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Strategies to Promote Value and Resilience in the American Lobster (Homarus americanus) Industry

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STRATEGIES TO PROMOTE VALUE AND RESILIENCE IN THE AMERICAN LOBSTER (*HOMARUS AMERICANUS*) INDUSTRY

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An Abstract of the Thesis Presented
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The American lobster (*Homarus americanus*) fishery is the most valuable single-species fishery in the United States and Canada (DFO, 2021; NOAA Fisheries, n.d.). Coastal communities on both sides of the border rely on the American lobster supply chain, which economically links the two countries with one another and with other countries around the globe. Ongoing disruptions (or shocks) threaten the functionality of the supply chain, and increased globalization leads to greater exposure to shocks as they are transmitted between systems. One research study described in this thesis aims to add value to the industry via post-harvest treatment of lobsters and the other aims to provide a greater understanding of the resilience of the supply chain. Added value and an improved understanding of the supply chain system's resilience stand to help the industry better endure future disruptions.

Chapter 2 of this thesis addresses methods of adding value to post-harvest, soft shell lobsters. Harder (higher grade) lobsters can be shipped further and sold for a higher price. A few days of storage post-harvest can allow soft-shell lobsters to harden. I use feeding, temperature, and ion supplementation treatments to attempt to increase lobster weight and shell hardness over the course of 5-day trials. I also compare the industry's shell grading methods against durometer

measurements. I found that the treatments used in this study did not significantly affect weight or shell hardness. The cold, ion-supplemented treatment prevented weight loss over time when compared with other treatments, however, it was also associated with increased mortality during transportation trials. Diets supplemented with minerals (such as calcium and magnesium) is a promising treatment which merits further research. More durometer testing is recommended to further examine overlap between grades, as such overlap may indicate that the industry is facing financial loss due to subjective grading practices.

Chapter 3 of this thesis uses the COVID-19 pandemic as a case study to observe the resilience of the American lobster supply chain. I examine both the impacts of the pandemic on the supply chain as well as the responses of the industry. I use the food system resilience action cycle (Tendall et al., 2015) to frame this research and social media and formal interview datasets to understand how the sector adapted through the pandemic. This research elucidated the supply chain's current resilience and how it may be made more resilient to future disruptions. This project also exposed potential disconnects between segments of the supply chain through the examination of maladaptations (responses which decrease system resilience). Those responses most effective in carrying the industry through the pandemic were found to be the result of collaboration between stakeholders and sectors: local support for stakeholders and a reliance on business relationships strengthened the industry in the face of disruption.

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CHAPTER 1

INTRODUCTION

The American lobster (*Homarus americanus*) fishery is a culturally and economically significant industry for New England and the Canadian Atlantic provinces, accounting for approximately 1.1 billion USD in landed value in 2020 (DFO, 2021; NOAA Fisheries, n.d.). The industry links not only the U.S. and Canada in a tightly coupled economic system, but also connects these two countries with others around the globe. As coastal communities on both sides of the border are reliant on this fishery, it is critical to understand how it may be made more valuable and resilient.

The American lobster supply chain (LSC) has multiple segments which work in tandem to bring lobster from the seafloor to the end consumer. Members of these segments work in different silos which are highly interconnected but interact with the market differently. This separation can lead to tension when challenges arise. In this way, the supply chain does not always act as a unified system: short- and long-term disruptions have a multitude of impacts on each segment of the supply chain. The American lobster industry faces a multitude of ongoing challenges, the impacts of which vary spatially and temporally. These include challenges specific to the industry, such as "shrink" (lobster mortality within the supply chain), as well as global disruptions, such as the COVID-19 pandemic or the global financial crisis of 2008. The studies described in this thesis collectively aim to provide a greater understanding of these challenges and the resilience of the supply chain, as well as to evaluate proposed solutions for increased profitability.

Chapter 2 of this Dual Degree Masters thesis satisfies the requirements of the Marine Biology degree. It addresses the issue of increasing profitability by adding value to post-harvest, soft shell lobsters. Shrink spells loss for affected businesses as lobsters experience mortality while traveling through the supply chain. 2.1 million pounds of lobster were lost to shrink in 2021 (Leeman & Gutzler, 2022). Due to this and other issues, there is a demand for value to be added to live lobsters while they are in the supply chain. Live lobster dealers often hold recently caught lobsters in temporary storage for several days prior to shipping. If harvested in a soft-shell state, a few days of storage can allow the shell to harden. Lobsters with harder shells (higher shell grades) are more valuable because they can better survive shipping (Estrella, 2002; Factor, 1995; Pereira & Josupeit, 2017). The highest grade lobsters can be sold to satisfy the demand for live lobster in the overseas market, particularly in Asia. Asian countries, especially China, are key consumers of not only American lobster, but other lobster species from around the world as well (Hart, 2009; Pereira & Josupeit, 2017; Tannen, 2020).

Biological experiments described in Chapter 2 were conducted in collaboration with and were in part sponsored by Ready Seafood Company, a lobster dealer and processor in Portland, Maine. They assessed the effects of post-harvest feeding, temperature, and ion supplementation treatments on lobster weight gain, shell hardness, and survival. We critically evaluate the pros and cons of these methods to add value to live post-harvest lobsters. This work also examined the reliability of the industry's shell grading methods against more objective durometer measurements. In addition, this project adds to a growing body of knowledge regarding the impact of abiotic factors on lobster physiological processes – an important topic as climate change continues to affect the world's oceans.

Chapter 3 satisfies the requirements for the Marine Policy degree. This chapter contributes to the growing body of work on how seafood systems respond to disruptions. Increased globalization means greater connectivity, leading to greater exposure to shocks. This necessitates the consideration of the way in which shocks spread across international seafood systems. The underlying question of this work is, "how can resilience be built?" More specific questions which guide this research include the following: how has the industry responded to these disruptions? Which are short term responses, and which are long term adaptations which should be expected to continue into the future? One of the main objectives of this work is to identify the impacts of the COVID-19 pandemic on the LSC and to collect and assess responses of the industry. This study is one of the first to observe how the LSC has adapted to the pandemic as it has continued (instead of focusing only on the first several months of the shock). As this global disruption has impacted all stakeholders of the supply chain, it is a suitable case study for the ways in which shocks not only ripple across borders, but also across segments of the supply chain (Chenarides et al., 2021; Hobbs, 2020; D. C. Love et al., 2021).

This research used a multi-method approach to study how the American lobster supply chain system responded in the face of the COVID-19 pandemic disruption. First, stakeholders throughout the supply chain were informally interviewed with regards to their professional experiences during the disruption, with focus in particular on how they were impacted in the context of their involvement with the LSC and how they responded to the disruption. Second, social media analysis was undertaken to ascertain the capability of one social media site (Twitter) to accurately reflect these topics, namely by comparison to data which was provided by stakeholders in formal, IRB-approved interviews. The novel aspect of this work is its stepwise development through a deductive and inductive methodology: the coding method was shaped

both deductively by theory (the food system action cycle from Tendall et al. (2015)) and inductively through interviews. Using the food system resilience action cycle developed by Tendall et al. (2015) to frame this research, social media and formal interview datasets were used to understand how the sector adapted and learned from the early stages of the COVID-19 pandemic. This research elucidated the current resilience of the LSC and how it may be made more resilient to future disruptions. This project also allowed for the consideration of what changes might be made in the industry to allow the supply chain to run in a more unified manner by exposing potential disconnects between segments of the supply chain.

Through the biological experiments reported in Chapter 2, I found that the feeding, temperature, and ion supplementation treatments used in this study did not significantly affect weight or shell hardness over the course of 5-day treatments. The cold, ion supplemented treatment came the closest to succeeding in increasing the weight or shell hardness of experimental lobsters. However, this treatment was associated with higher mortality during simulated transport trials when compared with the industry standard treatment (cold, no ion supplementation during holding), suggesting that these treatments are not likely to be economically beneficial for the industry, at least under the conditions tested. In addition, more durometer testing (with different durometer types) should be used for lobster grades other than B to supplement the data found in this work. If overlap in durometer values is often found between lobsters graded at different levels, then the industry may be facing loss due to subjective grading practices: lobsters which could be considered a higher grade are possibly being labeled as a lower grade. Although it is unlikely that the industry would change grading practices, durometer use during staff training could ensure that all graders are using the same standard for each lobster grade and this information could be used to calibrate between grades.

Analysis of the social media and interview datasets in Chapter 3 was consistent with the template of the food system resilience action cycle posited by Tendall et al. (2015). New versions of the cycle derived from the social media and interview datasets were found to be similar to one another, showing that social media data can accurately portray industry responses to this type of disruption. However, maladaptations (responses which decrease system resilience) arose alongside adaptations (responses which increase resilience) during the disruption, and both should be taken into account in future use of this theoretical framework. Positive, adaptive responses deemed most important and enduring for getting the industry through the pandemic were borne out of collaboration between stakeholders and sectors: support for and amongst stakeholders at a local level, as well as a reliance on dependable business relationships bolstered the industry against the disruption. Some examples of maladaptations which arose during this disruption include unreported sales, a persistent culture of secrecy within the industry, and contentious responses which caused conflict. One conclusion from this analysis is that closer collaboration among sectors can prevent the erosive effects of maladaptive responses and promote the industry's resilience.

The lobster industry has faced a plethora of challenges in recent years and will continue to do so. Some concern interactions of the lobster with its environment pre- and post-harvest, and some involve social interactions among agents in the supply chain. Both have economic consequences. The research projects described in the following two chapters complement each other by examining both of these types of challenges. The aggregation of supply chain challenges can be problematic for the LSC. Continued research across all segments can add value to the industry and increase our understanding of its resilience, which may help it better withstand future disruptions.

CHAPTER 2

CAN POST-HARVEST ENVIRONMENTAL MANIPULATION ADD VALUE TO LIVE AMERICAN LOBSTERS?

2.1 Introduction

2.1.1. Context

The American lobster (*Homarus americanus*) fishery in the Northwest Atlantic is the most valuable single-species fishery in the United States and Canada (1.1 billion USD landed value in 2020) and is traded to 90 countries around the world (DFO, 2021; NOAA Fisheries, n.d.; Stoll et al., 2018). The lobster industries in the United States and Canada collaborate closely, and represent a tightly coupled economic system. As many coastal communities on both sides of the border are reliant on this fishery, it is critical to understand how increased efficiency in the use of this marine resource may lead to both greater profitability and sustainability. This is a critical part of establishing the concept of a "Blue Economy," which promotes a system balancing human needs with the conservation and sustainability of resource use (Smith-Godfrey, 2016).

This collaborative research project with Ready Seafood Co., of Portland, Maine, tests whether value can be added in the live-lobster trade by hardening lobster shells via either feeding or short-term water chemistry and temperature manipulation in post-harvest holding tanks. This would mean that industry members get more value out of each lobster caught. Multiple environmental factors influence the timing of the molt cycle, especially (but not exclusively) temperature as well as diet (Factor, 1995; Thakur et al., 2017; Tremblay & Eagles, 1998). Due to molting occurring in the spring, summer, and autumn months (leaving lobsters with softer

shells), this is the time when post-molt, lower grade lobsters (B-grade) can be harvested (Factor, 1995; Thakur et al., 2017). Pre-molt lobsters have harder shells (Comeau & Savoie, 2001; Gardner & Musgrove, 2006; Tamm & Cobb, 1978). There is a latitudinal difference in molting seasons determined by the onset of favorable temperatures. At warmer, lower latitudes, such as in the Long Island Sound (U.S.), molting occurs as early as late spring (Groner et al., 2018). At cooler, higher latitudes, such as in the southwestern Gulf of St. Lawrence, molting occurs later in the year – between the months of July and September (Comeau & Savoie, 2001; G. P. Ennis & Canada. Department of Fisheries and Oceans, 1981; Tremblay & Eagles, 1998).

