP employed (OceanAdapt, 2021). [1]

[1] https://oceanadapt.rutgers.edu/

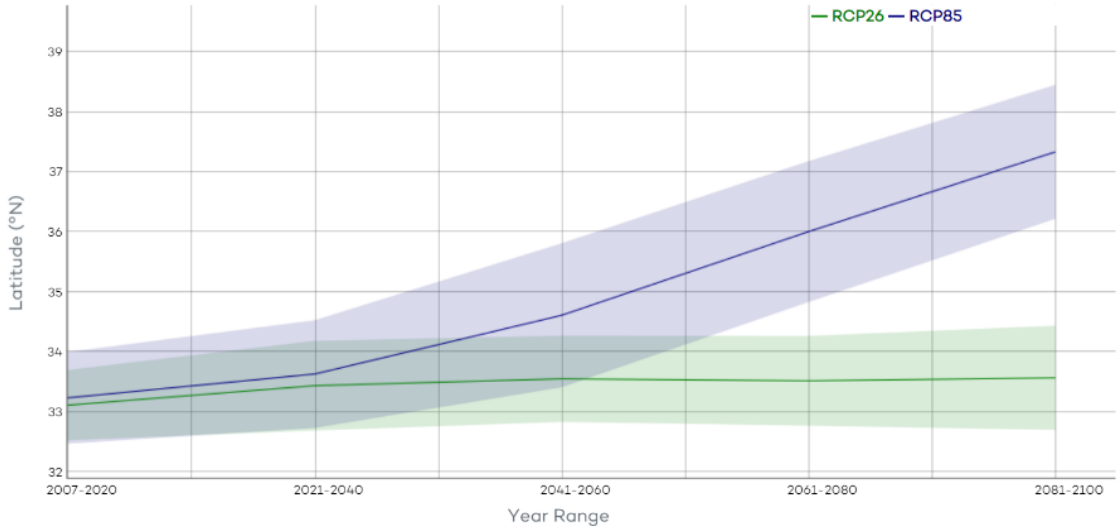

Figure 5. Predicted future centers of biomass for black sea bass under RCP2.6 and RCP8.5 (OceanAdapt, 2021).

At the same time, in response to climate-driven changes in ocean condition, a number of commercially important species in the Gulf of Maine are expected to decrease in abundance over the course of the century. For example, a 1-2 ˚C increase in temperature in the Gulf by 2050 could cause the Gulf of Maine stock of American lobster (*Homarus americanus*) to decrease in abundance by 42-62% (Le Bris et al., 2018). Such a decline would match the fishery's scale around the year 2000, when it was far less productive than its current state (Pershing et al., 2021). The literature generally projects that lobster in the Gulf of Maine will shift its distribution in a northerly and more offshore direction under future ocean conditions (Kleisner et al., 2017; Morley et al., 2018; Pershing et al., 2021). Climate change is similarly expected to negatively impact other important Gulf of Maine species, such as sea scallops (*Placeopecten magellanicus*)—largely due to future projections of increased acidification—and Atlantic cod (*Gadus morhua*; Hare et al., 2016). These results highlight the need to understand the impacts of such distribution changes on fishermen and management and how to best reduce the industry's vulnerability to rapid, climate-driven change.

Of the many species expanding and shifting their ranges in response to the changing climate, black sea bass has emerged as a sentinel species for the impacts of warming waters on species' distributions (Goldsmith, 2021). Black sea bass is a migratory fish species found in the Northwest Atlantic Ocean. This species has historically inhabited waters from Cape Hatteras, North Carolina to Cape Cod, Massachusetts, and prefers to dwell around structures such as natural or artificial reefs.[2] In recent decades, the northern stock of black sea bass has been experiencing a rapid range expansion along the NES, expanding beyond its historical range and into the Gulf of Maine (Bell et al., 2015; McBride et al., 2018; McMahan et al., 2020; Slesinger

[2] https://www.mass.gov/info-details/learn-about-black-sea-bass#life-history-

et al., 2021). Although a warm water adapted species, black sea bass have been observed in more northern waters since the 1970s (McBride et al., 2018; NOAA, 2021). Findings from Bell et al. (2015) indicate a significant northward shift of 150-200 km in the species' spring center of biomass over the past 40 years. The distribution of black sea bass in the NES was found to be strongly related to temperature (Bell et al., 2015). In fact, a warm core ring intrusion even in January, 2017 brought juvenile black sea bass into Rhode Island sound, an unheard of occurrence in winter months (Gangopadhyay et al., 2019).

Looking farther north, the species has demonstrated successful spawning and recruitment in the Gulf of Maine despite historically rarely inhabiting the region (McBride et al., 2018). Reviewing the literature and two 40-year trawl surveys, McBride et al. (2018) found that black sea bass spawning in the Gulf of Maine has likely occurred since the early 2000s. Figure 6 illustrates the northward expansion of black sea bass from 1978-2016 along Cape Cod, Massachusetts. Cape Cod represents the boundary of the Gulf of Maine and Southern New England waters—data from this area therefore provides useful insight into stocks that are expanding or shifting into the Gulf from more southern waters. As indicated by Figure 6, black sea bass have exhibited substantial movement north of Cape Cod into the southern Gulf of Maine since the start of the 21st century.

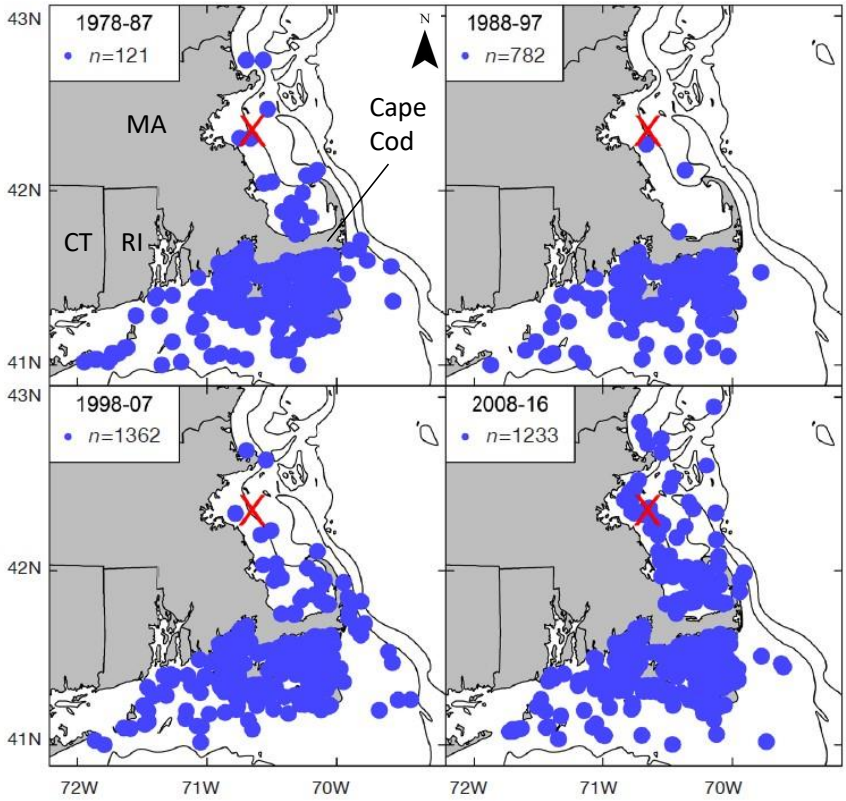

Figure 6. Occurrence of age-0 black sea bass in fall trawl surveys conducted by the Massachusetts Division of Marine Fisheries (MA DMF) and NEFSC (adapted from McBride et al., 2018).

The last four decades have seen black sea bass settlement increase roughly 1˚N in latitude, in conjunction with warming temperatures in the southern Gulf of Maine (McBride et al., 2018). Black sea bass landings in the Gulf of Maine, both in terms of weight and dollar value, reflect this trend in the species' expansion, with landings generally increasing since 2010 (Figure 7). The majority of these landings are in Massachusetts, where the black sea bass fishery is more developed due to its historical presence in more southern portions of the Commonwealth. As the northern black sea bass stock has quickly expanded into the Gulf of Maine, both science and management have been challenged to understand what the future holds for this species and how to address such changes.

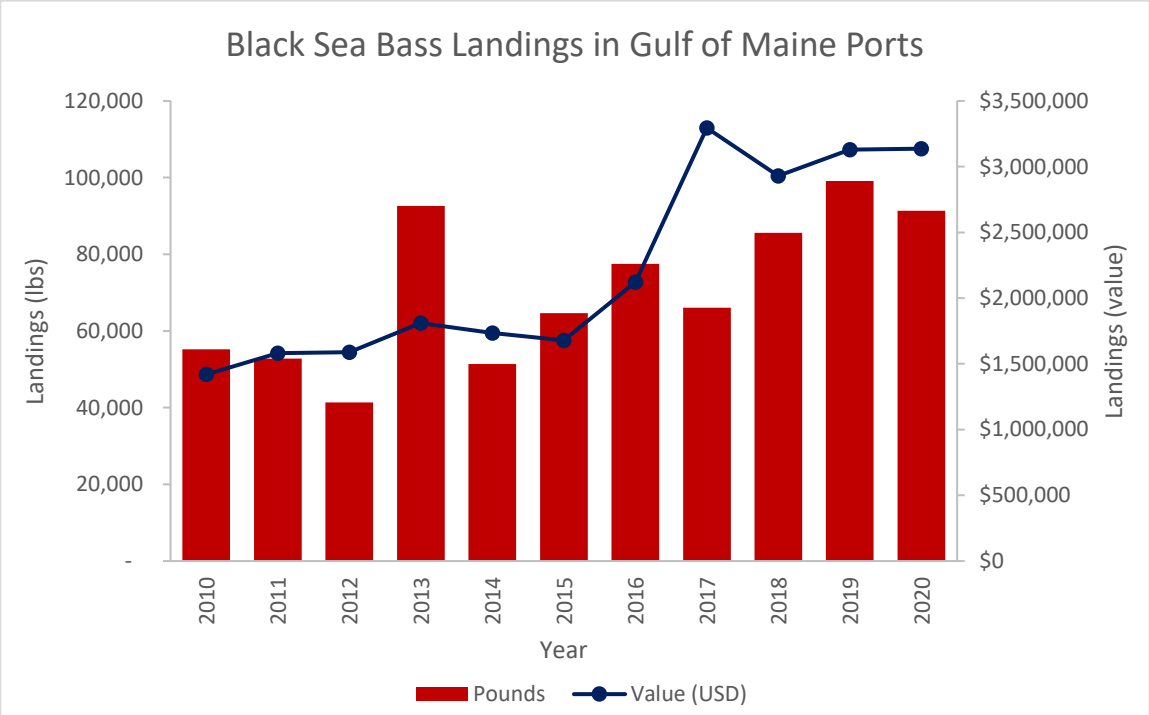

Figure 7. Black sea bass landings in terms of pounds (left vertical axis, red bars) and value (right vertical axis, blue points) in Gulf of Maine ports from 2010-2020. Gulf of Maine ports are those located in Maine, New Hampshire, and parts of Massachusetts with easy access to Gulf waters (port list located in Appendix 1). Data obtained from the Atlantic Coastal Cooperative Statistics Program (ACCSP).[3]

[3] https://www.accsp.org/

Implications of climate-driven stock shifts and expansions

Potential future loss of commercially important fish species in the Gulf of Maine due to climate change will force necessary adaptation on the part of both fishermen and managers (Pershing et al., 2021). The literature agrees that increasing fisheries' resilience to climate change is of high importance given ongoing rapid change in the ocean (Cinner & Barnes, 2019; Holsman et al., 2019; Ojea et al., 2020; Whitney et al., 2017). Ojea et al. (2020) notes that resilience to climate change in the fishing industry occurs within the fishery social-ecological system, with adaptation serving as a promising approach for improving climate resilience. The literature identifies several climate adaptation strategies for fishermen, including fisheries diversification, supplementing income with non-fishing work, and changing gear use (McClenachan et al., 2020; Ojea et al., 2020; Stoll et al., 2017). Stoll et al. (2017) evaluates Maine commercial fishermen's abilities to adapt to change, highlighting the capacity to change target species and diversify fishery portfolios as a high degree of adaptability. Young et al. (2019) also identify diverse fishery portfolios as an effective adaptation strategy, in addition to fleet mobility.

Over the past several decades, northward shifts in species distributions have been reciprocated by fishery shifts as well (Pinsky & Fogarty, 2012). Partially due to regulatory and economic constraints, however, fisheries have only shifted roughly 10-30% as much as their target species (Pinsky & Fogarty, 2012). These constraints include fuel cost considerations, state fishery management boundaries, quota allocations, and vessel size constraints (Pinsky & Fogarty, 2012). In the Gulf of Maine, fishermen can only shift their operations so much in order to follow northward shifts of commercially important species, as the northern portion of the Gulf extends into Canadian waters that cannot be fished by U.S. fishermen. With the future loss of traditional target species in the Gulf of Maine evident, pivoting to emerging fisheries may be an effective approach to resisting the negative consequences of climate change.

While climate-driven stock shifts and expansions present myriad challenges to fishermen and managers, they can also create opportunities. Gulf of Maine ports (those located in Maine, New Hampshire, and portions of Massachusetts) have benefitted from climate-driven change with regard to the growth of the lobster fishery. Warming waters and tidal mixing in recent decades have created optimal habitat conditions for lobster in the Gulf of Maine (Goode et al., 2019). Since the 1980s, lobster landings in the Gulf have risen astronomically, jumping from around 40 million pounds annually in the '80s to nearly 160 million pounds in 2016 (Figure 8). At the same time, lobster landings in Southern New England ports (those located in Connecticut, Rhode Island, and the south coast of Massachusetts) have just about collapsed, declining by nearly 88% between 1997 and 2018 (Figure 8). Increases in ocean temperature in the NES region has stimulated these divergent trends, with Southern New England's warm waters limiting the availability of juvenile habitat and inhibiting recruitment, while temperatures in the Gulf of Maine have become a "goldilocks zone"—warm enough for juveniles to thrive but not so warm that larvae cannot survive. The Gulf of Maine's optimal habitat allows for increased recruitment and population growth (Goode et al., 2019; Le Bris et al., 2018). Thus, climate change has

dramatically contracted lobster's suitable thermal habitat in Southern New England waters while creating optimal conditions for the species to flourish in the Gulf of Maine.

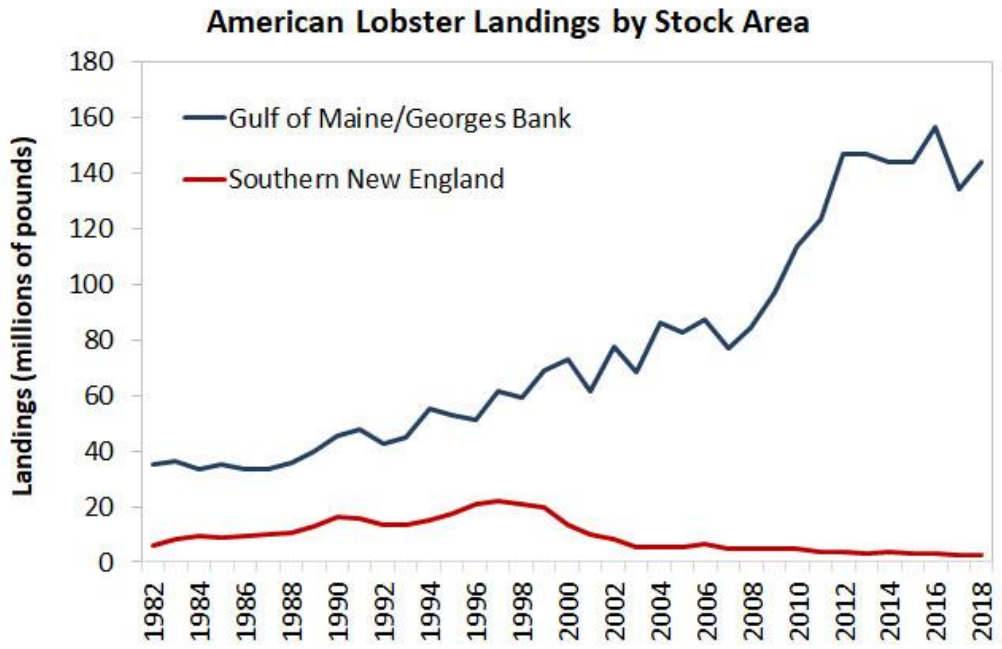

Figure 8. Historical landings of American lobster in the Gulf of Maine/George's Bank and Southern New England (Atlantic States Marine Fisheries Commission [ASMFC], 2020).

Southern New England serves as an example of a region that has already experienced dramatic climate-driven impacts to its fisheries. Figures 8, 9c, and 9d highlight the rapid rate of the Southern New England lobster stock's collapse. With lobster's decline in Southern New England, the region has witnessed increased abundances of traditionally Mid-Atlantic species, such as black sea bass (Figure 9). This region has addressed the need to diversify its fisheries and has tried to capitalize on the opportunities presented by climate-driven stock expansions (of black sea bass) while facing the challenges of climate-driven stock shifts (of lobster).

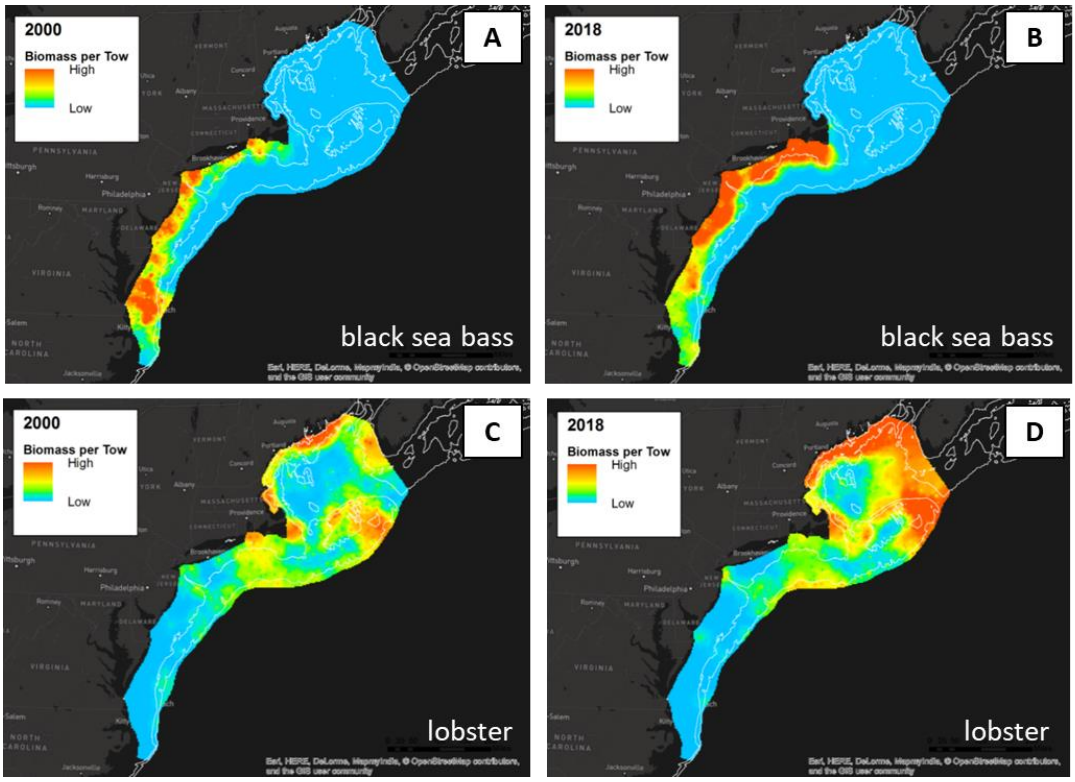

Figure 9. Maps of black sea bass (a, b) and lobster (c, d) fall abundances in 2000 and 2018 based on biomass per tow from fall trawl surveys (OceanAdapt, 2021).

Serving as the border between the Gulf of Maine and Southern New England, Massachusetts has helped facilitate participation in its emerging black sea bass fishery through its regulations, potentially increasing the fishing industry's resilience to climate change. Historically, Massachusetts lobstermen had been landing finfish bycatch from their lobster pots. In 1991, Massachusetts instituted a regulation that required fishermen to have a finfish pot permit to land species in that way. In order to eliminate the barrier of an additional permit required for lobstermen to continue landing finfish bycatch, Massachusetts built in an exception to this regulation. The Code of Massachusetts Regulations (CMR), 322 CMR § 6.12(8)(d) states that:

> *Fishermen with a valid commercial coastal lobster permit may possess and land whelk and finfish species including, but not limited to, black sea bass, scup, and tautog captured in a lobster pot, provided the aggregate weight of the finfish and whelk catch does not exceed the weight of lobsters during a single commercial fishing trip.*

This exception to the restrictions of possessing and landing fish using traps allows Massachusetts lobstermen to land black sea bass and other finfish species that are caught as bycatch in their traps. Although fishermen do not need a species-specific pot/trap permit (e.g., a black sea bass

fish pot permit), the regulations still require those landing this bycatch to maintain the fishery-specific permit for the landed species. Other measures regulating the bycatch's fishery still apply, as well, such as quota allocations (e.g., black sea bass landed as bycatch still count towards the state's allocated quota) and minimum fish sizes. Figure 10 illustrates lobster fishermen participation in this "program," specifically focusing on landings of black sea bass.

