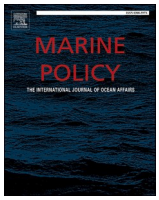
Marine Policy 173 (2025) 106543

Contents lists available at ScienceDirect

Marine Policy

journal homepage: www.elsevier.com/locate/marpol



Socioeconomic indicators of resilience in Maine's American lobster fishery

Theresa L.U. Burnham [a,*], Joelle Kilchenmann [a,b], Carla Guenther [c], Maggie O'Shea [d], Kathleen Reardon [e], Joshua S. Stoll [a,b]

[a] School of Marine Sciences, University of Maine, Orono, ME, United States
[b] Ecology & Environmental Sciences Program, University of Maine, Orono, ME, United States
[c] Maine Center for Coastal Fisheries, Stonington, ME, United States
[d] Program in Ecology, Evolution, Environment & Society, Dartmouth College, Hanover, NH, United States
[e] Maine Department of Marine Resources, Boothbay Harbor, ME, United States

ARTICLE INFO

Keywords:
Fisheries management
Socioeconomic indicators
American lobster
Participatory research

ABSTRACT

The American lobster (*Homarus americanus*) is an iconic component of the sociocultural and economic fabric of the state of Maine, where the commercial lobster fishery supports thousands of livelihoods. However, landings have recently declined, raising concerns about the long-term trajectory of the fishery, and highlighting the need for research to evaluate how changes to the fishery will impact harvesters and coastal communities. To address this need, we used a collaborative, mixed-methods approach to identify eight indicators that describe socioeconomic resilience in the lobster fishery from 2008 to 2022. Sufficient secondary data was available to fully quantify two of the indicators, coastal accessibility and operational condition, which track changes in housing availability and affordability, and the condition of a lobstermen's business over time, respectively. We found spatial heterogeneity in the trends of both indicators over time, indicating that the socioeconomic impacts of changes to the fishery may vary along the coast. For example, coastal accessibility has declined in all coastal regions of Maine over time but the decline has been the most pronounced in the southern region. Our results lay the groundwork for continued development of socioeconomic indicators of resilience in Maine's lobster fishery and can support the initiation of a long-term monitoring program to identify and respond to changes in socioeconomic condition of the lobster fleet. This research may also serve as a model for quantifying socioeconomic components of other fisheries around the world, many of which are facing an evolving landscape of social, economic, regulatory, and environmental shifts.

1. Introduction

1.1. Lobster as the social and economic backbone of fisheries in Maine

The American lobster (*Homarus americanus*) fishery in Maine is among the most valuable commercial fisheries in the United States and supports thousands of jobs in coastal communities across the state [32]. However, since peaking in 2016, lobster landings have decreased by 27 % through 2022 and because of its social, economic, and cultural importance in many coastal and island-based communities across Maine, this trend raises concerns about the long-term trajectory of the fishery [1,33]. Lobster fisheries in southern New England have already experienced precipitous decline in the previous decades [34,4]. Several interrelated hypotheses point to reasons for the decline, including increased fishing pressure [8], recruitment decline [12], reduced conservation practices among fishermen [22], higher prevalence of disease [35], declining habitat suitability [37], and climate change [25]. Irrespective of what is driving the change, the downward trajectory of the lobster biomass raises questions about the future of the fishery and how a continued decline will impact lobstermen[1] and coastal communities in Maine. The aim of the research presented in this paper was to develop an initial set of socioeconomic indicators to track "resilience" in the fishery that could support the lobster industry, coastal communities, and managers as they prepare for change and develop effective response strategies.

* Corresponding author.
E-mail address: theresa.burnham@maine.edu (T.L.U. Burnham).

[1] The terms "fishermen" and "lobstermen" are used to describe all harvesters. In our experience, sector participants prefer this designation to "fishers".

https://doi.org/10.1016/j.marpol.2024.106543
Received 14 June 2024; Received in revised form 25 November 2024; Accepted 27 November 2024
Available online 10 December 2024

1.2. A monitoring "gap" in the lobster fishery

Existing efforts to monitor the Maine lobster fishery primarily focus on biological parameters. The Maine Department of Marine Resources (Maine DMR) oversees five annual monitoring programs that include a sea sampling survey (est. 1985), the Maine-New Hampshire inshore trawl survey (est. 2000), a ventless trap survey (est. 2006), a lobster settlement survey (est. 1989), and a larval survey (est. 2018)(Fig. 1A) [40]. Collectively, these surveys cover most of the lobster life cycle, from reproduction to the adult phase (Fig. 1A) and additional funding is being invested in studying the larval stages of lobster as well [40].

While these surveys likely make lobster one of the most extensively monitored wild-capture fisheries in the world, they provide relatively limited information about the condition of the fishing fleet. The socioeconomic condition of the lobster fleet may be detectable in changes of how harvesters prepare to fish (e.g. how many trap tags they buy), go fishing (e.g. how many fishing trips they take), and earn when they sell their catch (Fig. 1B). Similarly, a harvester's socioeconomic condition may influence how they participate in their community, provide for their family, or achieve personal well-being (Fig. 1B). Importantly, these dynamics can be positively and negatively influenced by broad-scale changes and shocks, such as geopolitical conflict, market disruptions, and changing coastal community demographics [16,17]. The COVID-19 pandemic – which disrupted all segments of the seafood economy – offers a recent example of the disconnect between the health of fish stocks and the performance of fisheries [23,26], but it was not a unique occurrence. In fact, the last few major disturbances in the lobster fishery have been triggered by sudden changes in supply chains and markets, rather than a decline in lobster abundance [30,36]. Acknowledging that the wellbeing of those who participate in the fishery are not always coupled with the status of the lobster resource, there have been recent calls for independent socioeconomic indicators that can complement existing biological indicators [4].

1.3. Developing sentinel indicators to support timely decision-making

Acknowledging that monitoring the lobster biomass alone is not enough to adequately prepare for future socioeconomic and environmental changes in the lobster fishery, the focus of this research was on developing a parsimonious suite of socioeconomic indicators that the lobster industry, coastal communities, and managers can use to monitor resilience of the fleet and detect early signs of vulnerability. Socioeconomic indicators are "quantitative measures of social conditions designed to guide choices at several levels of decision making" [3]. Unlike discrete variables such as fish size, volume of catch, or number of participants in a fishery, some variables, like resilience, cannot be measured directly. These variables, called latent constructs, require the identification of indicators that represent the underlying phenomena of interest [10]. Indicators for fisheries have been developed in a range of places and at different scale, but do not exist in the lobster fishery in Maine [14,13,18,19,20,31]. Although indicators cannot replace the richness or depth of information from traditional ethnographic methods, one important advantage is that they provide quantitative data about the social and economic conditions that can be more readily integrated into existing decision-making processes [20]. Developing socioeconomic indicators is particularly important given the rapid socioeconomic and environmental changes that are occurring in many fisheries, and therefore this research also has the potential to be a model for other places and in other fisheries. In this paper, we describe the context within which our research occurred and the participatory, mixed-methods approach we used to develop our initial set of socioeconomic indicators for the lobster fishery. We also discuss our results, limitations, and next steps. Results presented in this paper are meant to be viewed as the initial outputs for what we envision has the potential to be a long-term socioeconomic monitoring effort.