Harvesters distribute their lobsters through the supply chain via dealers, cooperatives, and sometimes even directly to consumers (Billings, 2014). This study zeroes in on the period during which post-harvest lobsters are held alive in recirculating tanks at the dealer before being transported to the retailer or end-consumer. Live lobster dealers often hold recently caught lobsters in temporary storage for several days prior to shipping (T. Beard & McGregor, 1991; Boyd, 2009). If harvested in a soft-shell state, especially during the warm months, a few days of storage could allow the shell to harden, making the lobster more suitable for long distance shipping, and therefore more valuable. Lobsters with harder shells (higher shell grades) and can better survive shipping, lowering the chance of mortality in the supply chain (referred to by the industry as “shrink;” Factor, 1995). The highest grade lobsters are strong enough to survive shipping, and are sold to satisfy the demand for live lobster in the overseas market, particularly in Asia (Billings, 2014; Shaughnessy, 2018). Hard shelled lobsters are less sensitive to stressors in the supply chain (e.g. handling, low dissolved oxygen levels, and overcrowding) than are lobsters that have recently undergone molting due to associated physiological changes (Estrella, 2002; McLeese, 1956). Post-molt lobsters have lower levels of hemolymph proteins which are

necessary for oxygen transport as well as enduring environmental stressors and food unavailability (Bernardi et al., 2015; Oliver & MacDiarmid, 2001; Wang & Mcgaw, 2014). In addition, the soft shells of post-molt lobsters are more vulnerable to damage due to poor handling. As a result, soft shell lobsters may only be sold live locally, or otherwise sent to processors to be sold as lobster tails or meats to both domestic and international markets (Billings, 2014). Asian countries, and China in particular, are key consumers of not only American lobster, but other lobster species from around the world as well. High global demand for live lobster translates to a higher boat price for hard shelled lobster (Billings, 2014).

As lobsters grow, they molt, losing their hard exoskeleton, and grow a new larger one that will harden over several weeks (Comeau & Savoie, 2001; Waddy et al., 1995). The growing lobster is thus periodically vulnerable while in its soft-shell state. Research on the lobster molt cycle and shell hardening in particular has been a long-standing topic of interest for scientists (Bentov et al., 2016; Factor, 1995; Luquet, 2012). Because of its large size and availability, the American lobster has been a model species in the study of the crustacean molt cycle. This information is not just important from an economic standpoint (as lobster shell grade influences lobster value and shipping survivability), but is also vital to our understanding of the effects of rapidly changing conditions due to climate change on lobsters and other crustaceans.

My work complements related research at the University of Maine to monitor and mitigate stress points in the lobster supply chain from harvester to dealer, the aim being to develop a predictive model for mortality several days into the supply chain based on simple behavioral and physiological indicators (Gutzler, 2019; Leeman & Gutzler, 2022). Taken together, these studies have important implications for how lobsters can cope with altered

environmental conditions after they are removed from the wild and before reaching the end consumer.

2.1.2. Lobster shell hardening

Calcium is a critical element in crustacean biology. Lobsters are able to take up calcium and carbonate ions from seawater in order to synthesize calcium carbonate, which is particularly important for mineralization of the exoskeleton (Fig. 2.1) (Kunkel & Jercinovic, 2013; Madin, 2010; Wheatly et al., 2002). This mineral occurs in several forms, including crystalline calcite and amorphous calcium carbonate (ACC). While much calcium is lost during ecdysis, lobsters can store some internally as ACC in gastroliths and hemolymph until it is time to release it to the new exoskeleton in post-molt (Ahearn et al., 2004; Luquet & Marin, 2004; Middlemiss et al., 2016; Neira-Carrillo et al., 2017). Post-molt lobsters will also consume their recently shed exoskeleton given the opportunity, and seek out a more mineral-rich diet than hard-shelled lobsters so that they may replenish their calcium stores (G. Ennis, 1973; Gallagher et al., 1982; Herrick, 1911; Kunkel et al., 2018; Leavitt et al., 1979; Tlusty et al., 2007). Calcite is a component of the exocuticle, which serves as an environmental acid buffer, whereas ACC generally resides in the exo- and endocuticles and supports the exoskeleton structurally (Al-Sawalmih et al., 2008; Kunkel et al., 2012; Raabe et al., 2005). Carbonate apatite (a phosphate) also plays a role in the structural integrity of the cuticle, and is an important component of structural partitions or "trabeculae" in the exocuticle (Kunkel, 2013; Kunkel et al., 2012; Kunkel & Jercinovic, 2013). The carbonate apatite trabeculae form the innermost layer of the exocuticle, surrounded by a carbonate apatite lining, with calcite forming the epicuticle (Kunkel et al., 2012; P. Romano et al., 2007). The dissolution of calcite and other cuticle

compounds in the water forms a thin, protective, and alkaline layer around the outside of the shell (Fig. 2.1) (Castro et al., 2012; Kunkel & Jercinovic, 2013). This layer protects the lobster against bacterial diseases such as epizootic shell disease (ESD; associated with *Flavobacteriaceae* and strains of *Pseudoalteromonas gracilis*). ESD appears to enter through the pore canals of lobster and erode the carapace (Chistoserdov et al., 2005; Cobb & Castro, 2006). It first attacks the epicuticle and exocuticle, then the calcified endocuticle, leaving pillars of chitin while eating away the surrounding proteins and lipids (Meres et al., 2012; Smolowitz et al., 2005).

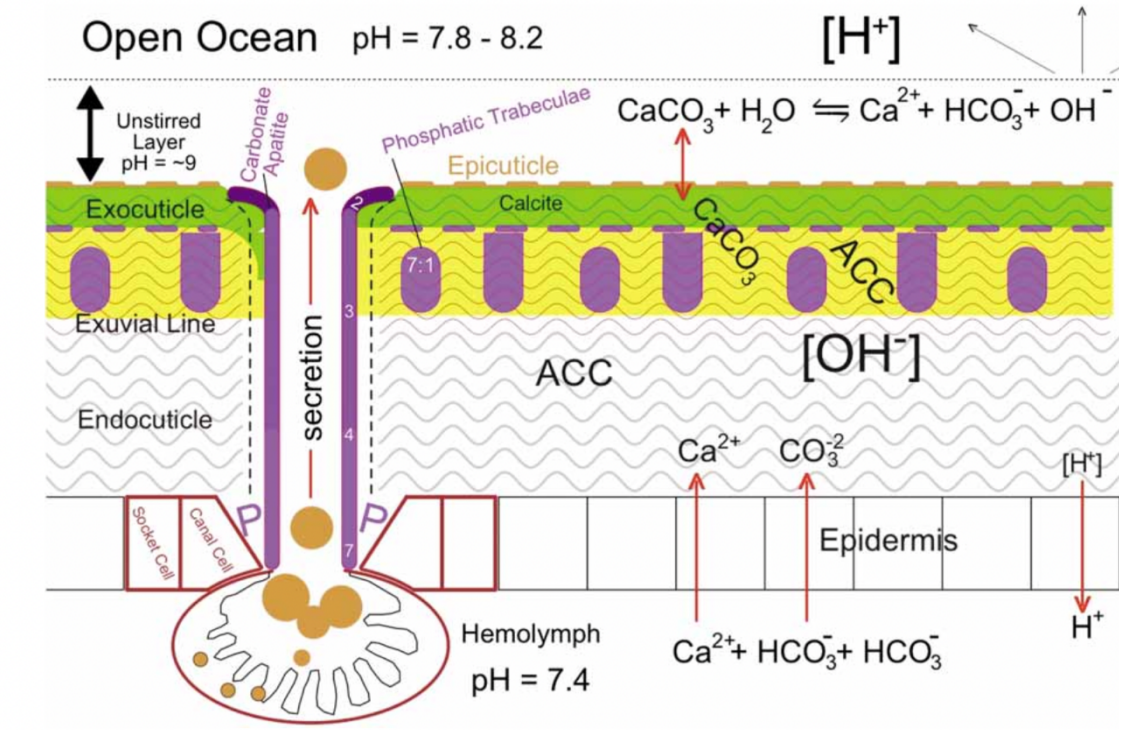

Figure 2.1. Cross-section of lobster carapace cuticle. This diagram includes information on calcium carbonate uptake and usage, which is integral for lobster shell hardening (from Kunkel & Jercinovic, 2013).

Shell hardening requires both sclerotization, which brings chitin into the linked protein structure of the exoskeleton, and calcification, which integrates the necessary calcium carbonate into the shell's makeup (Kunkel et al., 2012; Luquet, 2012). After a molt, the exoskeleton hardens via calcium carbonate uptake, which adds inorganic material to the organic α-chitin matrix of the shell (Boßelmann et al., 2007; Erko et al., 2013). Post-molt shell hardening also confers resistance to damage by predation, agonistic encounters with other lobsters, and handling during commercial harvesting and transport.

Calcium uptake can occur both from the diet through the digestive tract and from the surrounding water through the gills. Manipulating water chemistry and diet, therefore, can influence shell hardening via an influence on calcium concentration. Both forms of calcium uptake are an integral part of mineralization (Wheatly, 1999; Zanotto & Wheatly, 2002). Climate change affects a lobster's ability to form its shell: aragonite, a particularly soluble and crystalline form of calcium carbonate found in seawater, decreases in concentration with increased ocean acidification (OA) (Bragg, 1924; Yamamoto-Kawai et al., 2009). Crustaceans require an adequate aragonite concentration in sea water for their calcification processes. Aragonite saturation state (ΩAr) is a measure of relative aragonite concentration in water. When ΩAr is greater than 1.0, shells can be formed, but when the saturation levels dip below 1.0, calcium carbonate structures will start to dissolve (Fabry et al., 2008). Even ΩAr values below 3 can cause stress for some shell-dependent marine organisms (NOAA, n.d.). Therefore, as the ocean acidifies and ΩAr falls, it takes increasing metabolic work to build a shell.

Elevated partial pressure of CO_2, or pCO_2, affects calcification of crustacea (and can even cause exoskeleton dissolution in some species) (Ries et al., 2009; Whiteley, 2011). Reduced pH (due to an increase in carbon dioxide reacting with water) leads to lower concentrations of

carbonate ions available for shell formation (Doney et al., 2009; Feely et al., 2004). Lower pH was found to cause decreased structural integrity in both the carapace and claws of Tanner crabs (Dickinson et al., 2021). However, effects of reduced pH vary from species to species: in juvenile red king crabs (*Paralithodes camtschaticus*), reduced pH led to reduced microhardness but higher calcium content in the chelae, although the impact of these changes to chela function is unknown (Coffey et al., 2017). There was also an increase in calcium weight percent of the cuticle in low pH conditions in red rock shrimp (*Lysmata californica*) (Taylor et al., 2015). pCO_2 and the interaction of pCO_2 and temperature have also been observed affecting genes responsible for shell formation in American lobster (*Homarus americanus*) postlarvae (Niemisto et al., 2021). In some species of marine calcifiers, net calcification can actually increase under heightened pCO_2 levels (Ries et al., 2009). Effects of these changing environmental conditions affect marine species differently, on the basis of the diversity of their shell-hardening processes, including pH regulation, solubility of their exoskeleton, and ability to relocate carbonate ions or take up bicarbonate for conversion into carbonate (Cameron & Wood, 1985; McLean et al., 2018; Ries et al., 2009; Roer & Dillaman, 1984). In part due to the latter two factors, decapod crustaceans are thought to be resilient to elevated pCO_2 (McLean et al., 2018). Species more heavily calcified than crustaceans, such as corals and mollusks, have been found to be more negatively impacted by acidification (Kroeker et al., 2013). A number of other abiotic factors can also affect shell hardening of crustaceans. For example, lowered alkalinity can slow post-molt bicarbonate uptake and calcification in European lobster (*Homarus gammarus*) (Middlemiss et al., 2016). Salinity affects calcium levels in the hemolymph, and higher levels of salinity has been shown to lead to greater rates of molt success in whiteleg shrimp (*Litopenaeus Vannamei*)

and Margaret River marron (*Cherax tenuimanus*) (Li & Cheng, 2012; Rouse & Kartamulia, 1992).

In their natural environment, lobsters experience a pH of ~8.1 and are intolerant of salinities below 25 ppt (Dall, 1970; Keppel et al., 2012; Wahle et al., 2015). Temperatures can vary between 0-25°C (Qadri et al., 2007). In the facilities of some dealers, such as Ready Seafood, recirculating tank systems are used to hold water conditions steady. Tanks are kept at ~ 4°C, with salinity at 28-32 ppt, a pH of ~8, and goals of 100% oxygen saturation and ammonia levels of 0 (C. Brown, personal communication, August 10, 2022). If lobsters are to be shipped (especially as air freight internationally), holding them in cold and highly oxygenated water assists in their survival (T. W. Beard & McGregor, 1991; Estrella, 2002; Morris & Oliver, 1999; Pozhoth & Jeffs, 2022). At most co-ops and dealers' facilities, lobsters are held in flow-through, floating tanks off of docks, meaning that these lobsters experience ambient ocean surface conditions, although in many cases, aeration systems are installed to enhance oxygen concentration and flow (C. Brown, personal communication, August 10, 2022).

