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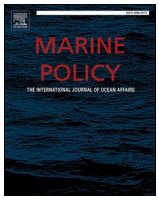

Full length article

Observations, perceptions and concerns of the American lobster industry regarding the range-expansion of Black Sea Bass

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ABSTRACT

Fisheries in the U.S. Northeast are being impacted by the effects of climate change in part due to the range expansion of potential predators and competitors. In the Gulf of Maine, the American lobster (*Homarus americanus*) fishery has expressed concerns about the range-expansion of Black Sea Bass (*Centropristis striata*). Black Sea Bass occupy similar habitats to lobsters and commonly prey upon decapod crustaceans. However, state independent trawl surveys do not effectively track the Black Sea Bass range expansion, highlighting the value of fishers' observations and perceptions of this dynamic change. Using a quantitative mixed-mode survey, commercial lobster fishers' ecological knowledge of Black Sea Bass in the Gulf of Maine was assessed. Fishers noted increasing abundances of Black Sea Bass that coincided with warmer years. Furthermore, the degree to which lobster fishers view that Black Sea Bass will negatively impact the lobster fishery was best predicted by if they think that Black Sea Bass are eating lobsters. This study revealed that fishers are observing the range-expansion and increased prevalence of Black Sea Bass in the waters that they fish for lobsters, which is extremely valuable because it addresses an important gap in our understanding of how climate change is impacting the Gulf of Maine ecosystem. Documenting species range shifts and their potential impacts will benefit ongoing and future fisheries management decisions such as whether efforts to target and remove these species in their newly expanded range should occur.

1. Introduction

There is increasing concern over climate change and its consequences on fisheries. Fisheries already face threats such as loss of revenue due to reduced catch allowances, fish population collapses, and loss of habitat. Rapid climate change can stress and disrupt biological and ecological processes such as fish physiology, ecosystem productivity, and food web dynamics. Given that fisheries provide a significant source of protein and bolster food security, these impacts present broader societal challenges. There is a need to continue assessing the effects of climate change on local ecosystems, including projecting future change and predicting potential impacts on harvested species [1–5]. In the northeastern United States (U.S.), commercial fisheries landed 516.7 million pounds of finfish and shellfish in 2019 totaling $1.5 billion USD in revenues [6]. Thus, fisheries impacted by climate change could also result in significant economic disruption and reduced wellbeing among coastal communities.

As a result of changes in water temperature, specifically warming waters, species often shift their distributions to higher latitudes and deeper waters to avoid temperature stress [7–9]. Wallingford et al. [10] defined a range-shifting species as "a species tracking its environmental niche through a range expansion or relocation beyond its historical range." These distributional changes in turn may lead to ecological and evolutionary consequences for ecosystems. Marine organisms are expanding their ranges by up to an order of magnitude faster than terrestrial species due to higher connectivity between communities and fewer barriers to widespread dispersal [4,10–12]. A challenge to predicting the impacts of species range expansions into a recipient ecosystem is the paucity of information about these species in their newly expanded range.

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The socio-economic impacts of range expansions on fisheries have obvious potential negative implications such as the displacement of important and economically valuable existing species. However, there may also be positive benefits of novel species entering a system if they offer a potential new fishery resource and reduce pressure on other existing fisheries [4,13,14]. Wallingford et al. [10] proposed that management should either facilitate range expansions if they promote ecosystem services and biodiversity or discourage them if they have the potential to negatively impact sensitive or rare species and communities. Resource managers should also incorporate how stakeholders perceive these changes and their potential socio-economic impacts or benefits into ongoing and future management efforts [15–18].

The use of fisher ecological knowledge (FEK) in research and resource management has grown in recent years [19,20]. Because of fishers' extensive knowledge about the species that they harvest and the ecosystem more broadly, FEK is incredibly valuable in establishing historical trends of species' distributions and abundances, as well as for documenting change [21–23]. Assessing FEK to document potential species range expansions could provide a more holistic understanding of how a species' distribution has changed and its effects on native communities [24]. FEK can also help inform policy and ecosystem status of fisheries in the region. Fishers often spend more time in natural environments, make detailed observations, and have a keen understanding of where they fish, which could have important implications for fisheries research, conservation, and management [24,25]. In the case of the range-expansion of a novel species, fishers accounts can determine the prevalence of these species and their impacts. FEK can determine how problematic an impact might be to the ecosystem and the fishers' wellbeing and livelihoods. Data from diverse sources such as from fishers' observations and perceptions can help inform management of species and policy change. In addition to harnessing FEK to document ecological change, it is important to assess impacts and develop strategies to help fishing communities respond and adapt to these large-scale and time-sensitive challenges [26,27].

The American lobster (*Homarus americanus*) fishery is iconic to the U. S. Northeast region and has become one of the most valuable fisheries in the country, generating over $925 million USD in revenue in commercial landings in 2021 [28]. Furthermore, the fishing industry in some states in the region such as Maine and New Hampshire rely heavily on lobsters, as lobsters account for most of the economic value of their commercial fisheries landings [29,30]. The lobster fishery has been an economic driver for many coastal communities throughout northern New England for decades [31,32]. Despite its high landing yields and economic output, the Gulf of Maine American lobster fishery is already being impacted by the effects of climate change. Sea surface temperatures are rising in the Gulf of Maine region faster than 99 % of the rest of the world's oceans [33]. The impacts of warming waters on the physiology, reproduction, and movement of lobsters have been well documented [34–36]. For example, warming waters have been associated with decreased survival of larval lobsters, and increased incidence of shell disease among adult lobsters [37–40], resulting in drastic declines in American lobster landings in southern New England [41]. Furthermore, novel predator species like Black Sea Bass expanding into this region may be adding to predation pressure on the American lobster [42,43].