2. Methods

A modified version of the methodology described by Jacob et al. [19] was used to identify, develop, and test socioeconomic indicators of resilience in this study. We describe our approach as "modified" because we centered our approach around collaboration with the lobster industry (including those engaged in supporting the sector such as seafood buyers and local government officials), thereby making our approach more participatory than the original method (see Section 2.2 below). Our approach also sought to focus on integrating near real-time data streams (i.e., those which are generated on short time intervals (i.e., daily, weekly, or monthly). Here, we begin by describing the study system, our approach to collaboration, and our methods in more detail.

2.1. Study system

Maine is the northeastern most state in the United States and has a long and rocky coastline that spans eight coastal counties, stretching from the Piscataqua River in the southwest to Passamaquoddy Bay on the US-Canadian border (Fig. 2). With 37 % of the state's 1.4 million people based in the two most southwestern coastal counties (York and Cumberland), Maine's coastline becomes progressively more rural from the southwest to the northeast of the state (Table 1; [39]). This gradient is also associated with observable declines in median income, education level, and health care coverage (Table 1). In contrast, 47 % of the ex-vessel value of the lobster fishery in 2022 was reported in the easternmost region of the state (Washington and Hancock counties), while just 17 % is attributed to the southernmost area (Cumberland and York counties)[1]. The differences in rurality, demographics, and fisheries-dependence mean that there are socioeconomically distinct subregions in coastal Maine. These regions are locally referred to as "Southern," "Midcoast," and "Eastern" (or "Downeast") Maine. Off the coast, the state lobster fishery in Maine occurs across seven lobster management zones (A-G) that are co-managed by Maine DMR and zone-specific councils that are made up of local harvesters (Fig. 2). The seven zones span from Zone A in the far east, bordering Canada, to Zone G on the southern edge of the state, bordering New Hampshire (Fig. 2).

2.2. Partnership and collaboration

The initial idea for this research was proposed by the Maine Lobstermen's Association, which is the largest fishing association in the region, and was supported by a letter that was signed by 70 fishermen from Maine. Members of our core research team included staff from Maine DMR, the Maine Center for Coastal Fisheries, and the University of Maine. To increase awareness about the research and encourage collaboration and feedback on the project from the lobster industry and other interested parties, we also adopted the practice of hosting "open" monthly meetings over the first two years of the project in which we shared updates about the research and invited input on our methods and preliminary results. These meetings also provided an opportunity to discuss synergistic projects and opened doors for new collaborations and data sharing. A total of 70 people participated in the eighteen open meetings that we hosted and helped to shape the design and implementation of the project.

2.3. Defining resilience

The first step in developing socioeconomic indicators for the lobster fishery was to define "resilience." Resilience can be broadly understood

Fig. 1. Conceptual diagram showcasing the (A) biological life cycle of the American lobster and (B) components of the socioeconomic condition of the American lobster fishery.

as "the ability of groups or communities to cope with external stresses and disturbances as a result of social, political and environmental change" ([2]:150). To create a context-specific and operationalizable definition, semi-structured interviews were conducted with members of the Maine lobster fishery and other knowledgeable industry professionals (n = 38) over a 5-month period between May and September 2021.[2] Interviews were primarily conducted in-person, though for logistical reasons we also relied on phone or online video conferencing in some instances. We intentionally recruited participants in the fishery with diverse experiences [7] and from across the state from the Maine-New Hampshire state-line to the US-Canadian border. Participants were asked a series of questions about their views on the status of the lobster fishery as well as probing questions about the factors that contribute to the resilience of the fishing fleet. Interviews included both Likert-scale and open-ended questions. The Likert-scale questions had a scale of 1–5, where a response of 1 indicated strong disagreement, 2 indicated disagreement, 3 indicated neutrality, 4 indicated agreement, and 5 indicated strong agreement. The Likert-scale questions were designed to evaluate respondents' views on specific factors that might impact resilience and/or vulnerability such as ex-vessel price, landings, property taxes, and physical health. These questions were informed by prior research related to fisheries indicators as well as our research team's existing knowledge of the lobster industry in Maine. A series of open-ended questions were also asked to allow for inductive discovery of socioeconomic factors that were not captured in the Likert-scale questions. Interviews ranged in length from 45 minutes to 2 hours. All interviews were recorded and anonymized IDs were assigned to each recording in order to preserve the confidentiality of interviewees.

2.4. Developing candidate indicators

Initial transcripts were produced from each interview recording using Otter AI software and then manually checked for accuracy. Responses to the Likert-scale questions were transposed into a spreadsheet and analyzed in R (Version 2023.09.1 +494). Open-ended responses were analyzed using the qualitative analysis software NVivo 12 [27] and a grounded theory approach was deployed to identify emergent factors influencing resilience that were not captured in the Likert-scale questions [15]. These factors were identified by the research team through an iterative categorizing exercise in which emergent topics that were related to similar topics were nested or consolidated. Using the combined results of the Likert-scale questions with the emergent factors from the qualitative analysis, we generated a list of "candidate" indicators that became the foundation of our definition of resilience in the Maine lobster fishery.

2.5. Identifying descriptive data

The next stage of the process was to identify quantitative indices for each of the variables associated with resilience identified in Step 2.3. Previous studies have used a variety of secondary data sources to measure latent constructs, but one acknowledged limitation is that macro-level socioeconomic data often has poor temporal resolution, which makes it difficult to use to detect early signs of change or sudden shifts. To address this problem, we wanted to focus on datasets that had high spatial and temporal resolution, hypothesizing that we might be able to do so because we were focusing on a single fishery (lobster) in a relatively constrained geographic area (Maine) and therefore we could utilize industry-specific datasets that are directly related to the latent construct of resilience. Datasets were identified based on input from participants in our open meetings as well as one-on-one meetings with relevant organizations and agencies throughout the first year of the research project. The raw data was manually checked for quality and systematically tidied for analysis. All code and data were archived in Github and the associated datasets that we generated are archived in the R package gomfish [9].

2.6. Defining beta indicators of resilience

Having identified quantitative indices, secondary data collected to describe each of the candidate indicators was summarized to the regional spatial scale, and the finest temporal scale possible across all the data sets. Principal axis factoring (PAF) was then conducted on the correlation matrix of the summarized data for each candidate indicator. Principal axis factoring is a type of exploratory factor analysis whose output, the factor score, represents the observed correlation between variables by a latent construct [28]. To determine which indices were to be used to describe each candidate indicators, we used indices that achieved a Kaiser-Meyer-Olkin measure of sampling adequacy above 0.500, a Bartlett's test of sphericity significance about 0.0, determinant of the correlation matrix above.0001, and total explained variance of at

[2] While our sample size represents a small proportion of fishery participants in Maine (n=~5600 in 2022), research on the minimum number of qualitative social science interviews required to garner a plurality of ideas within a group suggests that 12–60 interviews is sufficient [6,24].