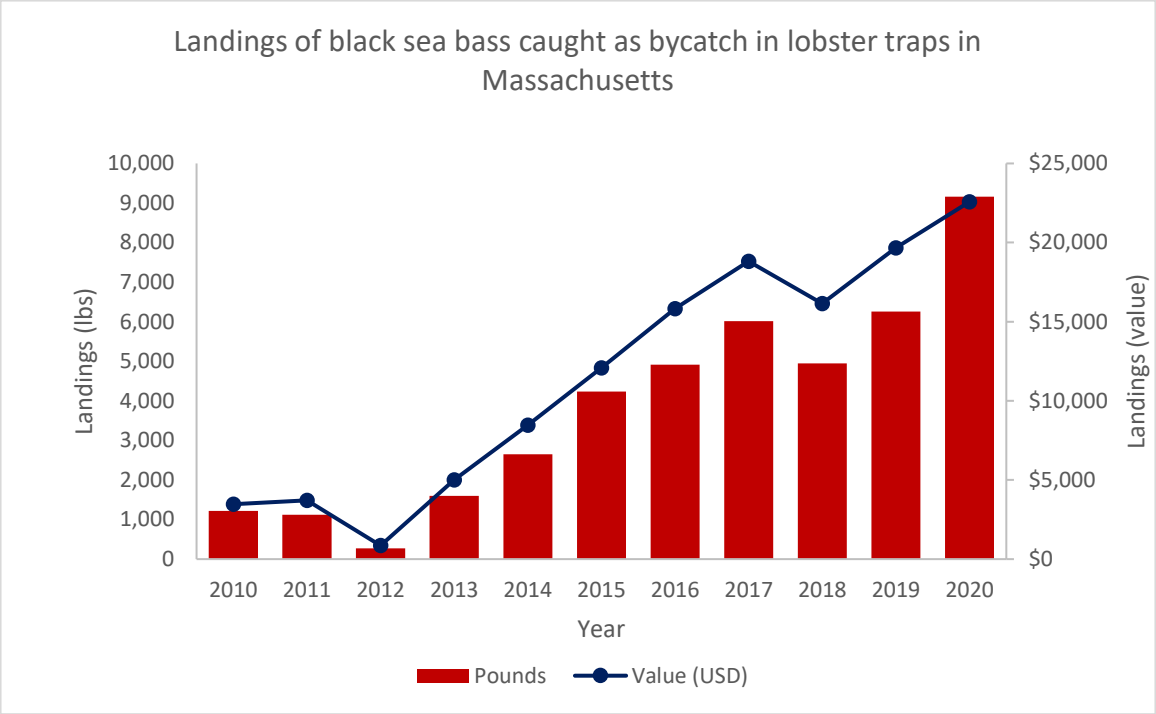

Figure 10. Landings of black sea bass in Massachusetts that were caught as bycatch in lobster traps, per 322 CMR § 6.12(8), in terms of pounds and dollar value (data provided by Massachusetts Department of Marine Fisheries [DMF]).

Since 2010, landings of black sea bass caught as bycatch in lobster traps have increased over seven-fold, from approximately 1,200 pounds in 2010 to over 9,000 pounds in 2020 (Figure 10), while total landings of black sea bass in Massachusetts over the same time period have only tripled.[4] This represents growing participation in this program that outpaces that of the fishery's growth overall. Value has also increased substantially in the past decade, with black sea bass bycatch landings rising from a total value of about $3,500 in 2010 to approximately $22,500 in 2020 (Figure 10). In 2020, black sea bass caught and landed as bycatch in lobster traps accounted for roughly 1% of all commercial black sea bass landings in Massachusetts.[3] Although it appears small, this proportion demonstrates reasonable participation in the fishery on the part of lobstermen. This steady climb in bycatch landings suggests an increase in sea bass bycatch that reflects the increased availability of the species in Massachusetts waters. Figure 10 may also indicate rising demand for black sea bass such that lobstermen find it worthwhile to land sea bass

[4] Data provided by the Massachusetts Division of Marine Fisheries (DMF).

caught as bycatch. Ultimately, this regulation exception aids in facilitation of and participation in the emerging black sea bass fishery, providing lobstermen with some adaptability and an opportunity to diversify their catch when possible.

The increased availability of warmwater species like black sea bass could present opportunities for new markets, but will depend on if policy can adapt and facilitate harvesting opportunities (Pershing et al., 2021). Through 322 CMR § 6.12(8), Massachusetts has made some effort to facilitate opportunities for the emerging black sea bass fishery. In Maine, however, only 12% of fishermen hold licenses for emerging commercial fisheries that are projected to increase in the future (Stoll et al., 2017). Participation in emerging fisheries is often challenged by substantial barriers to entry. The literature notes a few of these barriers, such as limited entry fisheries and difficulty increasing quota allocations for emerging species (Stoll et al., 2017), but approaches to overcome these barriers are not widely researched. Further, management faces challenges in promoting these opportunities. Existing approaches to managing quotas and assessing stocks will be challenged as species distributions continue to change (Gullestad & Bakke, 2021; Kleisner et al., 2017; Link et al., 2011).

Black sea bass life history and management

Fisheries management in the U.S. is infamously complex, involving several different agencies and myriad rules and regulations. This section provides a brief overview of black sea bass life history and management, including management's history and its ongoing changes.

Black sea bass are a protogynous hermaphroditic fish species, meaning most individuals begin their lives as females and become males as they mature and grow. They are a relatively long-lived species, reaching sexual maturity between 1-3 years old and living up to eight (for females) and twelve (for males) years of age.[5] Individuals may reach up to 2 feet in length and 9 pounds in weight. On the U.S. Atlantic coast, the species is found from Maine to Florida. Research has defined two distinct black sea bass stocks in the Atlantic—the Mid-Atlantic (North Carolina to Maine) and South Atlantic (South Carolina to Florida) stocks. The designation of these two stocks indicates that these distinct populations exhibit life history and morphometric differences (Roy et al., 2012). Each stock is managed by different agencies, with the Mid-Atlantic Fisheries Management Council (MAFMC, or "the Council") and Atlantic States Marine Fisheries Commission (ASMFC, or "the Commission") managing the Mid-Atlantic stock, and the South Atlantic Fisheries Management Council (SAFMC) managing the South Atlantic stock. Because the South Atlantic black sea bass stock does not inhabit the NES region, this research focuses on the Mid-Atlantic stock only.

Throughout the year, black sea bass are fairly mobile and move between coarse bottom habitat and structured habitats such as rocks, shipwrecks, or reefs (Black Sea Bass Working Group, 2017). Because black sea bass primarily utilize structured habitats, there has been concern regarding the ability of trawl surveys to accurately assess stock status (Black Sea Bass Working

[5] https://www.fisheries.noaa.gov/species/black-sea-bass

Group, 2017). The species generally migrates to more offshore and southern areas in the fall and back to more northern inshore areas in the spring to spawn. In more southern portions of the NES region, particularly the Mid-Atlantic Bight, black sea bass maintain important recreational and commercial fisheries (Northeast Fisheries Science Center (NEFSC), 2017; Bell et al., 2015). Black sea bass are caught in both state (0-3 miles offshore) and federal (3-200 miles offshore) waters. Since 2002, per Amendment 13 to the Summer Flounder, Scup and Black Sea Bass Fishery Management Plan (FMP), the state and federal black sea bass fisheries have been managed jointly by the ASMFC and MAFMC, with ASMFC largely responsible for the inshore (state) fishery and MAFMC responsible for the offshore (federal) fishery. These agencies jointly manage both the commercial and recreational fisheries from Cape Hatteras, North Carolina up the coast into Maine.

MAFMC and ASMFC work alongside NOAA's National Marine Fisheries Service (NMFS) to develop and implement regulations and other management measures. Catch and landings limits, minimum fish sizes, open and closed seasons, gear regulations, permit requirements, and other measures are employed to manage black sea bass in the NES region (MAFMC, 2021). Based on stock assessments performed by NOAA, the MAFMC's Scientific and Statistical Committee (SSC) establishes recommended annual Acceptable Biological Catch (ABC) levels that must be approved by the Council. The approved ABC is then divided into commercial and recreational Annual Catch Limits (ACLs), also known as each fishery's coastwide quota. The ACLs are indicated in the Summer Flounder, Scup, and Black Sea FMP. Historically, 51% of the ABC has been allocated to the recreational fishery, with the other 49% allocated to the commercial fishery (MAFMC, 2021).

Prior to 1996, black sea bass was not part of a FMP. In recognition of declines in the Mid-Atlantic black sea bass stock, MAFMC and ASMFC jointly developed Amendment 9, which incorporated a black sea bass FMP into the existing summer flounder FMP (ASMFC & MAFMC, 1996). Amendment 9 instituted the requirement of a commercial moratorium permit, issued by NMFS, for fishing black sea bass in federal waters. Initially, vessels were only eligible for a moratorium permit if a.) they had landed and sold black sea bass at any point between 1988 and 1993, b.) the vessel was under construction in 1993 but landed and sold black sea bass in 1994, or c.) the vessel was replacing another vessel of similar harvesting capacity, owned by the same individual. Vessels with federal moratorium permits were, and still are, required to fish in accordance with federal rules regardless of if they are fishing in federal or state waters. The establishment of a black sea bass FMP was intended to help mitigate overfishing and allow the stock to recover.

In 2003, Amendment 13 to the FMP determined a quota allocation system that remained in place until 2022. The Amendment implemented a coastwide quota that facilitated state-by-state allocations determined by MAFMC and ASMFC. Quotas have been and still are distributed to the Atlantic states (from North Carolina to Maine) based on their contribution to total commercial landings for the period of 1988-1997 (Table 1; MAFMC & ASMFC, 2002). Under this quota system, states may trade or combine quota. To prevent quota overages, it is up to the states themselves to implement appropriate measures and close the fishery when the quota has

been reached. Regardless of where black sea bass are harvested, landings for sale in one state contribute to that state's quota (MAFMC & ASMFC, 2002). For example, black sea bass harvested in federal waters off the coast of New York and landed in Massachusetts count towards Massachusetts' allocated quota.

With quota allocations determined by historical landings, it is difficult to establish and grow an emerging black sea bass fishery in states such as Maine and New Hampshire, where the quota allocation remains substantially lower than more southern states (Table 1). In 2021, however, MAFMC and ASMFC developed a complimentary Amendment and Addendum to the FMP that modifies the state allocations of the coastwide black sea bass commercial quota originally implemented in 2003 (Atlantic States Marine Fisheries Commission, 2021). These actions were taken in order to address changes in black sea bass distributions in the 21st century while also considering historical dependence on the fishery. Implemented at the start of 2022 for state waters and later in the year for federal waters, the new allocation system establishes baseline allocations that are used to then determine final allocations. Baseline allocations contribute to 75% of a state's quota, while the remaining 25% is based on the most recent regional biomass proportions determined in the stock assessment (ASMFC, 2021). As such, state allocations may change in response to the results of the stock assessment, except for Maine and New Hampshire, whose allocations will each remain at 0.40%. This reflects the states' present lack of interest in the black sea bass fishery. As biomass continues to increase in the Gulf of Maine, however, allocations for Maine and New Hampshire will be unaffected, while that of Massachusetts could increase. Northern Gulf of Maine states are largely uninvolved in black sea bass management.

Table 1. Historical state quota allocations and new baseline allocations for the commercial black sea bass fishery (Atlantic States Marine Fisheries Commission, 2021).

State	Historical Allocation	New Baseline Allocation	Baseline and Biomass-Based Allocation
Maine	0.50%	0.25%	0.40%
New Hampshire	0.50%	0.25%	0.40%
Massachusetts	13%	12.77%	15.64%
Rhode Island	11%	10.81%	13.23%
Connecticut	1%	3%	3.67%
New York	7%	7%	8.57%
New Jersey	20%	19.65%	20.10%
Delaware	5%	5%	4.11%
Maryland	11%	10.81%	8.88%
Virginia	20%	19.65%	16.14%
North Carolina	11%	10.81%	8.88%

Stock assessment approach

Two types of stock assessments exist for managed species in the U.S., including black sea bass: research track and management track. Both assessments are conducted and coordinated by the Northeast Region Coordinating Council (NRCC), a group consisting of members from ASMFC,

NEFMC, MAFMC, NOAA's Greater Atlantic Regional Fisheries Office (GARFO), and NEFSC (NEFMC, 2020). Historically, research track assessments occur every four years, and take about 1-1.5 years to complete for black sea bass, but may take several years for other species. These assessments may evaluate one or a number of stocks of interest, as well as a single issue or new model that may be applicable to multiple stocks. The purpose of research track assessments is to obtain data, decide what data to use, and generate models using this data to characterize the stock in question. Management track assessments utilize research track assessment results to support management actions. The MAFMC's SSC, who is largely involved with black sea bass management track assessments, may reject the research track assessment results and provide suggestions and recommendations for the next assessment. Figure 11 provides more information on the processes for each type of stock assessment.

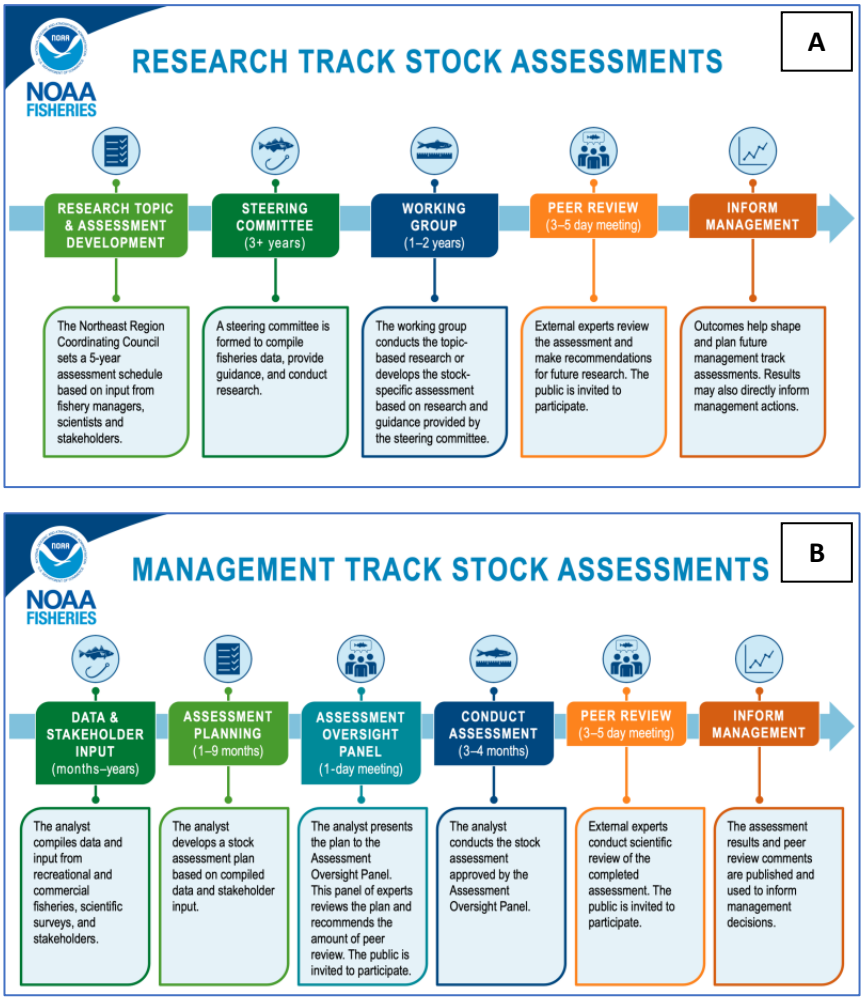

Figure 11. Graphics detailing the processes for research track (a) and management track (b) stock assessments (from NMFS, 2022).[6]

[6] https://www.fisheries.noaa.gov/new-england-mid-atlantic/population-assessments/management-track-stock-assessments

The first black sea bass stock assessment was conducted in 1991 by the NEFSC using trawl survey data. In 1995, a Virtual Population Analysis (VPA) model was employed to estimate stock status, but results maintained a low level of certainty and were not considered appropriate for determining stock status, particularly with a hermaphroditic species such as black sea bass. In 2002, a tag-recapture approach was implemented, but results from this method were again considered too uncertain. A length-based model was utilized in 2008 with more positive results—still, it was recommended that managers heed caution when applying the results for management purposes. In 2011, a statistical catch at age model was used but not accepted for management use. Ultimately, it was concluded that new data was needed to produce a stock assessment suitable for management purposes (Black Sea Bass Working Group, 2017).

In advance of the 2016 assessment, researchers recognized the need to incorporate spatial factors into the black sea bass stock assessment. Since then, the Mid-Atlantic stock has been broken up into two sub-units to account for spatial differences in the assessment model. These sub-units are the areas north of Hudson Canyon up through Maine (northern portion of the Mid-Atlantic stock) and south of Hudson Canyon to Cape Hatteras, North Carolina (southern portion of the stock). Sub-units do not represent separate stocks, but exist solely for the purposes of stock assessment modeling (Black Sea Bass Working Group, 2017). For the 2016 assessment, survey data consisted of NMFS winter and spring trawl surveys and state trawl survey data from Virginia to Massachusetts. These surveys do not extend north of Massachusetts. Recreational catch per unit effort (CPUE) and commercial landings were also used. The 2016 stock assessment added a number of data types to its analysis (Black Sea Bass Working Group, 2017).

At the time of this writing, the next black sea bass research track assessment is ongoing. Changes to the rules governing stock assessments now allow research track stock assessments to occur on a more dynamic, as-needed basis. The assessments may be continuously updated to provide new information when necessary. For example, if the SSC rejects the model produced during the research track assessment, a new assessment may be conducted as soon as possible, rather than four years from the first assessment's completion. Further, the ongoing stock assessment is incorporating even more data sources than in previous assessments, including ventless trap surveys which can target structured bottom (Marissa McMahan, personal communication). With the new formulation of black sea bass quota allocations, it is important to produce accurate stock assessments—the ability to conduct assessments more dynamically, in addition to employing new data sources, may improve stock assessment accuracy.

1.2 Commercial fisheries and management in the U.S. Northeast Shelf region: a social-ecological system

Fisheries are widely considered to be social-ecological systems (SESs; Ojea et al., 2020). SESs are defined in many ways, but Kasperski et al.'s (2021) definition holds resonance for commercial fisheries: "an ecological system of interdependent organisms or biological units interacting with a social system of interdependent humans deriving benefits from uses of the ecosystem as well as from the state of the ecosystem." This definition highlights the interdependence of fisherman and fisheries managers in this system. Without fishermen and the fishing industry, fisheries managers would not exist. Conversely, history has illustrated that a

lack of management in the industry can allow the tragedy of the commons to play out, leading to the collapse of important fisheries. The relationship between fishermen and managers is a tenuous one that persists in the pursuit of sustaining this SES.

Growing research has focused on how to effectively manage SESs (Nuno et al., 2014; O'Higgins et al., 2020; Virapongse et al., 2016). Because climate-driven changes have challenged existing management structures, experts in the field of environmental management, policy, and science have started to call for more transdisciplinary, innovative management approaches (Virapongse et al., 2016). These transdisciplinary management approaches are often referred to as an "SES-based environmental management approach" (Virapongse et al., 2016), but this study uses the term, "social-ecological management." The concept of SESs recognizes that management problems are generally made up of systems and sub-systems that include resource users, institutions and rules (O'Higgins et al., 2020). In the fishermen-manager SES, these represent fishermen, managers and their associated government agencies, and the regulations that dictate fishermen's actions. Considering the perspectives of multiple stakeholders is an important aspect of social-ecological management that is often overlooked in traditional management approaches (Nuno et al., 2014). As such, this study relies on qualitative data elicited from two integral stakeholders in the NES region fisheries SES.

Although the commercial fisheries SES is a large system made up of numerous players, including processors, distributors, and scientists, fishermen and managers play particularly important roles in this system. While there has been substantial research investigating climate-driven stock shifts in the NES, little research has focused on fishermen and manager perspectives on the challenges and opportunities presented by such shifts and expansions. Further, the literature does not discuss the ways in which fishermen and managers can facilitate the associated opportunities. Utilizing black sea bass in Southern New England and the Gulf of Maine as a case study, and eliciting manager and fishermen perspectives of individuals across the NES region, this novel study investigates the following research questions:

- What challenges and opportunities do climate change and climate-driven shifts and expansions of fish stocks pose to commercial fishermen and managers in the NES region?
    - In particular, what challenges and opportunities are presented by the expanding mid-Atlantic black sea bass stock
- What are the barriers to facilitating and taking advantage of potential opportunities presented by stock expansions and shifts in the NES?
- How can Southern New England's experience with shifting and expanding stocks help inform managers and fishermen in the Gulf of Maine as these changes move up the coast?

Given the research gaps noted above, understanding how fishermen and managers at the frontlines of climate change view these changes and perceived opportunities for adaptation can

provide valuable insight that will aid in preparing for inevitable future change. Investigating how Southern New England has adapted to changes in commercially important species distributions could be critical to planning for the future in the Gulf of Maine. This case study may very well inform how the SES of fishermen and managers can increase climate resilience in the northern portions of the NES region. Ultimately, understanding these perspectives has implications for how cooperative strategies can produce equitable approaches to fisheries management in the face of climate change.

2. Research Methods

Climate-driven expansions and shifts of fish stocks pose a major threat to fisheries along the NES. However, they may also present opportunities for climate adaptation. To understand the impacts of climate-driven changes, particularly shifting and expanding stocks, and the associated opportunities and challenges, semi-structured interviews and a focus group were employed to elicit the perspectives and insights from commercial fishermen and fisheries managers in the NES region. Although this research focuses on The Gulf of Maine and Southern New England, managers overseeing fisheries throughout the entire NES area (North Carolina-Maine) are included because they participate in the management of species undergoing stock expansions such as black sea bass, even as the species move beyond their historical range and into the Gulf of Maine.

