FEATURE

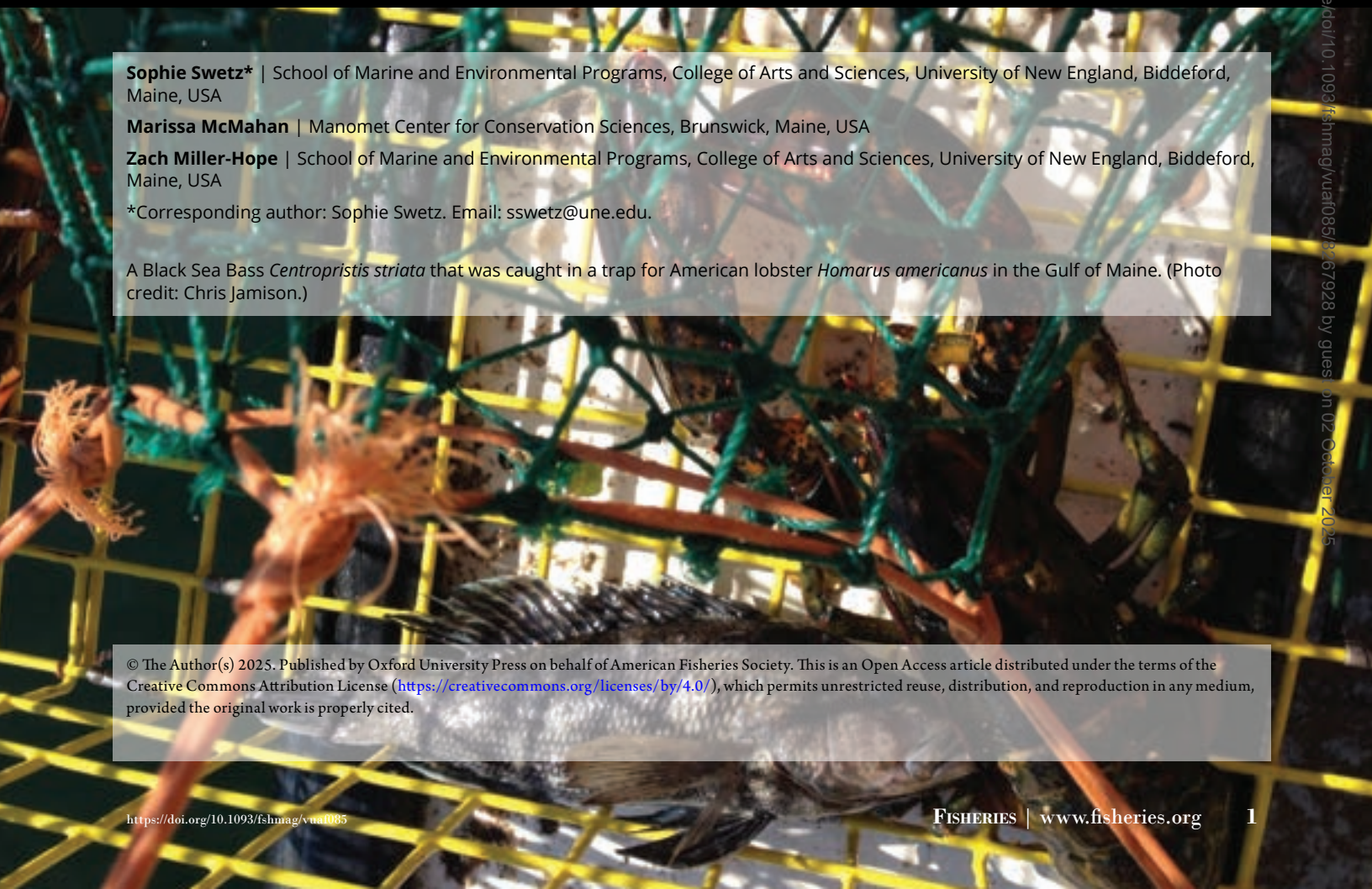
Climate resilience in the fisheries social–ecological system: Capturing opportunities from emerging species in the Gulf of Maine

Sophie Swetz* | School of Marine and Environmental Programs, College of Arts and Sciences, University of New England, Biddeford, Maine, USA

Marissa McMahan | Manomet Center for Conservation Sciences, Brunswick, Maine, USA

Zach Miller-Hope | School of Marine and Environmental Programs, College of Arts and Sciences, University of New England, Biddeford, Maine, USA

*Corresponding author: Sophie Swetz. Email: sswetz@une.edu.



A Black Sea Bass *Centropristis striata* that was caught in a trap for American lobster *Homarus americanus* in the Gulf of Maine. (Photo credit: Chris Jamison.)

https://doi.org/10.1093/fshmag/vuaf085

ABSTRACT

Climate-driven ocean warming is reshaping marine resource distributions globally. In the U.S. Northeast Shelf (NES) in particular, rising temperatures are causing economically valuable fish stocks to shift and expand their ranges, presenting challenges for fishermen, resource managers, and other stakeholders. The Gulf of Maine American lobster *Homarus americanus* is one affected stock that is expected to continue its northward and offshore movement. Given Maine's reliance on its lobster fishery, building climate resilience into the fisheries social–ecological system (SES) is crucial. Although research on climate resilience in fisheries SESs is increasing, the literature lacks examples of practicable approaches. Through discussions with NES stakeholders, the expansion of mid-Atlantic Black Sea Bass *Centropristis striata* into the Gulf of Maine emerged as a potential diversification opportunity for Maine's fisheries. This idea draws from a lobster trap bycatch-based approach used in southern New England. Existing management structures lack the adaptability necessary to provide new, accessible harvest opportunities (only 12% of Maine fishermen hold licenses for emerging commercial fisheries). Instead, we propose a social–ecological management framework that integrates local ecological knowledge, permits sustainable retention of climate-resilient emerging species, and supports marketing efforts to increase demand for new fisheries. Our work underscores the importance of starting small with emerging species. Although we focus on the NES, this approach may be replicated in other regions with similar fisheries SES archetypes.