Black Sea Bass (*Centropristis striata*) are a commercially and recreationally important species along the east coast of the U.S. and Gulf of Mexico. Black Sea Bass are managed in two stocks: the Southeast U.S. Continental Shelf and the Northeast U.S. Continental Shelf. Black Sea Bass are considered a data poor species due to their complex reproductive cycle and limited information on their lifespan and habitat requirements [44]. Fisheries independent surveys have yet to document the extent of Black Sea Bass in the Gulf of Maine because they prefer structured habitat such as cobble-ledge bottom [45,46] that is not conducive to trawl surveys such as the Maine-New Hampshire and Massachusetts Inshore Trawl Surveys. The highest biomass of the northern stock of Black Sea Bass is generally centered around the U.S. Mid-Atlantic region and, historically, Black Sea Bass were considered rare north of Cape Cod, Massachusetts [45,47,48]. In recent years, however, recreational and commercial fishers (including the lobster industry) have reported catching Black Sea Bass in southern Gulf of Maine waters, and Black Sea Bass are frequently encountered as far north as mid-coast Maine [42,49–54]. Fishers have encountered Black Sea Bass in their gear such as in lobster traps [55,56]. Given the abundance of lobster traps deployed throughout the coastal waters of the Gulf of Maine, the lobster industry could potentially provide valuable information on the distribution and abundance of Black Sea Bass in the region.

It is unclear how Black Sea Bass are perceived by coastal fishing communities in the Gulf of Maine, limiting efforts to integrate stakeholder knowledge into ongoing and future management efforts. Black Sea Bass occupy similar structured habitats to lobsters and commonly prey upon smaller decapod crustaceans including lobsters, which could lead to negative perceptions and impacts to the fishery [42,57]. Conversely, given their growing prevalence in the Gulf of Maine, Black Sea Bass could provide an economic subsidy for a region that has relatively few recreational sportfish and commercial fishery resources [30]. Thus, Black Sea Bass in the Gulf of Maine could simultaneously be both a novel threat to the extremely valuable lobster fishery and a new economic opportunity for the region. Given the direct threat that its expansion poses to the lobster fishery and the need for more information on its expansion, efforts to quantify and highlight their observations and perceptions of this phenomenon are needed.

This study documents the observations and perceptions of commercial lobster fishers from Southern New England and Gulf of Maine, spanning the states of Massachusetts (MA) and Maine (ME), which collectively account for the vast majority of the U.S. lobster fishery. Using a quantitative mixed-mode survey, the observations and perceptions of commercial American lobster fishers were documented and assessed in response to the range-expansion of Black Sea Bass. The objective of this study was to quantify the lobster industry's observations to determine where and when Black Sea Bass are occurring in the Gulf of Maine as well as what drives whether they perceive this range expansion as a threat to the lobster fishery and/or an additional fishery resource opportunity.

2. Material and Methods

2.1. Survey design and data collection

A quantitative mixed-mode survey was used to document the observations and to understand the perceptions of commercial American lobster fishers in response to the range-expansion of Black Sea Bass. The addresses and emails of commercial American lobster fishers were obtained from the Massachusetts (MA) Division of Marine Fisheries and Maine (ME) Department of Marine Resources in May/June of 2021. The survey population included 1028 lobster fishers from MA and 4704 lobster fishers from ME.

Fishers were grouped into regions within each state corresponding to their license management zone: MA state waters south of Cape Cod (Cape Cod South, "CCS"), MA state waters north of Cape Cod (Cape Cod North, "CCN"), ME state waters between the New Hampshire border and Cape Small (southern ME, "SME"), ME state waters between Cape Small and Cape Rosier (midcoast ME, "MID"), and ME state waters from Cape Rosier to the Canadian border (downeast ME, "DEM") (Fig. 1). In the most southern regions (CCS and CCN), lobster landings have declined, whereas in the northern regions (SME, MID, and DEM), landings have either remained stable or increased [41]. Furthermore, the landings for Black Sea Bass and population abundances have increased from south to north along the Gulf of Maine [28,58]. Average coastal water temperatures between Southern New England and northern Gulf of Maine can differ by almost 10°C during the summer months [41,59]. There are also