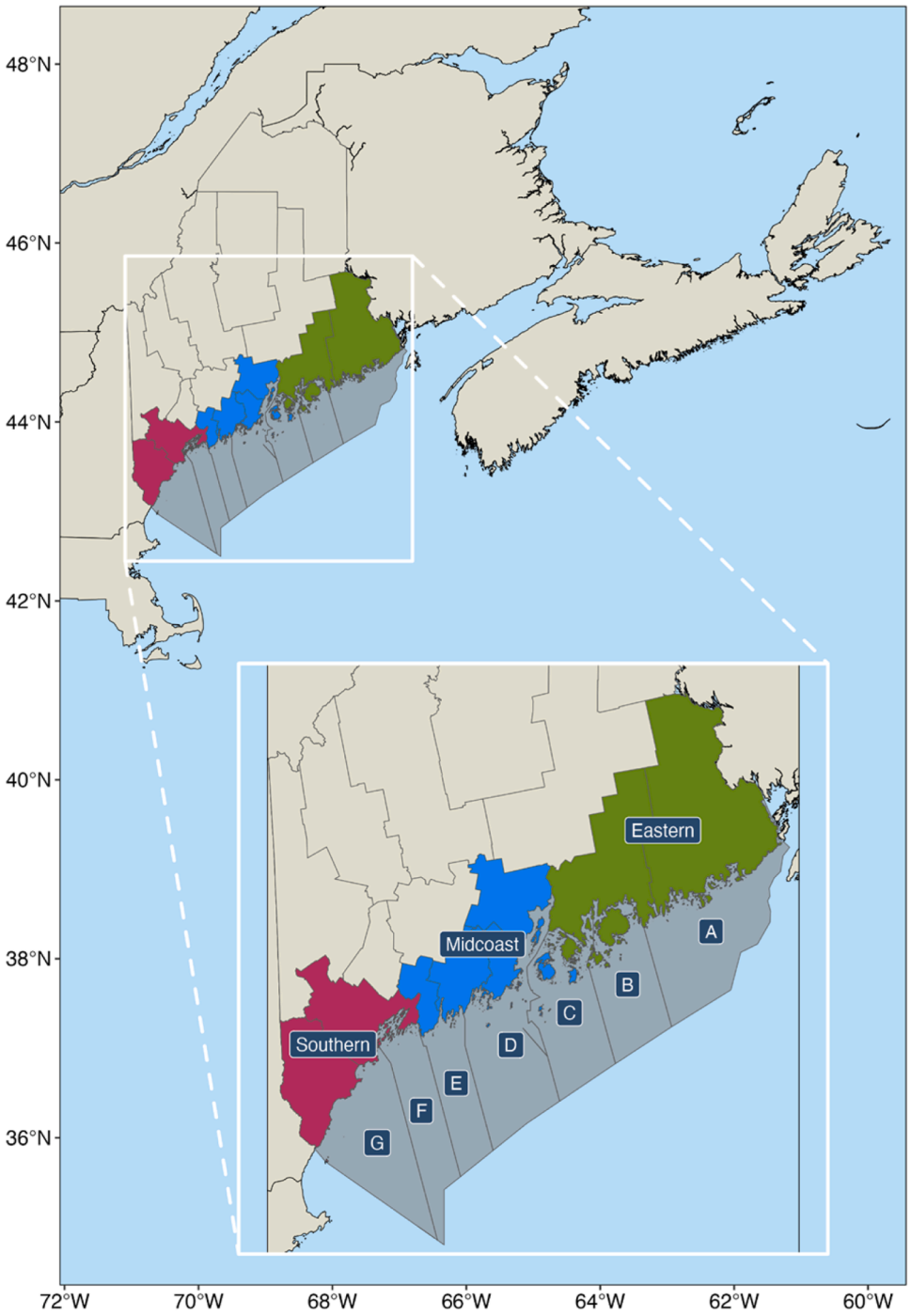


Fig. 2. Map of the northeastern United States and southeastern Canada, highlighting the coastal Maine study area, including coastal regions (Southern, Midcoast, and Eastern) and lobster management zones (G-A).

least 45 % (outlined by [14]).

3. Results

3.1. Importance of the Maine lobster fishery to coastal communities

We conducted 38 interviews with individuals across our study system, including 11 people in eastern Maine, 17 in midcoast Maine, and 10 in southern Maine. Respondents across all three regions considered the lobster fishery to be important to the social or cultural identity of the communities where they live (95 %), but the relative dependence that communities have on the health of the lobster fishery were reported differently, reflecting the regional differences discussed in Section 2.2. When asked if they agree that the overall status or wellbeing of their community is an indicator of how the fishery is doing, all respondents in eastern Maine responded in the affirmative (100 %), while far fewer agreed in midcoast (50 %) or southern (33 %) Maine. Similarly, when respondents were asked if most people in their community are connected to the lobster fishery, there was unanimous agreement in eastern Maine, while 75 % in midcoast Maine and 50 % in southern Maine agreed. Similarly, 90 % of respondents in eastern and midcoast Maine agreed with the statement that the lobster fishery is an important economic driver in their community, while 62 % of southern interviewees shared this perspective.

Table 1
Demographic and socioeconomic comparison of coastal counties in Maine.

State Subregion	Coastal County	Demographic Characteristics			Proportion of Population				Total 2022 Value (M)
		Population	Population Density (people/sq mile)	Median Income	Over 65	High School Graduates	Without Health Insurance	In Poverty	Commercial Lobster Fishery
Southern	York	216,732	218.7	$73,856	22.40 %	94.40 %	6.80 %	8.30 %	$18.21
	Cumberland	307,451	367.7	$80,679	20.60 %	95.70 %	5.80 %	7.70 %	$43.93
Midcoast	Sagadahoc	37,393	147.2	$73,343	24.70 %	94.10 %	6.60 %	8.70 %	$5.41
	Lincoln	36,215	79.4	$62,121	29.60 %	93.90 %	9.10 %	9.20 %	$24.50
	Knox	41,164	112.7	$63,399	28.20 %	93.60 %	8.40 %	10.50 %	$104.99
	Waldo	40,241	55.1	$59,880	25.20 %	93.10 %	8.70 %	13.10 %	$0.69
Eastern	Hancock	56,701	35.7	$60,354	27.00 %	95.20 %	9.00 %	11.00 %	$120.65
	Washington	31,437	12.3	$46,689	26.30 %	91.20 %	10.60 %	18.20 %	$53.36

3.2. Defining resilience in the Maine lobster fishery

Based on prior research related to socioeconomic indicators in fisheries as well as our team's expertise, we created a set of factors that we expected may impact resilience in Maine's lobster fishery. We used a Likert-scale (See Section 2.3.) to evaluate harvester's agreement that this set of factors does in fact impact resilience, and found that levels of agreement were variable across factors and between regions (Table 2). Qualitative textual analysis of responses to open-ended questions revealed additional factors impacting resilience. These outputs were then aggregated thematically by the research team with input from participants in the open meetings to produce a set of eight "candidate" indicators that became our working definition of resilience (i.e. the latent construct) (Table 3). These eight indicators describe different components of resilience in the fishery: business investments, coastal accessibility, community change, financial health, personal spending, physical and mental health, operational condition, and risk taking (Table 3).

Interestingly, all of the factors presented in Likert-scale questions corresponded to at least one of the emergent indicators, though none of them corresponded to either business investments or personal spending. This result highlights the importance of an interview tool that allows for both deductive and inductive discovery of factors impacting resilience because without the inclusion of open-ended questions, two important indicators may not have been revealed.