INTRODUCTION

Fisheries are widely considered "social–ecological systems" (SESs), comprised of both social and ecological subsystems that continuously interact across individual, collective, and governance scales (Ojea et al., 2020). The SES concept recognizes that management problems are generally made up of systems and subsystems that include resource users (fishermen), institutions (fisheries management bodies), and rules (the regulations and collective rules that dictate fishermen's actions; O'Higgins et al., 2020).

Climate resilience in the context of fisheries refers to the capacity of a fishery to cope with climate change impacts (such as a stock shift) without transforming to a different state (Ojea et al., 2021). Building climate resilience across all sectors of the fisheries SES is a major focus area in light of rapid, climate-driven changes and resource shifts (Eurich et al., 2024), and growing research has focused on how to effectively manage natural resources as SESs (Mason et al., 2022; Nuno et al., 2014; O'Higgins et al., 2020; Virapongse et al., 2016). The traditional approach to fisheries management and science throughout the world has long been based on managing a single species in isolation rather than accounting for the dynamic interactions within the ecosystem as a whole (Hare, 2020; Kasperski et al., 2021). 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 that integrate both socioeconomic and ecological considerations (Collins et al., 2011; Hare, 2020; Kasperski et al., 2021; Liu et al., 2007; Ostrom, 2009; Virapongse et al., 2016). Managing natural resources as SESs is often referred to as an "SES-based environmental management approach" (Virapongse et al., 2016); however, for the purposes of this study, we employ the term "social–ecological management."

Climate-resilient fisheries SESs generally apply adaptive and transformative approaches to address challenges, such as ocean warming and species range shifts, rather than coping within the fishery's "status quo" (Ojea et al., 2020). For example, climate adaptation strategies include fisheries diversification, supplementing income with non-fishing work, and changing gear use (McClenachan et al., 2020; Ojea et al., 2020; Stoll et al., 2017), but the literature suggests that a diverse fishery portfolio is the strongest adaptation strategy (Le Bris et al., 2018; McClenachan et al., 2020; Stoll et al., 2017; Young et al., 2019). The development of new markets for range-shifting species, along with adaptive co-management, could improve climate resilience within the fisheries SES (Ojea et al., 2020). Existing regulatory frameworks and the extensive, complex processes involved in fisheries management limit the expedience of establishing new commercial fisheries from emerging species. However, commercial utilization of unintentionally caught emerging species in existing fisheries presents a promising approach to fisheries diversification in regions experiencing rapid, climate-driven change.

The U.S. Northeast Shelf (NES) region (Figure 1) is one of the fastest warming marine environments in the world (McHenry et al., 2019; Saba et al., 2016). Between 1960 and 2014, NES ocean temperatures increased approximately 2°C, and they are expected to continue warming through the 21st century (Brickman et al., 2021; Kleisner et al., 2016, 2017; McHenry et al., 2019; Mills et al., 2013; Pershing et al., 2016). The Gulf of Maine (GOM) in particular is warming faster than 99% of the world's oceans (Pershing et al., 2016), causing an extended duration of warm summer sea temperatures (Slesinger et al., 2021). Because colder winter temperatures are a limiting factor for habitat suitability in the GOM, sea temperature is expected to play a critical role in future species distributions (Hare et al., 2016; Kleisner et al., 2017; Pershing et al., 2021). As temperatures have warmed, several economically valuable NES fish stocks have shifted or expanded their spatial distributions beyond their historical ranges (Kleisner et al., 2016; Slesinger et al., 2021).

Here, we examine pathways of fisheries resilience through the lens of two NES species that are being impacted by warming waters: the American lobster *Homarus americanus* and Black Sea Bass (BSB) *Centropristis striata*. For American lobster, the 21st century has seen favorably warming waters and tidal mixing in the GOM, creating optimal conditions for recruitment and population growth (Goode et al., 2019) and coinciding with a 61% increase in commercial landings in Maine between 1997 and 2018 (Maine Department of Marine Resources, 2025a). Over the same period, southern New England (SNE) waters warmed such that lobster recruitment and juvenile habitat availability were diminished, corresponding with a decrease in the region's commercial landings by a staggering 88% (Atlantic States Marine Fisheries Commission [ASMFC], 2020a). Maine lobster generates approximately US$1 billion annually, supporting the livelihoods of roughly

Figure 1. The U.S. Northeast Shelf region.

5,000 commercial lobster license holders and an additional 4,000 jobs throughout the supply chain (Donihue & Tselikis, 2018; Wallace & Colgan, 2023; Zou et al., 2021). In 2023, the lobster fishery contributed 76% of the value and nearly 50% of the total weight of Maine's commercially harvested marine resources (Maine Department of Marine Resources, 2024, 2025b). Other economic contributions from the state's lobster fishery are more difficult to quantify. Research by the Maine Office of Tourism indicated that over 25% of surveyed summer visitors and 40% of surveyed fall visitors in 2021 traveled to the state in order to consume lobster (Maine Office of Tourism, 2022; Waterman, 2022).

Despite the GOM's lobster "goldilocks" zone, where waters are warm enough for juveniles to thrive but cold enough for larval survival, climate models of mean GOM sea surface temperature and bottom temperature have projected increases of 1.1–2.4°C and 1.5–2.1°C, respectively, by 2050 (Brickman et al., 2021). A 1–2°C increase in temperature in the GOM by 2050 could cause the lobster stock to decrease in abundance by 42–62% (Le Bris et al., 2018), sending the fishery into levels of production equivalent to its scale around the year 2000, when landings were roughly 50% of their current levels (Pershing et al., 2021). Lobster stress indicators in the GOM in recent years suggest that the stock may already be experiencing increasingly stressful conditions, including high water temperatures (ASMFC, 2020a). The GOM stock of American lobster is projected to shift its distribution in a northerly and offshore direction, where stressful conditions may be less prevalent (Kleisner et al., 2017; Pershing et al., 2021). Given the lobster fishery's economic value, declines in the GOM's lobster stock could lead to substantial economic fallout. As such, it is important to develop approaches for reducing the industry's vulnerability to rapid, climate-driven change.