Semi-structured interviews with active or recently-retired fishermen from the Gulf of Maine (n=4) and Southern New England (n=6), as well as a focus group with active fisheries managers from the NES region (n=5), were conducted to determine their views on the challenges and opportunities that climate change and shifting and expanding fish stocks pose to these groups (Given, 2008). Similar questions were asked of each group and questions focused on the following themes:

- Changes observed or noticed over the course of their careers;
- Challenges and opportunities presented by these changes;
- Barriers to taking advantage of potential opportunities; and
- Concerns for the future.

A full list of questions asked of each group is included in Appendix 2.

The results of the focus group and semi-structured interviews provide insight into the ways in which climate-driven changes impact the fishermen-manager SES. Resulting data also reveal the potential opportunities presented by such changes and the challenges associated with capitalizing on those opportunities. Ultimately, understanding these opportunities and challenges has the potential to impact fishermen, fisheries managers, and other individuals involved in the SES (e.g., processors, distributors).

2.1 Focus group and semi-structured interviews

Between February and March, 2022, I conducted semi-structured interviews with individuals who fish commercially in the Gulf of Maine and Southern New England, as well as a focus group with fisheries managers from the NES region. The sample groups represent three populations: Gulf of Maine commercial fishermen (GOM), Southern New England commercial fishermen (SNE), and fisheries managers from the NES region (FM). Focus groups were not employed with fishermen groups due to accessibility and logistical concerns—most fishermen contacted expressed willingness to participate in an interview, but not a focus group. Eligibility criteria for subjects were as follows:

- Fisheries managers must work for an agency or council in the NES region. This can be a state (e.g., Maine Department of Marine Resources [DMR]), inter-state (e.g., MAFMC), or Federal (e.g., NOAA) agency. Managers may maintain a range of experiences in the field but should not possess any less than one year of experience.
- Gulf of Maine commercial fishermen must fish out of Maine, New Hampshire, or northern Massachusetts (i.e., the Gulf of Maine). There will be no restrictions on the subjects' type of fishing (state versus Federal waters) or target species. Fishermen may maintain a range of experiences in the field but should not possess any less than one year of experience. Subjects may be active or retired, provided they retired in the last 3 years or less.
- Southern New England commercial fishermen must fish out of Rhode Island, Connecticut, or southern (south coastal) Massachusetts. There will be no restrictions on the subjects' type of fishing (state versus Federal waters) or target species. Fishermen may maintain a range of experiences in the field but should not possess any less than one year of experience. Subjects may be active or retired, provided they retired in the last 3 years or less.

The three groups were each asked similar questions during the focus group and semi-structured interviews (Appendix 2). Questions focused on the challenges and opportunities presented by shifting and expanding fish stocks in the NES region, as well as the ways in which managers and fishermen deal with these challenges and opportunities. Fishermen from both groups were asked to discuss the changes they have observed on the water over the course of their careers. This allowed for first-hand accounts and fishermen's perceptions of these changes. In addition, participants were asked questions at the end of the session regarding their perceptions of 322 CMR § 6.12(8)(d).

The focus group was conducted over Zoom (video call) and semi-structured interviews occurred over the phone. Utilizing the focus group format allowed participants to engage with each other in discussion of the questions asked, stimulating larger conversations. Using the one-on-one semi-structured interview format provided participants a space to answer questions freely without concern of judgment from others. Interviews also provided individuals with more time to discuss their own thoughts and perspectives.

2.2 Focus group and interview recruitment

Fisheries managers were identified first by creating a list of fisheries management agencies in the NES region. Using publicly available staff lists located on government agency websites, individuals that work in management positions were identified and recruited using the email address provided on the agency's website. In some cases, the chain referral or "snowball sampling" method was used, and participants provided the contact information of another staff member within their agency that would be willing to participate (Frankfort-Nachmias et al., 2015). The manager focus group included five (n=5) fisheries managers from several different agencies in the NES region. Managers worked for state, federal, and inter-state management bodies, with experience in the field ranging from 1 to 20 years. Participants represented the Mid-Atlantic, Southern New England, and Gulf of Maine subregions of the NES.

Fishermen were identified by contacting relevant experts in the field with connections to the fishing industry. Several fisheries organizations in the region were also contacted. These experts and organizations provided contact information for potential participants who were then recruited via email or phone. Snowball sampling was employed in order to obtain additional participants. The Gulf of Maine fishermen group included four (n=4) fishermen, all from the state of Maine. Gulf of Maine fishermen interviewed represented the southern and mid-coast regions of Maine. The participating Maine fishermen primarily targeted lobster (using fixed gear), in addition to engaging in other fisheries on the side. Gulf of Maine fishermen's experiences ranged from 10 to 50 years. Southern New England fishermen interviewed (n=6) represented Connecticut, Rhode Island, and the south coast of Massachusetts. These fishermen targeted lobster, scallops, squid, groundfish species, menhaden, black sea bass, and tuna. Their experiences ranged from 30 to more than 40 years. Gear types used by these fishermen are traps (fixed gear), trawls, and rod and reel.

2.3 Data analysis

Raw data obtained from the focus group and interviews (recordings) were transcribed using Otter.ai web-based software. Transcriptions were reviewed several times to correct any mistakes generated by the software. The data were cleaned to remove filler words, such as "um," "like," and "you know," where appropriate. After reviewing and cleaning the individual transcripts in Otter.ai (one for FM, six for SNE, and four for GOM), they were exported to Microsoft Word documents and compiled into three separate documents for each population. Data were cleaned to remove all identifiable information such that the remaining data were anonymous. Text from the interviewer was also removed during the cleaning process. The data underwent several cleaning and reduction "cycles" in order to eliminate unusable data from the documents. The same data cleaning and analysis process was utilized for the three populations.

The resulting useable data was organized into sub-groupings, or "chunks" using the chunking method. Chunks represented the themes initially gleaned from preliminary data review and analysis. To further organize and analyze the data, chunks were separated into clusters during the initial data coding process. The coding process was repeated several times to reduce the number of clusters into a final set of codes. During this process, the original language derived from interviews and the focus group was preserved to the extent possible. These codes represent the

major themes that emerged from the data. Codes were both derived from the data (inductive codes) and from the research questions themselves (deductive, or *a priori*, codes). Sub-themes present within these codes were also utilized to represent and analyze the data. The resulting themes and sub-themes reveal each population's thoughts and perspectives on this study's research questions. Figure 12 provides a visual representation of the qualitative data analysis processes employed in this study.

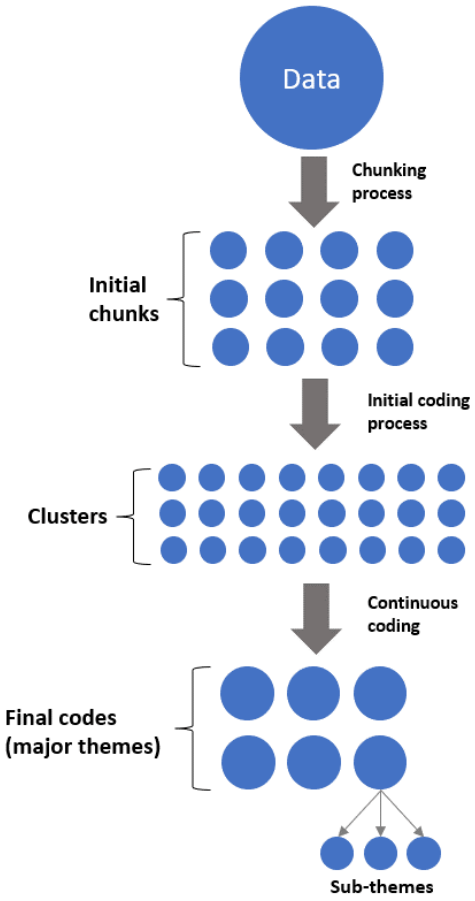

Figure 12. Graphic illustrating the qualitative analysis process used to analyze data derived from interviews and the focus group.

Inductive and deductive (a priori) methods were used to determine effective avenues for facilitating opportunities and increasing resilience among fishermen. All groups were asked questions that elicited discussions of ways to develop emerging fisheries (inductive approach). The researcher also asked participants to share their perspective on 322 CMR § 6.12(8)(d), the exception to Massachusetts' lobster trap regulations. These perspectives highlighted whether or not fishermen and managers believed a regulation like this could help grow emerging fisheries or facilitate the opportunities presented by emerging species (deductive approach).

3. Results

Semi-structured interviews and focus group discussions identified emerging themes that shed light on the research topic. These resulting themes are presented in the following sections by population.

3.1 Fisheries managers

Seven major themes emerged from the FM analysis. These themes are presented in Table 2 and represent the primary points of discussion throughout the focus group session.

Table 2. Coded themes resulting from the FM analysis.

Theme	Description	Code type
Data collection challenges	Knowing what data managers need; collecting data effectively in the midst of rapid change	Inductive
Data analysis and interpretation challenges	Understanding the data and what it indicates; effectively communicating data to managers	Inductive
Applying data and analysis to management	Providing management with information they need to make decisions; making sound management decisions based on existing data	Inductive
Dynamic and real-time management	Climate change creating the need to adapt current approaches, including adding flexibility to management actions; existing management procedures struggling to function under continued climate change; barriers to enacting dynamic, real-time management approaches	Inductive
Emerging species: opportunities and barriers	Opportunities that may be presented by shifting and expanding stocks; the barriers that get in the way or make it difficult to take advantage of those opportunities	*A priori*
Balancing management changes	The efforts put towards and the challenges of implementing different management changes; the lack of stability that this creates, the resistance to those changes, balancing those changes	Inductive
Other climate-driven challenges facing fishermen	Other factors resulting from climate change and shifting stocks that create challenges for fishermen; social-climate combination challenges, challenges keeping up with rapid change	Inductive

The resulting themes reveal data-related challenges as a substantial concern among fisheries managers. Data was discussed enough to warrant three separate themes for the over-arching topic: data collection challenges, data analysis/interpretation challenges, and applying data/analysis to management. Other challenges noted by managers included providing dynamic and real-time management and implementing and balancing management changes.

Managers also described the potential opportunities that shifting and expanding stocks might present to fishermen, highlighting in particular the barriers associated with facilitating potential opportunities. When asked to comment on the challenges that climate change poses to fishermen,

managers touched on several different factors, both directly and indirectly driven by climate change.

At the end of the focus group session, I asked the participants if there was anything else they wanted to share on the topic of climate-driven changes and the impacts to fisheries management or fishermen. One participant explained that one of the most important things for her as a manager is "making sure that [she is] trying to keep [her] sights on all the different perspectives of how climate change is impacting fisheries management as a whole. It's decisions that managers have to make, the livelihoods of fishermen, the information that science is giving us, and blending that all together and producing viable paths for management" Her statement demonstrated the complexity of dealing with change in fisheries and reinforced climate-driven impacts to this SES as a "wicked problem" (Head & Alford, 2015; O'Higgins et al., 2020).

Data collection

Results from the fisheries managers focus group indicated data collection as a major challenge presented by climate change and shifting and expanding fish stocks. Figure 13 presents a conceptual framework outlining the data collection challenges theme, including the sub-themes gleaned from the data and select quotations demonstrating fisheries managers' perspectives on this issue. When discussing data collection challenges, managers highlighted three major challenges associated with data collection: knowing what data to collect, collecting data under tight budgets, and utilizing a wealth of data types (Figure 13).

Figure 13. Conceptual framework depicting the sub-themes and select quotations derived from the major theme, data collection challenges

Fisheries managers discussed the challenges of knowing what data is needed in order to make management decisions in a time of constant change. In particular, uncertainty was raised regarding whether managers have the data necessary for reacting to climate-driven changes, such as shifting and expanding stocks. This concern was further supported by statements indicating

that fisheries scientists and managers are likely not aware of the full scope of data needed to make informed management decisions.

Some managers discussed how collecting the data necessary for managing an ever-changing system has become difficult given constraining budgets. One participant stated that, “The cost of surveys are going up and the funding is not.” Another believed that data collection could likely be more efficient, but explained that modifying survey methods can be daunting for scientists. She noted that efficiency can sometimes be hindered by the fear of losing long time series associated with existing surveys and survey methods. She expressed that, “sometimes I think that we should be wiser about our efficiency of what we are collecting in order to get the best information that we can.” Further, one manager felt that data collection processes could probably be improved in some ways, but tight budgets can hinder those efforts. These responses demonstrated the challenges facing fisheries management due to mounting costs of data collection and an increasing need to understand more about an ever-changing ecosystem.

When discussing the data needed for making effective management decisions, participants generally expressed the importance of using a wealth of data types. One participant referenced fishery-dependent data as a useful data source, mentioning that she believed some of that data could be used better. However, she also described the challenges associated with that type of data, noting, “I think the challenge there is, what is the survey method? Is it random sampling? Is it just, [fishermen are] gonna got catch fish where they always catch fish? Once you get into those methods, I think that’s where the details really matter.” Multiple data sources are particularly important for understanding a SES that continues to be influenced by climate change. Another participant explained how it is important to fully understand how a species’ biomass is changing regionally when making allocation decisions, adding that landings data are not sufficient on their own.

Data analysis and interpretation challenges

Managers discussed the challenges climate change creates in terms of analyzing and interpreting data. With unprecedented climate-driven changes occurring in the NES region, fisheries managers expressed how difficult it can be to translate data into meaning. One participant stated that it is challenging to know “what the data is really telling us or might be telling us because, obviously, you can’t say for sure exactly what is going to happen. Taking that insight, the science that we have available to us and interpreting it [is challenging].” Another manager echoed this concern regarding uncertainty by saying, “what is the data telling us? How certain can we be? What is it telling us about the future? And then what can we do about that?” These questions illustrated managers’ feelings regarding the complexity of data analysis and interpretation when working with changing ecological systems. Similarly, one participant explained the difficulty in compiling data analyses and communicating results to managers such that they can understand them and use them for making decisions. Managers also noted the complexity of the NES ecosystem and the rate at which changes are occurring amplifies this challenge.

Integrating other sciences into fisheries management was also mentioned. One manager felt that management should be “bringing more of the additional sciences into the information that we’re

looking at." While she noted that this has been occurring more often, she felt that "there probably should be some more blending and meshing" of the sciences.

Applying data and analysis to management

Fisheries managers agreed that "one of the biggest challenges with climate change is information and how to apply that information." One manager discussed how, although scientists provide managers with great information, it is still difficult to make decisions based on that knowledge. Another noted the specific challenge of planning for the future. Considering the issue of allocation, she explained that "thinking long-term versus short-term is difficult at times for those making policy decisions." One participant explained the difficulty of ensuring that management has the information needed to focus on current, near-term, and long-term changes. In general, managers acknowledged the substantial uncertainty caused by climate-driven changes such as shifting and expanding stocks. For example, one manager noted, "in terms of something like sea bass, [a concern I have is] being able to recognize and predict and respond to those shifts—is it temporary, is it permanent?"

Further, managers pointed towards the timeliness of science and management as a major challenge under climate change. One participant explained that in terms of the data used to make decisions, management is "always at least a year behind on the data." With regard to the contentious issue of allocation changes, she described how those decisions are "usually based on changes that we've already seen, as opposed to changes that we think are gonna happen in the future."

One manager described her concern regarding potentially outdated reference points in fisheries management. Although there is an inherent assumption about equilibrium in fisheries management, she explained that, "in climate change, we just can't continue to make that assumption about an equilibrium state. And so I often question the validity of our reference points and climate change, or how useful those reference points may be 5-10 years from now." She shared her perspective on how this plays out in the management realm, stating that, "There's certainly species that I can think of where I think the reference points are no longer attainable. And I think there's other species where the reference points are probably more conservative than they have to be." This highlighted managers' concerns with applying data and analysis to management.

Dynamic and real-time management

Dynamic and real-time management emerged as a major theme from the fisheries managers focus group. Results demonstrated that managers have difficulty providing adaptive and responsive management under the current management system. One participant described how managers are often "bound by certain regulations and prescriptive procedures and policies," hinting at the difficulty this presents when confronted by climate-driven changes. Elaborating on the somewhat restricted nature of fisheries management, another participant explained that, "our role is somewhat limited to controlling fishing mortality. And when natural mortality ends up being a larger influence on the stock's productivity because of climate change, then that's a challenge to our current approach where we're kind of limited in how much we can influence."

These two statements emphasize that managers are challenged in terms of how they can respond to changes, according to approved policies, regulations, and procedures.

Participants generally viewed the existing management system as a somewhat limiting factor in responding to shifting and expanding fish stocks, in particular. For example, one manager explained that in terms of quota allocation, “there's that inherent sense of geography in our fisheries management…And when the distribution of species errs from what we previously established, I think that's where it can be quite challenging to determine who gets those fishing access privileges or rights and how is quota distributed.” The “inherent sense of geography” described here was a major topic of conversation among focus group participants. Managers believed the existing management structure in the NES region is not designed to handle shifting and expanding fish stocks. A participant noted that “As these species really do start to move between councils, it will be harder to make those changes because it'll involve more than one management body.” Another explained that geography also determines who gets a vote in each management council. For example, because black sea bass is managed by the MAFMC, Mid-Atlantic states can vote on proposed management changes for that species, whereas New England states are given partial votes. Thus, “as species are coming into an area, and you're going to that other management council to try to get a piece of the pie, you're never going to win, because you're always going to get out-voted. So our system isn't set up to be nimble in that way.”

The allocation of coastwide quota is a focal issue surrounding shifting and expanding stocks. In addition to the jurisdictional challenges associated with allocation, managers commented on the lengthy process required for changing allocations. One stated that because of that prolonged process, there can be “huge disconnects between when the distribution changes happen and when that is factored into the management process.” Managers described how building adaptability into management is happening, albeit slowly.

One manager viewed the current response to shifting and expanding stocks as reactive, rather than proactive: “We’ve kind of been handling things so far in terms of shifting and expanding stocks in a piecemeal fashion, one species at a time.” She expressed that there would be value in developing approaches that can be applied more routinely and systematically across species and on certain time intervals in order to be prepared for changes as they are happening—not afterwards. Other managers described how more frequent reviews and adaptable management strategies are being built into allocation plans. Adaptability emerged as an important goal among participants. Some explained that they believe management has the ability to be more dynamic, but it is challenging to move away from historic approaches and towards new ones. One manager stated that, “We do have concepts and ideas to be more nimble and adaptable, but there's this hesitation to walk into those because of what you've always had in the past.”

Emerging species: opportunities and barriers

Several barriers to potential opportunities from emerging species were identified by managers. These included permits and regulations, allocated quota, and market demand. Table 3 lists these barriers as well as select quotations from managers that describe how these factors can limit potential opportunities.

Table 3. Factors cited by fisheries managers as barriers to seizing potential opportunities presented by shifting and expanding fish stocks and select quotations.

Permits and regulations	Allocated quota	Market demand
I think getting access to limited permits can sometimes hinder opportunity on these species	*Fisheries that are already quota-managed, it's really difficult to jump into that*	*If there's new species that could be an opportunity, there might not be the market demand*
I think in general regulations can make it hard [for fishermen] to move to something new and to adapt because you kind of lock people in into a certain way of doing things and then things are kind of built up around that.	*I think there's always opportunity if you have a fishery, in particular a fishery that is not quota managed, that's coming into your area, because there are not so many bounds around that fishery, and you can jump into it and start fishing on it.*	*Often sea bass, that's kind of a desirable appearance of a species here that has market value and everything*
For areas that you do have an unlimited fishery, it's easy to pivot and get into something else. But everybody and their brother can pivot and get into it so your ability to actually make a living off of it may be harder.	*It really depends on what's coming into your area and whether that's a [quota] managed fishery or not.*	*I think just in general that can be a challenge that [there's] not a market or a demand that is local and ready to go, like some of the existing fisheries are*

Fisheries managers were asked if they thought an exception such as 322 CMR § 6.12(8)(d) would be a good way to establish or grow emerging fisheries from shifting and expanding species. One manager believed that it could help grow emerging fisheries, but it would need to be coupled with marketing and outreach to educate the community about this new species. Landing species as bycatch was considered by another participant as a potential method for testing a market for emerging fisheries. Others felt that the constraints in Table 3 would still get in the way of seizing potential opportunities. For example, landing black sea bass bycatch from lobster traps would still contribute to the state's allocated sea bass quota.

Participants also discussed management's role in facilitating potential opportunities from climate-driven stock shifts and expansions. One explained that "if you don't constantly review and look at the information that you have and adapt your management to that, then you're not going to be able to provide industry the positives." Without regularly reviewing the information, she believed that managers miss out on providing those opportunities. Another manager cited the ability to transfer quota between states as a way that management facilitates opportunities. She believed that transferring quota between entities was "a flexibility that can help jurisdictions out if there are changes in distribution," referencing Maine's reliance on this process for its menhaden fishery.

Balancing management changes

Participants described implementing and balancing management changes as a major challenge exacerbated by shifting and expanding stocks. Results from the focus group identified three sub-themes within this larger theme: Figure 14 presents a conceptual framework of this them and its associated sub-themes.