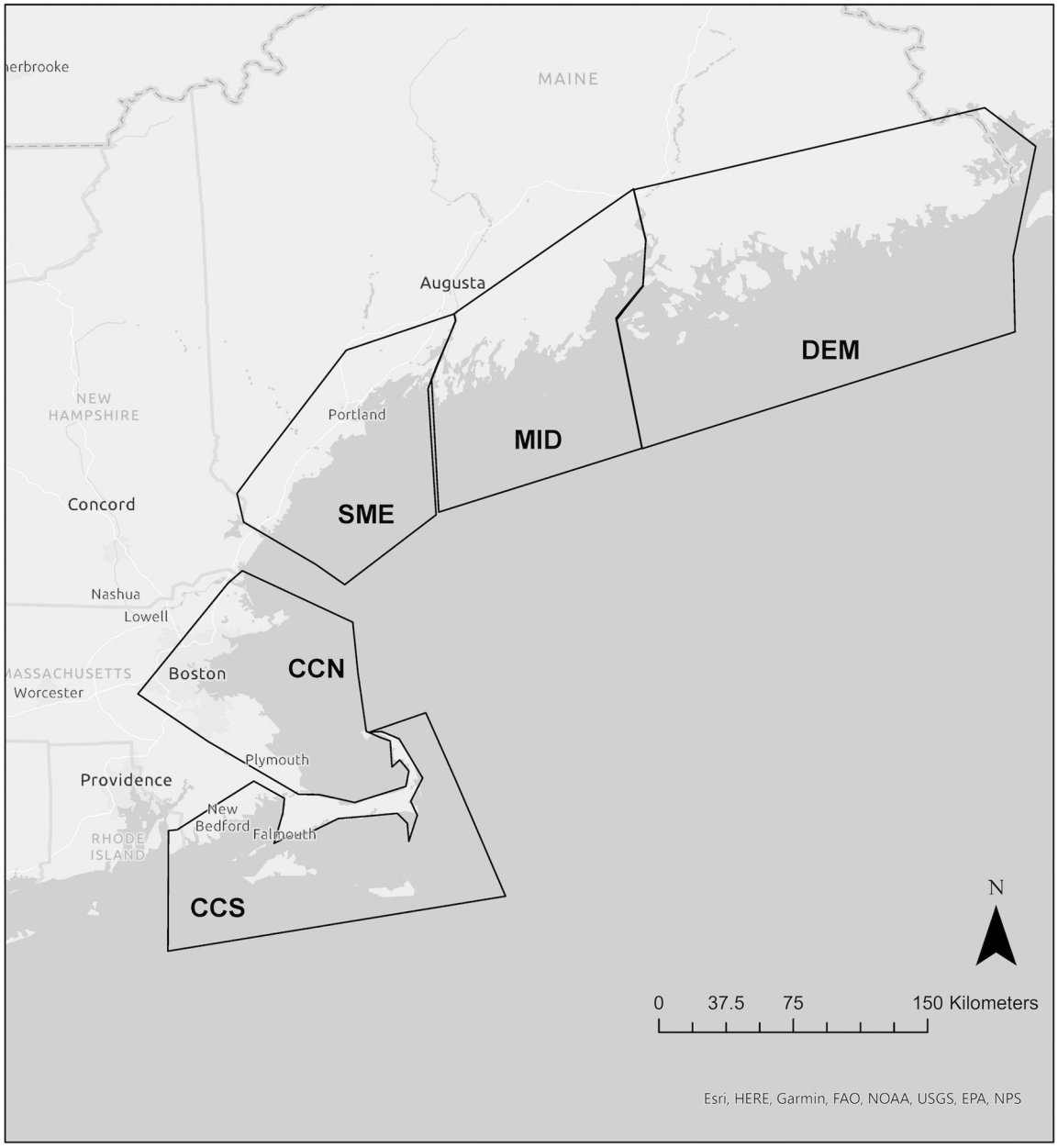

Fig. 1. Location of commercial lobster fisher survey regions in downeast Maine (DEM), midcoast Maine (MID), southern Maine (SME), Massachusetts north of Cape Cod (CCN), and Massachusetts south of Cape Cod (CCS).

demographic and economic differences between the states of Massachusetts and Maine. The population density is higher in coastal Massachusetts than in Maine [60]. Maine is the epicenter of the American lobster fishery, bringing in approximately $740 million annually; in Massachusetts, the lobster fishery generates more than $125 million in revenue [28,29].

Within each region, 300 fishers were randomly selected and were sent surveys through Qualtrics XM online survey software (Qualtrics Labs Inc., Provo, UT) via an email invitation, 300 additional fishers were sent surveys via postal mail, and another 50 fishers were sent the survey via both postal mail and email. In CCS, due to the smaller number of commercial lobster fishers in the region, all 126 fishers were sent surveys via postal mail and 50 of those fishers were also emailed the survey (Table 1). Those who received a postal survey received a code unique to each potential participant. Recipients of the postal survey also had the option to complete the survey on-line using this code. Those who received the online survey were sent individual emails via the Qualtrics online survey software. Surveys were distributed in June of 2021. All survey participants' information was de-identified with the exception of the region that they were from. All survey methods were approved by Northeastern University's Institutional Review Board (IRB # 13–11–25). Gift certificates to a name-brand outdoor recreation store were raffled as an incentive. The survey was open until November of 2021.

Survey questions were divided into five categories: 1) fisher characteristics, 2) Black Sea Bass observations, 3) perceptions on Black Sea Bass range expansion and impacts on lobsters, 4) fishers' satisfaction or considerations of management of Black Sea Bass, and finally, 5) fisher demographics (Table A1). Survey questions were optional, thus not every question yielded the same number of total responses. Fisher characteristics questions documented a fisher's number of years spent fishing, number of traps fished, the percent contribution of commercial lobster fishing to their household income, and the year in which they were born. Questions about the distribution and abundance of Black Sea Bass asked for fishers' observations of changes in the frequency of Black

Table 1
Regional distribution of mixed-mode surveys and responses from downeast Maine (DEM), midcoast Maine (MID), southern Maine (SME), Massachusetts north of Cape Cod (CCN), and Massachusetts south of Cape Cod (CCS). Adjusted total surveys include responses that were started, submitted incomplete, and submitted complete. Adjusted total surveys did not include unopened, blocked, bounce-back emails, and postal mail returned to sender. See Table A2 for details on distribution and retrieval of surveys.

Region	Qualtrics	Postal	Both	Adjusted Total Surveys	**Responses Received**
DEM	300	300	50	436	**38**
MID	300	300	50	469	**45**
SME	300	300	50	470	**50**
CCN	300	300	50	493	**64**
CCS	0	126	50	189	**23**
Totals	1200	1326	250	2057	**220/2057 10.7 % Response Rate**

Sea Bass sightings in recent years (Likert scale: 'More frequent'; 'About the same frequency'; 'Less frequent'), the year when their catch of Black Sea Bass was most abundant, the locations ('Offshore'; 'Nearshore/coastal'; 'None') in each season that Black Sea Bass were abundant, and the depth(s) and bottom type(s) where Black Sea Bass are most typically caught.

Perception questions evaluated the factors that fishers felt are the most important drivers influencing changes in Black Sea Bass sightings and their thoughts on what Black Sea Bass eat. Both of these were unstructured, open-ended questions, and common responses were coded for analyses. The most common entries that were coded for drivers influencing changes in Black Sea Bass sightings were the following: 'climate change,' 'fishing area location', 'increase in prey,' 'lack of predators,' 'management/regulations,' 'rare/no change', 'warmer water/water temperature.' Responses to what Black Sea bass eat were used to determine if lobster fishers think that Black Sea Bass eat lobsters. Fishers' level of concern regarding the impact of the Black Sea Bass range expansion on the lobster fishery (Likert scale: 'Harmful'; 'Neutral'; 'Beneficial') was assessed. Finally, fishers were asked whether they would like to see more, less, or no change in Black Sea Bass abundances. Fishers from MA were also asked about their views on the current state management regulations for Black Sea Bass, whereas those from ME were asked whether they would target Black Sea Bass commercially and/or recreationally if either was permissible.

Statistical analyses were conducted using the Statistical Package for the Social Sciences (SPSS). Classification tree analyses using the Chi-squared Automatic Interaction Detection Method (CHAID) were conducted to determine the strongest predictor(s) (independent variables) of fishers' observations and perceptions. Region, number of years of lobster fishing, percentage of income, and whether fishers thought Black Sea Bass consume lobsters were used to best predict fishers' perceptions regarding 'how an increase in the abundance of Black Sea Bass would impact the American lobster fishery.' Finally, the variables of region, number of years lobster fishing, percentage of income, whether fishers thought Black Sea Bass consume lobsters, and fishers' thoughts on how an increase in the abundance of Black Sea Bass would impact the American lobster fishery were used to best predict if fishers 'would prefer Black Sea Bass to become more or less abundant'. The maximum tree depth was set at 3, the minimum cases in parent nodes were set at 50, and the minimum cases in child nodes were set at 20.