Over a sufficient course of time (~40 days) studies have shown that feeding treatments can increase lobster weight gain and shell hardness (Donahue et al., 1997; Donahue & Bayer, 1998). In the Donahue et al. 1997 study, lobsters were fed daily with cod fish racks, herring, or one of three pelleted diets with varying amounts of supplemental vitamin D (0 µg, 60µg, or 250 µg). In the Donahue and Bayer 1998 study, lobsters were fed ad libitum with fish racks (cod, salted grouper, or salmon) or a pelleted diet with either low or high fat content. However, preliminary unpublished research suggested that a feeding treatment over a shorter period of time (7 days) did not have a significant impact on shell grade – though this treatment also provided only one crushed mussel per six lobsters for each trial (Shaughnessy, 2018). Manipulation of not

only the type of food provided to lobsters, but also the amount fed and duration of the trials will lead to varying impacts on experimental lobsters. Manipulating the calcium content or other minerals of a fed diet could also lead to increased growth and shell hardness: Davis et al. found that dietary mineral content influenced the ash content of whiteleg shrimp carapaces (*Penaeus vannamei*) and that calcium metabolism was influenced by the uptake of other minerals (1992). Dietary and aqueous mineral supplementation were also found to be an effective means of enhancing growth performance in whiteleg shrimp in low salinity conditions (Veeranjaneyulu & Krishnaveni, 2018). The work described in this chapter will test whether feeding with a pelleted diet or water chemistry treatments can affect American lobsters over a brief window of time (5 days) under simulated industrial conditions, and will additionally take into account downstream effects of treatments in simulated transport trials.

Elevated temperature, reduced pH, and hypoxia associated with climate change will physiologically stress the American lobster. The geographic range of the American lobster in the coastal Northwest Atlantic is especially susceptible to the effects of climate change. The Gulf of Maine in particular has been warming more rapidly than 99% of the world's oceans (Pershing et al., 2015). Its average annual sea surface temperature has been increasing since the late 1800s, and since 1960, warming has occurred twice as quickly as earlier changes (Fernandez et al., 2020). This swiftly changing temperature has implications for the success of the American lobster in its natural habitat at all life stages, as well as its success as a product post-harvest. OA can adversely affect the exoskeleton of crustacean species. This has implications for a future with ongoing and intensifying climate change: not only are temperatures likely to continue to rise, but weather anomalies and increased fluctuations in temperature and other abiotic factors could spell

trouble for lobsters. This study therefore fulfills a need to increase the efficiency of the American lobster industry in order to derive the greatest value from its harvested, live product.

2.1.3. Objectives and hypotheses

The main question of this research project is whether lobster shell hardness can be increased through post-harvest feeding, temperature or ion supplementation treatments. I hypothesized that lobster body weight and shell hardness would increase faster with 5 days of feeding treatment, elevated temperature, and/or ion supplementation relative to untreated control lobsters. I also hypothesized that these treatments would not adversely affect lobster behavioral indicators or survival. In addition, this project sought to compare industry grading standards to durometer-measured shell hardness values.

2.1.4. Anticipated outcomes and implications

As in any business, the American lobster industry strives to find ways to make the most efficient use of the harvested resource to maximize value and profitability. Finding a way to increase shell grade of post-harvest live lobsters could enhance their value, and therefore industry profits (notwithstanding the added costs of holding lobster for extra time or the risk of mortality). Moreover, discrepancies between subjective grading by hand versus more accurate and precise measurements made with a durometer may also indicate a need to reassess industry grading procedures. Mis-grading lobsters could mean financial loss for the industry. In addition to these economic implications, this study contributes to the growing body of knowledge regarding the ways in which environmental parameters can affect lobster physiological processes – an important topic as climate change continues to challenge the fishery.

2.2 Methodology

2.2.1. Measuring shell hardness

When measuring shell hardness, professional lobster dealers use a qualitative and rather subjective method: holding the lobster in one hand they squeeze both the left and right sides of the carapace to feel its resistance and determine the animal's shell grade. Specific shell grading methods are kept proprietary by businesses in the lobster industry. Because of that, methods may differ slightly between dealers, however, grading practices must be similar enough to meet buyer expectations across the industry and across locations. Harvested lobsters are generally sold off the boat as new shell (soft) or old shell (hard) lobsters. Wholesalers then grade the lobsters, splitting the new shell category into B grade or A grade, resulting in three categories (listed here by increasing value): B grade, A grade, and old shell (C. Brown, personal communication, August 10, 2022). Project collaborator Ready Seafood was involved with the grading of experimental lobsters: lobsters were initially graded at Ready Seafood by their "grade team" to provide consistent grading throughout experiments. New graders are trained for 2 days by managers, and subsequently have their grading checked for accuracy by an experienced grader.

Shell hardness metrics are still being developed, and industry laboratories will often simplify, using available equipment. In all biological experiments of this study, I used a Shore A durometer to acquire a quantitative measure of shell hardness. Measurements were made at the "soft spot" used by industry professionals (both sides of the carapace where there is flexibility or "give") and a standardized site chosen based on carapace morphology (Fig. 2.4). The soft spot was the softest spot that could be found on the side of the lobster's carapace (and so wasn't necessarily in the same location from lobster to lobster). The general area in which the soft spot can be found is laterally between the cervical groove and the end of the carapace (Fig. 2.4). The

standardized site is located by following a straight line across the carapace from the lobster's cervical groove (Fig. 2.4). The statistical null hypothesis of no difference in shell hardness as measured by the Shore A durometer at the standardized site and the soft spot was tested with a Student's t-test.

The Shore A durometer (FstDgte, digital) was appropriate for this study of lobster exoskeleton hardness because it is not too sharp or forceful for B-grade lobster shells. A durometer designed for spiny lobster shells was found to be inappropriate for the American lobster as the shell would break. The Shore A durometer type was selected from several options: Shore 00 durometers are used for the softest materials, Shore A for medium hardness, and Shore D for the hardest materials. Some of the lobsters in past experimental trials were found to score at the high end of the Shore A's range, however, I could not upgrade to a Shore D durometer, as they are outfitted with a sharper indenter foot which can even pierce through the carapaces of old shell lobsters.

As part of this study I conducted an analysis both at the Ready Seafood facility in Portland, ME and at the Darling Marine Center in Walpole, ME to compare durometer measurements to shell grades assigned by industry professionals (n = 293 lobsters). Measurements of crustacean shells via durometer is an established method for obtaining objective shell hardness values: Comeau and Savoie (2001) utilized durometer readings to assess molt stages in American lobster as part of an effort to better understand molt frequency and growth of the species in the southwestern Gulf of St. Lawrence. In their efforts to determine the effectiveness of durometer usage for the rock lobster industry, Gardner and Musgrove tested various sites on lobsters for consistency and reliability of the durometer's measurements (Gardner & Musgrove, 2006). Despite a durometer's usefulness in testing shell grade, however,

dealers do not currently use them as it is faster to grade by hand (C. Brown, personal communication, October 17, 2022). In these experiments, durometer measurements provided some clarity regarding the subjectivity of the "squeeze method" used to assign shell grades. Across all experimental lobsters, the average weight was 541g and the size range was 82.55-99 mm (length of carapace). I measured lobsters across grades, including B-grade, A-grade, and old shell lobsters. However, the lobsters measured were mostly in the B-grade category, as B-grade lobsters were used for my feeding, temperature, and ion supplementation experiments.

2.2.2. Feeding trials

In the summer of 2019, I tested the hypothesis that a short-term feeding treatment would add weight and increase the shell hardness of treated lobsters. In each of six 5-day trials, I compared the change in weight and shell hardness of 12 fed and 12 unfed B-grade lobsters. Resulting replicates for this experiment was n=130 lobsters for weight change and n=54 lobsters for shell hardness measurements. Lobster grade was determined by professionals at Ready Seafood and B-grade lobsters were provided for each trial. These lobsters were held at a co-op or wharf before being driven to Ready Seafood, where they arrived ~12-24 hours post-harvest. Lobsters remained in tanks at the Ready Seafood facility for ~6-12 hours before I picked them up for the experiment. Lobsters were fed each day they were held, including the day on which they were transported from Ready Seafood. The daily food ration for each lobster in the fed treatment was ~4-5 g desiccated Zeigler shrimp broodstock pellets (3/32" (2.4mm) pellets, with 40% minimum crude protein, calcium and magnesium content included in 12% ash: https://www.zeiglerfeed.com/Literature/Shrimp%20Broodstock.pdf) and fed lobsters were given 3 hours to consume the food. This limited time frame was due to the dissolution of pellets if left

in water for too long. ~4-5 g were used as lobsters were found to eat slightly less than this amount each day. Pelleted diets have been utilized in both lobster pounding as well as other lobster feeding experiments (Donahue et al., 1997; Donahue & Bayer, 1998; Skonberg et al., 2001). The lobsters were fed once a day, usually beginning between 10 and 11 A.M. Pellets were desiccated before feeding and after collection to ascertain dry weight and observe how much of the food had been eaten. Lobsters were housed communally (6 lobsters per tank), separated by individualized plastic containers with holes allowing open exchange in a flow-through seawater system at the University of Maine's Darling Marine Center. Fine mesh covered the holes of each container, such that water could flow through but food loss was minimized. Because of the flow-through configuration, water temperature was not controlled artificially, and it climbed slightly over the course of the summer with an overall average temperature of ~17°C (see temperature charted in Figure 2.2).

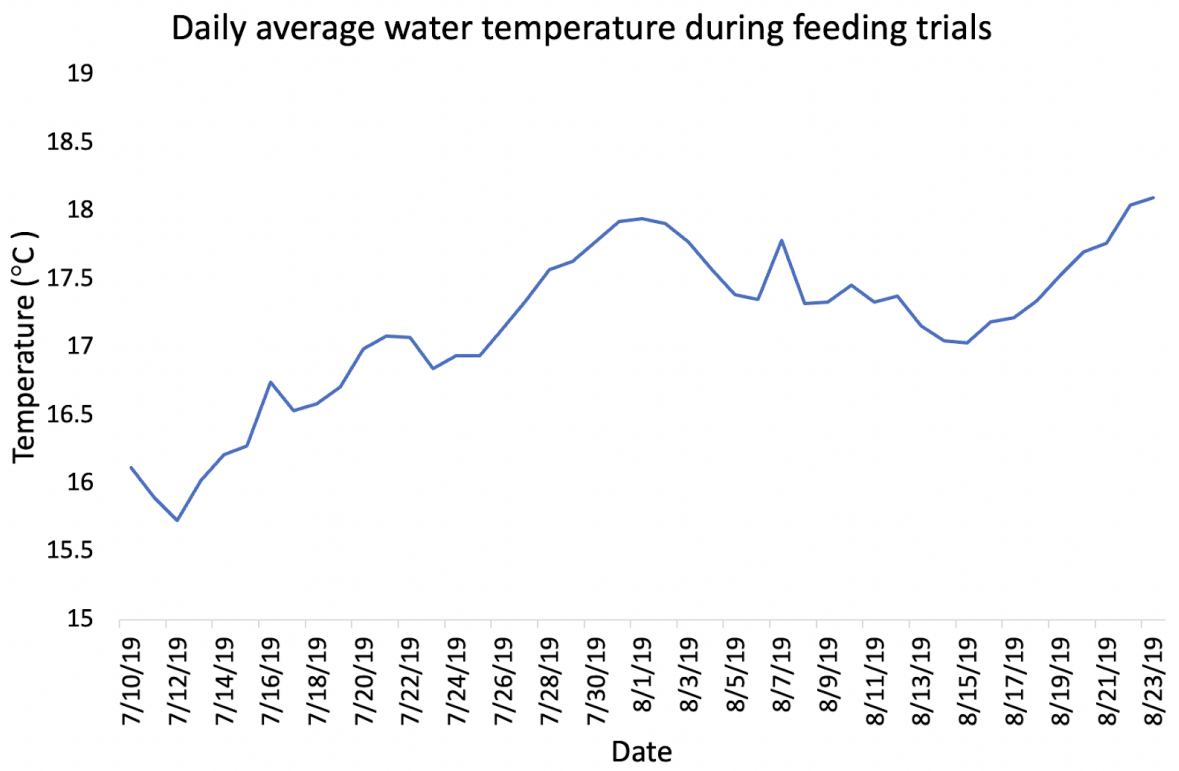

Figure 2.2. Daily average water temperature during feeding trials. Water temperature in flow-through tanks at the Darling Marine Center during feeding trials. A HOBOware logger took temperature data every hour (resulting in multiple data points over the course of each day). Temperature gradually increased over the course of the summer.