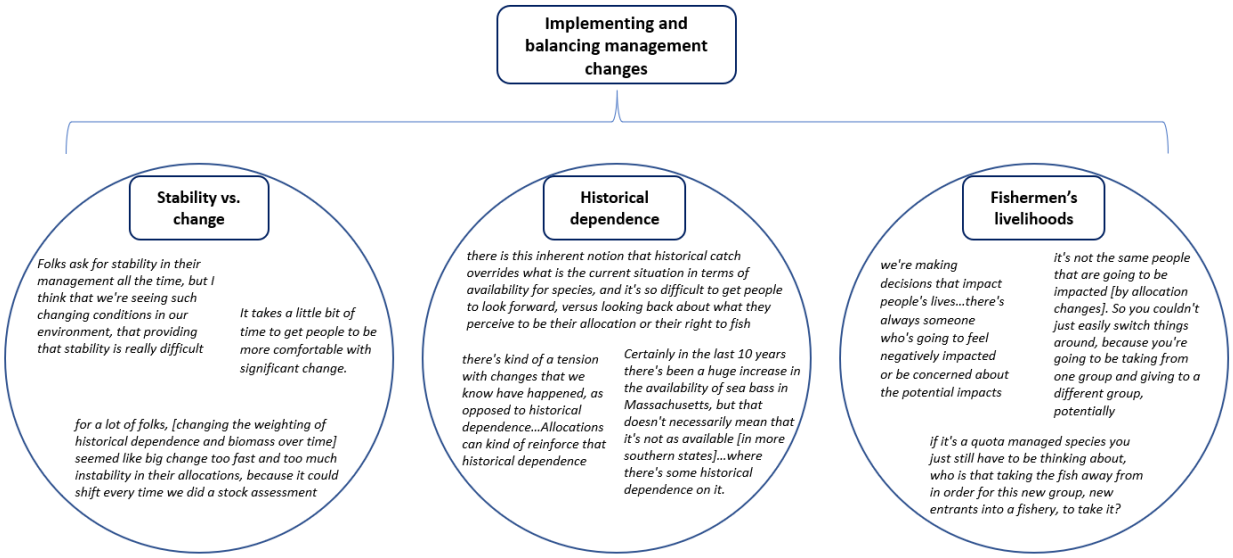

Figure 14. Conceptual framework depicting the sub-themes and select quotations derived from the major theme, implementing and balancing management changes

Fisheries managers discussed the difficulty of providing stability in the face of climate change. They expressed that making changes to allocations can be met with resistance because it generates instability. This exhibited the challenge that managers face in terms of maintaining as much stability as possible while also responding appropriately to shifting and expanding fish stocks.

The tension between historical dependence on fisheries and changes in species distribution was another challenge fisheries managers raised. One manager described how historical dependence on a fishery can take precedence over that species' biomass and availability. She noted that it is challenging to get people to "look forward" towards changing distributions rather than look back towards "what they perceive to be their allocation or their right to fish." Another participant expounded on this issue by citing the expansion of black sea bass: "Certainly in the last ten years there's been a huge increase in the availability of sea bass in Massachusetts, but that doesn't necessarily mean that it's not as available [in more southern states]…where there's some historical dependence on it." Managers found that balancing fishing access between the communities at either end of a stock's shifting or expanding range is a substantial challenge.

Managers emphasized that their decisions, particularly those related to allocation, impact fishermen's lives. As a result, one manager stated that "there's always going to be someone who's going to feel negatively impacted or be concerned about the potential impacts." Other

participants elaborated on this statement, explaining the reality of adjusting allocations according to changes in species distributions: in order to increase one group's allocation, you have to take allocation from another group. This demonstrated the significance of manager's responses to shifting and expanding stocks, as the outcomes of their decisions impact fishermen's livelihoods.

Other climate-driven challenges facing fishermen

Managers identified several other climate-driven challenges that they believed fishermen face. These challenges fell into three sub-themes: climate resilience and adaptation, keeping up with change, and social-climate combination challenges (Figure 15). Climate resilience and adaptation challenges included discussions of fishery diversity and fishermen adapting to species movements within their range. Notably, one manager described her concerns regarding fishery diversity in Maine. She explained, "The situation I'm trying to avoid is: you have your allocation for species that are currently there, those leave, so you don't really have a ton of fish landed from those species, but you don't yet have the new allocations for the species that are now in your waters."

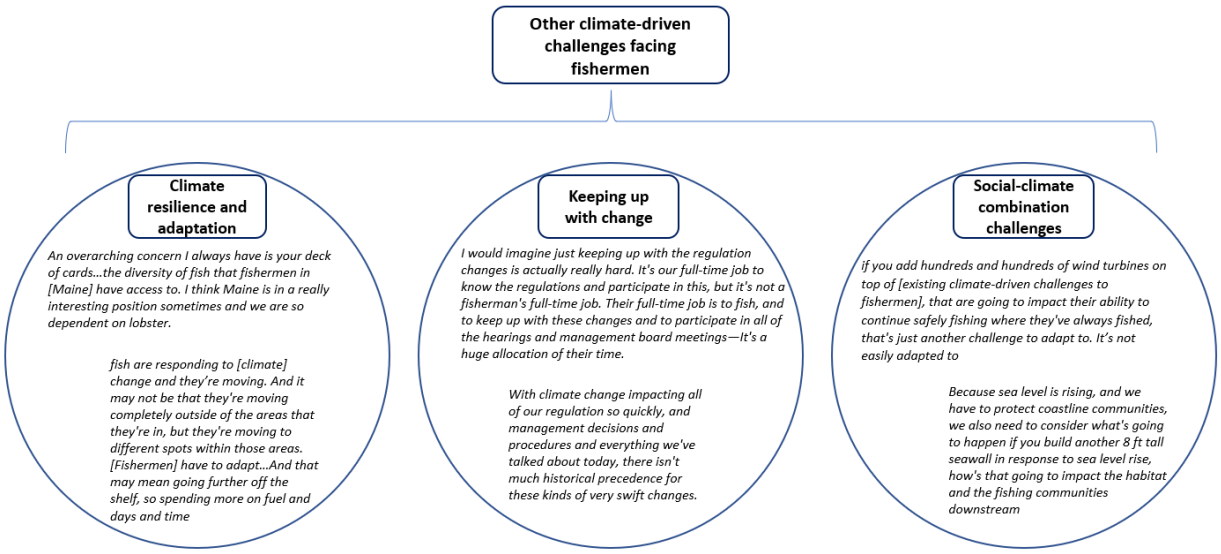

Figure 15. Conceptual framework depicting the sub-themes and select quotations derived from the major theme, other climate-driven challenges facing fishermen.

Keeping up with change was identified as another challenge facing fishermen. One manager commented that staying up to date with fisheries regulation changes is likely difficult for fishermen since it is a substantial allocation of their time. She noted that, "It's our full-time job to know the regulations and participate in this, but it's not a fisherman's full-time job. Their full-time job is to fish."

Social-climate combination challenges—those driven by human efforts to combat climate-driven changes—were also discussed. One participant described how fishermen are already challenged by myriad changes, and offshore wind development forces additional adaptation on them. Another manager mentioned how development intended to increase coastal communities'

climate resilience can inadvertently impact fisheries. She noted that coastal development can impact important fish habitat, ultimately affecting fishermen.

3.2 Southern New England fishermen

Seven major themes emerged from the SNE analysis. These themes are presented in Table 4 and represent the major topics raised across Southern New England fishermen interviews.

Table 4. Coded themes resulting from the SNE analysis.

Theme	Description	Code type
Observed changes and drivers of change	Changes that fishermen have observed on the water throughout their careers; drivers of these changes; expectations for the future given changes that have already occurred	*A priori*
Climate-driven challenges and associated impacts to fishermen	Challenges presented by climate-driven changes, including stock shifts and expansions; impacts these changes have had on fisheries	*A priori*
Emerging species: opportunities and barriers	Potential opportunities for engaging in emerging fisheries from expanding species; factors that facilitate or prevent development of those opportunities	*A priori*
Climate resilience and adaptation	The ways climate-driven change has forced fishermen to adapt; adaptation strategies; challenges to adapting	Inductive
Data, science, and adaptive social-ecological management	Integrating fishermen's observations and insights into management; the desire for social-ecological management that responds to fishermen's observations, necessitated by ongoing change; science, data and its application to management	Inductive
Social-climate combination challenges	Challenges initially driven by climate change that impact fishermen, such as offshore wind development	Inductive
Looking towards Maine	Thoughts on what to expect in Maine given changes experienced in Southern New England; challenges Maine fishermen will likely face; advice for Maine fishermen	*A priori*

Observed changes and drivers of change

Five out of six fishermen interviewed stated that they had observed a general northward or eastward trend of many fish stocks. One stated that he has seen, “overall, multi-species, from sea bass to squids, a move north.” He elaborated that he believed this northward movement of species has been occurring all along the U.S. Atlantic coast. One lobster fisherman from Connecticut explained that lobsters are moving further east. After pausing for a moment to think, he then stated, “I mean, everything has kind of moved further east.”

Fishermen also noted increased abundances of several species that were historically more associated with the Mid- or South Atlantic rather than Southern New England. These included black sea bass, summer flounder, bonita, Spanish mackerel, and squid species. One interviewee noted that fishermen in Southern New England now catch fish that they would normally never

catch, such as grouper. He attributed some of these catches to warmwater eddies that carry fish up the coast. An increase in forage fish was also mentioned, as one fisherman described increases in menhaden and mackerel.

Some fishermen noted large increases in the abundance of *Illex* squid in Southern New England waters. One also noted that *Illex* and *Loligo* squid species both seem to be occupying more northern areas throughout the winter than is typical. He explained that, even when groundfishing off of George's Bank, he can end up with "tremendous" amounts of *Illex* squid in his net.

Interviewees described a boom in the black sea bass population over the past decade. One explained that "the sea bass used to be really popular down North Carolina ways and stuff, and now you're seeing them move up into our area in some pretty good numbers." He noted that fishermen never used to catch that much sea bass unless you travelled to the Mid-Atlantic. Another mentioned that when he started fishing back in the 1980s, "the sea bass, in particular, they weren't very common. And now, maybe the past 10 or 12 years, there's been a shift in population dynamics and those fish have become more common inshore here." A fisherman from Massachusetts described how the waters he fishes have become "inundated with sea bass."

Of note to one fisherman was the increased frequency of "weird" years lately. He explained how one year a jellyfish-like species emerged in Southern New England in huge volumes: "They were everywhere. You couldn't even tow a net without clogging your net up with these jellyfish." This year produced another anomaly, with large abundances of baby butterfish. In sum, he noted that "there has been some obvious changes that I personally have seen, that I have never seen before."

Southern New England fisherman discussed the different reasons for some of these changes. Commenting on the changes he has witnessed, one fisherman explained that, "if you've got a rise in temperature certain fish are definitely gonna move away and certain fish are gonna come in." For example, he noted that because lobsters "don't like warm water at all," they've been moving up into more northern, colder waters. He also described how pesticides entering Long Island sound were part of the decline in Southern New England's lobster stock. Most fishermen agreed that spraying for pesticides was the primary factor leading to the loss of lobster in their region, with a couple noting the combination of pesticides and warming waters. One fisherman from Connecticut explained that changes in water quality in Long Island Sound have caused declines in most species there: "Long Island Sound … used to be as dark as a glass of Coca Cola or a cup of tea… And then starting maybe around 2000, maybe late 90s, it started clearing up until it became really crystal clear… I think that before, when it was darker, murkier, had more nutrients in the water, we had an abundance of species." He said that, now, that area is mostly made up of migratory species that spend the summer there and leave in the winter.

One fisherman said that he was not convinced the climate is changing. He described the reason for the substantial increase in black sea bass that he has observed in Massachusetts as a result of competition in their historic range, as well as the moratorium on the commercial spring fishery of spawning sea bass. Another interviewee wasn't sure of the cause for black sea bass' expansion and increased abundance, but suggested it could be climate-related: "I don't know whether that's

trying to follow this certain state of the climate, whereas it used to be perfect for [black sea bass] down south way some and then now they're more happy up our way." With regard to the rate of change in Southern New England waters, one fisherman stated, "Over my lifetime, fishing anyways, I've seen a lot of different things happen, but none as much as the last like six or eight years and I attribute it to climate." He expressed that, because of the rapid nature of these changes, "we just can't deny that it's something to do with the climate."

Thinking about what the future holds in light of the climate-driven changes he has witnessed, one fisherman explained, "I always say that, give it ten to twelve years and Rhode Island will be the new Florida—or at least Virginia anyways." Another interviewee echoed this sentiment, stating that there will definitely be changes in the future. He explained that he has been seeing some brown shrimp in Southern New England waters every year, going on to say, "I keep on wondering how long it is before we actually are fishing on a biomass of shrimp that's big enough to harvest and sell." Uncertainty was a common sentiment towards the future of fishing in Southern New England. Referring to climate change, one fisherman stated, "I don't know what's going to happen in the next ten year. If it keeps going at the rate that it is…I guess there'll always be something to catch, it just might not be what we do [now]."

Some commented that they believed some of these changes are starting to occur north of Southern New England in the Gulf of Maine. One fisherman stated, "I don't have any experience, but I do know some fishermen in Maine—they're seeing a lot more sea bass in Gulf of Maine waters." Others noted that striped bass and menhaden have made their way up to Maine waters. Describing an increase in striped bass in Southern New England as well, one interviewee said, "there's a lot of stripers that move through, and then they're moving more towards Maine, too. I say Maine but I'm sure it's up to like Nova Scotia." Most Southern New England fishermen overall expressed that many species of fish have been shifting or expanding in a northerly direction, both in terms of moving into and out of their region.

Climate-driven challenges and associated impacts to fishermen

Challenges driven by changes in temperature and the abundance of black sea bass were of note to fishermen. Some described how lobstermen are reliant on colder water due to its role in lobster habitat suitability. One stated, "For the lobster guys, temperature change in Rhode Island is horrible. They're all going out of business." He also explained that "for most [fishermen], they're not necessarily looking at the temperature, but they're looking at the result," with the result being decreased lobster landings and the associated loss in revenue.

The increased abundance of black sea bass was also associated with the loss of lobster in Southern New England. Two fisherman described black sea bass as "voracious," and both noted that the species eats everything. Another stated, "The only problem is the sea bass are very destructive to lobster populations. We'll sometimes catch black sea bass with three or four juvenile lobsters [in their stomachs]." Referring to black sea bass, one interviewee explained, "There's a lot more of them around now, so overall, I think you'll start seeing the lobsters decline around here. It's just bound to happen—there's way too much sea bass." Another said that he attributed some of the problems with the lobster fishery to the "ever-growing" population of black sea bass in the region. One fisherman described the inverse relationship between the

abundance of lobsters and the abundance of black sea bass and cod. He explained that when these predatory species were at low levels in the 1990s, the abundance of lobsters was very high, with Southern New England fishermen landing around ten pounds of lobster per pot. Now, he stated that he is "lucky to catch a pound a pot."

Figure 16 illustrates the impacts fishermen described in terms of rising temperatures and black sea bass abundance. These two factors were noted as diminishing lobster landings, and ultimately causing financial challenges to the lobster fishing community.

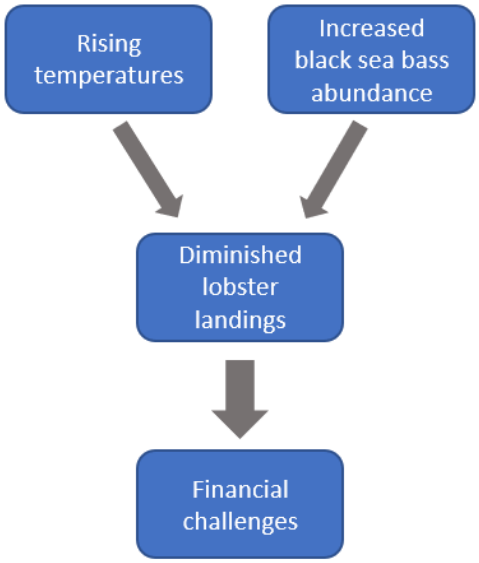

Figure 16. Flowchart illustrating the impacts of rising temperatures and black sea bass abundance on lobster fishermen, derived from fishermen interviews.

One fisherman also described how climate change has impacted fluctuations in fish populations. He explained that many years ago, stocks would decline, but fishermen knew that the stock would always come back. These cycles have been impacted by climate change, though: "now we're factoring so much more climate change, at a way more rapid rate…you don't know if something's gonna come back like it used to." In addition, the inconsistency of where fish are located was raised, as one interviewee described how fishermen can no longer look back in their logbooks to know when or where a target species will show up.

The financial effects of climate change emerged as an evident concern among fishermen. One explained how fishermen certainly experience the results of climate change: "[fishermen] see what happens with change…they see the reality in their pocketbook. And there's no better way of understanding pain, when all of a sudden you can't pay your bills because you didn't make any money." Summarizing the impacts that shifting and expanding fish stocks have on fishermen, he stated: "What's a boom for one person is bad to the other. So if the fish move north, then the guys down south are gonna cry. If the fish go deeper, then the inshore guys are gonna cry and the offshore guys will do better. It depends on where you are and where the fish go to."

Emerging species: opportunities and barriers

Fishermen discussed emerging species, the potential opportunities that they present, and the barriers to seizing those opportunities. One interviewee explained how changing temperatures and resulting species shifts and expansions have been beneficial for some groups of fishermen: "For certain people temperature change has worked out great, like the lobstermen up in Canada, for the *Illex* fishermen." Warming waters in Southern New England have likely led to the increase in *Illex* squid in that region, whereas it has caused the lobster stock to shift northward into Canadian waters. Fishermen generally acknowledged that opportunities for increased harvest are presented by shifting and expanding species. Black sea bass and *Illex* squid were the two species that fishermen discussed the most in terms of potential opportunities. One interviewee described how big booms of *Illex* have generated substantial revenue amongst squid fishermen, but was quick to point out that they are a difficult species to work with in terms of processing. He explained that once caught, *Illex* need to be stored in a refrigerated seawater (RSW) tank onboard, or else they will rot quickly. This technological need represents a challenge for fishermen looking to get into the squid fishery as populations boom in Southern New England. Another fisherman further elaborated on this challenge, describing how it's not easy to pivot to other fisheries, especially squid: "we're not rigged up really to go out and stay out in the canyons and go fishing and put in those 30-foot seas working on squid." The vessels needed for squid fishing prevent easy entry into the fishery.

With regard to the increase in black sea bass in Southern New England, one fisherman believed fisheries management was "totally not taking advantage" of the opportunity this species presents to fishermen. Interviewees identified three major barriers preventing them from seizing opportunities resulting from the expansion of black sea bass, as well as other species: trip limits and regulations, allocated quota, and market demand (Table 5).

Fishermen expressed frustration with how management has handled the increase in expanding species, particularly black sea bass. Interviewees felt that the trip limits for black sea bass have been much lower than they could be. One stated that if he could save 150-200 pounds of sea bass per trip, rather than 50 pounds, that could help him reduce the number of days he needs to fish per week to make a living. He explained that near the end of the fishing season, management will often increase the trip limits in order to harvest the annual quota. This drives derby-like fishing, and at a time of the season (winter) when fishing is most dangerous. Spreading the quota out by raising trip limits and eliminating "derby fishing" was preferred among fishermen interviewed because it allows them to maintain a higher, more steady income. Several discussed how the increased abundance of black sea bass has caused substantial bycatch of the species. Further, the low trip limit has meant that black sea bass are often being killed and thrown back into the water when caught by trawls. For example, one fisherman explained, "you get a tow where you get like 5-600 pounds, 1,000 weight of sea bass, and once you bring them up to the surface, they're not doing too good. And you can save 50 pounds." One interviewee described how it would be beneficial to be able to land this bycatch and prevent waste: "We're killing it all, so just let us catch what we're catching. We're not going to target it, it's going to be a bycatch." Others agreed with this sentiment that landing bycatch prevents the waste of fish that are likely going to die anyways from the trauma. Existing trip limits impact those targeting black sea bass as well.

Because the larger sea bass are sold for a higher price per pound, fishermen are incentivized to only keep the largest fish. One fisherman lamented, “it’s frustrating when you can only save 50 pounds of jumbos and you’re throwing the rest overboard.” Another explained that “so many fish get thrown overboard because, unfortunately, they’re not all jumbo sea bass.”

Table 5. Factors cited by Southern New England fishermen as barriers to seizing potential opportunities presented by shifting and expanding fish stocks and select quotations.

Trip limits and regulations	Allocated quota	Market demand
To tell us that sea bass needs to be 50 pounds because we only have a certain quota, like, what? Everybody get their shit together and start to see the trends of what's going on. If Rhode Island's got the stocks right now…figure out something, just don't throw it all overboard, most of it dead.	*even though you've got the fish off of your coast, doesn't mean that you're going to get good access to it.*	*Even though we catch a lot of black sea bass in southeastern Massachusetts, you don't see it on the restaurant menus very much because I don't think that the restaurants are willing to pay for sea bass locally what they're willing to pay in New York and in other markets.*
They’re on our back steps and they're dying because there's so many of them, and you can only save like 50-100 pounds.	*The problem up until the last couple of years was that the regulations wouldn't allow us to harvest very many of them. So that was really a huge hurdle for us.*	*You don't go to your local restaurant and find sea bass on the menu. You just don't.*
If I could save 150-200 pounds of sea bass a day—the price is good on them—think about the impact that would have just on fishing a four-day week.	*As it's [black sea bass] come up our way, it just gets gobbled up in bureaucracy and doesn't get to where it should get to, which is the fishermen.*	*sea bass usually commanded $4.00-$4.50 per pound, and more if you got it at the right time.*
A couple of years ago, the sea bass was so thick…we were throwing over 5, 600 to maybe 1,200 pounds of sea bass to keep like 5 or 600 pounds of squid.	*the whole problem comes back to, if you're only dealt with so much quota, then you can only have so much growth.*	*price per pound is what determines whether or not bycatch is going to be feasible…Nobody's gonna bring fish in that they lose money on.*

Quota was another barrier to opportunities that fishermen cited. An interviewee discussed how having a species in abundance in your waters does not necessarily mean you will be able to access it. In fact, one fisherman noted that obtaining more black sea bass quota was a significant hurdle. Another explained the dilemma created between historical dependence on fisheries and species expansions:

> "If we could get more sea bass [quota], Rhode Island could be a bigger player in sea bass. Traditionally North Carolina is. Now they're coming up here to fish them, and then they're taking them home. Are they really still the guys? Or should we be credited with having something at our doorstep?"