3. Results

A total of 220 surveys were received, with an overall response rate of 10.7 % out of an adjusted total of 2057 that were sent. The adjusted number of surveys sent, and hence the response rate, did not include Qualtrics email invitations that were unopened, blocked or bounce-backs, nor did it count surveys sent by postal mail that were returned to sender. Surveys received and counted as a response included those that were started and either submitted incomplete or completed (Table 1; Table A2). Most participants completed the survey via email invitation sent by Qualtrics (26.8 %; n=133 out of 496) compared to receiving the survey by postal mail alone (5.3 %; n=70 out of 1313) and receiving the survey by both postal mail and Qualtrics email invitation (6.9 %; n=17 out of 248). Each region accounted for between 10 % and 29 % of overall survey responses (n=220 total surveys received), with the most responses (29 %) coming from CCN. For the entire survey, 60 % (n=133 out of 220) of the respondents were from ME, whereas 40 % (n=87 out of 220) were from MA.

3.1. Fisher characteristics and observations

Many of the respondents (n=44 out of 134 responses to this question) were born between the years of 1955–1960 (Fig. A1), and all respondents had an average of 32.2±14.8 years of fishing experience. Fishers who responded through Qualtrics Online Survey format were born in later years (mean year 1966±2) compared to those who mailed back their survey (mean year 1958±2). Additionally, fishers who completed the survey online had 29.7±1.4 years of fishing experience compared to 35.6±1.7 years of fishing experience for those who mailed back their survey responses. Fishers (n=52 out of 89) observed the greatest abundances of Black Sea Bass in their traps between the years 2010 and 2012 and between 2018 and 2020 (Fig. 2). Fishers indicated that they caught more Black Sea Bass during the summer season and at nearshore/coastal sites, though this pattern varied slightly regionally (Table A3). For example, in CCS (total responses received n=21), Black Sea Bass were most frequently caught during the summer and fall seasons (86 % and 57 %, respectively). Meanwhile, farther north in CCN, SME, MID, and DEM, fishers caught Black Sea Bass more commonly during the summer season with over 50 % of responses indicating this season (65 %, 71 %, 76 %, 58 %; total responses n=46, 31, 33, 26, respectively), and less than 50 % of responses catching Black Sea Bass in the other seasons (Fig. 3). Fishers (total responses n=141) observed Black Sea Bass most frequently at depths around 30–60 feet (44 %). There was no clear trend for fishers' observations of Black Sea Bass preference for bottom type (total responses n=139). However, there was a slightly higher proportion of fisher sightings of Black Sea Bass on sand bottom habitat in MA than in ME.

3.2. Perceptions of Black Sea Bass

Perceptions of Black Sea Bass sightings and drivers of changes in sightings varied among regions. Fishers from CCS (43 %; n=9 out of 21) noted Black Sea Bass sightings have become "much more frequent," and 44 % of fishers (n=16 out of 32) from the SME region said that sightings have become more frequent. Meanwhile, close to 50 % of fishers from each region north of CCS (CCN (n=20 out of 48), MID (n=20 out of 36), and DEM (n=17 out of 29) also noted "about the same frequency" in sightings. For the perceived drivers of these changes in sightings, fishers from CCS (36 %; n=8 out of 22) indicated "management/regulations" as a driver. For CCN, SME, and MID, around 50 % of fishers from each region stated "warmer water/water temperature" as a driver for increased Black Sea Bass abundances (CCN: n=16 out of 32; SME: n=12 out of 25, and MID: n=9 out of 18). At the most northern end of the study region, fishers from DEM (42 %; n=8 out of 19) indicated that Black Sea Bass sightings were "rare" or said that they experienced "no change."

3.3. Predictors of perceptions of the impacts of Black Sea Bass on the lobster fishery

Overall, 52 % (n=65 out of 126) of fishers thought that an increase in the abundance of Black Sea Bass would have a harmful impact on the American lobster fishery (Fig. 4). The decision tree analysis determined

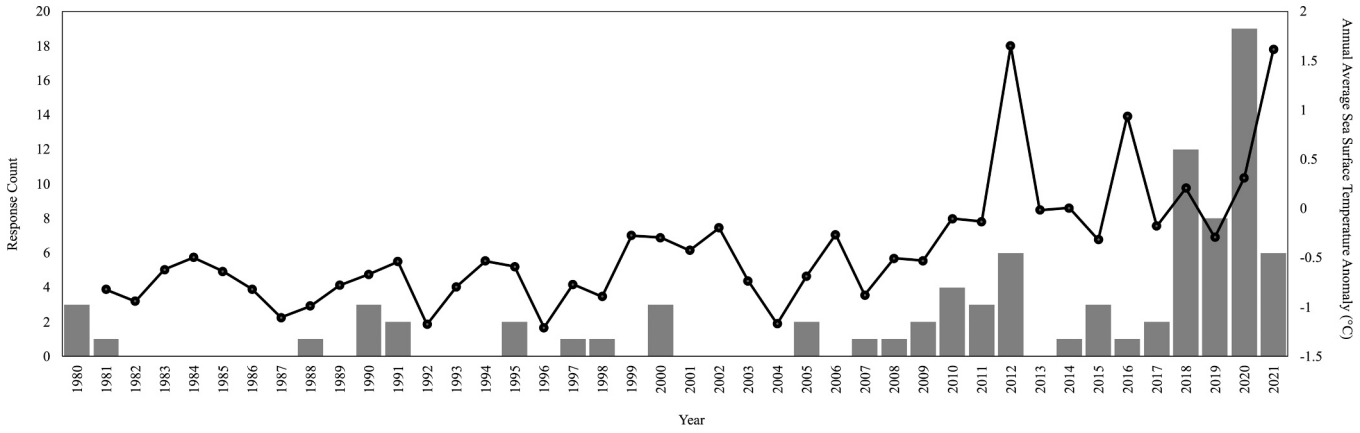

Fig. 2. Bars represent counts of fishers' observations of the year in which Black Sea Bass were most abundant for all regions combined. The black line represents average annual sea surface temperature anomalies (NOAA OI SST V2 High Resolution Dataset for Gulf of Maine [72] provided by A. Kemberling [71]).