Table 3
List of candidate indicators, their definitions, and their data classification status.

Candidate Indicators	Definition	Data Classification
Coastal accessibility (CA)	Accessibility and affordability of coastal housing	Rich
Operational condition (OC)	Expenses and cost proxies of a lobstermen's business	Rich
Business investments (BI)	Expenditures on business-related items and services	Limited
Community composition (CC)	Demographic characteristics of coastal communities	Limited
Financial health (FH)	Overall financial portfolio of fishery participants	Limited
Risk taking (RT)	Physical risk of a lobstermen's fishing effort	Limited
Personal spending (PS)	Non business related expenditures	Poor
Physical & mental health (PMH)	The physical and mental health status of participants	Poor

3.3. Operationalizing candidate indicators of resilience

To operationalize the eight emergent indicators (Table 3), 66 datasets were sourced from 11 organizations that relate to the eight candidate indicators (Table 4). The process of accessing each dataset was variable, but often involved an initial meeting(s) with the organization that owned the dataset to explain the research project and our specific needs, followed by a data request, and follow-up exchanges about the data. Both the format and the quality of the data that were shared with

Table 2
Mean Likert scale responses, and their standard deviations (sd) across Maine ("Overall") and by region ("Southern", "Midcoast", "Eastern") related to a suite of factors impacting resilience in the American lobster fishery. Through qualitative analysis, each of these factors was assigned to a related emergent indicator (See Table 3 for definitions and abbreviations).

Factor Impacting Resilience	Overall		Southern		Midcoast		Eastern		Related Indicator(s)
	mean	sd	mean	sd	mean	sd	mean	sd	
Fishermen's mental health	4.2	0.9	4.4	1.1	4.1	1	4.2	0.7	PMH
Loan deferments	4.1	1	4.4	0.7	3.6	1.3	4.5	0.5	FH
Property values	3.9	1.3	4.8	0.5	3.8	1.5	3.2	1.1	CA
Total lobster landings	3.8	1.2	3.8	1.5	3.3	1.3	4.3	0.9	FH, OC, RT
Community demographics	3.7	1.4	4.2	1.4	3.8	1.3	3.1	1.4	CC
Ex-vessel price of lobster	3.6	1.5	3.5	1.6	3.1	1.6	4.1	1.2	OC
Number of student licenses	3.3	0.9	3	0.8	3.4	0.9	3	1.1	CC
Conversion rate of student licenses to commercial licenses	3.1	1	2.6	0.8	3.1	0.9	3.5	1.1	CC
Fishermen's need for mental or physical health care	2.9	1.1	3	1.2	2.2	0.9	3.7	0.7	PMH
Fishermen's substance use	2.8	1	3	1.1	2.5	1	3.3	1	PMH
Number of marine resource violations	2.8	1.2	2.7	1.4	2.3	1.1	3.6	0.9	OC, FH
Property taxes	2.7	1.5	1.9	1.4	2.7	1.6	3.1	1.2	CA
Price of bait	2.6	1.2	2.5	1.1	2.1	1.1	3.2	1.1	OC
Fishermen's physical health	2.5	1	2.6	1.3	2.3	1	2.7	0.9	PMH
Fishermen's pursuit of health care	2.5	1	2.4	0.8	2.2	0.9	3	1.3	PMH
Substance use in the community	2.5	1.2	1.9	1.5	2.3	1.1	3.1	1.1	PMH
Number of active lobster licenses	2.2	1.1	1.9	0.6	1.9	1.1	2.7	1.3	PMH, CC
Petty crime in the community	1.9	0.8	1.7	0.8	1.9	1	1.9	0.6	OC, FH

Table 4
All sources of secondary data, the specific variables collected from each source, and the candidate indicators that they contribute to. See Table 3 for abbreviations and definitions.

Data source	Data variable	Candidate Indicators							
		OC	CA	BI	CC	FH	RT	PS	PMH
Airbnb.com	New airbnbs		■						
	Total airbnbs		■						
ERA5	Risk index						■		
Greater Atlantic Regional Fisheries Office	Total boat registrations			■					
	New boat registrations			■					
	Proportion of new registrations			■					
Maine Bureau of Motor Vehicles	Total trailer plates			■					
	Total commercial truck registrations			■					
Maine Department of Inland Fisheries and Wildlife	Resident ATV registrations							■	
	Total ATV registrations							■	
	Proportion of resident ATV registrations							■	
	Total boat registrations			■					
	Resident snowmobile registrations							■	
	Total snowmobile registrations							■	
	Proportion of resident snowmobile registrations							■	
Maine Department of Marine Resources	Total trap tags sold			■					
	Total lobster licenses				■				■
	Individual daily landings	■				■	■		
	Total landings	■				■	■		
	Price per pound (adjusted to 2022 USD to account for inflation)	■				■	■		
	Total trips	■					■		■
	Vessel length						■		
	Harvester age						■		■
	Total harvester logbook licenses								
	Total harvester logbook trips								

(*continued on next page*)

Table 4 (*continued*)

	Crew aboard								
	Total gear fished								
	Individual daily gear								
	Total catch								
	Individual daily catch								
	Total gear fished								
Maine Housing Authority	Affordability index								
	Median income								
	Median home price								
	Total households								
	Number of affordable homes sold								
	Income:price ratio								
Maine Marine Patrol	Lobster resource violations								
	Total resource violations								
	Proportion lobster violations								
Maine Real Estate Transfer Tax Documents	Total home buyers from Maine								
	Total home buyers 'from away'								
	Total real estate transfers								
	Proportion of home buyers 'from away'								
Realtor.com	Median listing price								
	Days on market								
	Median listing price per square foot								
	Average listing price								
	Total listing count								
US Coast Guard	Total marine casualties								

our research team were highly variable. In several instances, data were provided as PDFs and disaggregated by year and coastal town. Data were formatted and checked for quality in R (Version 2023.09.1 +494). Non-confidential data associated with each variable is publicly available as part of the gomfish R package [9](Table 4).

The availability and quality of the data associated with each candidate indicator was highly variable and was the primary determinant of how indicators were able to be operationalized. We categorized each of the candidate indicators as either data-rich, data-limited, or data-poor based on the availability and characteristics of the data and the outcome of the PAF analysis described in the methods (Table 3). Data-rich indicators have a suite of data sets that represent the indicator and pass the criteria tests required to conduct PAF. Data-limited indicators are represented by several variable data sets but they do not pass required analytical criteria tests. Finally, data-poor indicators are those described by a low number of variable data sets that are missing key components of the indicator as a whole. Within our candidate indicators, coastal accessibility and operational condition emerged as data-rich, business investments, community composition, financial health, and risk-taking fall into the data-limited category, while personal spending and physical and mental health are characterized as data-poor indicators.It is important to note that an indicator's data classification is not a measure of the indicator's importance or relevance to describing the resilience of the lobster fishery, but is simply a recognition of the current status of the availability and quality of historical variable data to describe them. Because each of the 8 indicators presented were developed using direct input from fishery participants, they should all be considered highly relevant components of resilience in the Maine lobster fishery and their continued development should remain a high research priority. The collection of additional data sets to describe data-limited and data-poor indicators can lead to their promotion to data-rich status and the ability to fully operationalize them, and presents an opportunity for future research.