Balancing biomass and historical dependence is one of the larger challenges with handling species shifts and expansions. One fisherman stated that there has been a lot of opportunity with increased abundance of different species, but that the problem rests on how quota is allocated among states: "if we go back to the management of them, the quota was divided up based on where those fish were back in the '80s or '70s…so, among other things, that's always been a challenge." Referring to black sea bass, another fisherman stated that, "as it's come up our way, it just gets gobbled up in bureaucracy and doesn't get to where it should get to, which is the fishermen." He explained that, even if black sea bass trip limits were to increase for Southern New England states, the fishery's growth will still be limited by quota allocations. The success of fisheries management in facilitating opportunities was mentioned by one fisherman, however. He expressed optimism about a new director within his state's fisheries management: "[The new director] has done a decent job at trying to make sure we have opportunities. For example, in the last couple of years, we've traded menhaden quota for sea bass quota and stuff like that. I know that he's also lobbied…for a bigger part of the pie, and we've gotten that."

Interviewees also discussed the role that market demand plays in taking advantage of opportunities. Fishermen indicated that the black sea bass market is strongest in New York and New Jersey, and it is not as valuable in New England. Black sea bass is not typically, if ever, served at New England restaurants according to the fishermen interviewed—"That's a codfish, haddock, halibut, tuna, traditional New England fisheries area of the world." The price of sea bass was still described positively by fishermen, with a couple quoting prices around $4.00-$4.50 per pound. One fisherman believed growing the black sea bass market in Southern New England is a matter of consumer acceptance. He explained that, for example, "ten years ago, it'd be very rare to find mackerel in the fresh fish counter, and now you're seeing it more and more…it's just gonna take some effort on either the buyers or the retailed to get it out there."

When asked about their perspective on the exemption to Massachusetts' lobster regulations, 322 CMR § 6.12(8)(d), fishermen generally felt that it was a helpful regulation. Particularly due to the challenges that Southern New England lobstermen have faced, the fishermen interviewed generally felt that this kind of exemption could especially benefit the lobster fishery. One stated, "lobstermen are getting crushed…the price of fuel now is going through the roof, you got the price of bait, which has never been so high. So anything else they can do to supplement their days fishing, I'm 100% in favor of." He also added that he believed lobstermen should be able to land every fish they catch in their pots. This sentiment was common among the fishermen interviewed, who felt that throwing bycatch back into the water was wasteful. One fisherman from Connecticut explained that he is able to land whatever is caught in his lobster traps: "As long as I have a permit for it, we can keep it all in the pots…up to what the daily limit is…we keep cod, sea bass, black fish, tautog…I mean, that pays for the oil or pays for some of the bait." Some fishermen emphasized, though, that it all depends on price per pound. While a lot of fish

are thrown back over, they are not always species of value. One stated that you normally make money on black sea bass, making it worthwhile to land as bycatch. A couple fishermen believed that landing sea bass in this way could be a good start to growing the fishery, and that it could be applied to other expanding species in the future.

Two fishermen explained that something like 322 CMR § 6.12(8)(d) helps smaller vessels, but would not make an impact on larger vessels such as the ones they work on. One stated that the amount of money you would generate from landing bycatch up to the equivalent weight of your own target species, but not above the current trip limit, would not generate an amount of money that would matter to a bigger boat with a crew. The other fishermen explained that, "if there's any regulations that help those guys make a little bit more money every day, I'm all for it. But it's not going to help me."

Climate resilience and adaptation

Fishermen also described the challenges of adapting to change. One fisherman expressed pessimism about the ability for fishermen to adapt to changing conditions. He believed fishermen only have two options for adapting: travelling farther away from their traditional fishing grounds to catch fish or leaving fishing altogether. Travelling farther offshore or away from a vessel's home port is expensive and ultimately not feasible for smaller boats, however. He stated that, "For a lot of the inshore boats, their options are limited." The extent to which fishermen have to adjust their fishing location varies though, as he noted sometimes fishermen will adapt by working harder to find fish in different areas within the general region.

Another fisherman described how he has had to adapt to the decline of lobster in Southern New England: "After they sprayed [pesticides] in '99 and killed the lobsters, then it's been a gerbil wheel of different fisheries and different boats and everything from doing work from Army Corps of Engineers to clamming…we do other things than fish just because we have to." Doing other jobs on the water has been a way to supplement his income from fishing. He also described the challenges associated with diversifying his fishing portfolio: "Any money we're making with one fishery, we're putting into another. We got into the scallop fishery, that's pretty expensive to get into and more expensive to stay in it. But if we don't do it, we're out of business." Another interviewee explained that some Southern New England lobstermen have pivoted to fishing for crabs. While crabs used to be "useless" bycatch, some lobster fishermen will now target them.

Of note was one fisherman's discussion of how the current fisheries management system can hinder adaptation by limiting fishermen's abilities to pivot to other fisheries. He explained that fishermen used to have diverse fishery portfolios, "but now you're stuck in a box."

As species shift and expand into more northern areas, one fisherman expressed concern for accessing those species if they enter certain gear-restricted areas. For example, if squid keep occupying more northern areas of the region, they may end up in large-mesh fishing areas, where the smaller mesh sizes of trawl nets that are used to fish for squid are not permitted. He explained that to prevent this conflict, he has discussed conducting a "Nørdmore grid-type study." A Nørdmore grid is a type of net that allows groundfish escapement but still has smaller sized mesh in order to capture species such as squid.

Data, science, and adaptive social-ecological management

As fishermen shared their perspectives on the confluence of data, science, and adaptive social-ecological management, three sub-themes were identified: observations vs. actions, adaptive management, and fishermen participation in management (Figure 17).

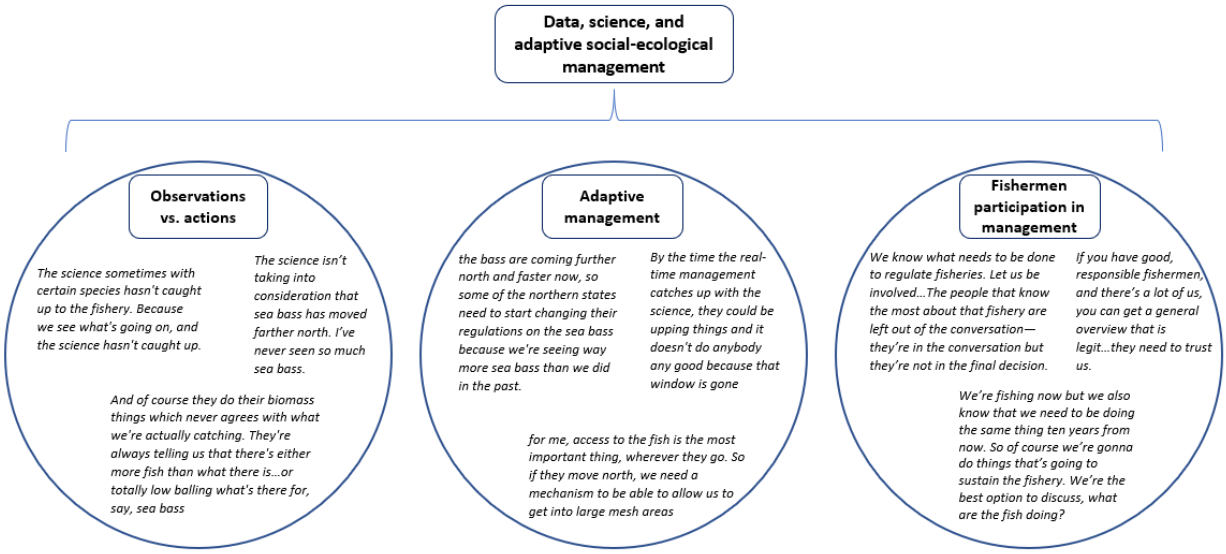

Figure 17. Conceptual framework depicting the sub-themes and select quotations derived from the major theme, data, science, and adaptive social-ecological management.

Fishermen believed there is often a disconnect between what they observe on the water and the data used by managers as well as the associated management decisions. They described a lag between the science conducted to inform fisheries management and the reality of the state of the fishery. One interviewee explicitly stated, "there's a lot of disconnect between reality and these regulations that fisheries management puts in." Most fishermen expressed that this disconnect has resulted in regulations that have either negatively impacted them or diminished the growth of their fishery. One stated that, "we've kind of almost missed the boat on some of this stuff because they totally low-balled how much stock is out there." Several fishermen specifically cited black sea bass as a fishery that has been impacted by a lack of adequate data. One noted that he did not think discard data is being incorporated into management. For example, "when [fisheries observers are] observing 5,000 pound tows of sea bass, and they can only save like 50 pounds, that kind of [information] isn't getting used. Some of that [data] would be an important thing to get back to the right people, but it doesn't." Another stated that "the science hasn't caught up to the sea bass yet. The sea bass is so thick, it's unbelievable." As a result, most believed that Southern New England states have not been allocated as much of the coastwide quota as they should have been or that their individual state had the trip limit set too low. One fisherman expressed his disappointment with black sea bass modeling efforts and the resulting regulations. He explained that the fisheries models being utilized "tell a really good story about the sea bass, but the way that [managers] use the models makes them think that they're being overfished."

Most fishermen expressed a desire for adaptive management practices that are able to effectively respond to shifting and expanding stocks. One interviewee noted that the concept of "real-time management" has never come to fruition. He explained that by the time management has caught up to understanding the science of what is going on with a fish stock, it is too late to do anything about the fishery because the window of opportunity has closed. Concerning real-time management, he stated, "We have never ever seen where we're telling [management] we're catching a lot of something, you need to up the limit, and they went ahead and did it. As the fish move north, fishermen want managers to respond in a way that allows them to harvest species that are increasing in abundance. One fisherman explained how observing the trends of who is fishing where can indicate what needs to change in terms of regulations. He described seeing vessels from southern states such as North Carolina fishing in Southern New England offshore waters: "We go out there, we're like a half hour from the fishing grounds…and I can have 50 pounds. And I see these guys from North Carolina…catching all these sea bass and then they're running home with them." He believed that this warrants an increase in quota for northern states where these fish are being harvested. Another fisherman indicated the importance of management ensuring that fishermen can access target species as climate-driven changes continue. If fish move into large-mesh areas, for example, it is important that there are adaptive management mechanisms in place that will allow small-mesh vessels to access those areas.

Half of the fishermen interviewed expressed the need for fisheries management, but also emphasized the benefit of more fishermen involvement. Some fishermen interviewed explained how they felt left out of management despite their wealth of knowledge. One interviewee stated, "Until recently, I felt like a lot of fisherman information was just discarded." Others echoed this sentiment and explained that their knowledge and information is often discounted. Another fisherman emphasized that he believed fisheries managers do not trust fishermen, leading to their exclusion from the management process. He explained, "Let us help with managing the ocean. Everybody thinks that because we have self-interests that we're gonna request all these crazy management things. We're not, we understand." The fisheries management council (FMC) model was also discussed by interviewees. One fisherman believed it was a good model, but it doesn't end up working in fishermen's favor. Another stated: "I don't care who's been on [the councils], fishermen or whatever, somebody's always got their agendas and wants to see something go the way they want it to go. And if you influence enough other council members, there's not a lot of them…" This illustrated the difficulty of managing multiple perspectives in fisheries and the challenges that this model can create. Ultimately, fishermen generally believed their knowledge and observations could be better-integrated into fisheries management.

Looking towards Maine

Because Southern New England fishermen have experienced an influx of expanding species, they were asked to comment on how they felt this phenomenon would impact fishermen in the Gulf of Maine, and whether they had any advice for them. Interviewees generally believed climate-driven species distribution changes would create opportunities for Maine fishermen to harvest these species. One fisherman believed that lobstermen in Maine would benefit from landing black sea bass caught as bycatch in their traps in terms of protecting the lobster population. "Maine lobster is it—it's its own brand. You got to do whatever you can to protect

that brand, and so by catching and retaining sea bass you're protecting juvenile lobsters, I can tell you that right now. That's for sure." This fisherman felt optimistic about the potential for a black sea bass fishery in Maine and explained that there are people in Maine that will make the black sea bass market grow once they are abundant enough.

One interviewee commented that species such as sea bass, squid, whiting, scup, and summer flounder were moving into Gulf of Maine waters. Referring to Gulf of Maine fishermen, he stated that "they're actually going to face some of the bigger challenges that we've gone through already." He emphasized this concern by saying, "the guys up in Maine are going to be facing some things and if they don't have the quota, they're going to be just as frustrated as we were." That same fisherman believed there is a great opportunity for emerging fisheries in Maine, but explained that Maine fishermen will have to "figure out how to get around all the bureaucracy and actually do the right thing." He expressed some optimism in that he thought Maine's fisheries management agency often does the best they can for the commercial fishing community, but recognized it would still be a challenge for fisheries managers in Maine: "it's really going to just take some hard work out of the Maine Council to try to get their fishermen more of this quota."

In terms of how quota is dispersed among states when species change their range, another fisherman described concern for the future. Because the black sea bass fishery is subject to a coastwide quota, he was not sure how management would address the challenges created if Maine decided they wanted to have a greater portion of that quota. He expressed how this scenario would impact him, too: "that's a concern because we don't fish bass year-round, but there are a lot of times during the year that bass pays our fuel bill…and I think that in itself is a big deal."

One fisherman offered advice for his counterparts in the Gulf of Maine. He recommended that when Maine fishermen start seeing species shifting or expanding into their region, they should document everything. This would allow fishermen to "prove" that they have been observing these species in their waters over time. He explained, "I know everyone's against the logbook…but at the end of the day, if there's going to be any documentation, it has to go through some method that's traceable."

Social-climate combination challenges

Three out of the six fishermen interviewed also raised concerns regarding the challenges created by offshore wind development. This topic was noteworthy because of its connection to climate change—ultimately, offshore wind development is a vessel for climate change's indirect impact to fishermen. Some fishermen were particularly worried about the effect that wind farms would have on migratory species. They cited the uncertainty of how these structures and the electrical cables connecting them to each other and to land could impact species. One fisherman summarized this concern by stating that "everybody's worried about temperature changes, salinity changes, whatever it is—that's not the real issue. The real issue is that's all going to change once the wind farm's up."

3.3 Gulf of Maine fishermen

Six major themes emerged from the GOM analysis. These themes are presented in Table 6 and represent the major topics raised across Gulf of Maine fishermen interviews.

Table 6. Coded themes resulting from the GOM analysis.

Theme	Description	Code type
Observed changes and drivers of change	Changes that fishermen have observed on the water throughout their careers; drivers of these changes	*A priori*
Climate-driven challenges and associated impacts to the lobster fishery	Challenges presented by climate-driven changes, including stock shifts and expansions; impacts these changes have had on the lobster fishery	*A priori*
Emerging species: opportunities and barriers	Potential opportunities for engaging in emerging fisheries from expanding species; factors that facilitate or prevent development of those opportunities	*A priori*
Climate resilience and adapting to change	The resilience of Maine's fishing industry to climate-driven changes; adapting to climate-driven changes; management assisting fishermen with adapting to climate-driven changes	Inductive
The future of Maine fisheries	What the future holds for fisheries in Maine and the lobster fishery, in particular	*A priori*
Social-climate combination challenges	Challenges initially driven by climate change that impact fishermen, such as offshore wind development and north Atlantic right whale protection areas	Inductive

Emerging themes illustrate that lobstermen view warming waters as a disruption to the lobster industry and a concern for the future. Changes observed primarily focused on rising temperatures and the resulting increase in “out of place” species in Gulf of Maine waters. With regard to expanding species, fishermen believed there could be potential opportunities associated as abundances of species such as black sea bass increase but were quick to cite the barriers that would likely prevent them from capitalizing on those opportunities.

Lobstermen also described their possible lack of resilience to change due to low fishery diversity in the state of Maine. They revealed that the reliance on lobstering, combined with the recognition that waters will likely continue to warm, is a major concern for the fishery’s future. Other challenges noted by fishermen included those indirectly caused by climate change, such as offshore wind development and seasonally closed zones for the protection of north Atlantic right whales.

Observed changes and drivers of change

The Gulf of Maine fishermen interviewed all noted that they have observed positive increases in water temperature over the course of their careers. In fact, this was the first observation interviewees mentioned when asked about the changes they have witnessed on the water. One fisherman immediately responded that water temperature was “obviously” something he has observed. Describing the dramatic changes seen, he explained, “usually you'll see like 58, 59,

maybe 60 [degree water]. And last year, a lot of times I saw like 60 to 70 degree water. Way up inside. So it's not common to see that like that." Another fisherman stated that the temperature was the biggest change he has seen. Some participants described the 2021 season as particularly warm in the Gulf of Maine, with one stating that it "was probably the warmest water temp I've seen where I'm fishing now." Several cited 2012—the warmest average annual SST in the Gulf of Maine on record—as the beginning of many water temperature-driven changes in the Gulf.[7] Referencing the 2012 lobster season, one fisherman believed "that was when there was a more general realization [of warming waters and associated effects] among the greater population of fishermen."

Interviewees drew connections between increases in water temperature and observed changes in species. Participants stated that they believe the recent rise in temperature has led to an increase in the lobster population in more offshore areas. For example, one fisherman stated, "There's areas offshore that people had tried to fish before and there never was a lot of lobsters, and through this [warming], from 2012 until now, they've found lobsters are very prolific out in these deeper waters offshore." Some fishermen also noted a change in the timing of Gulf of Maine lobster's seasonal molt and migration offshore, with one explaining that, "the shedder run now starts usually before the Fourth of July. It didn't used to…Over many years, it has seen that [lobsters] shed earlier and start to move offshore earlier."

Fishermen also noted increased catches of many "out of place" species, particularly black sea bass. According to one fisherman, "black sea bass are everywhere." Interviewees indicated that they have observed these increases in black sea bass and other out of place species in the past 5-15 years. One fisherman noted that, "I've seen the biggest changes In Maine in the last like 15 years with new species and weird species where I'm fishing." He expanded further, adding that, "Ten-some years ago, we started getting black sea bass in abundance. And when I say abundance, I mean in June is when we typically catch them around here—five in every trap. I've trapped for black sea bass as a kid [in New Jersey], and five in every trap, that's a lot. That means there's a lot of black sea bass there." Participants also noted a surprising increase in triggerfish catches in the past ten years. Fishermen expressed that observations of these species have become more frequent ever year, with one stating, "You talk to people and it's like, yeah, see more and more triggerfish every year, more and more black bass every year." Observations of species such as black sea bass and triggerfish were associated with increased water temperature. It was noted by one fisherman that the increase in black sea bass coincided with the increase in temperature, starting more substantially around 2012.

Other "unusual" species noted by interviewees included summer flounder, squid, blue crabs, hake, scup, butterfish, great white sharks, and leatherback sea turtles. Some also expressed the irregularity of seeing certain species in atypical areas. For example, a few fishermen noted seeing humpback whales and great white sharks in relatively shallow waters. These observations were associated with an increase in forage species in those areas, potentially due to temperature.

[7] https://www.gmri.org/stories/gulf-of-maine-warming-update-summer-2021/

Regarding the rate at which some of these changes have occurred, one fisherman said he didn't believe the changes witnessed have been too rapid. Although all of the interviewees expressed that changes are evident, one stated that the Gulf of Maine has not experienced a substantial change in species composition due to climate change, yet.

In discussing what they have seen change on the water over the course of their careers, fishermen noted the relevance of their observations to the big picture of fisheries and climate in the Gulf of Maine. Fishermen recognized that one observation does not always mean much, but over time and aggregated across fishermen, these consistent observations can amalgamate into a valuable dataset. For example, one fisherman stated, "I catch one [out of place species] and it's like, oh that's interesting, but it doesn't really mean anything that I've seen one fish because things get out of whack. But then you get in and it's like, oh, look at this cool thing I caught today, and you send somebody pictures and they're like oh, yeah, I got one last week, and somebody [else] was saying they got one last year." Another fisherman stated, "Anecdotally, I'm a layman, I understand, but I'm on the water 200 and some days a year. I think my observations mean something."

Climate-driven challenges and associated impacts to the lobster fishery

As fishermen discussed climate-driven challenges and the associated impacts to the lobster fishery, three sub-themes emerged: changing systems, the spatial shift in the lobster fishery, and other climate-related impacts. Figure 18 presents a conceptual framework outlining climate-driven challenges and associated impacts to the lobster fishery, including the sub-themes gleaned from the data and select quotations demonstrating interviewees' perspectives.

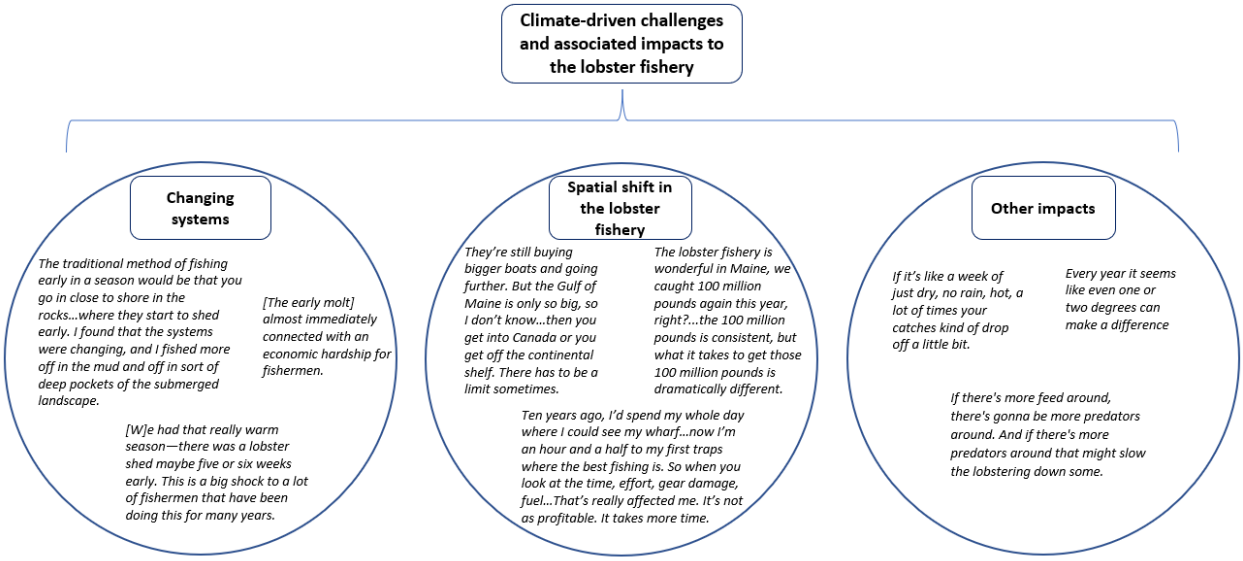

Figure 18. Conceptual framework depicting the sub-themes and select quotations derived from the major theme, climate-driven challenges and associated impacts to the lobster fishery.