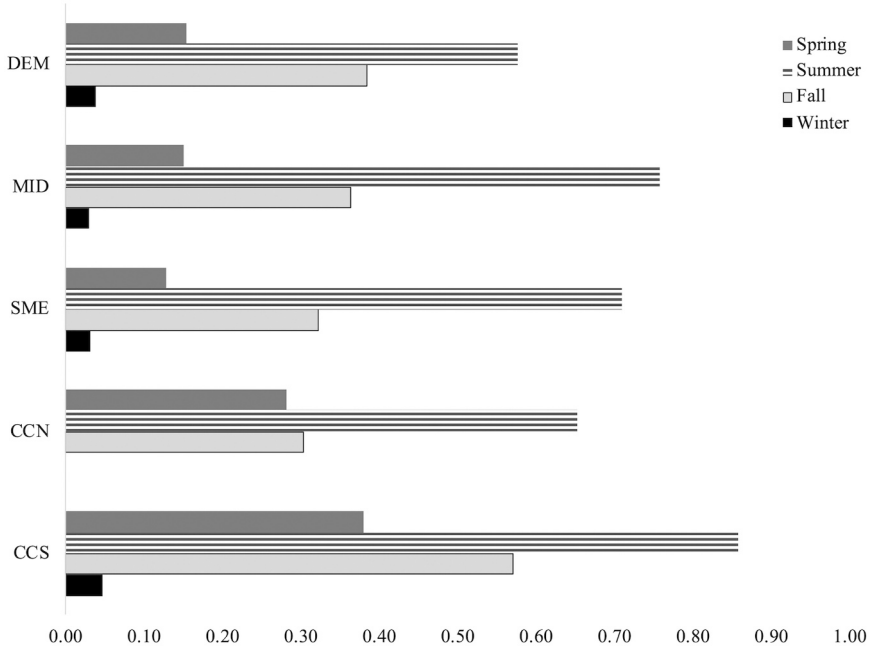

Fig. 3. Percentage of responses of seasonal Black Sea Bass sightings nearshore and coastal locations.

that whether fishers thought that Black Sea Bass eat lobsters was the most important predictor of if they think Black Sea Bass will harm the lobster fishery (Fig. 4). In particular, those fishers who think that Black Sea Bass eat lobsters mostly believed that Black Sea Bass would negatively impact the lobster fishery (76 %; n=41 out of 54). Conversely, fishers who did not indicate that Black Sea Bass eat lobsters largely stated that Black Sea Bass would have a neutral impact (63 %; n=45 out of 72), while 33 % (n=24 out of 72) of these fishers perceived that Black Sea Bass would still harm the lobster fishery versus 4 % thought that Black Sea Bass would be beneficial.

Overall, 45 % of respondents (n=74 out of 166) reported seeing more frequent sightings of Black Sea Bass over time during their years as a commercial lobster fisher. The majority (56 %; n=71 out of 127) of these fishers would like to see 'no change' in Black Sea Bass abundance. Meanwhile, 20 % of fishers would like there to be fewer Black Sea Bass, and 24 % indicated that they would prefer an increase. The impact of Black Sea Bass on the lobster fishery was the most important predictor of fisher views on how they would like to see Black Sea Bass abundances change (Fig. 5). Specifically, of those that thought Black Sea Bass would have a beneficial or neutral impact to the lobster fishery, 65 % (n=42 out of 64) wanted more Black Sea Bass and 30 % of the respondents (n=19 out of 64) wanted no change. Conversely, of the fishers who thought Black Sea Bass would have harmful impacts to the lobster fishery, 46 % (n=29 out of 63) preferred no change in Black Sea Bass abundances while 35 % (n=22 out of 63) wanted Black Sea Bass to become less abundant (Fig. 5). For those who saw more frequent sightings of Black Sea Bass, 31 % of fishers want to see fewer Black Sea Bass (n=20 out of 65). Interestingly, for those who saw the same frequency of Black Sea Bass, 75 % of these fishers (n=39 out of 52 fishers) indicated that they would prefer no change in abundances.

Regionally, 42 % of CCS fishers (n=8 out of 19) wanted Black Sea Bass to become 'less abundant' as opposed to becoming 'more abundant' (32 %) or 'no change' (26 %). For the other regions, the most common response was a desire for 'no change' in Black Sea Bass abundances. All CCS fishers who responded that they wanted Black Sea Bass to become less abundant also thought Black Sea Bass were harmful to the lobster fishery. For the three ME regions combined (n=68), there were 66 % (n=45 out of 68) who responded that they do want Black Sea Bass abundance to change. Out of these ME fishers, 38 % (n=17 out of 45) also indicated that they think that Black Sea Bass are negatively

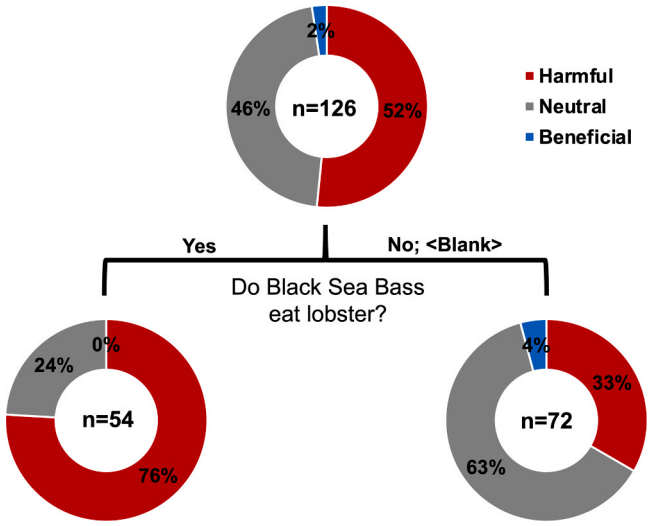

Fig. 4. Results of classification tree analysis to identify the most powerful explanatory variables of impacts of increased Black Sea Bass abundance on the lobster fishery. Separate branches indicate statistical differences at $P \leq 0.05$. Value in the center of each circle reflects number of responses.