3.4. Declining coastal accessibility

The coastal accessibility indicator is a measure of housing accessibility and affordability in coastal regions of Maine. This indicator provides an annual, regional factor score to assess the degree to which coastal accessibility has changed annually since 2016 (the earliest year that all variables were available). A total of 17 variables were fed into the PAF, and the following four passed criteria testing and explain 70 % of the variance in the latent construct of coastal accessibility: the average number of days a home is on the housing market (hereafter days on market); the Maine Housing Authority Housing Affordability Index (HAI); median income, and the total number of short-term rentals (Airbnbs). Since 2016, the coastal accessibility factor score has declined in all regions, with the strongest decrease occurring in southern Maine. This factor score is influenced by the trends of the individual variables analyzed in the PAF: the HAI and the days on the market decreased while median income and the total number of short-term rentals increased. During the same time period, the median number of days on market declined by over 30 days in all regions, with eastern Maine experiencing the largest decrease of 75.3 days. The HAI is the ratio of the median home price to the home price that would be affordable to the median income earner using less than or equal to 28 % of total income (Maine State Housing Authority n.d.). Values less than 1 are considered unaffordable. Fig. 3 A shows that affordability has declined in all regions since 2016, but only coastal regions exhibit an HAI less than 1 in 2021, meaning they are considered unaffordable to the median income earner. In addition, median income increased in all regions (Fig. 3B). Finally, short term rentals have increased in all regions since 2016, with a particularly pronounced increase in 2020, shown in Fig. 3B. Across all of Maine the total number of short term rentals has increased nearly 400 % from 1046 in 2016–5038 in 2021.

3.5. Operational condition in the lobster fishery

The operational condition indicator is an annual, regional measure of earning and cost proxies of a lobsterman's business. Of the seven variables analyzed with PAF, the following six variables passed criteria testing and explain 62 % of the variance: average price per pound (adjusted to 2022 USD to account for inflation), average individual daily lobster landings, average crew aboard, total gear fished, total fishing trips, and total landings. Over the 15 year time period (2008–2022) for which data is available, operational condition decreased in southern and midcoast Maine, and increased in eastern Maine. While southern Maine had the highest factor score in the first two years of the time series, operational condition has been highest in eastern Maine since then. The difference in the operational condition factor score between regions has varied widely over time, with a maximum difference of 3.96 in 2018 and a minimum difference of 0.21 in 2009 (Fig. 4A). The operational condition factor score is influenced by the trends in the individual variables analyzed using PAF. Mean price per pound has been consistent across regions, remaining between $4.44 and $6.54, with the exception of 2021 when it spiked to $8.39 (Fig. 4B). Total amount of gear fished and total trips, both of which represent fishing effort, were lowest in all regions in 2022. The number of crew aboard has increased slightly in eastern Maine, from 1.7 to 1.9, but has remained relatively stable in midcoast and southern Maine. Individual daily landings have increased in all regions since 2008, with values highest in the east and lowest in southern Maine, though the difference in individual daily landings between

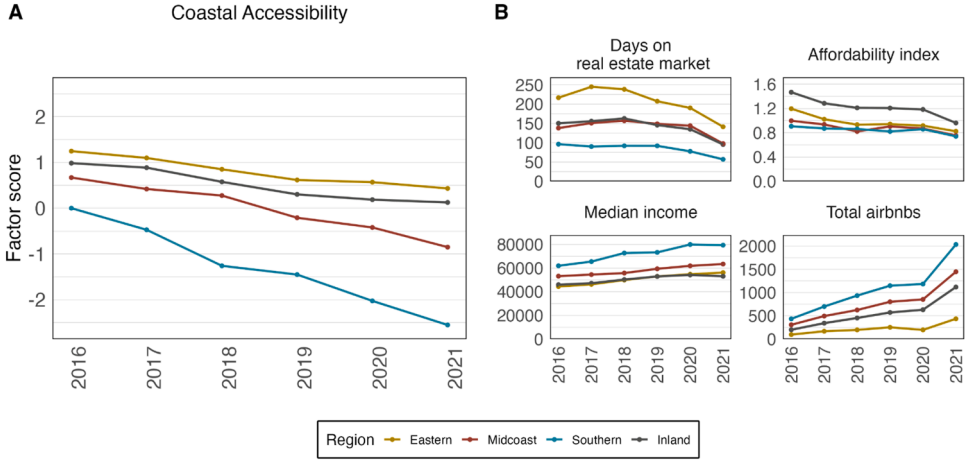


Fig. 3. (A) Factor score for the coastal accessibility indicator and (B) that data that underlies the principal axis factoring analysis.

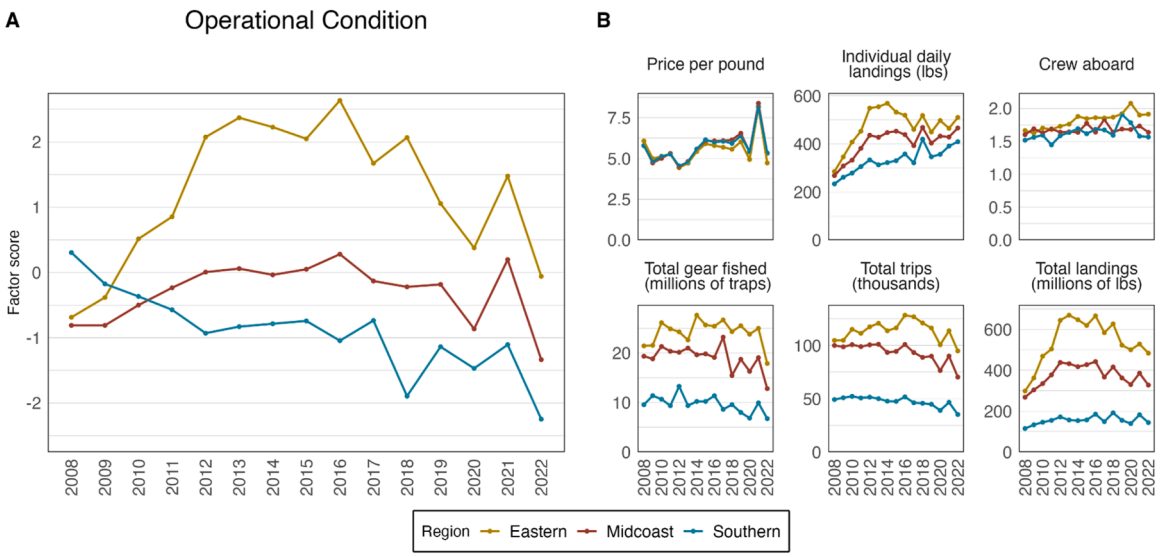


Fig. 4. (A) Factor score for the operational condition indicator and (B) that data that underlies the principal axis factoring analysis.

regions has varied over time.

3.6. Data gaps

An indicator's data richness is not a sign of its importance or relevance to the fishery, but simply a recognition of the current status of the availability and quality of historical variable data needed to adequately describe them. The data-limited indicators are business investments, community composition, financial health, and risk-taking, and while we collected several variable data sets to describe each of these indicators, those data sets did not pass the criteria tests required to perform PAF. The data-poor indicators, personal spending, and physical-, and mental-health, were categorized as data-poor due to the lack of availability of public, no-cost, variable data sets necessary to fully describe them. While we did collect data sets related to the data-poor indicators, they were not adequate for thoroughly representing constructs of socioeconomic condition of the lobster fishery.