Some fishermen discussed the impacts of changing systems in the lobster fishery. They described how the shift towards an earlier timing of the lobster molt during the fishing season surprised lobstermen and caused some economic impacts. Commenting on the earlier molt, one fisherman said, “I remember back in 2012 in April, which, usually, if you get 2-300 pounds, you're doing good. And I remember in April in 2012, we were doing like 7-800 pounds a day of shedders (softshell). It was mind boggling.” Another fisherman explained how he noticed this trend in the shift earlier than many scientists and other fishermen, and used it to his advantage: “The traditional method of fishing early in a season would be that you go in close to shore in the rocks and this is where they [the lobster] start to shed early and things like that. I found that the systems were changing, and I fished more off in the mud and off in sort of deep pockets of the submerged landscape.” Commenting on the economic hardships it created, however, one fisherman explained that the early shed meant there was no pre-existing market that early in the season for lobster. Further, the rise in temperatures caused some lobsters to die in storage or even in the traps. He stated that, “All these things led to an immediate drop in the price. And so it was very soon that fishermen realized and the public realize that these warming events are soon translated into economic events.”

The spatial shift in Maine’s lobster fishery was frequently discussed in interviews. They explained that the last decade or so has seen a decline in the inshore lobster fishery and a shift towards fishing further offshore. One fisherman stated that, “Ten years ago, I’d spend my whole day where I could see my wharf…now I'm an hour and a half to my first traps where the best fishing is.” He noted that this has affected him substantially due to the increased time, effort, fuel, and resulting gear damage associated with fishing in more offshore areas, which ultimately makes it less profitable. The same fisherman explained that, “the best nearshore lobstering I've ever experienced in my life was 10 or so years ago in 4-12 feet of water in the heads of all the bays that I fish in. And that fishery is over.” Fishermen who described this trend focused on the investments necessary for offshore lobster fishing in the Gulf of Maine. One stated, “The lobster fishery is wonderful in Maine, we caught 100 million pounds again this year, right?...the 100 million pounds is consistent, but what it takes to get those 100 million pounds is dramatically different.” He cited the increase in larger, much more expensive fishing vessels that make up Maine’s commercial lobstering fleet, noting that there are now “million-dollar lobster boats up and down the coast of Maine.” It was also mentioned that this information needs to be factored into understanding the viability and health of the lobster fishery. Another fisherman echoed this perspective, saying “a lot of people make huge money, but they also have to spend huge money.” Still, some fishermen expressed that the situation is not dire, and they still catch plenty of lobsters inshore.

Other climate-related impacts to the lobster fishery were noted by some fishermen. One commented that, “I think the only thing that's really affected the lobstering is the weather, really. When you get those long, dry, no rain hot spells, the lobsters don't really crawl, they kind of just dig into the mud and try to stay cool I think. Seems like soon as we get some rain or cool weather they start to crawl a little bit.” He also stated that this can result in somewhat of a decline in catches during those warm, dry periods, and that, “Every year it seems like even one or two degrees can make a difference.” The increased presence of predators was also raised as a

potential factor in slowing down the lobster fishery. Some fishermen cited the return of cod and a rise in striped bass as possible influences. One stated that "I feel like the lobsters just stop crawling when they sense that there's a lot of stripers around, too, because they'll eat short lobsters just like cod do, non-stop." It was noted that as forage fish increase, predators will also increase and potentially diminish lobster catches.

Emerging species: opportunities and associated barriers

Emerging species, the potential opportunities that they present, and the barriers to seizing those opportunities were a major discussion point during interviews. Fishermen generally recognized the potential for opportunities to arise as a result of climate-driven expansions of species into the Gulf of Maine, as well as the shifting lobster stock. Species identified as potential future fisheries included black sea bass, Jonah crab, and squid. Some interviewees agreed in their sentiment that Jonah crab could be easy to get into because it has always been part of Maine's lobster license. One fisherman explained that "people are interested in picking it up because nobody needs to go get a new permit and you don't need to get new gear and change everything to try something new." He recognized the challenge of developing a market for Jonah crab in Maine but discussed how some people in the state have been trying to promote the species and get it to people.

With regard to "new" species, however, fishermen pointed towards the barriers to taking advantage of such opportunities. The primary barrier indicated was permitting. One fisherman expressed that navigating the permitting process can already be a challenge for existing fisheries, hinting that it could be even more difficult for an emerging fishery. Another interviewee mentioned the high financial cost associated with obtaining the necessary permits. One fisherman explained his perspective on opportunities that could be presented by expanding species in the Gulf of Maine in detail, focusing on the expansion of black sea bass:

> "I grew up in a place where we trapped black sea bass, targeted them, and there was a robust market for them, and they're really great fish to eat, and there's no question in my mind a black sea bass market could be developed anywhere in the world…there's no way that any kind of opportunity for fishermen will exist moving forward because of the state Department of Marine Resources and the National Marine Fisheries Service, NOAA. There's zero regulatory environment that will allow expansion of fisheries, in my opinion."

His perspective illustrated a belief among most fishermen interviewed that fisheries management does not help facilitate potential opportunities offered by expanding stocks. Rather, some fishermen felt that the current management system can often hinder these opportunities. One fisherman, however, discussed the challenges that fisheries management encounters with facilitating these opportunities. He explained that when fish such as black sea bass move into the Gulf of Maine with warming waters, "it becomes a management problem of who can catch what, where, and when. And things like catch limits and things like that become a problem of dispersing what state gets what and how many."

When asked about their perspective on the exemption to Massachusetts' lobster regulations, 322 CMR § 6.12(8)(d), fishermen generally thought applying a similar regulation in Maine would be

beneficial. One fisherman emphasized that in order to allow a regulation like that in Maine there would need to be substantial modifications to the existing regulations since they currently don't allow lobstermen to land any bycatch. He followed up by stating, "I think that'd be a better way to do it than creating a whole new fishery…If people are allowed to go catch something, they will try it." Other participants acknowledged that fishermen will land bycatch if it has value. Considering black sea bass specifically, an interviewee stated that, "I don't know what the price of black bass is, but it's decent, I know people make money off of it," demonstrating the species' potential value as a bycatch product. One fisherman stated that he thought 322 CMR § 6.12(8)(d) "would be good for landing sea bass and things like that…Especially species that are on the rise." Another indicated how bycatch could help, saying, "If you could pay a helper off bycatch, that would be huge. It's a big load off your shoulders. Every day you go out and you never know what's gonna happen, and if you've got a helper or two helpers, that stress is huge on a captain." A particularly enthusiastic response was given by one fisherman who emphasized that he is "totally in favor of bycatch retention in the lobster fishery." Addressing the reasons some fisheries managers may oppose landing bycatch, he stated, "I do not want to portray myself as expert, but the amount of bycatch caught in lobster traps in terms of biomass is statistically insignificant in terms of that impact on that biomass…even for lobsters with traps, traps are highly inefficient." He noted that landing black sea bass caught as bycatch in lobster traps could also be a good source of data and that management could require fishermen report these landings as bycatch in order to obtain that data.

Fishermen were also asked if they thought an regulation exception such as 322 CMR § 6.12(8)(d) would be a good way to establish or grow emerging fisheries from expanding species in the Gulf of Maine. Responses to this question were mixed, but most believed that it would be an effective way to grow a fishery for species such as black sea bass. One fisherman clarified that while he is in favor of landing bycatch, he did not see how it could help truly grow a fishery. He explained that he would not consider landing bycatch as an emerging fishery, but rather profitable bycatch: "That would be a way to legitimately add to the per-day value of a lobsterman's, or woman's, catch for that day. For example, if I could keep and sell [summer] flounders and black sea bass, at the end of the year I probably have another $2,000. That's a big deal for me."

Climate resilience and adapting to change

Fishermen also described the lobster fishery's resilience to climate change, as well as the concept of adaptation. The diversity of Maine's fishing portfolio was raised by several participants as a concern. They generally viewed the lack of fishery diversity as a limitation to adapting to climate-driven changes. One fisherman stated that, "Overall, my concern is the lobster fishery in Maine is a single point of failure. The regulations in Maine have squeezed fishermen into this box of lobstering, and if the lobster fishery crashes in Maine, Maine fishing's done." Echoing this sentiment, another said that "if you had something else to the back your salary on a different species to fish on it'd be less stress…There's just not enough up here in Maine—you're either a lobstermen or you're a carpenter." Fishermen acknowledged that while other major fisheries exist, such as the tuna and scallop fisheries, they carry large barriers to entry and therefore don't serve as sufficient "fall back" options.

Participants recognized that trends of climate-driven change are likely to continue, with some indicating that there will eventually be a need to diversify. They generally agreed that fishermen are "not quite ready for the whole changing fisheries thing yet" in Maine. However, they believe that the future will demand some change. As one fisherman put it, "I think it's something we need to look forward to, but there's not a need for it yet. We'll have to move on when the water gets hot." Another expressed that the main hope among lobstermen is that there is a slow progression towards fishing other species, rather than a dramatic change where all of a sudden they cannot go lobstering anymore. He also indicated that the lobster fishery is already trying to diversify in some ways. Fishermen referenced more southern states such as New Jersey that have already been forced to adapt their fisheries to the loss of lobster: "The lobstermen know…that once lobsters start to clear out, Jonah crab move in. That's what some of those guys down out of New Jersey and stuff have found, and they've pretty much just shifted over." This fisherman also noted that other species present opportunities for adaptation, stating that, "there's all kinds of fish—the black bass is a pretty big fishery further south. And if I had enough of them here, and I could get a permit, I would probably try it. It's not possible and it's not feasible right now though." Other interviewees also expressed that they did not believe any expanding species have reached an abundance in the Gulf of Maine that warrants a true fishery yet.

One fisherman referred to aquaculture as a way to diversify his income. Although not many fishermen engage in the aquaculture industry, he believes that is going to change at some point. To him, it makes sense as an alternative source of income for fishermen because they already have much of the necessary gear and skills. He explained that, "I like I like being on the water and I like being self-employed, so it lets me keep doing that even if I can't go fish whatever I want to catch." The ease of obtaining an aquaculture lease and permit in comparison to a commercial fishing license was also cited as a reason to turn to ocean farming.

Adaptations that have already occurred within the lobstering community were also discussed. One fisherman described how the warming temperatures and resulting change in the timing of the lobster molt that began around 2012 forced fishermen to "transition from being very exact, almost exacting in when they're gonna set traps" to "realizing that they've got to be ready for earlier, and ready for other changes, or they're gonna get left behind." He discussed how the impacts of climate changes on lobsters and their movements began with changes in when lobsters would molt and migrate, and then progressed to a question of where they were moving. This, he explained, was the beginning of the transition to more offshore fishing.

When asked if they believed fisheries management is trying to help fishermen adapt to the future of climate change and warming waters, most fishermen did not think they were. One fishermen, however, stated that he believes management tries to help, though he is not sure it's always successful. He explained that, "they're trying to allow people a certain amount of effort in the fishery and still look after it, but it's a difficult job."

The future of the lobster fishery

Discussion of the future of Maine's lobster fishery revealed uncertainty among interviewees. They agreed that warming temperatures raised concerns for the fishery given lobster's suitable water temperature. While some fishermen expressed that species moving up towards the Gulf of

Maine as a result of climate change could pose threats to the lobster fishery, most were more concerned about lobsters shifting away from Gulf waters. One fisherman stated, “As far as trying to fish for lobster, I'm not really worried about the [expanding] species part, I'm more worried about the water temps. They'll just keep working their way towards Canada.” This reflects the trend of lobster landings favoring more northern portions of the Maine coast, noted by another fisherman: “So that's one of the scares—just that progression that we saw in Maine was [lobster] used to be doing much better in Southern Maine than the Mid-Coast and now they've been doing a lot better further Downeast…you can't just not see that. There's a definite trend.”

Some fishermen referenced the loss of lobster in Southern New England as a fear for what could happen in the Gulf of Maine. For example, one interviewee believed “temperature is gonna be a big, big challenge. If it keeps getting warmer and warmer, just like Rhode Island and Massachusetts and whatnot…their catch has declined huge.” The same fishermen expressed that although he would love to get his daughter into lobstering, his concerns for the future prevent him from doing so. However, most noted that lobster landings were still good throughout the region. One said that while he wonders what might happen to the fishery as the water continues to warm, he doesn’t believe water temperature is a five-year threat.

Another threat to the lobster fishery raised by one fisherman was the impact of late-season offshore lobstering on the whole population. Because lobsters seasonally migrate offshore in the fall and winter and then return inshore in spring and summer, he worries that the substantial offshore fishing pressure could hurt the abundance of inshore lobsters.

Social-climate combination challenges

Fishermen also raised concerns regarding the challenges created by offshore wind development and areas closed to lobstering as part of efforts to protect the north Atlantic right whale. Although not directly driven by climate change, one fisherman explains that warming waters have exacerbated the issues with right whales. He notes that climate change has caused myriad changes, which all come together to affect the whole food chain, ultimately creating a “backdoor effect on the whale issue with lobstering” in terms of where the whales are going. “It’s partly a climate issue and partly a social issue.” Offshore wind was also described as a social-climate combination challenge. One fisherman described how “fishermen [are] the first ones to see the effects of climate change and also the first to be affected by efforts to mitigate climate change.”

4. Discussion

Using black sea bass in Southern New England and the Gulf of Maine as a case study, this study elicits fishermen and manager perspectives of individuals across the NES region to answer several questions. Fishermen and fisheries managers are two integral populations within the SES explored. Thus, their perspectives provide valuable insight to help answer this study’s research questions. This research is designed to explore the challenges and opportunities that climate change and climate-driven shifts and expansions of fish stocks pose to commercial fishermen and fisheries managers in the NES region. Given the potential opportunities, this work also seeks to understand the barriers to taking advantage of opportunities that may be offered by climate-driven changes, particularly changes in species distributions. Lastly, climate-driven changes, the

challenges and opportunities they present, and associated barriers to seizing opportunities were closely examined in Southern New England through the lens of the potential reciprocal impacts to the Gulf of Maine. Information gleaned from Southern New England participants can therefore help prepare the Gulf of Maine fishing community for changes already experienced by their southern counterparts.

4.1 Challenges posed by climate change and resulting stock shifts and expansions

Challenges described by fisheries managers, Southern New England fishermen, and Gulf of Maine fishermen maintained some overlap, but also differed. Figure 19 illustrates where study populations aligned and diverged in terms of the major challenges they face as a result of climate-driven changes. All three groups described challenges related to data and science, climate resilience and adaptation, and social-climate combination challenges (Figure 19).

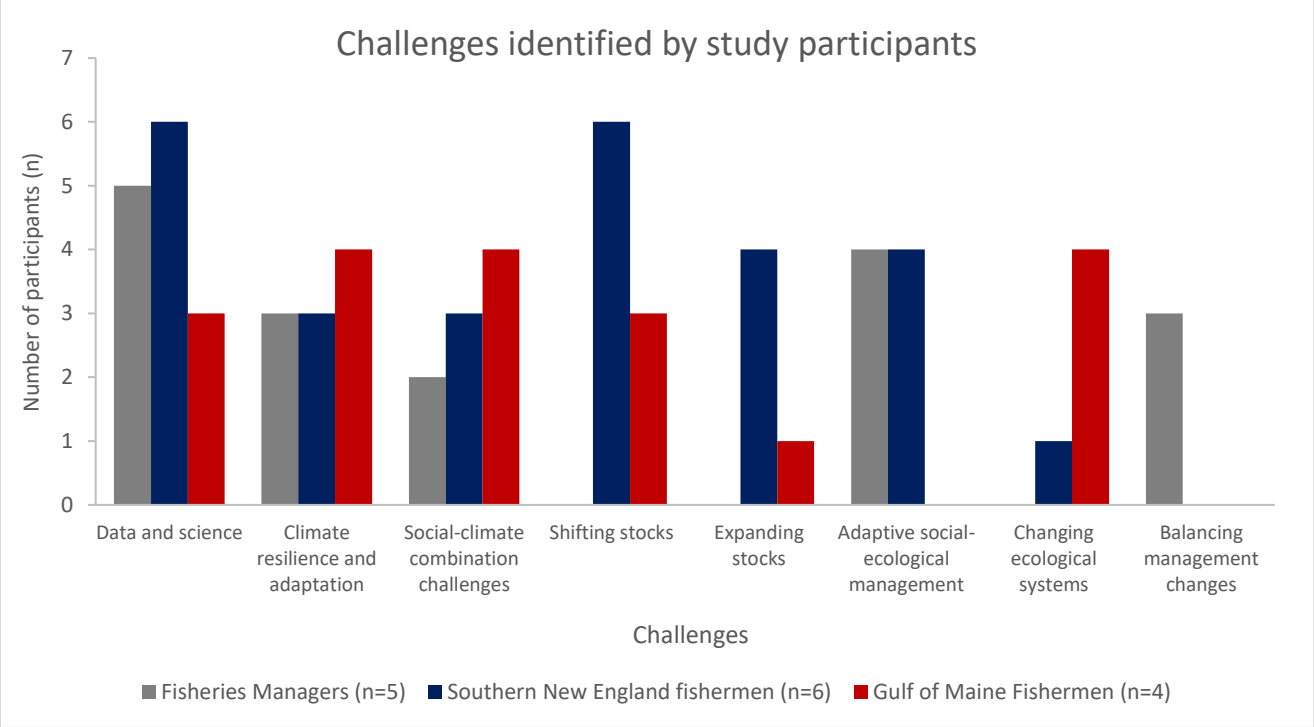

Figure 19. Bar graph showing the major challenges identified by study participants with the number of participants from each group who discussed these challenges.

Data and science

100% of participants from the SNE group (n=6) and FM group (n=5) and 75% of GOM participants (n=3) indicated data and science as a climate-driven challenge. Within this theme, groups differed somewhat in how they described data and science as a challenge. For example, fisheries managers discussed issues related to data collection, analysis, interpretation, and application to management actions. FM participants described how climate-driven changes such as stock shifts and expansions lead to uncertainty with knowing what data is needed, how to interpret it, and apply it to management. Managers also acknowledged that climate change

exacerbates the challenges created by a lack of timeliness of science and management. Fishermen from Southern New England also acknowledged the issue of timeliness in fisheries management. They described scientists and management playing "catch-up" to the changes in species distributions that have been occurring. This was particularly noted for black sea bass, as two fishermen discussed the science lagging behind the fishery's changes. At least three SNE fishermen and one fisheries manager believed that the issue of timeliness in management can lead to outdated management decisions. For fishermen, this was associated with a loss of potential opportunities. Southern New England fishermen also cited a disconnect between the data used by managers to make decisions and what fishermen observe on the water. Some fishermen believed certain valuable data points are not included in management decisions, such as discards. One interviewee also expressed that he did not feel that the models employed by fisheries managers are being used appropriately.

The three GOM fishermen that addressed the theme of data and science focused on translating observations into useable data. One interviewee expressed that he felt data obtained from fishermen can be used to create valuable datasets. Another explained how when he makes observations on the water, they can seem isolated and not necessarily indicative of larger trends. However, the observations shared among fishermen back onshore come together to paint a bigger picture of what is happening with species in the Gulf of Maine. These sentiments demonstrated the challenge of translating observations on the water into data off of which managers can base their decisions. SNE fishermen also expressed this concern when discussing the disconnect between their observations and the data reported by fisheries managers. This challenge was the basis for the establishment of the Commercial Fisheries Research Foundation's (CFRF) black sea bass research fleet in Rhode Island. The research fleet was developed in part because Rhode Island fishermen felt that the black sea bass quota allocation was low in comparison to what they were able to catch in their waters (Hannah Verkamp, personal communication). In addition, the research fleet was driven to fill data gaps on a species of particular interest to fishing industry members. Stakeholders in the fishery recognized a lack of available data on the northern portion of the black sea bass sock—particularly fishery-dependent data in SNE that could be used in stock assessments (Hannah Verkamp, personal communication). The research fleet produces fishery-dependent data, with fishermen conducting regular fishing activities and documenting their relevant observations on a pre-programmed tablet. The fleet is comprised of vessels using a variety of gear types, including lobster traps, fish pots, and trawls. At present, CFRF operates their black sea bass research fleet in Southern New England and the Mid-Atlantic.[8] The ongoing research track stock assessment for black sea bass is currently assessing how some of this data could be used in the stock assessment process (Hannah Verkamp, personal communication). The results of this study suggest that expansion of CFRF's black sea bass research fleet into the Gulf of Maine would assist with understanding the species expansion and help translate fishermen's observations into useable data.