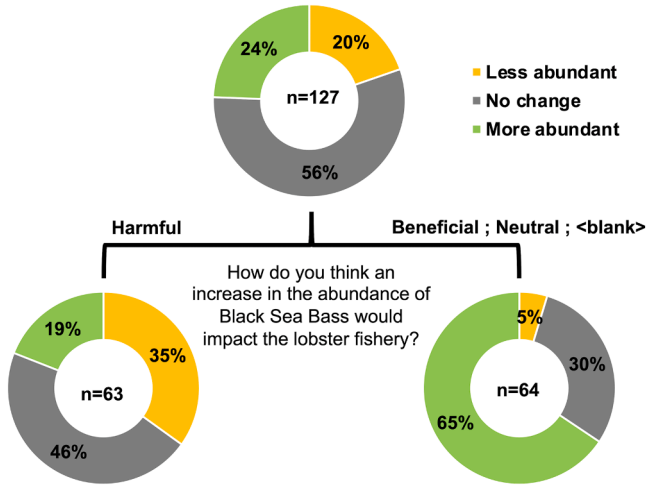

Fig. 5. Results of classification tree analysis to identify the most powerful explanatory variables of what fishers would like to see Black Sea Bass abundance to become. Separate branches indicate statistical differences at $P \leq 0.05$. Value in the center of each circle reflects number of responses.

impacting the lobster fishery.

Opinions on Black Sea Bass management varied by region in MA, whereas those about commercial and recreational Black Sea Bass fishing in ME were consistent across regions. Between the two MA regions, there was a difference in how satisfied lobster fishers are with the management of Black Sea Bass. For CCS, 58 % of respondents (n=11 out of 19) were dissatisfied with current state regulations managing Black Sea Bass. Conversely, only 8 % of CCN respondents (n=3 out of 40) were dissatisfied, and the predominant response was 'neutral' for CCN. For all ME regions, 50 % of respondents (n=39 out of 78) indicated that they would not consider fishing for Black Sea Bass commercially whereas 22 % (n=17 out of 78) said that they would consider commercially fishing for Black Sea Bass, and 28 % (n=22 out of 78) said 'Maybe'. Additionally, 67 % of ME fishers (n=52 out of 78) would not consider recreationally fishing for Black Sea Bass, whereas 15 % of fishers would consider it (n=12 out of 78).

4. Discussion

This survey quantified the observations and assessed the perceptions of commercial lobster fishers from throughout much of New England on the range-expansion of Black Sea Bass. Fishers noted increasing trends of Black Sea Bass abundance throughout portions of these regions that coincided with recent warming events in the Northwest Atlantic. Additionally, fisher perceptions of this range expansion demonstrated how beliefs are linked to if they think Black Sea Bass consume juvenile lobsters and negatively impact the fishery.

Black Sea Bass were more prevalent during the summer and fall in southern regions such as CCS, while in the northern Gulf of Maine they were more commonly caught in the summer. Environmental conditions in CCS likely support Black Sea Bass almost year-round, resulting in increased landings [61], spawning stock biomass, and recruitment [58] paired with CCS respondents observing Black Sea Bass "much more frequent[ly]" in recent years. Additionally, summers in northern regions provide optimal conditions for Black Sea Bass. The rate of warming is not completely linear with increasing latitudes, and there may be spots of warming and cooling occurring in the Gulf of Maine [62], or there are habitats where warming is occurring at faster and/or more extreme rates like that at nearshore and estuarine areas where Black Sea Bass are generally fished [63,64]. Consistent cold winters associated with the U. S. Northeast and New England states may be why Black Sea Bass have not become established in the northern Gulf of Maine. However, as the climate continues to change, especially if the region's winters continue to have less sustained cold temperatures [65] and bottom water ocean temperatures continue to increase [66], the distribution and abundance of fish and shellfish communities will likely also change [67,68]. Specific to Black Sea Bass, continued collection of fisher sightings paired with environmental data from fished areas throughout the Gulf of Maine will help determine the degree to which warming waters are driving their range expansion. This synchrony among ecological research, economic data, and FEK referenced in this study confirms that the Black Sea Bass is becoming established in the Gulf of Maine, and it agrees with previous research demonstrating this expansion [42].

Fishers reported catching the greatest abundances of Black Sea Bass between 2010 and 2012 and then again in 2018–2020, both of which correspond with warming trends. While this may be due to recall bias [69], or the idea that participants are better able to recall memories in the near-term, patterns of fishers' observations are also strongly aligned with measured change in the region's sea surface temperature. The observations of increased abundance during 2010–2012 coincided with the notable 2012 warm water temperature anomaly in the Northwest Atlantic Ocean [33,70], and are supported by a 2015 survey [53] that also observed increases in Black Sea Bass abundances during and after 2012. Marine heat waves in the Gulf of Maine have occurred in 2016 and 2018 [78], likely contributing to the survey results in this study identifying increased abundances in 2018–2020. Furthermore, when this survey was implemented in 2021, annual average sea surface temperature was 12.3°C, which was higher than the 2012 warming event [71,72]. In addition, there were fewer peak observations in the year 2019 when water temperatures in the U.S. Northeast shelf ecosystem were more moderate compared to record high temperatures in 2012 [73]. Overall, yearly regional temperature, Black Sea Bass landings, and spatial and temporal fisher observation data collectively suggest that Black Sea Bass abundances have been increasing in the Gulf of Maine in recent years, and that increasing sea water temperature is likely driving this range expansion.

The low response rate from this survey potentially limits our ability to generalize the results to the entire fishery in Maine and Massachusetts. In general, surveys assessing natural resources have been faced with declining response rates [74–76]. Survey fatigue may also be a factor since the lobster fishery, like many commercial fishing industries, has been surveyed extensively over the past decade. There is a need for meaningful engagement and collaboration to assess perceptions and

human-dimensions, and to build trust. Our survey response rate may also be low, and potentially biased, if fishers were more likely to respond if they have been observing Black Sea Bass in their traps. Because of this potential bias, we avoided generalizing observation rates to the entire lobster fishery. Moreover, our major findings about when and where lobster fishers are seeing Black Sea Bass, as well as the drivers of how they perceive Black Sea Bass are likely unbiased by the low response rate, given how fisher observations complement current scientific surveys. Furthermore, their concerns are valid given the documentation in the literature about management's inability to keep pace with the effects of climate change such as range shifts in fisheries [5].