It is important to note that all of the social indicators developed by this work were validated (Likert-scale questions) or identified (open-ended questions) through direct input from lobstermen and associated industry professionals. Therefore, they are key components of the socioeconomic condition of the Maine lobster fishery and their continued development should remain a high research priority. The promotion of data-limited and data-poor indicators to data-rich status will require the identification and collection of additional historical variable data sets that contribute to a fuller description of a given construct. The collection process should be designed to protect confidentiality of harvester's personal details and business practices and may benefit from collaboration with harvester-owned data repositories. There is an urgent need for increased data accessibility and transparency that would contribute to the promotion of all indicators to data-rich status, while maintaining harvester confidentiality.

4. Discussion

Responding to interest from the Maine lobster fishery in the face of ecological, economic, and social change, we developed a suite of social indicators of resilience that provides a foundation upon which to further develop and sustain a long-term socioeconomic monitoring program. In creating this suite of indicators, of which two are data-rich, four are data-limited, and two are data-poor, we validate a participatory, mixed methods approach to analyze non-traditional data sets in order to describe socioeconomic components of a marine fishery.

4.1. Regional differences

The lobster fishery is tightly linked to the social and cultural identity of communities across the coast of Maine (Table 2). However, the degree to which a community's wellbeing, connectedness, or economy is entwined with the lobster fishery varies by region. Overall, the lobster fishery's influence on these community characteristics follows a geographic gradient on the coast, with the influence being strongest in the east and decreasing as you move south. Interviewees in eastern Maine all agreed that their community's wellbeing and economy is impacted by how the lobster fishery is doing, and reported that most people in their communities are connected to the lobster fishery in some way. In contrast, only half of interviewees in midcoast Maine and just 33 % of interviewees in southern Maine agree that the lobster fishery drives their community's wellbeing. Importantly, the southern region in Maine has experienced the steepest decline in the factor scores for both the coastal accessibility and operational condition indicators (Fig. 3, Fig. 4). Taken together, these results indicate that the southern region is the least dependent on the lobster fishery for community wellbeing, and that the region has experienced substantial declines in two important components of fishery resilience. Investigating if and how declines in resilience indicators may influence or be influenced by different aspects of community dependence on the lobster fishery was outside the scope of this paper but is an important topic for future research.

Given the stark regional differences in the influence of the lobster fishery on coastal communities in Maine, it is important that socioeconomic indicators are spatially sensitive enough to detect regional change. Capturing how the individual components of a region's socioeconomic condition changes can allow fishermen and managers to advocate for spatially explicit support when necessary. This is particularly important in the context of applying socioeconomic indicators to new or existing policy frameworks because understanding the regionally specific impact of change can help managers to prescribe targeted response actions.

4.2. Interpretation of indicators

The data-rich coastal accessibility indicator shows a clear decline in the availability and affordability of housing across the state of Maine, with the south experiencing the fastest rate of change. This trend persists despite an increase in median income, suggesting that housing costs are rising disproportionately to income. This observation is supported by the increased number of short-term rentals in coastal Maine, which have

been found to drive up housing and rental costs [5].

The decline in coastal housing accessibility can directly affect lobster fishery participants in several ways. Firstly, lobstermen may live further from the coast where they work due to rising housing costs. Living further from the waterfront where they work presents a financial burden due to increased fuel expenses and also reduces the time lobstermen are able to spend working on the water, both of which have the potential to negatively impact a lobstermen's catch and earnings [11]. In addition, living further from the coast limits harvester's ability to monitor their assets on the water (e.g. boats, piers, etc.) that are vulnerable to storm damage. Seasonal support staff who participate in the lobster fishery can also be affected by declining coastal accessibility. These workers are likely to seek housing in the long-term rental market, the availability and affordability of which is diminished by the increasing number of short-term rentals [5]. Without access to affordable housing, seasonal workers may not be able to participate in the lobster fishery. Several interviewees expressed that it has been difficult to find and retain seasonal help, at least in part due to high housing costs, and the lack of help can diminish a lobstermen's earning potential.

The observed decline in coastal accessibility can also indirectly contribute to other challenges for lobstermen and coastal communities. For instance, short-term rentals have been shown to foster a higher demand for tourism, and in some communities, more tourism can lead to a shift from a natural resource economy to a tourism economy [38,41]. This shift can threaten the working waterfront if shoreside services and infrastructure are reduced or eliminated in favor of tourism-centered development. Fishermen in Maine specifically consider the rise in tourists and new residents from out-of-state as a potential driver of reduced access to the waterfront access points and infrastructure they need to operate [11,21,29]. Without convenient working waterfront access, fishermen may have to travel further to store their gear, reach their boat, or access their fishing grounds, all of which can lead to further increased financial burden as well as the opportunity cost of lost time [29]. Overall, the impacts of coastal accessibility directly influence fishery participant's access to housing but may also indirectly cause important challenges related to tourism, working waterfront access, and fishermen's earning potential.

Over the study period, the data-rich operational condition indicator has increased in eastern Maine and decreased in midcoast and southern Maine. While southern Maine had the highest factor score for operational condition in 2008, by 2011 it declined below the other two regions and consistently had the lowest relative operational condition. The variability between regions has ranged from 0.635 in 2009–3.96 in 2018. Two of the data sets underlying the operational condition indicator (individual daily landings and average price per pound) directly measure earnings, and the regional consistency in average price per pound suggests that individual daily landings is a stronger driver of regional differences in the indicator. In contrast, average crew aboard and total gear fished are indirectly connected to operational condition because while hiring more crew and fishing more gear can increase a lobstermen's daily operating cost, the increased fishing capacity has the potential to increase earnings. Therefore, when the conditions of the fishery are such that lobstermen are experiencing low earnings, they may increase their crew and gear in order to increase their earnings, and on the other hand, when earnings are generally high, employing more crew and fishing more gear may be more affordable and allow lobstermen to maximize their earnings.

4.3. Integration of multiple socioeconomic indicators

Each of the eight social indicators developed through the research described in this paper describes a specific facet of the socioeconomic condition of Maine's lobster fishery. Individually, they can help fishermen, managers, scientists, and other practitioners quantify relative, spatially-explicit trends in important socioeconomic sectors. Examined synergistically, the indicators offer a more holistic understanding of the overall socioeconomic condition of the Maine lobster fishery. This is a particularly important approach in the face of increasing perturbations and permanent regulatory change.

4.4. Policy and management implications

The development of socioeconomic indicators is an important first step to meaningfully integrate socioeconomic impacts of fisheries into formal stock assessments and fisheries management plans (FMPs). Long-term monitoring of socioeconomic indicators can establish a fishery's baseline socioeconomic condition and allow for the identification of improving or worsening conditions. As such, integrating socioeconomic indicators into stock assessments and FMPs is important because it can support management decisions to be responsive to changes in the socioeconomic condition of fishery participants. One pathway for integration is the creation of socioeconomic thresholds analogous to the existing biological thresholds that are the foundation of many stock assessments.