Wet weight was measured at the beginning and end of each trial. A scale was used to measure the wet weight of lobsters to 0.01 g. Lobsters were tipped and shaken gently to allow the runoff of excess water. Shell hardness was measured at the beginning and end of each trial during trials 4-6: this is because the lab did not have a durometer to utilize for shell hardness measurements at the beginning of the trials, and thereafter, a standardized measurement method had to be developed. For this reason, trials 1-3 have weight data, and trials 4-6 have both weight and shell hardness data. Thus, while 130 lobsters were utilized for analysis of weight change, only 54 were analyzed for change in shell hardness. Shell hardness was determined with a FstDgte digital Shore-A durometer.

The statistical null hypothesis of no treatment effect was tested with a Student's t-test for each dependent variable. It is important to note that while the communal housing of lobsters is realistic in the context of commercial live lobster facilities, it created a potential issue of non-independence or pseudo-replication of observations. To take this issue into account, data were analyzed both using individual lobsters (*i*) and tank averages (*t*) as replicates over the six trials.

2.2.3. Holding trials - temperature and ion supplementation treatments

This experiment sought to evaluate the joint and independent effects of seawater temperature and ion supplementation on shell hardening. In each of 11 trials, ~16 lobsters were divided equally among the four treatment combinations (prior to mortalities: total n=180 lobsters, n=44 tank averages). We chose not to include a feeding treatment in this experiment because of the risk of the presence of food altering water chemistry. In the summer of 2021, I manipulated temperature and ion concentration in a closed, recirculating tank system with 4 tanks. Each tank held ~56 L of water and was connected to a Polar Aurora Free Media 370GPH External Aquarium Filter. Both temperature and ion concentrations were manipulated in a 2x2 factorial experimental design. The tanks were held at consistent temperatures with Active Aqua ¼ HP chillers (model: AACH25HP): two tanks were held at ~5°C, and two at ~10°C. These low temperatures and the treatment duration were chosen to simulate industry holding conditions. Two of the tanks (one 5°C tank and one 10°C tank) were also supplemented with ions (calcium chloride and magnesium chloride). Water parameters over the course of the trials are given in Figs. 2.3.A-F. The compound added to the natural seawater was a combination of calcium and magnesium salts which supplemented ion concentrations in the treated tanks. The ion

supplement was formulated in Dr. Steve Jury's laboratory and was designed to target specific ion regulatory pathways to influence crustacean shell calcification (S. Jury, personal communication, 2021). The goal of ion supplementation was not to make the water hypersaline. Instant ocean was added when necessary to increase salinity to a normal range: lobsters typically live in salinities >25 ppt, but optimal salinity ranges from 29-35 ppt (Dall, 1970; Estrella, 2002). The compound added specific ions to the tanks: Ca, Mg, and bicarbonate, in order to influence concentration gradients and potentially enhance the uptake of these ions by the lobsters.

As in feeding trials, lobsters were weighed and tested for shell hardness with the durometer at the beginning and end of each 5-day trial. To assess how the temperature and ion supplementation treatments affected hemolymph protein levels, hemolymph samples were taken before and after each trial (n=207 lobsters). Hemolymph protein levels were tested by extracting ~1 mL of hemolymph from lobsters and measuring %Brix with a digital ATAGO pocket refractometer (PAL-1). Hemolymph samples were first taken from lobsters at Ready Seafood – these lobsters were from the same batch as experimental lobsters (came from the same source at the same time), but were not the exact ones which would undergo experimental treatment. This was to prevent additional stress on experimental lobsters prior to treatment. ~1 mL of hemolymph was also taken from experimental lobsters post-treatment for measurement of protein levels. Hemolymph protein was measured in this way from trials 2-11, with the exception of trial 9, as there were no syringes available at the time. In addition, behavioral indicators were used to assess lobster health (n=139 lobsters). Nine behavioral indicators were used to assess lobster health before and after each experimental trial, and the difference in behavioral indicators expressed before and after treatment was analyzed. These indicators included swimmeret movement, tail flipping, cheliped (movement/raising), eye retraction upon contact (at least one),

pereiopod reactivity (also known as dactyl pinch), third maxilliped (movement/held tight), mandible reactivity, antennae (movement/reactivity), and antennule (movement/reactivity). Each lobster was scored for these nine binary indicators. Although this experiment did not attempt to predict lobster mortality, Stoner's work on the reflex action mortality predictor (RAMP) approach served as a model for which behaviors to observe to test the treatments' effect on vigor and activity (see Stoner, 2012b). Observation of behavioral indicators has been used to assess sensory abilities as well as stress and vitality levels in a number of crustaceans, including lobsters, crabs, and prawns (Barrento et al., 2010; Bush et al., 1978; Stoner, 2012a; Vermeer, 1987; Walters et al., 2022).

I used a generalized linear model (GLM) analysis with least squares linear fitting to statistically evaluate the results of this experiment in separate tests on the dependent variables wet weight, shell hardness, hemolymph protein level, and behavioral indicators for trials 2-11. Trial 1 was excluded from this analysis because no calcium data were collected. Although the experiment was a 2x2 factorial design with two temperature categories (warm, cool) and two ion supplementation treatments (with, without), there was sufficient variability in the independent variables to treat them as continuous co-variates rather than categorical variables. This warranted the application of a GLM rather than a standard two-factor analysis of variance. As in the feeding trials, data were analyzed both using individual lobsters and tank averages as replicates.

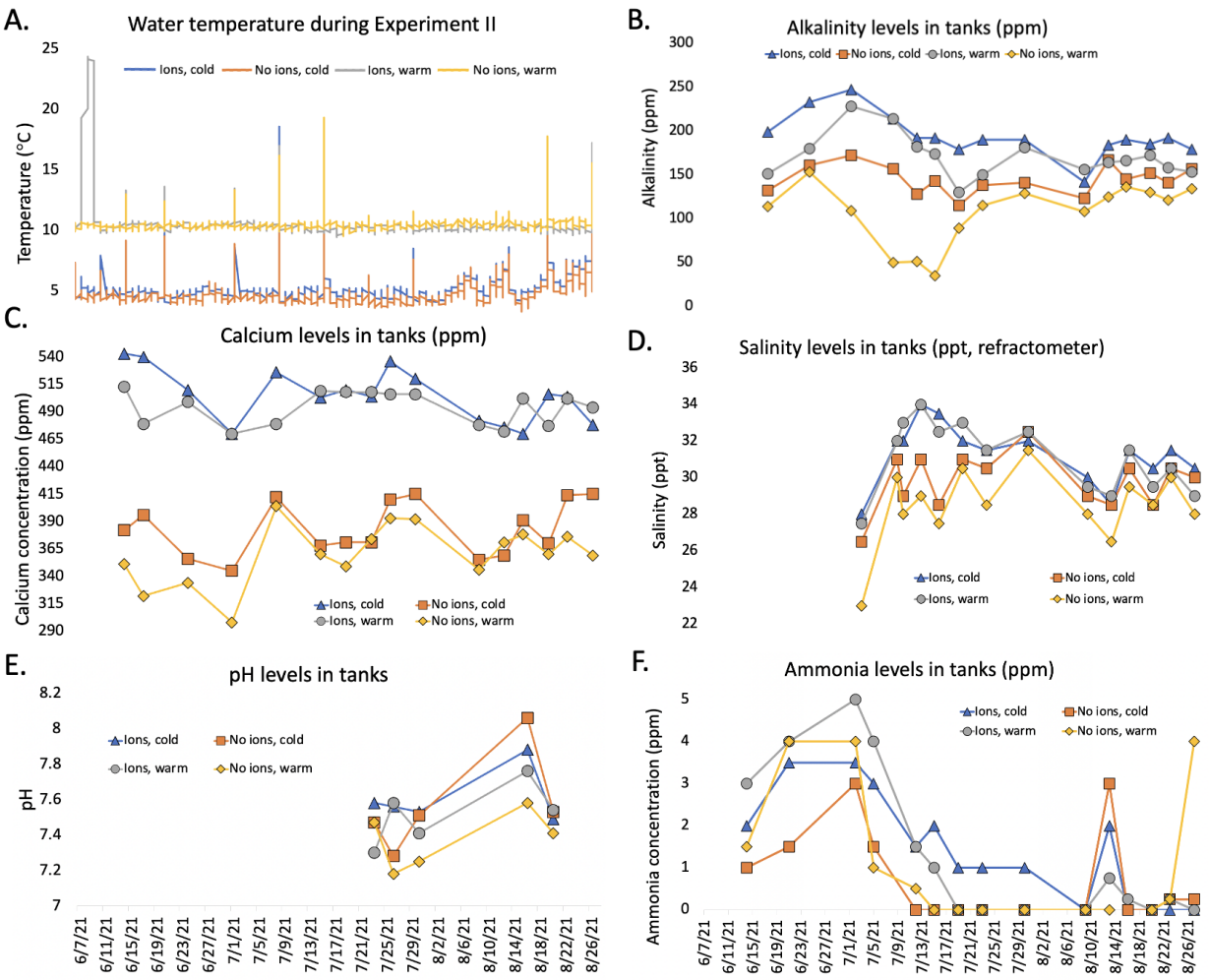

Figure 2.3. Water parameters during temperature and ion supplementation treatments.
A. Water temperature (°C) as measured in tanks over the course of all trials.
B. Alkalinity concentration (ppm) as measured in tanks over the course of trials 2-11.
C. Calcium concentration (ppm) as measured in tanks over the course of trials 2-11.
D. Salinity (ppt) as measured via refractometer over the course of trials 4-11.
E. pH as measured in tanks over the course of trials 7-10.
F. Ammonia concentration (ppm) as measured in tanks over the course of trials 2-11.

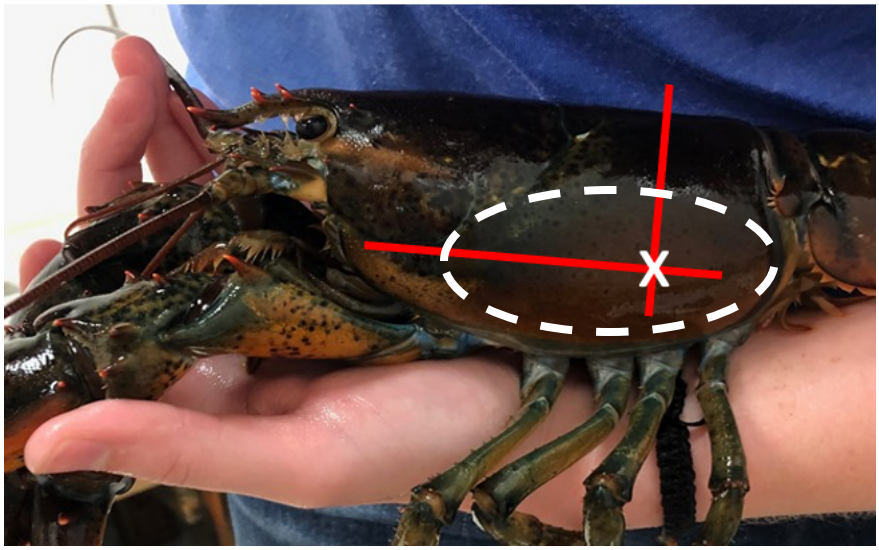

Figure 2.4. Location of standardized site and soft spot. A white X marks the location of the standardized site on a lobster's carapace. The dotted white oval shows the general area where the soft spot can be found on the carapace.

2.2.4. Simulated shipping trials

In total, 58 lobsters from the holding trials were tested in a simulated shipping trial. Hemolymph was extracted after both holding and transportation trials to allow for comparison of hemolymph protein and osmolarity before and after the shipping simulation. To test these metrics, an osmometer and protein light refractor were used. Lobsters experienced a ~2 hour drive from the Darling Marine Center to Saint Joseph's College (~108 km), where they were then housed in a refrigerated unit at 4.5-7.2°C. Every 24 hours, the lobsters were checked for behavioral indicators as well as survival. After 4 days, hemolymph was extracted from the lobsters to compare protein to results from day 1. Measurements of hemolymph protein and osmolarity were compared with paired t-tests.