Fisher perceptions of the drivers for changes in Black Sea Bass sightings differed between southern and northern regions of survey participants, with fishers in northern regions attributing increases to "warming waters/water temperatures," while those in southern regions attributing increased Black Sea Bass abundances to "management/regulations." Previous work in the region supports this difference in perception of drivers of abundance [51,53]. In particular, fishers in the southern region noted the inability to catch Black Sea Bass and lack of harvest, as quotas remain low relative to abundance, with respondents commenting on the desire for Black Sea Bass quotas to be higher. Notably, in 2023, the commercial quota for Black Sea Bass in Massachusetts was 741,071 lbs. By the end of the year, the percent landed reached 109.7 % [77] of the allocated quota. The fisher dissatisfaction expressed in our survey likely stems from the fact that local Black Sea Bass populations have increased dramatically over the past 1–2 decades, whereas the total allowable catch and associated quotas have yet to increase much here [77,78]. Fishers from Southern New England may have become accustomed to large populations of Black Sea Bass, perhaps explaining why they expressed frustration with their inability to land more Black Sea Bass. This study's findings agree with those of Pinsky and Fogarty [5], which found that fisheries management has struggled to keep pace with the rapid rate of fish range expansions to higher latitudes. Based on the comments raised by fishers in the forms of concern of increasing prevalence of Black Sea Bass and dissatisfaction with current management, one policy option could be to allow the lobster industry to land their Black Sea Bass catch instead of throwing them back. This option would support fishers in adapting by providing alternative sources of revenue, which is especially important in Maine [30]. Another option strongly supported by many fishers in this survey would be to increase quotas for Black Sea Bass in the commercial fishery in southern New England. This option would not likely affect them directly unless they are participating in both fisheries, but could still benefit lobster fishers indirectly if Black Sea Bass are consuming large numbers of juvenile lobsters in the Gulf of Maine and southern New England.

Concerns about Black Sea Bass among the lobster fishery were evident throughout survey responses and were largely driven by whether fishers thought Black Sea Bass eat lobsters. Black Sea Bass diets are mostly comprised of decapod crustaceans [42,57,79,80], and Black Sea Bass and juvenile lobsters tend to inhabit similar inshore habitats, including rocky ledge, cobble, and boulder bottom [81]. This overlap in habitat use coupled with the range expansion of Black Sea Bass likely has led to New England fishers reporting to local news that "*lobster traps … being pillaged by these [Black Sea Bass]*" [56]. Lobsters have been found in the stomachs of Black Sea Bass from their historical northern range limit of Southern Massachusetts and Rhode Island as well as from their newly expanded range north of Cape Cod, MA up to mid-coast Maine [42], [Cheng et al. unpubl. data]. Furthermore, if Black Sea Bass densities increase like they have in Southern New England, they likely will exert significant predation pressure on juvenile lobsters and other crustaceans. This study found that the lobster fishery is very concerned that Black Sea Bass pose a threat to juvenile lobsters and the lobster fishery.

While fishers in Massachusetts indicated dissatisfaction with Black Sea Bass quotas, in Maine, members of the lobster industry expressed little to no desire to commercially fish for Black Sea Bass if quota became available. Their further comments and reasons to not fish for Black Sea Bass highlighted the strong tradition of fishing for lobsters in this region, while also suggesting that market dynamics and issues of scale play a role in adapting to new fisheries. Fishers commented that Black Sea Bass is *"not what we fish for here in Maine,"* and that they were "*too busy catching lobster.*" Fishers also cited economic reasons such as a *"market [is] not available,"* and fishing for Black Sea Bass is *"not worth it."* Given data collected from this study and others [51,53], there is consensus from fishers that warming waters will likely negatively affect the lobster industry; however, their willingness to adapt is impacted by a number of factors. Optimism bias [82], which is the cognitive process in which people underestimate the likelihood of negative events affecting them personally and therefore do not stray from established activities, may be influencing fisher perceptions since lobster landings in Maine and northern Massachusetts remain relatively high. Another possible reason for little interest in Black Sea Bass as a fishery is likely due to the availability of adaptation measures such as access to assets (i.e., ability to land Black Sea Bass), low relative value (the dockside price for Black Sea Bass in 2022 was ~$2.73/lb. in Massachusetts, which is far lower than the dockside lobster price of ~$5.60/lb. [28]), limited flexibility (i.e., gear modifications), and lack of agency (i.e., involvement in fisheries management) [13]. The American lobster fishery accounts for more than 75 % of Maine's fishery value, with significant individual investments in infrastructure, such as large fishing boats [30]. While diversifying fisheries is often cited as a key element of adaptation, the logistical hurdles and financial costs associated with transitioning into new fisheries are substantial, as indicated by survey responses. The differences in perceptions of fisheries between states and even regions are also likely due to perceived baselines of species abundances relative to fishers' personal histories, dictating their future concerns and desires [83]. Decreased lobster landings and increased abundances of Black Sea Bass in Southern New England [28,41,58] aligned with the desire from lobster fishers in the southern region to increase quotas for these range-expanding species. Meanwhile, increased or stable lobster landings aligned with minimal concern in Maine for Black Sea Bass, with some Maine fishers indicating that Black Sea Bass are "*not worth it*" to fish for. These direct quotes from fishers and this study's decision tree analyses on perceptions of impacts of increasing abundance of Black Sea Bass to the lobster fishery reveal that a new fisheries species is largely viewed as harmful to this venerated fishery, and highlight the importance of narratives and lived experiences in fisheries science and decision-making.