This would be particularly impactful in the Maine lobster fishery because the current biological threshold in the stock assessment would require a reduction of over 50 % in the lobster resource stock in order to trigger management action [4]. The stock assessment recognizes that well before this reduction is met, the economic conditions of the lobster industry may degrade. As a result, a "Fishery/Industry Target," calculated as the 25th percentile of lobster abundance during the high abundance regime, was added to the stock assessment in 2020. The purpose of the Fishery/Industry Target is to provide a way to detect changes in the economic conditions of the fishery, and create an avenue to initiate management actions to stabilize the fishery and prevent economic harm. However, given that the Maine lobster fishery is currently facing a host of interrelated challenges related to ecological, regulatory, and social changes, there is an urgent need to modify the Fishery/Industry Target so that it can be directly responsive to a wide range of socioeconomic changes in the fishery. This need offers a golden opportunity to integrate socioeconomic indicators directly into the FMP of one of the most valuable marine fisheries in the United States. For example, setting a socioeconomic threshold related to the operational condition factor score would allow for the timely detection of changes to a harvester's business. Then, exploring trends in the variables that underlie operational condition could lead to the identification of the driver (s) of change. With this information, managers would be empowered to target industry engagement that can reveal the root causes of change and develop appropriate supportive actions. By developing thresholds for change in socioeconomic indicators, problematic declines can be quickly detected, drivers of the decline identified, and sector specific actions that would support harvesters and coastal communities can be created.

Future research can further the inclusion of socioeconomic indicators into FMPs and stock assessments by addressing two key limitations. First, in data-rich fisheries such as the American lobster, the stock assessment is informed by decades of fisheries-dependent data and fisheries independent biological surveys. However, the temporal range of socioeconomic indicators is dependent on the longevity of available secondary data sources, which in many cases are not as comprehensive. This provides an opportunity for the development of methods to address the temporal mismatch between biological and socioeconomic data. Second, many secondary data sources that can support the development of data-rich socioeconomic indicators are not readily available and accessible. For some data (i.e. fuel costs), private paywalls limit accessibility while for others, a lack of established data sharing mechanisms by government agencies or private businesses inhibit researcher's ability to collect them. Continued efforts to create collaborative relationships between data holders and fisheries researchers will support the integration of socioeconomic indicators into the fisheries management process and ultimately benefit harvesters and coastal communities. The Maine lobster fishery is just one of many marine fisheries around the

world that are navigating a complex and evolving landscape of significant social, economic, regulatory, and environmental shifts. The increasing use of ecosystem-based fisheries management provides an opportunity to substantially improve how the socioeconomic conditions of fishermen, seafood workers, and coastal communities are considered by fisheries managers and policymakers.

CRediT authorship contribution statement

Joshua S. Stoll: Writing – original draft, Supervision, Project administration, Methodology, Funding acquisition. **Kathleen Reardon:** Writing – review & editing, Methodology. **Maggie O'Shea:** Writing – review & editing, Formal analysis. **Carla Guenther:** Writing – review & editing, Methodology. **Joelle Kilchenmann:** Writing – review & editing, Visualization, Formal analysis. **Theresa L.U. Burnham:** Writing – original draft, Visualization, Validation, Supervision, Methodology, Formal analysis, Data curation.

Declaration of Competing Interest

The authors declare that they have no conflict of interest associated with this research.

Acknowledgements

Funding for this project was provided by the Mitchell Center for Sustainability Solutions at the University of Maine. Additional funding support from the National Marine Fisheries Service (Project # NA22NMF4690289) and the National Science Foundation (Project # 2220564) made this research possible. The authors wish to thank the Maine lobstermen and industry professionals who contributed to this research as well as those individuals who participated in the open meetings we held to solicit feedback on this work while it was in progress. We would also like to recognize the Social Oceans Lab at the University of Maine, and especially Tracy MacKeracher, Melissa Rhodes-Reese, Margaret Campbell, and Hannah Jarvis for their helpful contributions.

Data Availability

Data will be made available on request.