The BSB is a commercially and recreationally valuable migratory fish species found in the northwest Atlantic Ocean. The northeast continental shelf stock of BSB historically ranged from Cape Hatteras, North Carolina, to Cape Cod, Massachusetts. In recent decades, BSB have experienced a rapid range expansion into the GOM, which is predicted to continue into the future (Bell et al., 2015; Hare et al., 2016; McBride et al., 2018; McMahan et al., 2020; Northeast Fisheries Science Center, 2020; Pershing et al., 2021; Slesinger et al., 2021). In fact, landings within the stock's northern subunit, which extends from Hudson Canyon through the GOM, more than tripled between 2011 and 2021 and comprised 68% of commercial BSB landings in 2021 (ASMFC, 2020b, 2023).

In Massachusetts, lobstermen are able to capture opportunities from emerging species in a small way. Commercial lobster permit holders may land finfish that are incidentally caught in their lobster traps if (1) the weight of the bycatch does not exceed that of the landed lobsters on that trip and (2) they also hold the permit to harvest the bycaught species. Other measures regulating the bycatch fishery also apply, including quota allocations and minimum fish sizes. The regulations still require those landing this bycatch to maintain the landed species' fishery-specific permit, but they can land the species without holding the species-specific pot/trap permit (e.g., a BSB fish pot permit). A rule such as this represents some effort in facilitating opportunities for lobstermen to harvest emerging species.

This study employs qualitative social science research methodologies to investigate the impacts of shifting and expanding

fish stocks on the NES fisheries SES. In particular, we sought to understand climate resilience and adaptive capacity in this SES. The *Methods* section outlines the data collection process, which involved focus groups and semi-structured interviews grounded in established social science research methodologies. Findings are presented in a combined *Results and Discussion* section to allow for the integration of participant quotations alongside interpretive analysis. This format supports a contextualized understanding of the data by situating stakeholder perspectives within the broader discourse on fisheries governance and climate adaptation. We conclude with recommendations to enhance climate resilience and adaptive capacity within the NES fisheries SES while also acknowledging methodological limitations and considerations for future research.

METHODS

This study utilized an interpretivist research paradigm to capture stakeholder concerns, observations, and perceived opportunities as ocean conditions and species' ranges change. Semi-structured interviews with fishermen from the GOM ($n=4$) and SNE ($n=6$) were conducted to understand their observations, the challenges that they face, and any opportunities that they foresee from climate-driven changes. A focus group with fisheries managers ($n=5$) was also conducted to provide insight into fisheries governance in the context of climate-driven changes. Using exploratory qualitative research methods to obtain participant insights, experiences, and observations informed our understanding of climate resilience and adaptive capacity in the NES fisheries SES, particularly concerning the shift and expansion of commercially important fish stocks.

Questions posed to participants during the focus group and interviews (approved by the University of New England Institutional Review Board, project number 1221-23) varied slightly across the three groups but focused on five major topics:

1. changes observed or noticed over the course of their careers;
2. shifting and expanding stocks in the region;
3. challenges and opportunities presented by these changes;
4. barriers to taking advantage of potential opportunities; and
5. concerns for the future.

Participants were also asked about the regulation in Massachusetts that allows lobster harvesters to land finfish incidentally caught in their traps, as it relates to emerging species and increasing fishery portfolio diversity for harvesters.

Eligibility criteria for subjects were as follows:

- Fisheries managers must work for an agency or fishery management council (a regional body comprised of managers and stakeholders that develop fishery management plans and other specific management measures) in the NES region, including state, federal, or interstate agencies, and must possess at least 1 year of experience.
- Gulf of Maine commercial fishermen must fish in GOM waters out of Maine, New Hampshire, or Massachusetts. Fishermen may fish in state or federal waters and may fish for any target species. Subjects must possess at least 10 years of experience and should be actively fishing or recently retired ($\leq$3 years).
- Southern New England commercial fishermen must fish in SNE waters out of Connecticut, Rhode Island, or Massachusetts. Fishermen may fish in state or federal waters and may fish for any target species. Subjects must possess at least 10 years of experience and should be actively fishing or recently retired ($\leq$3 years).

Recruitment of fisheries manager participants was conducted by identifying individuals employed by management agencies in the NES region as determined from agency websites. Potential subjects were contacted via email. In some cases, the chain referral or "snowball sampling" method was utilized, whereby participants provided the contact information of another staff member within their agency that would be willing to participate. Conversations with fisheries managers occurred over Zoom in March 2022.

To obtain GOM and SNE commercial fisherman participants, we identified fishermen by contacting relevant experts in the field with connections to the fishing industry, such as cooperative researchers and individuals with a commercial fishing background. 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 to obtain additional participants. Participants with at least 10 years of experience in commercial fisheries were identified in order to gather information on changes that they have observed over time. Discussions with fishermen occurred over the phone in February and March 2022.

All conversations were recorded and transcribed for data analysis using Otter.ai Web-based software (Otter.ai, 2025). Raw data (transcripts) were grouped and analyzed by group (GOM fishermen, SNE fishermen, and NES fisheries managers). Data were organized into subgroupings ("chunks") by using the chunking method. Chunks represented the themes that were initially gleaned from preliminary data review and analysis. Chunks were then separated into clusters during the initial data coding process. This process was repeated several times to reduce the number of clusters into a final set of codes organized in a codebook. Codes, which represent major themes that emerged from the data, were derived from the data (inductive) and from the research questions themselves (deductive).