5. Conclusions

This survey revealed that the lobster industry is observing increased abundances of Black Sea Bass, and that they have been pivotal in documenting this range expansion into the Gulf of Maine. Moreover, their knowledge can fill critical gaps especially where scientific surveys are unable to provide data, thereby contributing to a more holistic understanding of changing ecosystem dynamics such as species range shifts and invasions. Furthermore, these efforts could be complemented by other methods such as hook and line, trap, and underwater video surveys to collect additional biological and ecological information [84–87]. Based on this and other surveys of fishers, Black Sea Bass are established in the southern Gulf of Maine and are expanding their geographic range northward [42,51,53]. Fishers expressed concerns that Black Sea Bass are negatively impacting the lobster fishery, which tended to coincide with their desire for future changes in Black Sea Bass populations and their level of satisfaction with current regulations and management. These results suggest that FEK can greatly contribute to fisheries management and our understanding of social-ecological systems, including those rapidly shifting due to climate change. Continuation of warming waters and intense seasonal variation are expected to alter the Gulf of Maine ecosystem and its resources further, including the distribution and abundance of valuable fishery species. In response, the ability of fishers to adapt, along with the successful management of current and

possible new resources, will benefit from the exchange of knowledge and collaboration among fishers, managers, scientists, and other relevant community groups [88].

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CRediT authorship contribution statement

Helen Cheng: Writing – review & editing, Writing – original draft, Visualization, Methodology, Investigation, Formal analysis, Data curation, Conceptualization. **Marissa D. McMahan:** Writing – review & editing, Methodology, Funding acquisition. **Steven B. Scyphers:** Writing – review & editing, Methodology, Funding acquisition, Conceptualization. **Loren McClenachan:** Writing – review & editing, Funding acquisition. **Jonathan H. Grabowski:** Writing – review & editing, Project administration, Methodology, Funding acquisition, Conceptualization.

Declaration of Competing Interest

None

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Appendix

Table A1
Summary table of survey questions.

Question Categories	
Fisher characteristics	• [Region implied] • Number of years commercial lobster fishing • Number of traps fish • % of income comes from lobstering • Year born
Observations	• Changes in Black Sea Bass sightings • Where (nearshore/ offshore) and when (time of year of year) are Black Sea Bass commonly caught • Depths at which Black Sea Bass are commonly caught • Bottom type at which Black Sea Bass are commonly caught • Year when catch of Black Sea Bass was most abundant
Perceptions	• Most important driver influence changes in Black Sea Bass sightings • Top three species that Black Sea Bass are eating / do Black Sea Bass eat lobster • What would fishers like to see Black Sea Bass become • How does increase in the abundance of Black Sea Bass impact: 1) native species abundance, 2) the lobster fishery, 3) personal livelihood, 4) community's economy • Overall impact of Black Sea Bass becoming abundant in the northern Gulf of Maine
Current actions	• (MA) Satisfaction of Black Sea Bass regulations • (ME) Consideration to target Black Sea Bass commercially/ recreationally

Table A2
Detailed regional distribution, methods, and responses of mixed-mode surveys and responses received from downeast Maine (DEM), midcoast Maine (MID), southern Maine (SME), Massachusetts north of Cape Cod (CCN), and Massachusetts south of Cape Cod (CCS). Qualtrics survey emails that were unopened, blocked or bounced-back to sender as well as postal mail that was returned to sender were not included in the adjusted total survey count.

Region	Qualtrics	**Adjusted Totals via Qualtrics**	Postal	**Adjusted Totals via Postal**	Both	**Adjusted Totals via Both**	**Adjusted Total Surveys**
DEM	300	87	300	299	50	50	436
MID	300	121	300	299	50	49	469
SME	300	122	300	298	50	50	470
CCN	300	149	300	294	50	50	493
CCS	0	17	126	123	50	49	189
Totals		496		1313		248	2057
Region		**Responses Received from Qualtrics**		**Responses Received from Postal**		**Responses Received from Both**	**Responses Received**
DEM		18		16		4	38
MID		29		14		2	45
SME		31		15		4	50
CCN		50		13		1	64
CCS		5		12		6	23
Totals		133		70		17	220
Response Rate		26.8 %		5.3 %		6.9 %	**10.7 %**

Table A3
Table of percentage of responses per region of where and when fishers generally caught the most Black Sea Bass. Note that this question was a multiple-answer type question and there were responses that indicated catching the most Black Sea Bass at both nearshore/coastal sites and offshore sites.

CCS (n=21)	Winter	Spring	Summer	Fall
Nearshore/ Coastal	0.05	0.33	0.86	0.57
Offshore	—	—	—	0.05
Nearshore/Coastal AND Offshore	—	0.05	0.10	—
CCN (n=46)	Winter	Spring	Summer	Fall
Nearshore/ Coastal	—	0.28	0.65	0.28
Offshore	0.11	0.04	0.02	0.15
Nearshore/Coastal AND Offshore	—	—	0.09	0.02
SME (n=31)	Winter	Spring	Summer	Fall
Nearshore/ Coastal	—	0.06	0.71	0.26
Offshore	0.13	0.10	—	0.06
Nearshore/Coastal AND Offshore	0.03	0.06	0.16	0.06
MID (n=33)	Winter	Spring	Summer	Fall
Nearshore/ Coastal	0.03	0.15	0.76	0.30
Offshore	0.03	0.09	0.09	0.06
Nearshore/Coastal AND Offshore	—	—	0.09	0.06
DEM (n=26)	Winter	Spring	Summer	Fall
Nearshore/ Coastal	0.04	0.15	0.58	0.35
Offshore	—	—	—	—
Nearshore/Coastal AND Offshore	—	—	—	0.04

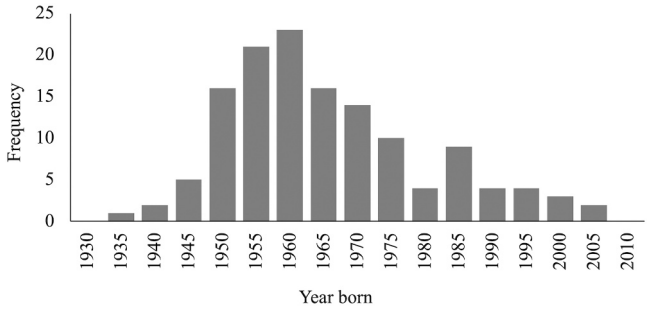

Figure A1. Histogram of fishers' year of birth (n = 144).

Data availability

Data will be made available on request.

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