References

[1] ACCSP (Atlantic Coastal Cooperative Statistics Program). (2022). Standard Atlantic Fisheries Information System (SAFIS). Available at https://www.accsp.org.
[2] W.N. Adger, T. Benjaminsen, K. Brown, H. Svarstad, Advancing a political ecology of global environmental discourses, Dev. Change 32 (2001) 681–715.
[3] F. Andrews, S. Withey, Social indicators of well-being, Plenum Press, Ann. Arbor. (1976).
[4] ASMFC (Atlantic States Marine Fisheries Commission). (2020). 2020 American Lobster Benchmark Stock Assessment and Peer Review Report. Atlantic States Marine Fisheries Commission, Washington, DC 548pp. https://www.asmfc.org/uploads/file/5fb2c4a82020AmLobsterBenchmarkStockAssmt_PeerReviewReport.pdf.
[5] K. Barron, E. Kung, D. Proserpio, The Effect of Home-Sharing on House Prices and Rents: Evidence from Airbnb, SSRN Electron. J. (2020), https://doi.org/10.2139/SSRN.3006832.
[6] W.B. Bekele, F.Y. Ago, Sample size for interview in qualitative research in social sciences: a guide to novice researchers, Res. Educ. Policy Manag. 4 (1) (2022) 42–50, https://doi.org/10.46303/repam.2022.3.
[7] H. Bernard, Social Research Methods: Qualitative and Quantitative Approaches, SAGE Publications, Inc, California, 2013.
[8] R. Boenish, Y. Chen, Spatiotemporal dynamics of effective fishing effort in the American lobster (Homarus americanus) fishery along the coast of Maine, USA, Fish. Res. 199 (2018) 231–241, https://doi.org/10.1016/j.fishres.2017.11.001.
[9] Burnham, T.L.U., Stoll, J.S., & Kilchenmann, J. (2023). gomfish: Gulf of Maine Fisheries and Socioeconomic Data. R package version 0.2.0, 2024. https://github.com/Social-Oceans-Lab/gomfish.
[10] D. Byrne, Complexity Theory and the Social Sciences: An introduction, Routledge, London, 1998.
[11] Carey, M. 2021. "The Critical Nature of Maine's Working Waterfronts and Access to the Shore." Island Institute. https://www.islandinstitute.org/wp-content/uploads/2021/11/WWFReport_web.pdf.
[12] J.T. Carloni, R. Wahle, P. Geoghegan, E. Bjorkstedt, Bridging the spawner-recruit disconnect: trends in American lobster recruitment linked to the pelagic food web, Bull. Mar. Sci. 94 (3) (2018) 719–735, https://doi.org/10.5343/bms.2017.1150.
[13] L.L. Colburn, M. Jepson, C. Weng, T. Seara, J. Weiss, J.A. Hare, Indicators of climate change and social vulnerability in fishing dependent communities along the Eastern and Gulf Coasts of the United States, Mar. Policy (2016) 1–11, https://doi.org/10.1016/j.marpol.2016.04.030.
[14] L.L. Colburn, M. Jepson, Social indicators of gentrification pressure in fishing communities: a context for social impact assessment, Coast. Manag. 40 (3) (2012) 289–300, https://doi.org/10.1080/08920753.2012.677635.
[15] J. Corbin, A. Strauss, Basics of qualitative research: Techniques and procedures for developing grounded theory, Sage, Los Angeles, CA, 2008.
[16] R.S. Cottrell, K.L. Nash, B.S. Halpern, T.A. Remenyi, S.P. Corney, A. Fleming, E. A. Fulton, S. Hornborg, A. Johne, R.A. Watson, J.L. Blanchard, Food production shocks across land and sea, Nat. Sustain. 2 (2019) 130–137, https://doi.org/10.1038/s41893-018-0210-1.
[17] J.A. Gephart, L. Deutsch, M.L. Pace, M. Troell, D.A. Seekell, Shocks to fish production: Identification, trends, and consequences, Glob. Environ. Change 42 (2016) 24–32, https://doi.org/10.1016/j.gloenvcha.2016.11.003.
[18] Himes-Cornell, A., & Kasperski, S. (2016). *Coastal Management Using Socioeconomic and Fisheries Involvement Indices to Understand Alaska Fishing Community Well-Being*. https://doi.org/10.1080/08920753.2016.1116671.
[19] S. Jacob, P. Weeks, B.G. Blount, M. Jepson, Exploring fishing dependence in gulf coast communities, Mar. Policy 34 (2010) 1307–1314, https://doi.org/10.1016/j.marpol.2010.06.003.
[20] S. Jacob, P. Weeks, B. Blount, M. Jepson, Development and evaluation of social indicators of vulnerability and resiliency for fishing communities in the Gulf of Mexico, Mar. Policy 37 (2013) 86–95, https://doi.org/10.1016/j.marpol.2012.04.014.
[21] T.R. Johnson, A.M. Henry, C. Thompson, Qualitative indicators of social resilience in small-scale fishing communities: an emphasis on perceptions and practice, Hum. Ecol. Rev. 20 (2014) 97–115.
[22] T.R. Johnson, M.D. Mazur, A mixed method approach to understanding the graying of Maine's lobster fleet, Bull. Mar. Sci. 94 (2018) 1185–1199, https://doi.org/10.5343/bms.2017.1108.
[23] C.J. Knight, T.L.U. Burnham, E.J. Mansfield, L.B. Crowder, F. Micheli, COVID-19 reveals vulnerability of small-scale fisheries to global market systems (Jun), Lancet Planet Health 4 (6) (2020) e219, https://doi.org/10.1016/S2542-5196(20)30128-5.
[24] E. Knott, A.H. Rao, K. Summers, C. Teeger, Interviews in the social sciences, Nat. Rev. 2 (2022) 73, https://doi.org/10.1038/s43586-022-00150-6.
[25] A. Le Bris, K.E. Mills, R.A. Whale, A.J. Pershing, Climate vulnerability and resilience in the most valuable North American fishery, Proc. Natl. Acad. Sci. 115 (8) (2018) 1831–1836, https://doi.org/10.1073/pnas.1711122115.
[26] D.C. Love, E.H. Allison, F. Asche, B. Belton, R.S. Cottrell, H.E. Froehlich, W. Zhang, Emerging COVID-19 impacts, responses, and lessons for building resilience in the seafood system, Glob. Food Secur. 28 (2021) 100494, https://doi.org/10.1016/j.gfs.2021.100494.
[27] Lumivero (2017) *NVivo* (Version 12) www.lumivero.com.
[28] O.A.,l Mabel, O.S. Olyemi, A comparison of principal component analysis, maximum likelihood and the principal axis in factor analysis, Am. J. Math. Stat. 10 (2) (2020) 44–54, https://doi.org/10.5923/j.ajms.20201002.03.
[29] Maltby, K.M., Kerin, S., & Mills, K.E. (2023). Barriers and enablers of climate adaptation in fisheries: Insights from Northeast US fishing communities. https://doi.org/10.1016/j.marpol.2022.105331.
[30] K.E. Mills, A.J. Pershing, C.J. Brown, Y. Chen, F.-S. Chiang, D.S. Holland, S. Lehuta, J.A. Nye, J.C. Sun, A.C. Thomas, R.A. Wahle, Fisheries Management in a Changing Climate: Lessons from the 2012 Ocean Heat Wave in the Northwest Atlantic, Source.: Oceanogr. 26 (2) (2013) 191–195, https://doi.org/10.2307/24862052.
[31] Nalini Morzaria-Luna, H., Turk-Boyer, P., & Moreno-Baez, M. (2014). Social indicators of vulnerability for fishing communities in the Northern Gulf of California, Mexico: Implications for climate change. https://doi.org/10.1016/j.marpol.2013.10.013.
[32] National Marine Fisheries Service, 2020. Fisheries of the United States 2018 2018. U.S. Department of Commerce, NOAA Current Fishery Statistics No. 2018.
[33] N.G. Oppenheim, R.A. Wahle, D.C. Brady, A.G. Goode, A.J. Pershing, The cresting wave: larval settlement and ocean temperatures predict change in the American lobster harvest, 84–10, Ecol. Appl. 29 (2019), https://doi.org/10.1002/eap.2006.
[34] J. Pearce, N. Balcom, The 1999 Long Island Sound Lobster Mortality Event: Findings of the Comprehensive Research Initiative, J. Shellfish Res. 24 (2005) 691–697.
[35] K.M. Reardon, C.J. Wilson, P.M. Gillevet, M. Sikaroodi, J.D. Shields, Increasing prevalence of epizootic shell disease in American lobster from the nearshore Gulf of Maine, Bull. Mar. Sci. 94 (2018) 903–921, https://doi.org/10.5343/bms.2017.1144.
[36] J.S. Stoll, B.I. Crona, M. Fabinyi, E.R. Farr, Seafood trade routes for lobster obscure teleconnected vulnerabilities, Front. Mar. Sci. 5 (2018) 587–588, https://doi.org/10.3389/fmars.2018.00239.
[37] K. Tanaka, J.-H. Chang, Y. Xue, Y. Chen, Mesoscale climatic impacts on the distribution of, Can. J. Fish. Aquat. Sci. 76 (2018) 608–625.
[38] C. Thompson, T. Johnson, S. Hanes, Vulnerability of fishing communities undergoing gentrification, J. Rural Stud. 45 (2016) 165–174, https://doi.org/10.1016/J.JRURSTUD.2016.03.008.

[39] UC Census Bureau (2020) State of Maine Decennial Census.
[40] J. Waller, J. Bartlett, E. Bates, H. Bray, M. Brown, M. Cieri, C. Clark, W. Devoe, B. Donahue, D. Frechette, H. Glon, M. Hunter, C. Huntsberger, K. Kanwit, S. Ledwin, B. Lewis, R. Peters, K. Reardon, R. Russell, C. Wilson, Reflecting on the recent history of coastal Maine fisheries and marine resource monitoring: the value of collaborative research, changing ecosystems, and thoughts on preparing for the future, ICES J. Mar. Sci. 80 (8) (2023) 2074–2086, https://doi.org/10.1093/icesjms/fsad134.
[41] C. Wang, Y. Xu, T. Zhang, Developing and validating a scale of tourism gentrification in rural areas, J. Hosp. Tour. Res. 46 (6) (2022) 1162–1186, https://doi.org/10.1177/10963480211014930/FORMAT/EPUB.