2.3. Results

2.3.1. Measuring shell hardness - Comparison of industry standard to durometer measurements

The scatterplots in Figs. 2.5A and B indicate a wide range of shell hardness as measured by a Shore A durometer at the standardized site and soft spot of industry graded lobsters, especially for those assigned to B-grade. The shell hardness values at the standardized site for n=287 lobsters are shown in Figure A, and the shell hardness values at the soft spot for n=286 lobsters are shown in Figure B. The number of replicates differ due to breakage at the soft spot (rendering measurement via durometer impossible). Shell hardness of B-grade and A-grade lobsters is significantly different at both the soft spot and the standardized site (soft spot: t=1.97, df=278, p=1.22E-15; standardized site: t=1.97, df=281, p=0.000507). Shell hardness measurements from n=254 B-graded lobsters indicate that the standardized site is significantly harder than the soft spot (t= 1.96, df=503, p=1.91E-49).

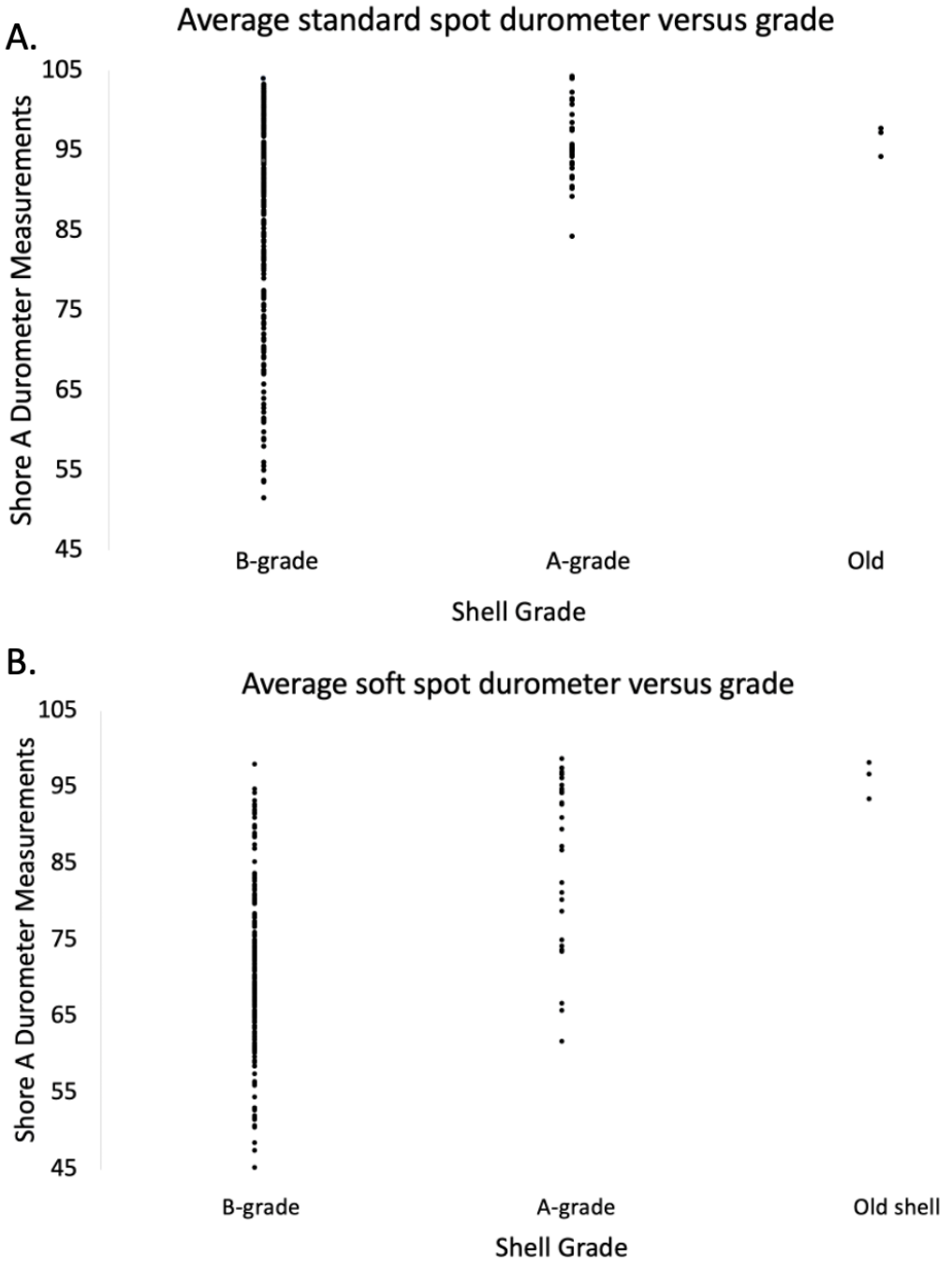

Figure 2.5. Comparisons of industry standard to durometer measurements. **A.** Comparison of average standardized site measured with a Shore A durometer and industry grade (n=287 lobsters). **B.** Comparison of average soft spot measured with a Shore A durometer and industry grade (n=286 lobsters).

2.3.2. Feeding trials

With n=130 lobsters, I observed feeding to have no significant influence on weight change as compared with unfed lobsters (t_i=0.226, df_i=128, p_i=0.821, Fig. 2.6; t_t=0.246, df_t=22, p_t=0.808). Fed (n=67) versus unfed (n=63) lobsters were compared in terms of percent weight difference. With regards to weight, statistical power was low: to resolve a 10% difference, power was 8.98%, and to resolve a 20% difference, the power was 21.45%.

With regard to shell hardness, feeding had a marginally significant impact at the soft spot (t_i=1.92, df_i=47, p_i=0.061; t_t=1.61, df_t=10, p_t=0.139), but not at the standardized site (t_i=0.943, df_i=52, p_i=0.350; t_t=0.748, df_t=10, p_t=0.472; Fig. 2.7). Positive effects of feeding were only observed at the soft spot (Fig. 2.7). Averages of the two sides of each lobster (standardized sites and soft spots) were used for these tests. Due to breakage at soft spots or standardized sites over the course of the trials, the total number of lobsters included in these statistical tests varied: n=54 for standardized site measurements, n=49 for soft spot measurements. As standardized sites and soft spots were often in close proximity to one another, a breakage in a lobster's shell likely meant that measurements could not be taken for either site. In addition, there were 6 lobster mortalities during trials 4-6, which were not measured for shell hardness.

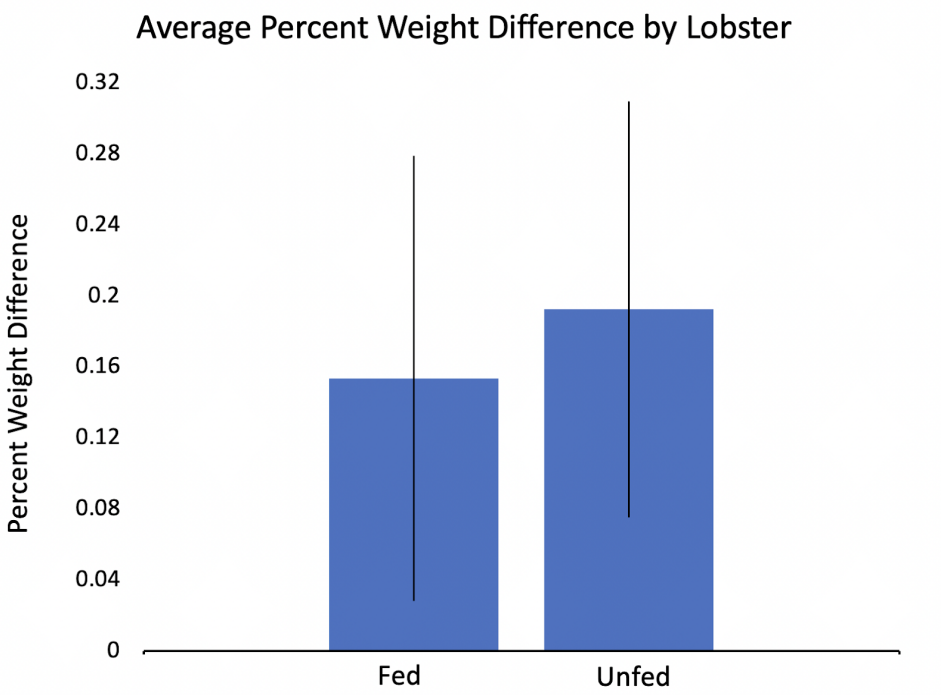

Figure 2.6. Weight change during feeding trials. Average ± 1SE percent weight change by lobster over 5 days in fed and unfed treatments during feeding trials (n=130 lobsters). See text for statistical analysis.

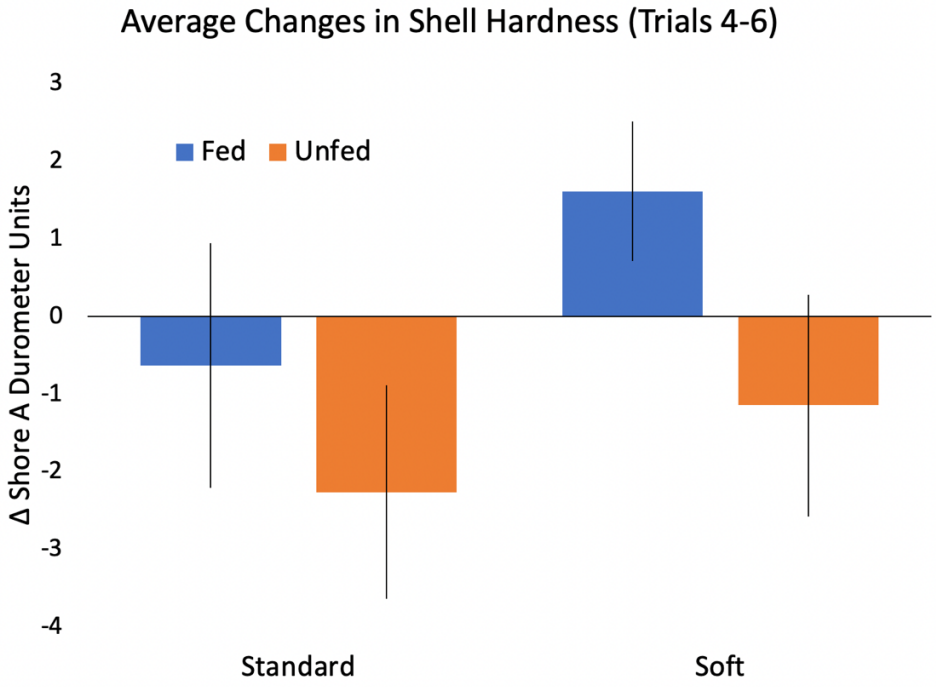

Figure 2.7. Change in shell hardness during feeding trials. Average change ± 1SE in shell hardness as measured with a Shore A durometer at the standardized site and soft spot of the lobster carapace during feeding trials 4-6 (n=54 lobsters). Shell hardness analysis was only conducted for trials 4-6; see text for statistical analysis.

2.3.3. Holding trials - temperature and ion supplementation treatments

While lobsters from all treatments tended to lose weight over the course of the trials, those exposed to the ion supplementation treatment lost significantly less weight than those in the control treatment regardless of temperature. Although lobsters in the cool treatment tended to lose less weight than those in the warm treatment, the temperature effect was not statistically significant. Consequently, there was no significant interaction between temperature and ion supplementation effects. The significance of this result was similar whether individual lobsters or tank averages were used as replicates in the statistical analysis (Fig. 2.8; Appendix Tables A.1.A and B). n=162 lobsters were measured to test the joint effects of temperature treatment and ion supplementation.

As for shell hardness, the cool temperature treatment had a marginally significant positive impact on soft spot hardness, however ion supplementation had no significant impact, nor was there a significant interaction (Fig. 2.9, Appendix Tables A.2.A and B). With respect to behavioral indicators, neither ion supplementation nor temperature had significant independent or interactive effects on vigor (Fig. 2.10; Appendix Tables A.3.A and B). No significant difference between treatments was found in terms of hemolymph levels as measured by the Brix index (Fig. 2.11; Appendix Tables A.4.A and B). The correlation coefficient between average hemolymph protein levels within each treatment and percent survival of lobsters in those treatments indicates a moderate positive, but insignificant, relationship between the two ($r=0.35$, $t=0.52$, $p=0.65$).