[8] http://www.cfrfoundation.org/black-sea-bass-fleet

Climate resilience and adaptation

The concepts of climate resilience and adapting to change were discussed by all three groups. 60% of fisheries managers (n=3), 50% of SNE fishermen (n=3), and 100% of GOM fishermen (n=4) described the challenges associated with climate resilience and adaptation. Results indicate that climate resilience is a significant challenge among Gulf of Maine fishermen, whereas SNE fishermen are not as concerned with resilience. The literature appropriately identifies adaptation as an important aspect of climate resilience (Ojea et al., 2020). Several adaptation strategies cited by fishermen in this study agree with other studies in the literature (McClenachan et al., 2020; Ojea et al., 2020; Stoll et al., 2017). However, few studies obtained the perspectives of fisheries managers and multiple fishing groups—and even fewer considered these perspectives together. The results of this study therefore add to an ever-growing body of literature concerning climate resilience in the fishermen-manager SES.

Fisheries managers discussed this challenge in the context of how it impacts fishermen. One manager identified how permitting makes it challenging for fishermen to adapt to change because they are locked into certain fisheries. SNE fishermen agreed with this sentiment, describing how management can hinder their ability to adapt due to tight regulations and access to permits. The diversity of fisheries that fishermen have access to was also indicated as an important aspect of climate resilience. Low fishery diversity in Maine was cited as a concern for both management and GOM fishermen, but was a major theme discussed among GOM fishermen. All four GOM interviewees raised concerns about the lack of fisheries besides lobster in Maine. One GOM fishermen described Maine's lobster fishery as "a single point of failure" for Maine fisheries as a whole. This single point of failure demonstrates concerns about low climate resilience in the Gulf of Maine. Fishermen worried that if something happens to the lobster fishery, whether it is climate-related, such as warm waters driving lobsters more north and offshore, or not, the fishing industry will suffer immensely. This concern is supported by the numbers: lobster is Maine's most valuable fishery, with over 80% of the value derived from commercially harvested marine resources in Maine coming from lobster in 2021.[9]

Managers described how fishermen have been adapting to change by fishing farther away from shore, which can be associated with financial challenges. Both fishermen groups also described the challenges of fishing further offshore. They acknowledged that this adaptation strategy is not necessarily possible for smaller vessels given the harsh conditions of offshore fishing and the large financial investment required to obtain a larger boat and support the amount of fuel required.

Social-climate combination challenges

Although not directly related to this research, indirect challenges created by climate change are important to address given the number of participants who cited them as a concern. These "social-climate combination" challenges include those driven by offshore wind development and areas closed to lobstering as part of efforts to protect the north Atlantic right whale (NARW). Climate change is either a driver of these challenges (offshore wind) or a factor that has

[9] https://www.maine.gov/dmr/commercial-fishing/landings/documents/ValueBySpecies.Pie.Graph.pdf

exacerbated them (right whale closures). 40% of managers (n=2), 50% of SNE fishermen (n=3), and 100% of GOM fishermen (n=4) described social-climate combination issues. SNE fishermen and fisheries managers only noted the challenges associated with offshore wind development, whereas GOM fishermen discussed wind farms and right whale closures. This is likely due to the demographics of the two fishermen groups. Because GOM fishermen interviewed were all lobstermen, areas closed to fixed gear impact them substantially. SNE fishermen interviewed only included one active lobsterman, with four others fishing with trawls. Further, geography plays a role given that SNE is not within the NARW critical habitat area, while the GOM is. Wind farms pose greater challenges to trawlers due to the cables and other equipment buried on the ocean floor, therefore causing greater concern among that demographic of fishermen. However, two GOM lobstermen also cited offshore wind as a concern for the future.

Shifting and expanding stocks

Challenges directly associated with shifting stocks were discussed among both fishermen groups. Specifically, 100% of SNE fishermen (n=6) and 75% of GOM fishermen (n=3) described the challenges driven by shifting stocks. A spatial shift in the Gulf of Maine lobster stock was identified as a current challenge by two GOM fishermen and a future challenge by three GOM fishermen. Most described the trend towards more offshore fishing, as the most lucrative fishing has transitioned from nearshore areas to dozens of miles away from the coast. This has created financial challenges for fishermen and a general concern for the future. Spending more money on fuel and added time for traveling to get to fishing locations is less efficient and can hurt a fisherman's bottom line. It also creates challenges in terms of the dangers of offshore fishing. Two GOM fishermen also discussed lobster's shift northward, expressing concern for what this will mean for the fishery's future. GOM fishermen referenced the sharp decline of lobster in Southern New England as a fear for their fishery. Should climate change and warming waters drive lobster towards more northern and offshore locations as is projected by the literature, that will substantially impact Maine's fishing industry as a whole.

Southern New England fishermen addressed shifting stocks primarily in terms of accessing species and the challenges created by how management handles distribution shifts. They noted that fish stocks have been shifting both into and out of Southern New England waters. As a result, there exists a concern that these species will "pass them by" unless they are adequately addressed. Increased abundances of shifting and expanding species in their region can lead to large amounts of bycatch and ultimately wasteful fishing that they want to avoid. Some fishermen worried that stock shifts, driven by climate change or otherwise, could make it more difficult to access certain species. One SNE fisherman noted the challenges created by species shifting and expanding into gear-regulated areas. He explained how fisheries management needs to develop some kind of mechanism that can address this issue.

Southern New England fishermen were the only group that explicitly described the challenges caused by expanding stocks. 67% of interviewees (n=4) highlighted how the expansion of black sea bass impacts lobster populations due to the species' voracious nature, believing that sea bass consume juvenile lobsters and larvae. Some fishermen also noted that they expect black sea bass will likely harm lobster stocks in the Gulf of Maine as the species continues to expand its range.

One GOM fisherman, although not explicitly, mentioned that future challenges were likely as stocks expand into the Gulf of Maine. Other GOM fishermen indicated that they were less concerned about expanding species and more concerned about warming waters affecting lobster populations.

Adaptive social-ecological management

Results indicated the importance of adaptive management practices that respond to changes in a timely manner. 80% of fisheries managers (n=4) and 67% of SNE fishermen (n=4) described the value of such management practices. Managers revealed the challenges associated with trying to provide responsive management actions, highlighting several factors that limit their ability to do so:

- Managers are bound by prescriptive procedures and policies that limit their ability to respond to climate-driven changes
- The inherent sense of geography built into the fisheries management system makes it challenging to respond to stocks that shift or expand outside their historical range
- The prolonged process required for making management changes prevents those actions from being temporally responsive

Fishermen generally acknowledged these limitations but also expressed that they could help address some of these challenges through participatory social-ecological management in which their knowledge and insight is integrated into the management framework. Two fishermen acknowledged that the FMC model is a good model, but it does not work well in practice. They felt that social-ecological management practices could be more effectively implemented in a different way, though they did not explicitly state how. Figure 20 provides a conceptual model illustrating the concept of social ecological management.

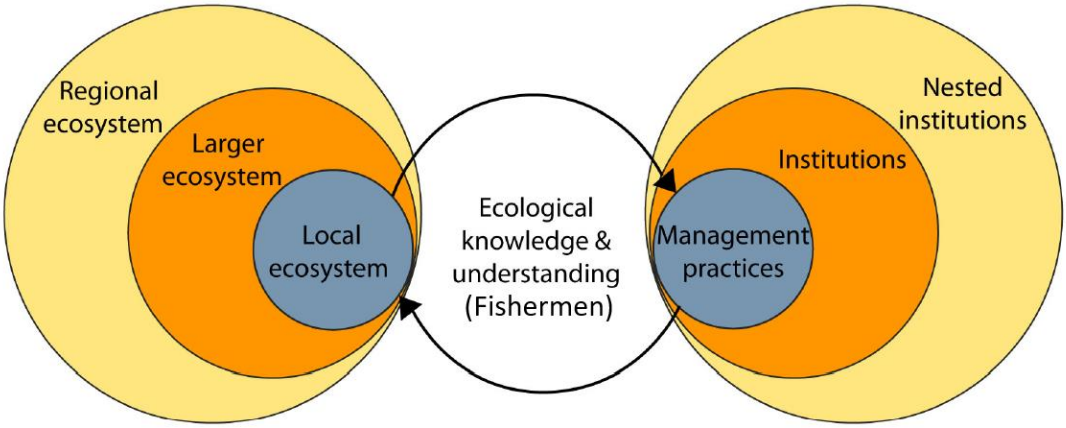

Figure 20. Conceptual model depicting social-ecological management. Adapted from Colding & Barthel (2019) to demonstrate fishermen's role in ecological knowledge and understanding.

Changing ecological systems

Changing ecological systems were demonstrated to be a challenge for Gulf of Maine fishermen. 100% of GOM fishermen (n=4) interviewed described this challenge, whereas only one SNE fisherman commented on this issue. GOM fishermen explained how changes in water temperatures have altered the ecological systems such that they have had to alter their fishing practices. This was primarily discussed in the context of warming waters causing an earlier lobster molt and also driving the species into different areas to stay cool. Fishermen revealed that warming waters can impact them by reducing their catches, but demonstrated that they have been able to adapt to changing ecological systems. This differed from the one SNE fisherman's perspective on these challenges. He described how changing systems have impacted typical population fluctuations of target species. As a result of climate change, these fluctuations may be exacerbated, leading to the loss of stocks.

Balancing management changes

60% of fisheries managers (n=3) identified the challenges associated with balancing management changes. They discussed the difficulty of making management changes that satisfy all stakeholders. Managers revealed that trying to balance change among different groups makes their job difficult, and with climate change necessitating more frequent changes, this challenge is amplified.

4.2 Emerging species: opportunities and barriers

Results indicated that despite the challenges, climate-driven changes present opportunities to the fishing industry. Specifically, climate-driven shifts and expansions of fish stocks can create opportunities for harvest as species emerge in areas they previously did not occupy.[10] Gulf of Maine fishermen believed the ongoing expansion of black sea bass is a potential opportunity. Fishermen from Southern New England also considered black sea bass' expansion to be an opportunity, in addition to summer flounder and the increase in *Illex* squid abundance due to warming waters. Fisheries managers did not specify a species that might present opportunities to fishermen, but generally believed opportunities could exist. Black sea bass is the focus of this study and represents a species rapidly increasing its abundance in the Gulf of Maine and consistently being caught in lobster traps, demonstrating potential opportunity driven by this species' expansion into the region.

Barriers

These potential opportunities were not discussed without highlighting the associated barriers, however. All participants (n=15) indicated barriers to seizing opportunities driven by shifting and expanding stocks. A breakdown of these barriers and the number of individuals from each population that discussed each barrier is presented in Figure 21.

[10] https://sustainablefisheries-uw.org/warner-lew-underutilized-species/

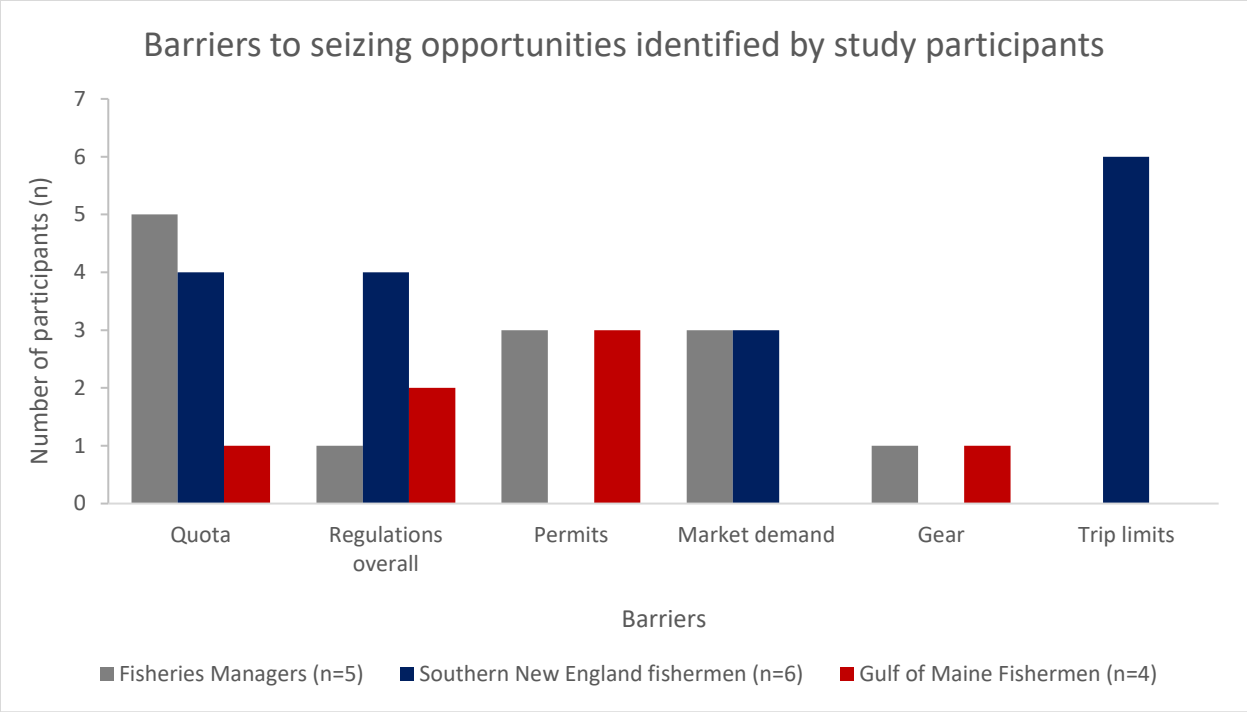

Figure 21. Bar graph showing the barriers to seizing opportunities identified by study participants with the number of participants from each group who discussed these barriers.

All three groups identified quota and regulations overall as substantial barriers to capitalizing on opportunities from shifting and expanding fish stocks. Managers believed quota was the greatest barrier to actualizing opportunities, with 100% of managers (n=5) describing this barrier. Results indicated that fisheries managers perceived quota to be the deciding factor in whether or not fishermen could capitalize on potential opportunities offered by quota-managed species. Four out of six SNE fishermen also identified the barriers that quota create for fishermen looking to take advantage of emerging species. GOM fishermen were not as focused on the barrier of quota as the other two groups, with only one interviewee discussing this barrier. Each group also cited regulations overall as a hindrance to seizing opportunities. The majority of SNE fishermen (67%, n=4) and 50% of GOM fishermen (n=2) referenced the regulatory system. Only one manager referred to fisheries regulations as an overall deterrent to facilitating opportunities for fishermen. Fisheries managers also indicated permits (n=3), market demand (n=3), and gear (n=1) as hurdles to jump in order to seize opportunities. Permits and market demand were more frequently discussed, with permitting emerging as one of the greatest factors preventing fishermen from taking advantage of opportunities. GOM fishermen also believed permits were a substantial deterrent to seizing opportunities, with 75% (n=3) of interviewees discussing this barrier. Gear was also mentioned by GOM fishermen, but was not considered to be a major obstacle. SNE fishermen did not mention permits, but cited market demand (n=3) and trip limits (n=6) as barriers. Trip limits were described by SNE fishermen as substantial obstacles to tackle in order to actualize opportunities. They expressed how low trip limits combined with increased abundances of expanding species such as black sea bass have led to large amounts of wasted bycatch.

The majority of participants (n=12) believed these obstacles were so great that they would likely impede fishermen's abilities to seize any opportunities, with 60% of managers (n=3), 75% of GOM fishermen (n=3), and 100% of SNE fishermen (n=6) expressing this perception. These results demonstrate that participants view obstacles presented by management structure (e.g., permits and trip limits) as more obstructing to seizing opportunities than non-management related obstacles (e.g., market demand and gear). This provides an important view into what would need to change in order to facilitate opportunities and increase climate resilience among GOM and SNE region fishermen.

Facilitating opportunities

Considering the substantial concern GOM fishermen expressed regarding climate resilience, taking advantage of emerging species presents a compelling opportunity. Fishermen from both regions acknowledged that facilitating such opportunities from emerging species would be beneficial to them. It is therefore important to understand:

- How fishermen can overcome the aforementioned barriers in order to seize opportunities presented by shifting and expanding fish stocks; and
- The ways in which fisheries management can facilitate these opportunities.

Approaches to overcoming market-based barriers to seizing opportunities were generally agreed upon among groups. Participants believed that to create any kind of valuable opportunity from a new and emerging species, there would need to be marketing and outreach to educate consumers about the product. Increasing the acceptance of a newer species such as black sea bass in New England takes time. Some fishermen felt that developing a market for black sea bass in Maine and growing the market more in Southern New England are both totally possible. Restaurants were one avenue that fishermen mentioned for increasing acceptance and growing demand for species such as black sea bass. One fisherman described a marketing collaborative in which a group of industry professionals travel to the west coast of the U.S. with lobsters and teach chefs how to cook lobster. He stated that this has helped grow market demand for lobster in other regions of the U.S. Approaches such as this could be effective with marketing black sea bass to the New England seafood industry.

Landing emerging species as bycatch was another approach to seizing opportunities discussed within each group. Fishermen indicated that the increased abundance of expanding species such as black sea bass means bycatch is going to occur regardless. When this happens, the fish caught as bycatch are not often likely to survive and thrive once returned to the water. In 2018, dead commercial discards of black sea bass were 1.591 million pounds, compared to 3.338 million pounds of total commercial landings for the year (NEFSC, 2020). In fact, commercial discards from 2014-2018 made up about 33% of total commercial removals, a significantly larger value than the proportion of commercial removals made up by discards over the 1998-2018 time period (17%). Researchers believe that this increase in discards is likely due to heightened availability of black sea bass in combination with existing quotas and other regulatory measures (ASMFC, 2021). Although these values represent coastwide data—from North Carolina through Maine—these commercial discards could be indicative of substantial bycatch in areas with low quotas

and trip limits respective to the available biomass. Thus, fishermen believed that landing these fish would be a way to reduce waste of fish that will not live anyways. In another region of the North Atlantic, Icelandic fishermen are required to land bycatch in order to reduce wasteful discards. Southern New England fishermen who fish using trawl gear were particularly supportive of this approach and viewed it as a way to add to their income and minimize wasteful bycatch. Two fishermen from the Gulf of Maine also felt this would be a beneficial way to grow a black sea bass fishery in the future, especially because sea bass are often caught in traps. In fact, in New Jersey where the black sea bass and lobster fisheries have historically overlapped, fishermen would repurpose lobster traps at the end of the lobster season to be used for trapping sea bass. Although specific fish pots exist, fishermen in New Jersey often prefer to use lobster traps for catching black sea bass because the larger vent size required for lobstering allows smaller fish to escape and reduces handling time of sublegal fish (Marissa McMahan, personal communication). With lobster traps serving as an effective method for harvesting black sea bass, such an approach appears suitable for the Gulf of Maine, where lobster fishing dominates the industry.

One GOM fisherman expressed, however, that he would consider landing sea bass as bycatch to be added income, but not a true fishery. This fisherman firmly believed that the regulatory environment for fisheries in the U.S. is too strict to allow for the growth of any emerging fisheries. An approach such as landing bycatch, though, could help fishermen earn some extra money. He still believed that it would be difficult to make something like that happen given the current management and regulatory system.

Many participants believed a regulation exception such as 322 CMR § 6.12(8)(d) would be beneficial. One fisherman from Connecticut explained that he often lands fish in this way, and that the resulting income helps to pay for expenses such as fuel and bait. Other fishermen perceived the regulation to help pay for similar expenses as well. One added that the additional money matters a lot to fishermen, who do not often have health insurance—he explained that an additional $2,000 per year could cover several doctor's visits, for example. Fisheries managers felt that this could be a good way to grow emerging fisheries, but caveated that other barriers (e.g., quota) would still be a hindrance.

In order for lobster fishermen to land bycatch, regulations in certain states would need to change. While 322 CMR § 6.12(8)(d) allows Massachusetts lobstermen to land bycatch from traps, provided they have the appropriate permit, and fishermen in Connecticut are able to do the same, this is not a common practice across New England. Further, fishermen still need to obtain the relevant permit, which is a challenge unto itself.

The role of fisheries managers in facilitating these opportunities was also discussed amongst the three groups. Managers explained that a barrier to facilitating opportunities is the need to be constantly reviewing the information available to them and making changes. One manager also mentioned the beneficial ability to transfer quota between states. She indicated that Maine relies on this process for its menhaden fishery. In the future, this could help facilitate a black sea bass fishery in Maine, however, that will rely on more southern states giving up their quota.

4.3 Learning from Southern New England

The fishermen-manager SES in Southern New England has been at the forefront of climate-driven changes in the NES region. Increases in expanding species such as black sea bass, and the climate-driven hampered recovery of lobster have challenged Southern New England. This study elicited the perspectives of fishermen and fisheries managers in Southern New England in order to gain insight into how climate-driven changes they have already experienced could impact the Gulf of Maine. As climate change continues to alter ecological systems in the NES, Southern New England may serve as a harbinger for change in the Gulf of Maine.

SNE fishermen believed that continued expansion of species would create opportunities in the Gulf of Maine. Some expressed that, as expanding species such as black sea bass have grown in abundance in Southern New England, they have had difficulty taking advantage of the associated opportunities. One fisherman expressed that the barriers to opportunities that they have experienced in SNE will likely be a challenge for fishermen in the Gulf of Maine. He stressed the importance of leveraging fisheries management to make these opportunities happen but was pessimistic about the ability to do so due to differing agendas and politics within the relevant FMCs. Another interviewee emphasized the value of landing black sea bass as bycatch in Maine, explaining that it is not only a way to add income to a lobsterman's trip, but also crucial to protect lobster from black sea bass predation. He recognized Maine's reliance on lobster and the need to do everything possible to protect the species. This recognition of Maine fisheries' low resilience to changes—whether climate or otherwise—is a critical aspect of this study.

This concern was echoed by one fisheries manager from Maine, who emphasized the negative impacts that could result from lobster shifting out of the Gulf of Maine, with no other fisheries around to fill the void. Given Maine's reliance on its fishing industry, with lobster the primary driver, building climate resilience is key. Other fisheries managers did not address this topic, which emphasizes Maine's tenuous position. Because other managers who participated in this study were not from Maine, they likely do not maintain the same fear for losing a stock. In short, their jurisdictions' reliance on a single species is not as strong as it is in Maine.