Qualitative analysis methods were employed to derive the major themes (codes) that emerged within each population (Given, 2008). Informed consent was obtained from participants prior to collecting data. Data collected through conversations with participants are confidential to protect individual participants and per the requirements of the University of New England's Institutional Review Board protocol.

The term "fisherman" herein is used to describe an individual who commercially harvests marine resources. This term is used for all gender identities and does not exclusively refer to male harvesters. We employ this term out of respect to the fishermen that prefer it over other terms, such as "fisher" or "fisherwoman" (in the case of a female harvester).

RESULTS AND DISCUSSION

Analysis of qualitative data obtained through the focus group and interviews revealed three central themes: climate vulnerability, climate resilience and adaptation, and social–ecological management in the fisheries SES.

Climate vulnerability

Discussions with several Maine fishermen highlighted their concern regarding the lack of fishery diversity in the state, viewing it as a limitation to adapting to climate-driven changes. One harvester described Maine's lobster fishery as "a single point of failure," explaining that "the regulations in Maine have squeezed fishermen into this box of lobstering, and if the lobster fishery crashes in Maine, Maine fishing's done." Maine-based fishermen overwhelmingly acknowledged the stress caused by the limited number of accessible fisheries in the GOM. One fisherman noted that for many people in Maine, "you're either a lobsterman or you're a carpenter." Most of the Maine harvesters that we spoke with recognized that while other major fisheries exist, such as Bluefin Tuna *Thunnus thynnus* and Atlantic sea scallop *Placopecten magellanicus*, they do not serve as sufficient fall-back options because of their short seasons, limited access permits, quota, or harvest reliability.

Fisheries managers highlighted similar perspectives. One fisheries manager described their concern about the lack of fisheries diversity in Maine, emphasizing how the state is "so dependent on lobster." Another fisheries manager believed that regulations typically make it hard for fishermen to adapt to change through participation in other fisheries because they "lock people into a certain way of doing things and then things are kind of built up around that." As of 2014, just 12% of Maine's commercial fishermen held licenses for emerging commercial species that were projected to increase in the future (Stoll et al., 2017). Managers also expressed the difficulty associated with managing fisheries to preserve abundance and ecosystem health while also maintaining viable opportunities for fishermen and the broader industry. Fishermen and fisheries managers alike believed that this was partially due to a lack of adaptive management practices. Managers explained that the existing management structure in the NES region is not designed to handle shifting and expanding stocks. The fisheries managers that we spoke with highlighted three major factors limiting their capacity to provide responsive management actions:

1. Managers are bound by prescriptive procedures and policies that limit their ability to respond to climate-driven changes.
2. 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.
3. The prolonged processes required for making management changes prevent those actions from being temporally responsive.

As stock distributions change, fisheries managers find that balancing fishing access between communities at either end of a stock's shifting or expanding range is a substantial challenge, as stock availability may decline in areas with historical dependence on the fishery. Managers generally acknowledged that existing approaches to managing quotas and assessing stocks may not be sustainable under future conditions.

Southern New England fishermen expressed concerns for their Maine counterparts. They believed that Maine fishermen will soon face the same challenges and frustrations they have experienced in recent years as stock distributions have changed in their waters. Referring to the expansion of BSB, one SNE harvester explained that if Maine fishermen "don't have the quota, they're going to be just as frustrated as we were." This fisherman believed that there is a great opportunity for harvesting emerging species in Maine, but they emphasized the challenges with overcoming existing barriers in order to actualize these opportunities. They expressed some optimism that the Maine Department of Marine Resources often does the best it can for the commercial fishing community; however, they recognized that it would still be a challenge for fisheries managers in Maine due to coastwide quota allocations.

Fisheries managers and harvesters also commented on a lack of timeliness in fisheries science and management that has only been exacerbated by rapid, unprecedented change. One fisheries manager stated that under normal circumstances, "we're always at least a year behind on the data." They also cited a lack of resources and funding as an additional constraint in staying up to date on climate-driven stock changes. Managers emphasized the substantial challenges facing fisheries management due to the mounting costs of data collection and the increasing need to understand more about an ever-changing ecosystem. The SNE harvesters that we spoke with elaborated on this shared perspective, explaining their belief that scientists and fisheries managers are constantly working to "catch up" to understand changes in species distributions that fishermen have already observed. Fishermen associated this lag between ecological changes and scientific understanding with lost harvest opportunities that could otherwise help to diversify their fishing portfolios.

Adaptive capacity and resilience to climate-driven changes

Some of the fishermen and fisheries managers that we spoke with believed that the emergence of BSB in the GOM could present opportunities to the industry. In the mid-Atlantic and SNE, the BSB retains strong commercial value, averaging over $3.25 per pound from 2011 to 2021 (National Marine Fisheries Service, 2024a), and SNE fishermen reportedly sell their catch for $4.00 per pound and even more for larger fish. Despite the value of BSB, fishermen and fisheries managers emphasized barriers to actualizing potential opportunities. They primarily highlighted regulatory- and management-related barriers, including quota allocation, permitting, and trip limits. These discussions repeatedly arrived at the theme of bycaught emerging species, particularly BSB. Conversations focused on how the increased abundance of BSB in SNE has led to substantial bycatch in both lobster pots and fishing trawls. Dead commercial discards of BSB have increased during the past several years due to low trip limits relative to stock abundance coupled with BSB susceptibility to barotrauma (ASMFC, 2021; Northeast Fisheries Science Center, 2020; Zemeckis et al., 2020). The SNE fishermen expressed considerable frustration over this

phenomenon, emphasizing the waste caused by low trip limits and other regulatory measures. Harvesters described discarding hundreds to thousands of pounds of BSB caught in trawls, the majority of which they believed would not survive. They felt that landing the bycaught fish would be less wasteful than discarding the fish, with one fisherman explaining, "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." Maine fishermen also reported catching BSB in their lobster traps. According to one GOM fisherman, about 10 years ago harvesters started to observe BSB "in abundance," with up to five fish in every trap in the mid-coast region.