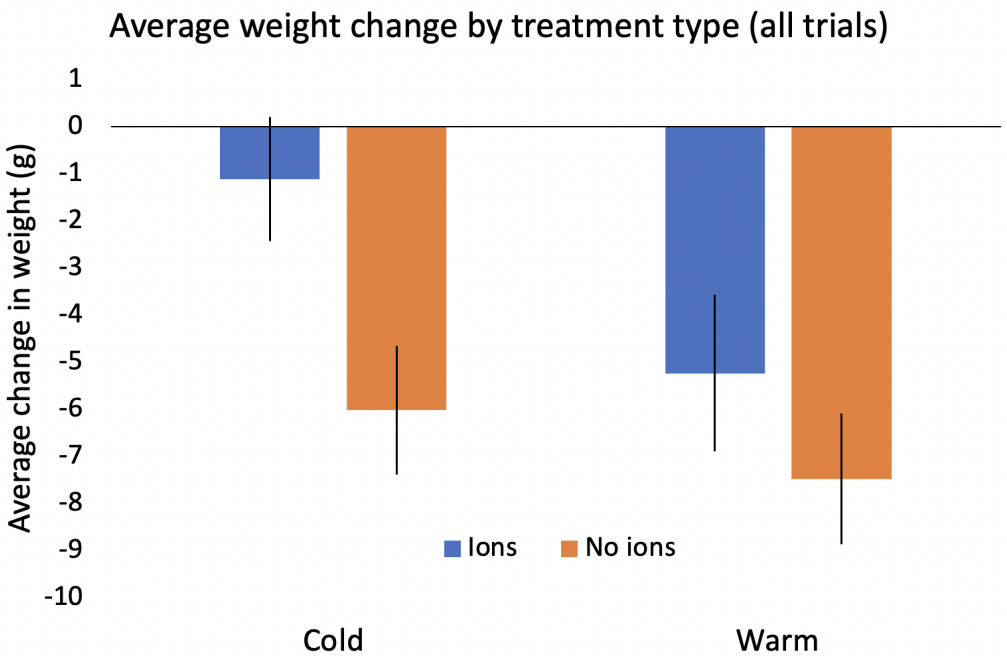

Figure 2.8. Weight change during temperature and ion supplementation treatments. Average change ± 1 SE in weight for each treatment type in holding trials evaluating the joint effects of temperature and ion supplementation. Statistical analysis of individuals in Table A.1.A (n=174 lobsters), of tank averages in Table A.1.B (n=38 tanks).

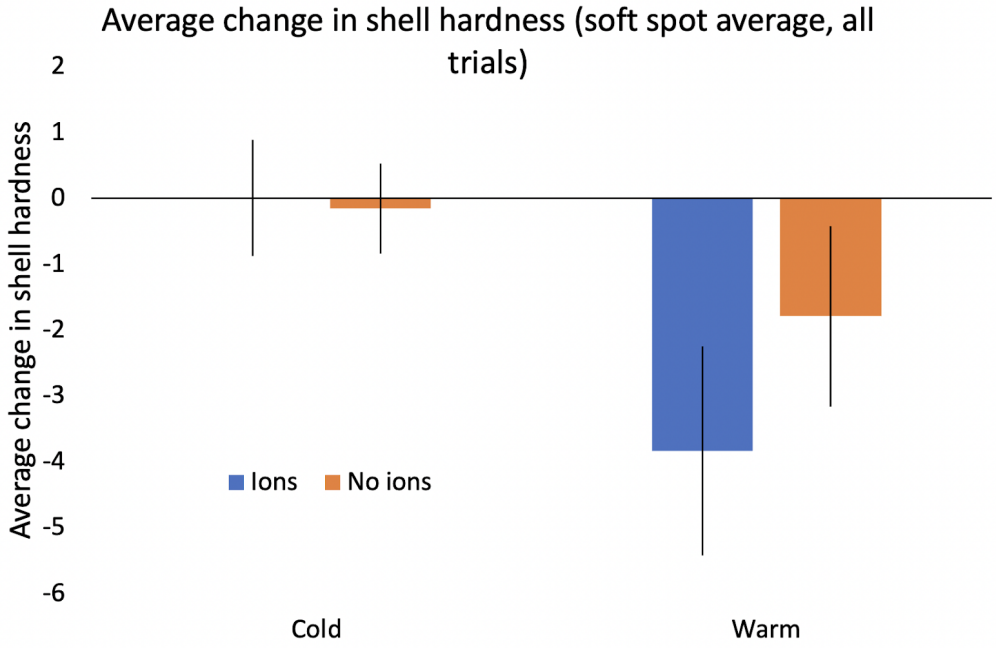

Figure 2.9. Change in shell hardness during temperature and ion supplementation treatments. Average change ± 1 SE in shell hardness for each treatment type in holding trials (ions and no ions refer to ion supplementation). Statistical analysis of individuals in Table A.2.A (n=174 lobsters), of tank averages in Table A.2.B (n=38 tanks).

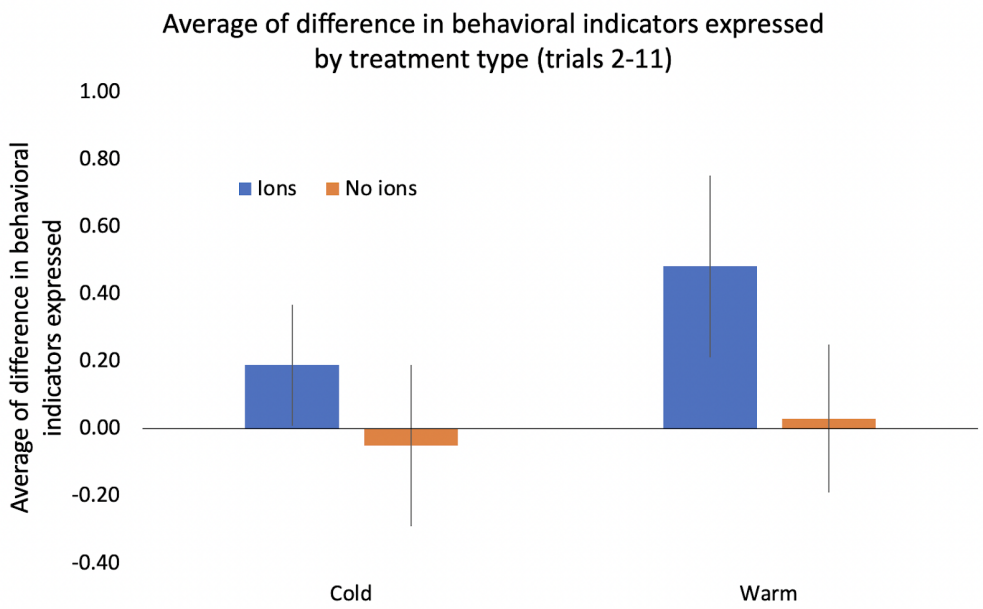

Figure 2.10. Change in behavior during temperature and ion supplementation treatments. Average ± 1 SE of differences in behavioral indicators expressed by treatment type in trials 2-11. (Ions and no ions refer to ion supplementation). Ion supplemented lobsters expressed a greater number of behavioral indicators post-treatment. Statistical analysis of individuals in Table A.3.A (n=139 lobsters), of tank averages in Table A.3.B (n=38 tanks).

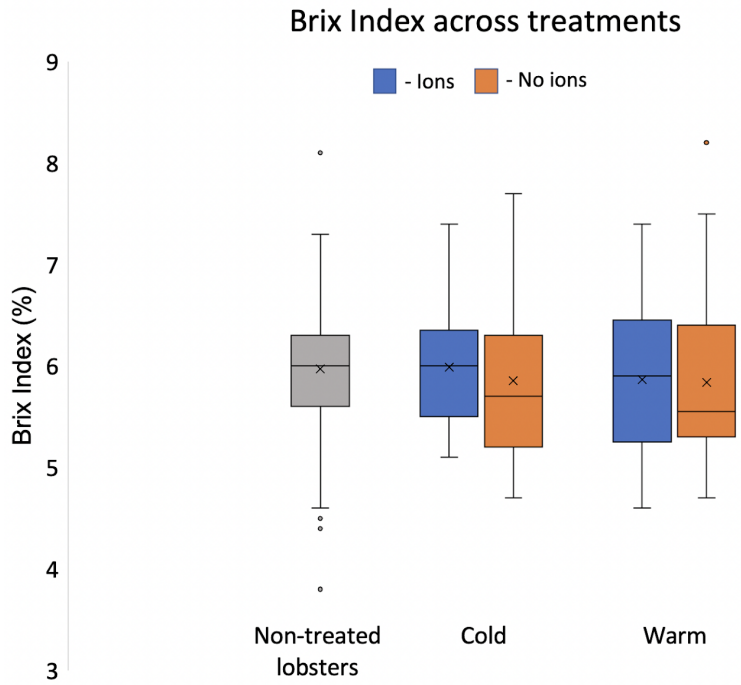

Figure 2.11. Brix index measurements during temperature and ion supplementation treatments. Brix index across treatments in holding trials (n=207 lobsters in total). "Non-treated lobsters" denotes 95 lobsters not treated but from the same pool from which the 112 lobsters in the experimental group were drawn.

2.3.4. Simulated shipping trials

No significant difference was found in hemolymph samples before and after the shipping simulation (cold, ion-supplemented: t=4.30, df=2, p=0.07; cold, non-ion supplemented: t=2.36, df=7, p=0.13; warm, non-ion supplemented: t=2.20, df=11, p=0.62 (K. Presby, personal communication, June 30, 2022). There were not enough surviving lobsters from the warm, ion-supplemented treatment to run a t-test. Hemolymph protein and osmolarity measurements did not show signs of increased stress in the experimental lobsters (K. Presby, personal communication, June 30, 2022). There was no significant impact of temperature or ion supplementation on the change in Brix index values over the course of transportation trials (Appendix table A.5).

With respect to survival during the experimental trials and subsequent shipping, in both cases, time trends suggest mortality was higher in the ion supplemented treatments relative to the non-ion supplemented treatments, regardless of temperature. Survival analysis via chi squared tests showed significant differences between treatments during both the holding and simulated transportation trials (holding trials: X^2 (1, N = 174) = 15.57, p = 0.0014; simulated transportation trials: X^2 (1, N = 58) = 14.76, p = 0.0020).