As for advice, one SNE fisherman recommended that as Maine fishermen observe increases in emerging species in their waters, they should document it. He acknowledged that using a logbook can be tedious, but it produces traceable documentation of observations. Using fishermen's logbooks as a source of data is not new in fisheries management. This method of data collection is known as historical ecology, a growing field that often utilizes nontraditional data sources, such as logbooks, oral histories, and other archival materials (Engelhard et al., 2016; McClenachan et al., 2015). Some researchers argue that using nontraditional data sources to fill data gaps, sometimes revealing surprising results, is imperative (McClenachan et al., 2015). Engelhard et al. (2016) demonstrates the value of applying these methods to management, emphasizing that historical ecology has been employed to inform management in the past and can continue to do so in the future. While historical ecology has been applied to understand gaps in data such as baseline abundances and population declines, it is yet to be used for understanding stock shifts and expansions. Historical ecology represents a promising avenue for documenting change in the Gulf of Maine, with the hope that fishermen's observations could be

integrated into management's overall understanding of species' shifts and expansions in the region.

5. Conclusions and Recommendations

This study seeks to understand the challenges and opportunities that climate-driven shifts and expansions of fish stocks along the NES region pose to fishermen and managers. With a focus on the expanding black sea bass stock, this work strives to understand the major challenges and barriers associated with facilitating potential opportunities. As with many challenges in fisheries and management, shifting and expanding stocks present a "wicked" problem. Despite the complexity of this issue, working towards approaches that overcome the challenges and barriers to opportunities is paramount to this research.

Quota and its state-by-state allocation play a pivotal role in the extent to which fishermen can take advantage of shifting and expanding fish stocks. Facilitating opportunities from emerging species must consider how harvest contributes to that state's allocated quota. Growing emerging fisheries from stock shifts or expansions ultimately relies on an appropriate quota allocation based on availability of species. By its very nature, the process for determining quota allocations amounts to a mathematical equation in which managers do their best to implement fairness and equity into the system, while making sure that the total allocations across states sum to 100%. Quota allocation is a complex and contentious issue that has been exacerbated by climate change-driven stock shifts and expansions. Balancing historical dependence and stock availability is a challenging task that managers are forced to navigate under the current system. Reallocating quota in response to changes in species distributions inherently takes from one group and gives to another. Managers are tasked to make decisions, using the best available science, on how to distribute quota among historically-dependent states and those with increasing abundances of a shifting or expanding species. This concept emphasizes the importance of fully understanding stock status to make informed decisions about quota allocations. Utilizing a wealth of data sources to sufficiently assess shifting and expanding stocks and implementing changes in a timely manner is a challenging undertaking for scientists and managers. However, it is also necessary in order to create opportunities for the fishing industry.

Data optimization emerged as a critical aspect of managing fisheries under climate change. Both fishermen and managers addressed this issue, with fishermen wanting to integrate their data and insights into management decisions and managers noting that they could probably be more creative and efficient when it comes to data collection. This realization presents an opportunity for a social-ecological management structure such as that illustrated in Figure 20 that better-utilizes fishermen's observations as data for management. The model used by CFRF's research fleet, including that for black sea bass, represents a valuable approach for moving towards social-ecological management in fisheries. Expanding this methodology to other geographic regions would likely increase management's understanding of shifting and expanding stocks. In the Gulf of Maine, this data collection system would help to document the presence of black sea bass and provide more information regarding the species' expansion. Better-understanding black sea bass' expansion into the Gulf of Maine can help appropriately identify and work towards facilitating

opportunities for fishermen in a region of low climate-resilience. This approach could ultimately help inform future coastwide quotas and state-by-state allocations.

Facilitating these opportunities, however, is a separate challenge. Managers believed that without up-to-date information on stock shifts and expansions, creating opportunities for fishermen is difficult. Fishermen reinforced this perspective, noting that they could help managers deliver real-time management solutions. Adaptive management is improved when fishermen are able to participate in the decision-making process. Further, participatory fisheries management can enable fishermen to collectively manage their own fisheries.[11] The FMC system is a sound model, but there are better ways to effectively deliver adaptive social-ecological management in this SES. With fishermen observing changes in real-time, creating a system that consistently uses their observations to determine how stocks are changing could help realize opportunities for fishermen. For example, the SES would benefit from a system in which management works cooperatively with fishermen in a consistent and more "real-time" manner, assessing live data and working to determine if fishermen should increase or decrease their harvest levels. As one fisherman explained, responsible fishermen want to see their fisheries sustained for years to come. Overfishing is not their goal. Incorporating fishermen's knowledge and data into managing fisheries can help improve climate resilience by facilitating opportunities from climate-driven stock distribution changes, additionally diversifying income across multiple species. With climate resilience occurring within SESs, it is evident that resilience cannot be built into just one part of the system—rather, it must be integrated system-wide.

Opportunities presented by stock expansions could therefore be facilitated by allowing fishermen to land bycatch of emerging species. Fishermen indicated that this would either be an effective route to develop emerging fisheries from species undergoing range shifts, or simply a way to diversify and increase their income throughout the year. With participatory adaptive social-ecological management, aided by analyzing live data from fishing vessels, fishermen can indicate when this opportunity is appropriate. For example, as fishermen begin to catch black sea bass as bycatch in amounts that consistently exceed their allowable trip limits, fishermen and managers can cooperatively develop solutions to landing bycatch without depleting the resource. Further, creating an avenue to land bycatch without needing a specific permit for that species reduces waste and improves the value of a fishermen's trip. In Massachusetts and Connecticut, fishermen can land bycatch from lobster traps, but only as long as they maintain the associated permit. Permitting was a major barrier to opportunities identified by fishermen and managers. While increasing permit availability can help fishermen diversify their fishing portfolio, it can also diminish profits due to the number of players in the fishery, which would likely result in low trip limits. Bypassing the permitting barrier, under appropriate circumstances (i.e., when expanding species are being caught as bycatch in excessive amounts), can facilitate potential opportunities and limit wasteful discards.

[11] https://sustainablefisheries-uw.org/seafood-101/management-enforcement/

6. Impact Statement

While climate-driven shifts and expansions create substantial challenges for fishermen and managers in NES, they may also lead to opportunities. Given low climate resilience in Maine fisheries, facilitating the opportunities presented by the expanding black sea bass stock is of critical importance. This research intended to understand the challenges and opportunities generated by black sea bass' expansion into the Gulf of Maine. More importantly, it sought to determine approaches to overcoming the barriers to these opportunities in order to increase climate resilience in Maine while concurrently bolstering lobstermen's incomes.

There exist various barriers to seizing opportunities presented by shifting and expanding stocks. The primary obstacles include permitting, bycatch regulations, and quota allocations. Further, managers struggle to provide these opportunities due to prolonged regulatory and data collection processes that result in outdated science and management decisions. Implementing adaptive social-ecological management approaches that rely on insight and data from fishermen can help to facilitate opportunities and produce more timely management actions in response to change.

This study revealed that landing expanding species such as black sea bass as bycatch in lobster traps can help develop emerging fisheries while also increasing lobster fishermen's incomes. With the mounting cost of fuel and bait, in addition to the need to travel further to catch lobster, fishermen can benefit from landing this bycatch. The current generation of Maine lobstermen may very well experience challenges posed by a shifting lobster stock. As Maine lobstermen continue to catch sea bass in their traps, it will become evident that the regulatory system must facilitate opportunities in order to build climate resilience in Maine's lobster fishery. The loss of Southern New England lobster and subsequent forced adaptation should be a lesson for the Gulf of Maine. Providing timely management actions is paramount in an ever-changing system—taking action before declines in other species necessitates this change is in the best interests of the fishermen-manager SES.

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8. Appendices

Appendix 1: List of ports designated as "Gulf of Maine" for use in Figure 7

Port Name	Port State
Androscoggin (County)	ME
Perry	ME
Washburn	ME
Bailey Island	ME
Brunswick	ME
Cape Cottage	ME
Cape Elizabeth	ME
Casco	ME
Chebeague Island	ME
Clapboard Island	ME
Cliff Island	ME
Cumberland	ME
Cumberland Center	ME
Cundys Harbor	ME
Cushing Island	ME
East Harpswell	ME
Falmouth	ME
Freeport (census name for Freeport Center)	ME
Great Diamond Island	ME
Harpswell	ME
Harpswell Center (Town name Harpswell)	ME
Long Island	ME
Orrs Island	ME
Peaks Island (Peak Island)	ME
Pine Point (Pine Point Beach)	ME
Portland	ME
Scarborough	ME
South Freeport	ME
South Harpswell	ME
South Portland	ME
West Harpswell	ME
Yarmouth (Town of)	ME
Cumberland (County)	ME
Ashville	ME
Bar Harbor (Town of)	ME
Bass Harbor	ME
Bernard	ME
Birch Harbor	ME
Blue Hill	ME
Brooklin	ME
Brooksville (local name South Brooksville)	ME
Bucksport	ME
Bunkers Harbor (birch harbor)	ME
Cape Rosier	ME

Castine	ME
Cranberry Isles	ME
Deer Isle	ME
East Blue Hill	ME
Eastbrook	ME
East Lamoine	ME
East Sullivan	ME
Egypt	ME
Ellsworth	ME
Franklin	ME
Frenchboro	ME
Gouldsboro	ME
Hancock	ME
Hancock Point	ME
Harborside (Cape Rosier)	ME
Herricks	ME
Hulls Cove	ME
Indian Point	ME
Islesford	ME
Lamoine	ME
Lamoine Beach	ME
Little Deer Isle	ME
Long Island	ME
Manset	ME
Mount Desert (Somesville)	ME
Naskeag	ME
Northeast Harbor	ME
North Sullivan	ME
Oceanville	ME
Orland	ME
Otter Creek	ME
Penobscot	ME
Pretty Marsh	ME
Prospect Harbor	ME
Salsbury Cove	ME
Schoodic	ME
Seal Cove	ME
Seal Harbor	ME
Sedgwick	ME
Somesville	ME
Sorrento	ME
South Blue Hill	ME
South Gouldsboro	ME
South Hancock	ME
Southwest Harbor	ME
Stonington	ME
Sullivan	ME
Summer Harbor	ME
Sunset	ME

Sunshine	ME
Surry	ME
Sutton Island	ME
Swans Island	ME
Tremont	ME
Trenton	ME
Verona	ME
West Gouldsboro	ME
West Tremont	ME
Winter Harbor	ME
Wonsqueak Harbor	ME
Hancock (County)	ME
Augusta	ME
Benton	ME
Benton Falls	ME
Gardiner	ME
Kennebec	ME
Oakland	ME
Pittston	ME
Vassalboro	ME
Winslow (census name for Winslow Center)	ME
Kennebec (County)	ME
Camden (census name for Camden Center)	ME
Clark Island	ME
Criehaven	ME
Cushing	ME
Friendship	ME
Georges River (South Warren)	ME
Isle au Haut	ME
Longcove	ME
Martinsville	ME
Matinicus (Plantation name Matinicus Isle)	ME
North Haven	ME
Owls Head	ME
Port Clyde	ME
Rockland	ME
Rockport	ME
St. George	ME
South Thomaston	ME
Spruce Head	ME
Spruce Head Island	ME
Tenants Harbor	ME
Thomaston (census name for Thomaston Center)	ME
Union	ME
Vinalhaven	ME
Warren	ME
Knox (County)	ME
Alna	ME
Boothbay	ME

Boothbay Harbor	ME
Bremen (Town of)	ME
Bristol (Bristol Mills)	ME
Broad Cove	ME
Chamberlain	ME
Damariscotta	ME
Dresden	ME
East Boothbay	ME
East Edgecomb	ME
Edgecomb	ME
Harrimans Point	ME
Isle of Springs	ME
Jefferson	ME
Loudville	ME
Medomak	ME
Monhegan	ME
Muscongus	ME
Newagen	ME
Newcastle (Newcastle Center)	ME
New Harbor	ME
Pemaquid	ME
Pemaquid Beach	ME
Pemaquid Harbor	ME
Pemaquid Point	ME
Round Pond	ME
Sheepscot	ME
South Bristol	ME
Southport	ME
Trevett	ME
Waldoboro	ME
Walpole	ME
West Boothbay Harbor	ME
West Bristol	ME
Westport	ME
West Southport	ME
Wiscasset	ME
Lincoln (County)	ME
Virginia	ME
Bangor	ME
Brewer (RR name Brewer Junction)	ME
Eddington	ME
Hampden	ME
Lincoln (census name for Lincoln Compact)	ME
Old Town	ME
Orrington (Orrington Corner)	ME
South Brewer	ME
Veazie	ME
Penobscot (County)	ME
Sebec	ME

Arrowsic	ME
Bath	ME
Bay Point	ME
Bowdoin	ME
Bowdoinham	ME
Five Islands	ME
Georgetown	ME
Montsweag	ME
New Meadows	ME
Phippsburg	ME
Popham Beach	ME
Richmond (census name for Richmond Center)	ME
Robinhood	ME
Sebasco	ME
Sebasco Estates	ME
Small Point (Small Point Beach)	ME
Topsham (census name for Topsham Center)	ME
West Bath	ME
West Point	ME
Woolwich	ME
Sagadahoc (County)	ME
Belfast	ME
Frankfort	ME
Islesboro	ME
Knox	ME
Lincolnville	ME
Northport	ME
Prospect	ME
Prospect Ferry	ME
Sandy Point	ME
Searsmont	ME
Searsport (census name for Searsport Center)	ME
Stockton Springs	ME
Waldo	ME
Winterport	ME
Waldo (County)	ME
Addison	ME
Baileyville	ME
Beals	ME
Bucks Harbor	ME
Calais	ME
Cherryfield	ME
Columbia	ME
Columbia Falls	ME
Cutler	ME
Deblois	ME
Dennysville	ME
Dyer	ME
East Machias	ME

Eastport	ME
Edmunds	ME
Harrington	ME
Indian River	ME
Jonesboro	ME
Jonesport	ME
Kennebec	ME
Lubec	ME
Machias (census name for Machias Center)	ME
Machiasport	ME
Masons Bay	ME
Meddybemps	ME
Milbridge	ME
Pembroke	ME
Perry	ME
Pigeon Hill	ME
Pleasant Point	ME
Quoddy	ME
Red Beach	ME
Robbinston	ME
Roque Bluffs	ME
South Addison	ME
South Lubec	ME
Steuben	ME
Trescott	ME
West Harrington	ME
West Jonesport	ME
West Lubec	ME
Whiting	ME
Whitneyville	ME
Wyman	ME
Washington (County)	ME
Arundel	ME
Biddeford (RR name Biddeford-Saco)	ME
Biddeford Pool	ME
Camp Ellis	ME
Cape Porpoise	ME
Eliot	ME
Kennebunk	ME
Kennebunkport	ME
Kittery (census name for Kittery Center)	ME
Kittery Point	ME
Ogunquit	ME
Old Orchard Beach	ME
Saco	ME
South Berwick	ME
Springvale	ME
Wells	ME
Wells Beach	ME

York	ME
York Beach	ME
York Harbor	ME
York (County)(in MSA 6400,6450)	ME
Exeter	NH
Rockingham	NH
Hampton (census name for Hampton Compact)	NH
New Castle	NH
Newington	NH
Newmarket (census name for Newmarket Compact)	NH
Portsmouth	NH
Rye	NH
Seabrook	NH
Rockingham (County)	NH
Dover	NH
Durham (census name for Durham Compact)	NH
New Hampshire (State)	NH
Barnstable	MA
Brewster	MA
Chatham (census name for Chatham Center)	MA
Dennis	MA
Eastham	MA
Harwich Port	MA
Nauset Heights	MA
Orleans	MA
Provincetown	MA
Provincetown Wharf	MA
Sandwich (census name for Sandwich Center)	MA
Truro	MA
Wellfleet	MA
Amesbury	MA
Beverly	MA
Danvers	MA
Essex (census name for Essex Center)	MA
Gloucester	MA
Haverhill	MA
Ipswich (census name for Ipswich Center)	MA
Lynn	MA
Manchester	MA
Marblehead	MA
Nahant	MA
Newbury	MA
Newburyport	MA
Peabody	MA
Rockport	MA
Rowley	MA
Salem	MA
Salisbury (Salisbury Center)	MA
Saugus	MA

Swampscott	MA
Essex (County)(in PMSA 1120,4160,7090)	MA
Cambridge	MA
Medford	MA
Somerville	MA
Watertown	MA
Braintree	MA
Cohasset	MA
Quincy	MA
Weymouth	MA
Norfolk (County)(in PMSA 1120,1200,6060)	MA
Duxbury (census name for Duxbury Center)	MA
Hingham	MA
Hull	MA
Kingston (census name for Kingston Center)	MA
Marshfield (census name for Marshfield Compact)	MA
Norwell	MA
Plymouth (census name for Plymouth Center)	MA
Scituate (census name for Scituate Center)	MA
Boston	MA
Chelsea	MA
Revere	MA
Winthrop	MA
Suffolk (County)	MA

Appendix 2: Questions asked during semi-structured interviews with Gulf of Maine fishermen (2A) and Southern New England fishermen (2B), as well as during the fisheries managers focus group (2C)

2A: Semi-structured interview questions for Gulf of Maine fishermen:

1. What kinds of physical changes have you observed on the water over the course of your career? Have these been long-term changes, rapid changes?
2. Can you describe any challenges that these changes present to you as a commercial fisherman?
    a. How have these changes affected you, if at all?
3. What are some of your greatest concerns as a fisherman for the future as stocks shift into and out of your region?
    a. What do you see as the biggest issue with stocks moving in and out of the area?
    b. What kinds of issues are created by stocks moving into and out of the region?
4. Are there any specific species expanding into the Gulf of Maine that pose greater challenges than others in light of shifting/expanding stocks? What are the challenges posed by those species?
5. Do you think these species' stock expansions present or have presented any opportunities to commercial fishermen in your region? If so, please explain.
6. How does the current fisheries management system hinder or facilitate potential opportunities that expanding stocks offer to fishermen?
    a. How does the system aid fishermen in adapting to climate-driven stock expansions, if at all?
7. What are some of the barriers to establishing fisheries from emerging species in the Gulf of Maine? Has management in your region helped facilitate participation in emerging fisheries (if so, explain)?
8. Are you aware of the regulation exception in Massachusetts that allows lobstermen to land finfish bycatch up to the equivalent weight of lobster landed in that trip (322 CMR § 6.12(8)(d))?
    a. If a regulation such as this one existed in your state, would you participate?
    b. Do you think this can help grow emerging fisheries from climate-driven stock shifts and expansions?

2A: Semi-structured interview questions for Southern New England fishermen:

1. What kinds of physical changes have you observed on the water over the course of your career? Have these been long-term changes, rapid changes?
2. Can you describe any challenges that these changes present to you as a commercial fisherman?
    a. How have these changes affected you, if at all?
3. What are some of your greatest concerns as a fisherman for the future as stocks shift into and out of your region?
    a. What do you see as the biggest issue with stocks moving in and out of the area?
    b. What kinds of issues are created by stocks moving into and out of the region?
4. Are there any specific species expanding into your region that pose greater challenges than others in light of shifting/expanding stocks? What are the challenges posed by those species?
5. Do you think these species' stock expansions present or have presented any opportunities to commercial fishermen in your region? If so, please explain.
6. How does the current fisheries management system hinder or facilitate potential opportunities that expanding stocks offer to fishermen?
    a. How does the system aid fishermen in adapting to climate-driven stock expansions, if at all?
7. What are some of the barriers to establishing fisheries from emerging species in your region? Has management in your region helped facilitate participation in emerging fisheries (if so, explain)?
8. As these changes we have discussed continue to occur in other regions such as the Gulf of Maine, how can fishermen and managers in that region adapt? Do you have any recommendations or advice?
9. Are you aware of the regulation in Massachusetts that allows lobstermen to land finfish bycatch up to the equivalent weight of lobster landed in that trip (322 CMR § 6.12(8)(d))?
    a. For non-Massachusetts fishermen: If a regulation such as this one existed in your state, would you participate?
    b. For Massachusetts fishermen: have you ever landed bycatch for emerging fisheries such as black sea bass through this “program”?
    c. Do you think this can help grow emerging fisheries from climate-driven stock shifts and expansions?

2C: Focus group questions for fisheries managers

1. How has climate change challenged existing management approaches/systems?
    a. List one of the most significant ways climate change has challenged existing management approaches/systems
    b. Follow up: Do you think that the current management system is prepared for these climate-driven changes?
2. What are some of your greatest concerns as a manager for the future as climate change continues to drive shifting and expanding stocks into and out of your region?
    a. What do you see as the biggest issue with stocks moving in and out of the area?
    b. What kinds of issues are created by stocks moving into and out of the region?
3. Are there any specific species expanding into or undergoing a stock expansion in your region that pose greater challenges than others in light of shifting and expanding stocks?
    a. What are the challenges posed by those species?
4. Do you think these species' stock expansions present any opportunities to your region? If so, please explain.
    a. Any opportunities to fishermen? Markets?
5. How does the current fisheries management system hinder or facilitate potential opportunities that expanding stocks offer to fishermen?
    a. How does the system aid fishermen in adapting to climate-driven stock expansions, if at all?
6. From your perspective as a manager, what do you think the greatest challenge is for fishermen in light of stock shifts and expansions?
7. Are you aware of the regulation in Massachusetts that allows lobster fishers to land finfish bycatch up to the equivalent weight of lobster landed in that trip (322 CMR § 6.12(8)(d))?
    a. Do you think a regulation such as this can help grow emerging fisheries from climate-driven stock shifts and expansions?
    b. What is your perspective on implementing a program like this in areas experiencing climate-driven shifts or expansions into the region?

Appendix 3: Systems map