The SNE and GOM fishermen indicated that landing bycatch would either be an effective approach to develop emerging fisheries from species undergoing range shifts or simply be a way to diversify and increase their income. Some Maine harvesters felt that this would be a beneficial way to grow a BSB fishery in the future, particularly because the species is often targeted with and caught in traps in the mid-Atlantic region—a valuable synergy with the American lobster fishery. In general, fishermen and NES fisheries managers indicated substantial interest in accessing and developing new commercial fisheries, even at small scales. According to one fisherman, "If people are allowed to go catch something, they will try it."

Since 2010, landings of BSB caught as bycatch in Massachusetts lobster traps have increased over sevenfold, from approximately 1,200 lb in 2010 to over 9,000 lb in 2020, while total landings of BSB in Massachusetts over the same period only tripled, in correspondence with quota increases. Further, the annual value from bycatch per harvester rose by over 400% between 2010 and 2020 from just $315 to approximately $1,600 (data provided by the Massachusetts Division of Marine Fisheries). This added revenue from bycatch can aid in covering mounting fuel and bait costs or can even help with financial burdens typically covered in a traditional workplace, such as healthcare. One Maine fisherman noted that if they could land BSB bycatch, it might amount to $2,000 at the end of the year. In the U.S. lobster fishery, where each fishing vessel is its own small, independent business, the fisherman explained, "That's a big deal for me."

Although commercial harvest of bycaught BSB in Maine waters would contribute to the state's allocation of the stock's quota for the entirety of the Atlantic coast (<1%), the Maine lobstermen that we spoke with indicated that interest in a BSB bycatch fishery would start small and likely would not exceed current availability. One harvester believed that although the lobster fishery remains profitable in Maine, it is imperative to look towards emerging fisheries for the future. Maine fishermen generally hoped that there will be a slow progression towards fishing other species rather than a dramatic shift. As BSB continue to expand into the GOM, Maine fishermen are poised to capitalize on the small but valuable opportunity to diversify their fishing portfolios and increase their resilience to rapid, climate-driven changes. Fishermen and fisheries managers expressed the importance of marketing emerging fisheries in order to adapt to changing regional fisheries portfolios. One Maine fisherman discussed a marketing collaborative in which Maine seafood industry professionals travel to the U.S. Pacific coast to teach chefs and other food industry professionals how to cook and serve lobster. They stated that the collaborative has helped to grow the market demand for lobster in other regions of the United States, adding value to the industry. Approaches such as this were viewed as a potential opportunity for local market development of emerging species, such as BSB.

The NES region's squid fishery represents an example of stakeholder-driven efforts to increase demand for underutilized and emerging species. As groundfish landings declined in the NES during the 1990s, the federal government encouraged harvesters to target squid due to its abundance. Ultimately, government-supported marketing efforts, investments in processing infrastructure, and incentives for restauranteurs increased the demand for squid in the region (Davis et al., 2023; Frank, 2014). Applying a similar effort to Maine-caught BSB could increase demand and aid in fishery development.

Social–ecological management

Data gaps and time lags described by stakeholders highlighted the potential benefits of gathering and applying data from harvesters on the water to generate management approaches that balance ecological and social considerations. Conversations with fishermen revealed a strong desire to participate more in fisheries science and management. Harvesters generally believed that their local ecological knowledge and on-the-water observations of climate-driven changes could help to fill data gaps in fisheries science. In fact, research suggests that community-level adaptation to change in fisheries may be more likely with fishermen that are engaged in management processes (McClenachan et al., 2020). Programs such as the Commercial Fisheries Research Foundation's BSB research fleet serve as successful examples of social–ecological management in the fisheries SES. Independent fishing captains comprise the research fleet and collect data on individual BSB length, sex, and disposition throughout SNE and into the mid-Atlantic (Heimann et al., 2023). Heimann et al. (2023) demonstrated the research fleet's effective collection of robust fishery-dependent data and the ongoing integration of those data into the North Atlantic BSB stock assessment and, ultimately, management decisions. Employing a similar industry-participating research initiative in the GOM would help to enhance the understanding of the stock's ongoing expansion, potentially assisting in the development of a feasible bycatch fishery in a region of low fisheries diversity.

Using industry participants to acquire timely, fishery-dependent data may indeed help in developing a BSB fishery in the GOM. Commercial lobstermen are required to submit daily landings reports to the relevant state management body. Incorporating a way to report bycatch data for each trip would generate valuable data on shifting and expanding stocks. For example, reports may ask harvesters whether they observed certain species on that trip, establishing a formal documentation process for shifting and expanding stocks of interest. As the BSB continues to expand its range and increase in productivity, landings data may indicate that the species is present in the GOM at an abundance that allows for the development of a fishery. Because the development of a BSB fishery in Maine is limited by quota allocations, these data may help the state to acquire more quota, thereby aiding in the fishery's growth.

It is also important to consider access to emerging species like BSB outside of the American lobster fishery. As new species emerge, there is an opportunity for developing management

frameworks that promote equitable access to marine resources. Here, we present an opportunity specific to lobster industry participants accessing BSB bycatch, but this should not be the only emerging species opportunity considered—particularly for species like the BSB, which supports an important recreational fishery in its traditional range (National Marine Fisheries Service, 2024).

Limitations

Limitations to this study include its small sample size and potential biases taken in the processes of coding and asking questions during interviews and the focus group. Gulf of Maine fishermen all participated in the Maine lobster fishery, of which there are approximately 5,000 license holders; our sample represents nearly 0.1% of that population. This small sample size means that we may have excluded valuable and different perspectives to inform our research. The same can be said for the other two participant groups; the small sample sizes may introduce biases and limit our research. However, this research was exploratory and serves to stimulate further investigation on this topic. Continuing this research with additional subjects would provide a more robust data set.