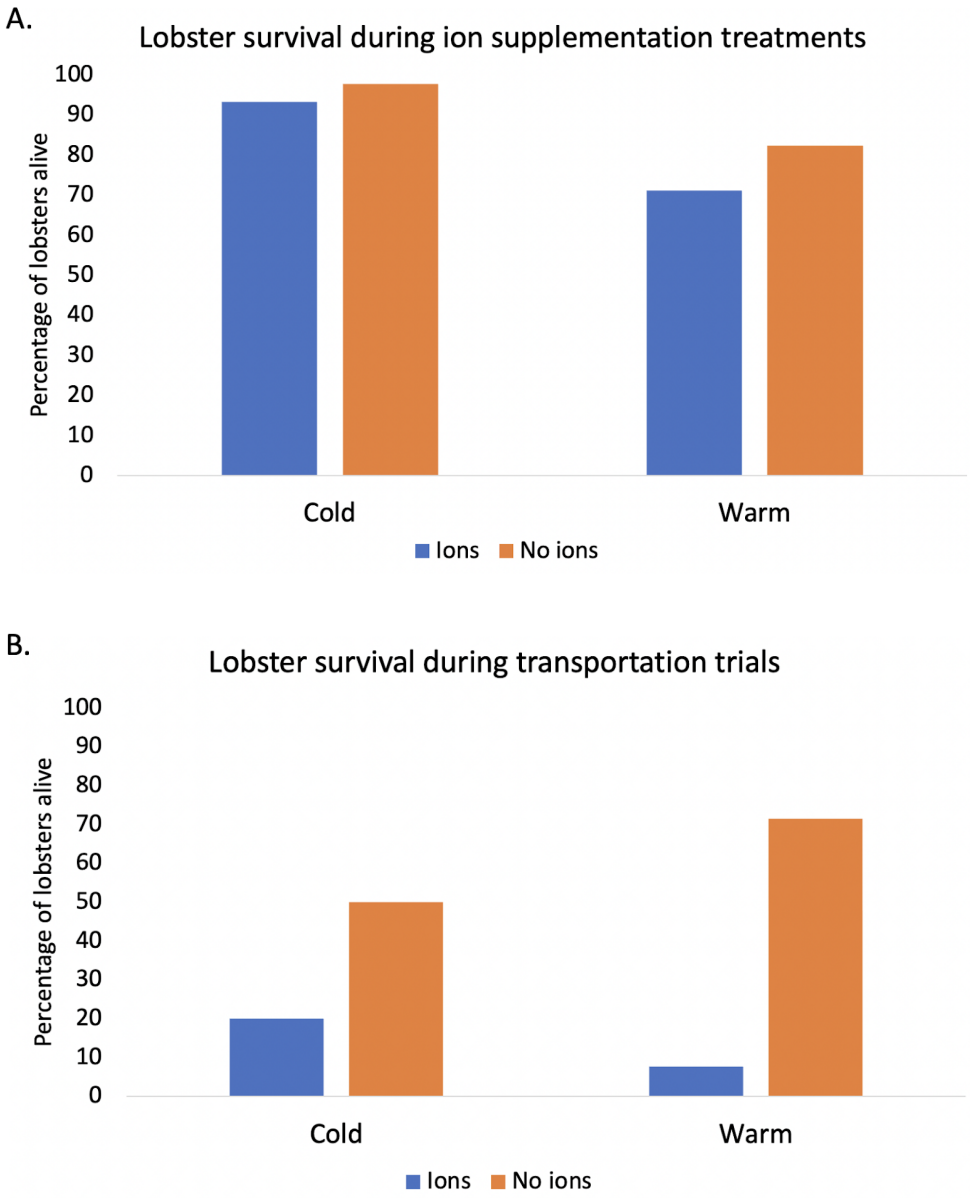

Figure 2.12. Lobster survival (%) after holding under temperature and ion treatments **(A)** and subsequent simulated transportation trials **(B)**.

2.4. Discussion

To our knowledge, the experiments conducted in this study provide one of the first assessments of whether feeding, temperature, and ion manipulations have potential to add value to lobsters held in short term captivity. In feeding trials, while the feeding treatment made little difference to weight change, it appeared to have a marginally positive effect on shell hardening

on the softest part of the shell over the treatment period. This may warrant further investigation, although from a business perspective the benefits of faster shell hardening would need to be weighed against the accumulating cost of feeding and mortality during the hold-over period. Previous studies have successfully increased weight gain and shell hardness in crustaceans, and have used methods such as longer feeding periods, feeding using fresh or frozen fish diets instead of a pelleted diet, or utilizing a pelleted diet which had been supplemented with minerals (which imitates a post-harvest lobster's mineral-rich diet) (Cheng et al., 2005; Davis et al., 1992; Donahue et al., 1997; Donahue & Bayer, 1998; Veeranjaneyulu & Krishnaveni, 2018). In holding trials, lobsters lost weight regardless of temperature and ion supplementation treatments, but those in the cold, ion-supplemented tank lost significantly less weight than those in the other treatments. Moreover, shell hardness decreased faster at warmer temperatures, and the ion supplementation did not significantly mitigate that effect. Simulated transportation trials performed after temperature and ion supplementation treatments showed that ion supplementation caused increased mortality down the supply chain, suggesting that even if ion supplementation had some positive effects on shell hardness, it would likely not be profitable for the industry under the conditions tested.

In addition, the comparison of professional grading to empirical measures of shell hardness revealed considerable variability in the shell hardness of lobsters, especially those assigned to grades A and B. The subjectivity of the grading practice may result in a loss of profit if lobsters are being under-graded, and could lead to consumer mistrust if they are over-graded. Although usage of a standardized site was necessary to allow for reproducibility of these experiments, shell hardness measurements indicated that the standardized site is significantly harder than the soft spot, which was used to imitate industry grading practices by finding give in

the lobster's carapace. Overall, this implies that the standardized site measurements and industry shell grading procedures are not directly comparable. There is an ongoing need for a quantitative scale which relates to the subjective industry standard of shell hardness. More data are needed at different shell grades (especially A-grade and old shell), and with different durometers to capture the higher and lower ends of shell hardness, as A-grade and old shell lobsters were often found to push the Shore A durometer to its upper limit. Adding data with other tools would mean extending the measured range of each shell grade as the durometers would show the upper and lower limits of those categories. If extensive overlap is evident after further data collection, alterations to industry training practices (e.g. added involvement of durometers) may be required to refine assignments of both A and B grade lobsters. One methodological limitation of this experiment is that breakage of shells can occur both when lobsters are measured by hand and by durometer. This could imply that the more you measure the lobster, the softer it may feel. Therefore, additional methods such as electron microscopy to further analyze the effects of ion supplementation on the lobster cuticle may yield more detailed results while also avoiding cumulative shell breakage (electron microscopy is used for finer scale work on other crustaceans, as shown by Rushton-Mellor & Whitfield (1993)).

In feeding trials, I found that feeding during a 5-day holdover period does not significantly impact the weight or shell hardness of lobsters. In this way, the results of the feeding treatment on lobsters generally corroborated Shaughnessy's previous unpublished results. There were 14 mortalities across 6 trials, 9 of which were unfed lobsters and 5 of which were fed. Future experiments could test the effect of feeding treatments over longer periods of time, but a cost-benefit analysis must be conducted to ascertain the value of such a treatment, given the possibility of higher mortality rates as lobsters are held for longer periods of time.

Although the increase in hardness at the soft spot of fed lobsters was not statistically significant, it stood apart from the other treatments which all showed a decrease in shell hardness. This result suggests that lobsters may utilize their resources to first strengthen the weakest part of their carapace (the soft spot) over other locations, and merits future study. In addition, unfed lobsters lost shell hardness at both the standardized site and the soft spot to a greater extent than fed lobsters (who lost shell hardness at the standardized site). This result suggests that feeding may provide some level of increased calcification to the lobster carapace that should be explored in future research.

In holding trials, I found that temperature and ion supplementation treatments did not have a positive impact on weight or shell hardness over the course of 5 days under the conditions tested. Further treatments similar to those used in the holding trials should be carried out which test various combinations of different temperatures and ion concentrations to ascertain effectiveness of this approach. Lobsters in the warm treatments by industry standards (10°C) suffered greater levels of mortality during holding trials, and also had a decrease in shell hardness in comparison to lobsters in the cold (5°C) treatments (Aiken, 1977). Higher mortality levels are expected at higher temperatures, as lower temperatures are known to retain a greater level of oxygen saturation in water and slow lobster metabolic rates (thus slowing the release of toxins such as ammonia) (Estrella, 2002; Perera et al., 2007). More data would need to be gathered (e.g. hemolymph magnesium and calcium levels) to ascertain the physiological processes behind the decrease in shell hardness. Lobsters in the warm, ion supplemented tank tended to express higher levels of vigor and activity than lobsters from other treatments, but also experienced the greatest level of mortality during transport trials, indicating that despite greater levels of activity, they were still more vulnerable during shipping. The expression of a greater

number of reflexes generally indicates a higher likelihood of survival in crustaceans (observation of these reflexes is utilized in live-trade grading and quality assessment) (Paterson et al., 2005; Spanoghe & Bourne, 1997; Stoner, 2012a, 2012b). The disconnect between lobster activity and mortality within holding and transportation trials emphasizes the importance of including other metrics in the RAMP model (such as physiological stress responses or injuries) in addition to assessing water parameters in order to predict mortalities: one of these metrics alone cannot paint a complete picture of the lobster's overall health (Stoner, 2012b).

During holding trials, there was less weight loss in the cold, ion supplemented treatment than in the industry control (cold, non-ion supplemented). This result could prove beneficial to the dealer, as less weight loss means retained value when the lobster is sold. However, a higher rate of mortality amongst ion-supplemented lobsters would offset those benefits . As seen in Figure 2.12, the industry control treatment (cold, non-ion supplemented) resulted in the highest rate of survival. This was followed by lobsters who were kept in cold, ion-supplemented water. Following that came the two warm treatments, with ion-supplemented lobsters experiencing the highest rate of mortality. Lobsters in ion supplemented, warm water experienced the highest level of mortality. The Brix values (across treatments) are low throughout holding trials because the lobsters used in these experiments are post-molt, B-grade lobsters. This is to be expected: total protein concentration is highest prior to molt and is lowest post-molt, meaning that soft-shelled lobsters generally have lower total protein levels than hard-shelled lobsters (Mercaldo-Allen, 1991; Retzlaff et al., 2007). A moderate positive relationship between average hemolymph protein values and percent survival of lobsters within each treatment indicates that the former measurement is a somewhat reliable predictor of lobster health.

Inconsistent water parameters over the course of holding trials could have impeded the lobsters' physiological processes which contribute to weight gain and shell hardening. Low salinity or high ammonia concentrations as shown in early trials in Figures 2.3D and 2.3F, respectively, could have caused such an issue: both low salinity and excess ammonia can inhibit growth (the former due to osmotic stress and the latter due to ammonia toxicity) (Bermudes & Ritar, 2008; Klymasz-Swartz et al., 2019; N. Romano & Zeng, 2013; Torres et al., 2011). Although tanks were covered with mesh lining in both feeding and holding trials, these covers might not have provided complete darkness. While feeding lobsters, they should be kept in a dark environment: feeding trials may have been improved through the use of opaque tank covers, as longer periods of darkness can increase food consumption (Factor, 1995).

The feeding trials described here failed to increase body weight or shell hardness, but it is notable that a pelleted diet optimized for those purposes (e.g. with supplemented calcium or magnesium) could potentially prove more effective and is one avenue for future study. One weakness of the feeding method is that it is not applicable to all lobster holding conditions: while lobsters in pounds are able to move about and feed freely, lobsters in a packed crate would not have uniform access to provided food. Because of this, holding methods would need to be taken into account and possibly altered to allow efficacy of this treatment. The temperature and ion supplementation treatments used in holding trials are more practical for implementation in dealers' lobster holding tanks. This is in part due to its more uniform application across all held lobsters, especially as they are often stored together at a high density in floating crates which have a capacity of ~45 kg of lobster. In addition, although feeding lobsters with fish such as herring has been observed to result in greater growth, weight gain, and shell hardness than a pelleted diet, the storage and usage of these fresh or frozen fish diet components is logistically

challenging and expensive for dealers (Conklin et al., 1983; Donahue & Bayer, 1998; Factor, 1995). For these reasons, manipulation of water parameters (rather than lobster diet) may be more logistically feasible as a method of adding value for members of the industry.

Future experiments should carry out trials over varied periods of time to assess how long it will take for treatments to be effective, as feeding treatments over the course of 40 days have proved effective in increasing weight and shell hardness (Donahue et al., 1997; Donahue & Bayer, 1998). However, industry constraints must also be considered, as trials longer than 5 days may be feasible, but trials as long as 40 days would not be realistic for the lobster supply chain. Feeding trials should also explore dietary mineral supplementation, as increased exposure to minerals such as calcium or magnesium may lead to more efficient growth or shell hardening (Davis et al., 1992; Veeranjaneyulu & Krishnaveni, 2018). Future studies should also continue to test the behavioral indicators of lobsters further down the supply chain, to determine the effects of these treatments over a longer time period. The simulated shipping trial found that not only did the ion supplementation fail to increase lobster viability, but also decreased survivorship after a 4 day shipping simulation when compared with a non-ion supplemented treatment (K. Presby & S. Jury, personal communication, June 30, 2022). This implies that even if the ion supplementation treatment could increase weight or shell hardness (which, in holding trials, it did not), additional costs further down the supply chain may mean that this treatment is not a worthwhile investment for industry members. Lobsters which expressed more behavioral indicators as a result of ion supplementation still faced increased mortality in transport trials post-treatment; this result emphasizes that behavioral indicators alone are not sufficient predictors of mortality in the supply chain.

The results of these studies hold important economic implications for the American lobster industry: how value may or may not be added to lobsters via shell hardening post-harvest, and whether the industry grading standards could be incurring financial loss by failing to accurately grade lobsters. The inclusion of transport trials also allowed for the observation of delayed effects of temperature and ion supplementation treatments. As lobsters experience stress before and after handling by dealers, it is important that experiments continue to take into account impacts surfacing in the days following treatment. These impacts play a role in the determination of a treatment's usefulness within the supply chain. In addition to these implications, this work also contributes to a growing body of knowledge about the ways in which live crustaceans in commercial supply chains respond to changing environmental conditions. This will only become more important to understand as the effects of climate change intensify over the coming decades, and it becomes increasingly important to make the most efficient use of our valuable marine resources.