Interview and focus group questions were intended to be open-ended and exploratory, but we acknowledge the potential biases in how questions were asked. During the coding process, biases may have been introduced by our own conceptual frameworks; to mitigate potential biases, we used strategies including memo-writing, peer debriefing, and relying heavily on participant quotations to ensure that the findings were grounded in data and not overly shaped by our expectations or interests.

CONCLUSIONS

This work suggests that participatory, adaptive, social–ecological management practices may widely appeal to fisheries SES stakeholders while also increasing the system's adaptive capacity and climate resilience. Conversations highlighted the importance of utilizing a systemic approach to increasing climate resilience in the fishing industry. Our research finds that any initiative aimed at augmenting climate resilience in the fishing industry should be integrated into fisheries management at the SES level and must be supported by both fishermen and managers to increase adaptive capacity. This research leads to three recommendations for improving climate resilience in fisheries SESs experiencing changes in species distributions:

1. Integration of local ecological knowledge and landings data for emerging species to help fill data gaps and understand rapid changes in species distributions, as well as develop adaptive management responses that include critical SES stakeholders;
2. cooperative facilitation of opportunities presented by emerging species, specifically through sustainable retention of climate-resilient bycaught species in lobster traps, as well as direct targeting by other small-scale harvest methods (e.g., hook and line); and
3. marketing collaboratives and efforts to increase demand for and aid in development of emerging fisheries.

It is important to understand the case-by-case differences in fisheries SES archetypes across the globe (Eurich et al., 2024). Specific implementation strategies will vary depending on the fisheries, communities, management strategies, and species involved, therefore necessitating involvement with key stakeholders throughout the process. Whether the community is on the leading or tailing edge of a stock shift or expansion, maintaining a diverse fishing portfolio emerges as a critical component of a climate-resilient fisheries SES. Further research into concrete, practicable approaches for increasing the diversity of species landed across cases that builds on these findings will increase our understanding of best practices for climate resiliency in the fisheries SES.

SUPPLEMENTARY MATERIAL

Supplementary material is available at *Fisheries* online.

DATA AVAILABILITY

Questions used for the focus group and semi-structured interviews are provided as Supplementary Material (see online Supplementary Material). Qualitative data from interviews and focus groups are not available per the University of New England's Institutional Review Board protocol.

ETHICS STATEMENT

This research was approved by the University of New England Institutional Review Board (project number 1221-23) and meets all required ethical standards.

FUNDING

None declared.

CONFLICTS OF INTEREST

None declared.

ACKNOWLEDGMENTS

We thank the fishermen and fisheries managers who graciously donated their time to provide their perspectives and insights, without which this research would not exist.

REFERENCES

Atlantic States Marine Fisheries Commission. (2020a). *ASMFC stock assessment overview: American Lobster.*

Atlantic States Marine Fisheries Commission. (2020b). *Review of the interstate fishery management plan for Black Sea Bass (*Centropristis striata*) 2019 fishing year.*

Atlantic States Marine Fisheries Commission. (2021). *Addendum XXXIII to the Summer Flounder, Scup, and Black Sea Bass fishery management plan: Black Sea Bass state-by-state commercial allocation.*

Atlantic States Marine Fisheries Commission. (2023). *Review of the interstate fishery management plan for Black Sea Bass (*Centropristis striata*) 2022 fishing year.*

Bell, R. J., Richardson, D. E., Hare, J. A., Lynch, P. D., & Fratantoni, P. S. (2015). Disentangling the effects of climate, abundance, and size

on the distribution of marine fish: An example based on four stocks from the northeast US shelf. *ICES Journal of Marine Science: Journal du Conseil*, *72*, 1311–1322. https://doi.org/10.1093/icesjms/fsu217

Brickman, D., Alexander, M. A., Pershing, A., Scott, J. D., & Wang, Z. (2021). Projections of physical conditions in the Gulf of Maine in 2050. *Elementa*, *9*, Article 00055. https://doi.org/10.1525/elementa.2020.20.00055

Collins, S. L., Carpenter, S. R., Swinton, S. M., Orenstein, D. E., Childers, D. L., Gragson, T. L., Grimm, N. B., Morgan, G. J., Harlan, S. L., Kaye, J. P., Knapp, A. K., Kofinas, G. P., Magnuson, J. J., McDowell, W. H., Melack, J. M., Ogden, L. A., Philip, R. G., Smith, M. D., & Whitmer, A. C. (2011). An integrated conceptual framework for long-term social–ecological research. *Frontiers in Ecology and the Environment*, *9*, 351–357. https://doi.org/10.1890/100068

Davis, A. G., Staudinger, M. D., & Mills, K. E. (2023). Identifying New England's underutilized seafood species and evaluating their market potential in a changing climate. *Frontiers in Marine Science*, *10*, Article 1226219. https://doi.org/10.3389/fmars.2023.1226219

Donihue, M., & Tselikis, A. (2018). *Lobster to dollars: The economic impact of the lobster distribution supply chain in Maine*. Colby College. https://bit.ly/4mI90rQ

Eurich, J. G., Friedman, W. R., Kleisner, K. M., Zhao, L. Z., Free, C. M., Fletcher, M., Mason, J. G., Tokunaga, K., Aguion, A., Dell'Apa, A., Dickey-Collas, M., Fujita, R., Golden, C. D., Hollowed, A. B., Ishimura, G., Karr, K. A., Kasperski, S., Kisara, Y., Lau, J. D., … Mills, K. E. (2024). Diverse pathways for climate resilience in marine fishery systems. *Fish and Fisheries*, *25*, 38–59. https://doi.org/10.1111/faf.12790

Frank, M. G. (2014, August 31). *The origin of an appetizer: A look at the creation of calamari*. Salon. https://www.salon.com/2014/08/31/from_chicken _tenders_to_calamari_the_strange_story_behind_the_creation_of_appetizers/

Given, L. M. (2008). *The SAGE encyclopedia of qualitative research methods*. SAGE Publications.

Goode, A. G., Brady, D. C., Steneck, R. S., & Wahle, R. A. (2019). The brighter side of climate change: How local oceanography amplified a lobster boom in the Gulf of Maine. *Global Change Biology*, *25*, 3906–3917. https://doi.org/10.1111/gcb.14778

Hare, J. A. (2020). Ten lessons from the frontlines of science in support of fisheries management. *ICES Journal of Marine Science: Journal du Conseil*, *77*, 870–877. https://doi.org/10.1093/icesjms/fsaa025

Hare, J. A., Morrison, W. E., Nelson, M. W., Stachura, M. M., Teeters, E. J., Griffis, R. B., Alexander, M. A., Scott, J. D., Alade, L., Bell, R. J., Chute, A. S., Curti, K. L., Curtis, T. H., Kircheis, D., Kocik, J. F., Lucey, S. M., McCandless, C. T., Milke, L. M., Richardson, D. E., … Griswold, C. A. (2016). A vulnerability assessment of fish and invertebrates to climate change on the Northeast U.S. Continental Shelf. *PLoS One*, *11*, Article e0146756. https://doi.org/10.1371/journal.pone.0146756

Heimann, T., Verkamp, H., McNamee, J., & Bethoney, N. D. (2023). Mobilizing the fishing industry to address data gaps created by shifting species distribution. *Frontiers in Marine Science*, *10*, Article 1043676. https://doi.org/10.3389/fmars.2023.1043676

Kasperski, S., DePiper, G. S., Haynie, A. C., Blake, S., Colburn, L. L., Freitag, A., Jepson, M., Karnauskas, M., Leong, K. M., Lipton, D., Masi, M., Speir, C., Townsend, H., & Weijerman, M. (2021). Assessing the state of coupled social–ecological modeling in support of ecosystem based fisheries management in the United States. *Frontiers in Marine Science*, *8*, Article 631400. https://doi.org/10.3389/fmars.2021.631400

Kleisner, K. M., Fogarty, M. J., McGee, S., Barnett, A., Fratantoni, P., Greene, J., Hare, J. A., Lucey, S. M., McGuire, C., Odell, J., Saba, V. S., Smith, L., Weaver, K. J., & Pinsky, M. L. (2016). The effects of sub-regional climate velocity on the distribution and spatial extent of marine species assemblages. *PLoS One*, *11*, Article e0149220. https://doi.org/10.1371/journal.pone.0149220

Kleisner, K. M., Fogarty, M. J., McGee, S., Hare, J. A., Moret, S., Perretti, C. T., & Saba, V. S. (2017). Marine species distribution shifts on the U.S. Northeast Continental Shelf under continued ocean warming. *Progress in Oceanography*, *153*, 24–36. https://doi.org/10.1016/j.pocean.2017.04.001

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

Liu, J., Dietz, T., Carpenter, S. R., Alberti, M., Folke, C., Moran, E., Pell, A. N., Deadman, P., Kratz, T., Lubchenco, J., Ostrom, E., Ouyang, Z., Provencher, W., Redman, C. L., Schneider, S. H., & Taylor, W. W. (2007). Complexity of coupled human and natural systems. *Science*, *317*, 1513–1516. https://doi.org/10.1126/science.1144004

Maine Department of Marine Resources. (2024). *Preliminary 2023 commercial Maine landings by ex-vessel value*.

Maine Department of Marine Resources. (2025a). *Historical Maine lobster landings*. https://www.maine.gov/dmr/sites/maine.gov.dmr/files/inline-files/lobster.table_.pdf

Maine Department of Marine Resources. (2025b). *Maine 2020-2024 Landings (live pounds and value) by Species*. https://www.maine.gov/dmr/sites/maine.gov.dmr/files/inline-files/LandingsBySpecies.Table_.pdf

Maine Office of Tourism. (2022). *2021 summer visitor tracking report*. https://motpartners.com/wp-content/uploads/2022/04/2021EconomicImpactVisitorTrackingReport.pdf

Mason, J. G., Eurich, J. G., Lau, J. D., Battista, W., Free, C. M., Mills, K. E., Tokunaga, K., Zhao, L. Z., Dickey-Collas, M., Valle, M., Pecl, G. T., Cinner, J. E., McClanahan, T. R., Allison, E. H., Friedman, W. R., Silva, C., Yáñez, E., Barbieri, M., & Kleisner, K. M. (2022). Attributes of climate resilience in fisheries: From theory to practice. *Fish and Fisheries*, *23*, 522–544. https://doi.org/10.1111/faf.12630

McBride, R. S., Tweedie, M. K., & Oliveira, K. (2018). Reproduction, first-year growth, and expansion of spawning and nursery grounds of Black Sea Bass (*Centropristis striata*) into a warming Gulf of Maine. *U.S. National Marine Fisheries Service Fishery Bulletin*, *116*, 323–336. https://doi.org/10.7755/FB.116.3-4.10

McClenachan, L., Scyphers, S., & Grabowski, J. H. (2020). Views from the dock: Warming waters, adaptation, and the future of Maine's lobster fishery. *Ambio*, *49*, 144–155. https://doi.org/10.1007/s13280-019-01156-3

McHenry, J., Welch, H., Lester, S. E., & Saba, V. (2019). Projecting marine species range shifts from only temperature can mask climate vulnerability. *Global Change Biology*, *25*, 4208–4221. https://doi.org/10.1111/gcb.14828

McMahan, M. D., Sherwood, G. D., & Grabowski, J. H. (2020). Geographic variation in life-history traits of Black Sea Bass (*Centropristis striata*) during a rapid range expansion. *Frontiers in Marine Science*, *7*, Article 567758. https://doi.org/10.3389/fmars.2020.567758

Mills, K. E., Pershing, A. J., Brown, C. J., Chen, Y., Chiang, F. S., Holland, D. S., Lehuta, S., Nye, J. A., Sun, J. C., Thomas, A. C., & Wahle, R. A. (2013). Fisheries management in a changing climate: Lessons from the 2012 ocean heat wave in the northwest Atlantic. *Oceanography*, *26*, 191–195. https://doi.org/10.5670/oceanog.2013.27

National Marine Fisheries Service. (2024a). *NOAA Fisheries commercial fishing landings database*. National Oceanic and Atmospheric Administration. https://www.fisheries.noaa.gov/foss/f?p=215:200:15712111862746

National Marine Fisheries Service. (2024b). *Black Sea Bass*. National Oceanic and Atmospheric Administration. https://www.fisheries.noaa.gov/species/black-sea-bass

Northeast Fisheries Science Center. (2020). *Operational assessment of the Black Sea Bass, Scup, Bluefish, and Monkfish stocks, updated through 2018 (Reference Document 20-01)*. National Marine Fisheries Service.

Nuno, A., Bunnefeld, N., & Milner-Gulland, E. J. (2014). Managing social–ecological systems under uncertainty: Implementation in the real world. *Ecology and Society: A Journal of Integrative Science for Resilience and Sustainability*, *19*, Article 52. https://doi.org/10.5751/ES-06490-190252

O'Higgins, T. G., Lago, M., & DeWitt, T. H. (2020). *Ecosystem-based management, ecosystem services and aquatic biodiversity: Theory, tools and applications*. Springer.

Ojea, E., Fontán, E., Fuentes-Santos, I., & Bueno-Pardo, J. (2021). Assessing countries' social–ecological resilience to shifting marine commercial species. *Scientific Reports*, *11*, Article 22926. https://doi.org/10.1038/s41598-021-02328-6

Ojea, E., Lester, S. E., & Salgueiro-Otero, D. (2020). Adaptation of fishing communities to climate-driven shifts in target species. *One Earth*, *2*, 544–556. https://doi.org/10.1016/j.oneear.2020.05.012

Ostrom, E. (2009). A general framework for analyzing sustainability of social–ecological systems. *Science*, *325*, 419–422. https://doi.org/10.1126/science.1172133

Otter.ai. (2025). *AI meeting note taker & real-time AI transcription*. https://otter.ai/

Pershing, A. J., Alexander, M. A., Brady, D. C., Brickman, D., Curchitser, E. N., Diamond, A. W., McClenachan, L., Mills, K. E., Nichols, O. C., Pendleton, D. E., Record, N. R., Scott, J. D., Staudinger, M. D., & Wang, Y. (2021). Climate impacts on the Gulf of Maine ecosystem. *Elementa: Science of the Anthropocene*, *9*, Article 00076. https://doi.org/10.1525/elementa.2020.00076

Pershing, A. J., Alexander, M. A., Hernandez, C. M., Kerr, L. A., Le Bris, A., Mills, K. E., Nye, J. A., Record, N. R., Scannell, H. A., Scott, J. D., Sherwood, G. D., & Thomas, A. C. (2016). Response to comments on "Slow adaptation in the face of rapid warming leads to collapse of the Gulf of Maine cod fishery." *Science*, *352*, Article 423. https://doi.org/10.1126/science.aae0463

Saba, V. S., Griffies, S. M., Anderson, W. G., Winton, M., Alexander, M. A., Delworth, T. L., Hare, J. A., Harrison, M. J., Rosati, A., & Vecchi, G. A. (2016). Enhanced warming of the northwest Atlantic Ocean under climate change. *Journal of Geophysical Research: Oceans*, *120*, 118–132. https://doi.org/10.1002/2015JC011346

Slesinger, E., Jensen, O. P., & Saba, G. (2021). Spawning phenology of a rapidly shifting marine fish species throughout its range. *ICES Journal of Marine Science: Journal du Conseil*, *78*, 1010–1022. https://doi.org/10.1093/icesjms/fsaa252

Stoll, J. S., Fuller, E., & Crona, B. I. (2017). Uneven adaptive capacity among fishers in a sea of change. *PLoS One*, *12*, Article e0178266. https://doi.org/10.1371/journal.pone.0178266

Virapongse, A., Brooks, S., Metcalf, E. C., Zedalis, M., Gosz, J., Kliskey, A., & Alessa, L. (2016). A social–ecological systems approach for environmental management. *Journal of Environmental Management*, *178*, 83–91. https://doi.org/10.1016/j.jenvman.2016.02.028

Wallace, R., & Colgan, C. S. (2023). *The economic impacts of the Maine seafood sector*. Seafood Economic Accelerator for Maine.

Waterman, M. (2022, July 6). *Lobster's claw-hold on Maine is strong*. The Working Waterfront. https://www.islandinstitute.org/working-waterfront/lobsters-claw-hold-on-maine-is-strong/

Young, T., Fuller, E. C., Provost, M. M., Coleman, K. E., St. Martin, K., McCay, B. J., & Pinsky, M. L. (2019). Adaptation strategies of coastal fishing communities as species shift poleward. *ICES Journal of Marine Science: Journal du Conseil*, *76*, 93–103. https://doi.org/10.1093/icesjms/fsy140

Zemeckis, D. R., Kneebone, J., Capizzano, C. W., Bochenek, E. A., Hoffman, W. S., Grothues, T. M., Mandelman, J. W., & Jensen, O. P. (2020). Discard mortality of Black Sea Bass (*Centropristis striata*) in a deepwater recreational fishery off New Jersey: Role of swim bladder venting in reducing mortality. *Fishery Bulletin*, *118*, 109–119. https://doi.org/10.7755/FB.118.2.1

Zou, C., Thunberg, E., & Ardini, G. (2021). *Economic profile for American Lobster (*Homarus americanus*) fleets in the northeastern United States (Reference Document 21-03)*. National Marine Fisheries Service, Northeast Fisheries Science Center.