CHAPTER 3

UNDERSTANDING RESILIENCY IN THE AMERICAN LOBSTER (*HOMARUS AMERICANUS*) FISHERY SUPPLY CHAIN IN THE WAKE OF COVID-19

3.1. Introduction

3.1.1. Shocks and vulnerability in seafood systems

Seafood systems are vulnerable to a variety of disruptions, or shocks, which occur at diverse spatial and temporal scales (Cottrell et al., 2019). Shocks can stem from resource conflicts, environmental change such as pollution and ocean warming, public health crises, and more (Baldos & Hertel, 2015; Fader et al., 2013; Hayakawa & Mukunoki, 2021). Some of these drivers, such as climate change, pose ongoing challenges to seafood systems around the world, and stand to only intensify in the future (Myers et al., 2017). For example, rising sea levels and increasingly frequent extreme weather events impede aquaculture production and seafood trade (Ahmed et al., 2019; Marques et al., 2010). Globalization of seafood systems makes them progressively more interconnected, and in turn more prone to shocks (Gephart & Pace, 2015). Greater connectivity via the globalization of food systems can pose a risk to both importing and exporting countries. For example, exporting countries transmit shocks to nations down the supply chain, such that smaller regions are also exposed to these exogenous disruptions (Dahl & Jonsson, 2018; Gephart et al., 2016). At a different scale, increased connectivity within an economic system can increase exposure to disruptions. When systemic shocks occur, they cause ripple effects across systems, across borders, and can sometimes aggregate into a new, greater problem altogether (Acemoglu et al., 2015). This has been illustrated in a variety of systems, including those which are economic and ecological: cascades within financial networks can lead

to systemic failure, and overfishing can threaten the stability of food webs through the collapse of fish stocks (Acemoglu et al., 2015; Plosser, 2009; Scheffer et al., 2005). Understanding how segments of seafood systems respond to systemic shocks – particularly those that demonstrate resilience to these shocks – is increasingly important for building robust systems, especially as the effects of a multitude of disruptions continue and intensify.

3.1.2. System resilience

Broadly speaking, resilience is defined as the ability to respond and adapt in the face of disruptions, without loss of functionality (see select definitions in Table 3.1). General resilience denotes the resilience of the whole system to all types of shocks, whereas specified resilience refers to the response of just one part of the system to a particular shock (Folke et al., 2010). Understanding resilience in supply chains and food systems is a mounting policy priority. In 2021 the Biden Administration issued an Executive Order that aims to strengthen the resilience of the nation's supply chains to pandemics, climate shocks, and other disruptions. As noted in the executive order, "resilient supply chains will revitalize and rebuild domestic manufacturing capacity, maintain America's competitive edge in research and development, and create well-paying jobs" (Executive Order on America's Supply Chains, 2021).

Table 3.1. Select definitions of resilience.

Author(s) and date	Definition
Folke et al. 2010	The capacity of a SES [(social-ecological system)] to continually change and adapt yet remain within critical thresholds.
Seekell et al., 2017	The global food system's ability to respond and adapt to disruptions.
Smith et al., 2020	Retaining the essential functions of the system while responding to shocks and disturbances.
Tendall et al., 2015	The capacity over time of a food system and its units at multiple levels, to provide sufficient, appropriate and accessible food to all, in the face of various and even unforeseen disturbances.
Walker et al., 2004	The capacity of a system to absorb disturbance and reorganize while undergoing change so as to still retain essentially the same function, structure, identity, and feedbacks.

This study draws on the food system resilience action cycle (Tendall et al. (2015); Figure 3.1) as an organizing framework for understanding and describing how the American lobster supply chain in both the U.S. and Canada was impacted by and responded to the disruptions caused by the COVID-19 pandemic. The food system resilience action cycle provides a framework for how a food system reacts to a shock over time, including five response stages which follow the start of the disruption. The sections of the cycle reflect the capacities of a food system to weather a disruption: the ability to absorb the impacts of a shock (absorb), flexibility and rapidity of response (react), and resourcefulness and adaptability (restore). Resistance, which has been characterized as the ability of a system to withstand disruption without changing, is represented by the absorb category (Grimm & Wissel, 1997). The cycle also notes the impact of stressors which continue to affect the system, even as it responds to a shock. Using this action

cycle to frame this research, data from a social media analysis and in-depth interviews with stakeholders from the lobster industry were used to describe how the sector coped with, and adapted from, the COVID-19 pandemic.

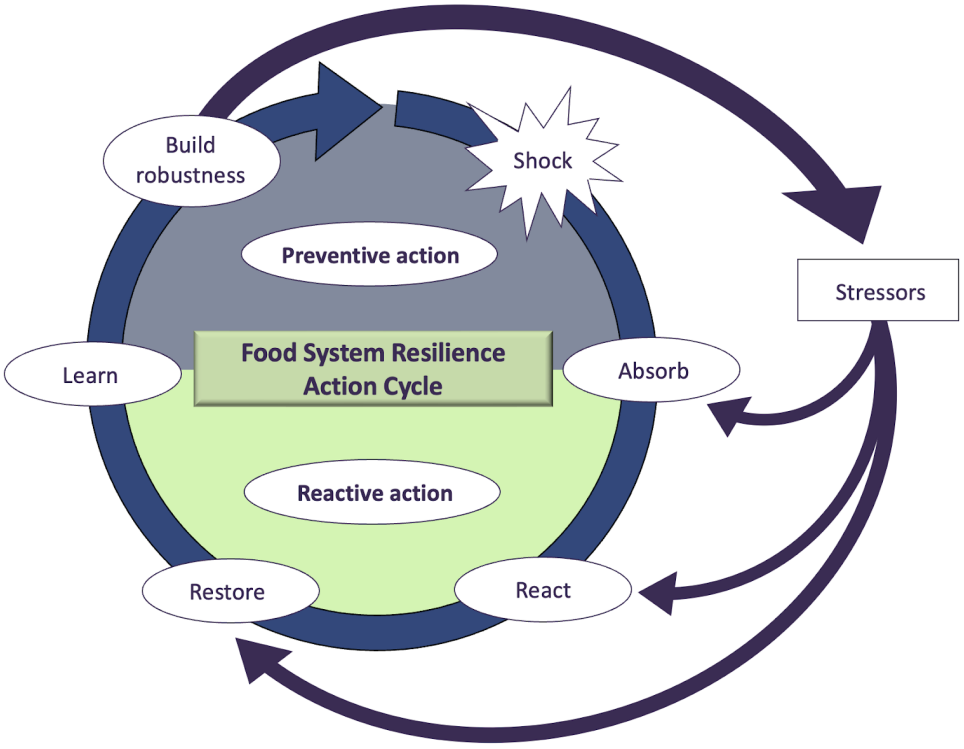

Figure 3.1. The food system resilience action cycle. The action cycle (as shown in Tendall et al. (2015)) shows the stages of a food system's reaction to a disruption over time.

3.1.3. COVID-19 disrupts the American lobster industry

The COVID-19 pandemic is an international public health crisis which began in early 2020. The pandemic has seriously impacted supply chains around the world, especially seafood industries (Chase, 2020). Impacts from the pandemic became visible in U.S. fisheries in early 2020, a time during the year when seafood businesses aim for top performance (40 to 60% of annual revenue for many Northeast fisheries is earned during the months between January and June; NOAA Fisheries, 2021). From January through June 2020, 78% of commercial harvesters

in Northeast fisheries temporarily suspended their fishing, with 48% halting fishing for one to three months (NOAA Fisheries, 2021). The American lobster industry, which relies heavily on international partnerships – especially trade partnerships between the U.S., Canada, and China – was affected by this disruption as supply chains broke down (Smith et al., 2020; Stoll et al., 2018). The shock also began just prior to Chinese New Year, a time when overseas demand for lobster is usually high (Whittle, 2015). The American lobster fishery is the most valuable single-species fishery in the U.S. and Canada, and is an important source of employment for coastal communities (DFO, 2021; NOAA Fisheries, n.d.).

The disruptions caused by the pandemic provide an opportunity to study the way in which shocks not only ripple across borders, but also across segments of seafood supply chains, including those associated with the lobster fishery. Emerging research on the pandemic has primarily focused on the first several months of the shock, but has yet to examine how systems have adapted to the pandemic as it has continued (e.g. Bennett et al., 2020; D. Love et al., 2021). Early responses to the pandemic have included actions at multiple levels of supply chains, ranging from harvesters selling directly to consumers in parking lots to international seafood businesses pivoting to domestic markets (Sorensen et al., 2020; Stoll et al., 2020). This research aims to not only identify lobster industry responses to the first two of years of the pandemic, but to also determine the longevity of each response and which of them appear to be incorporated as a permanent part of the way in which the lobster industry operates. This study will summarize and categorize the responses to the pandemic disruption by lobster supply chain (LSC) stakeholders in both the U.S. and Canada.

3.2 Methodology

The American lobster (*Homarus americanus*) industry served as a case study to research the resilience of a seafood system in the face of the COVID-19 pandemic. A novel approach was utilized in which multiple methods contributed in a stepwise manner, inductively and deductively building the study's methodology: social media data analysis was used to assess the impacts of and responses to COVID-19 by the industry through Tweets that were posted during the first year of the pandemic. It was hypothesized that the social media dataset was reliable and accurate in depicting actual events, but stakeholder perspectives were required for validation. In addition, the social media posts could include details which stakeholders may have since forgotten, especially a couple of years hence: recollection of experiences by interviewees can become obscured as time has passed since the event in question (Chen et al., 2014). Scoping meetings held between September and October of 2020 assisted in directing and designing the research to address issues most pertinent to industry stakeholders and also led to questions about adaptations moving forward. Using the insights from these methods, a research instrument was developed to formally interview stakeholders about their perspectives on the disruption. This instrument served to collect responses of the industry to the pandemic and assess their relative importance and duration.

3.2.1. Social media data

Data were collected from the social media site Twitter through the program TWINT (Twitter Intelligence Tool). Twitter is an informal (uninstrumented) environment with free APIs (Application Programming Interfaces) which is useful for mining data about a given topic of study (Anber et al., 2016; Chen et al., 2014). The program TWINT allows its users to "data

scrape" Tweets belonging to specified categories. Researchers can use TWINT to find Tweets related to a set of keywords, which were posted in a specified geographic area, or from a specified Twitter user. The researcher may also identify the time frame from which they would like to scrape posts. TWINT was used to mine Tweets from the beginning of the pandemic disruption through June 2020 based on relevant keywords (in this case, "lobsters" and "coronavirus"). The following command was used to collect posts relating to the interplay between the pandemic disruption and the LSC:

Command: sudo twint -s "lobsters,coronavirus" —since "2019-10-01 00:00:00" -o filename.csv —csv

Once collected, TWINT outputs were processed in Microsoft Excel for analysis. The post, time, time zone, and date on which each Tweet was posted were placed in a separate Excel spreadsheet for analysis. Each post was coded in terms of six categories (outlined in Appendix B): segment of the LSC, lobster type, location, topics, relevance to study (boxes checked if unrelated), and relevance type (whether the post addresses pandemic impacts, or responses to the pandemic: either coping or adaptation strategies). Each category had multiple bins for post characterization. These categories collectively measured the relevance of the individual Tweet to the relationship between the disruption and the ongoing function of the LSC. Linked news articles and pulled quotes were also included in separate columns of the spreadsheet.

The Twitter dataset was fully analyzed twice. In the second pass through the data, some codes were modified – these are marked as such in Appendix B. Cells were also added to include descriptions of coping or adaptation strategies found in the data. The results from coding this dataset and the viewpoints shared in the scoping conversations were jointly utilized to create the

research instrument with which stakeholders were questioned in formal interviews. Descriptive graphics were made from both the social media dataset and from the formal interviews held with stakeholders. Percent coverage of topics was calculated for figures by taking the frequency of Tweets in which a topic was coded and dividing it by the total number of related Tweets, then multiplying by 100.

3.2.2. Interview data

A ground truthing process of formal interviews held with stakeholders throughout the LSC was used to validate, refute, or expand upon the findings from the social media analysis. Although some analyses of social media data utilize news stories for ground truthing (e.g. Aiello et al., 2013), this Twitter dataset already included many posts which included news articles. For that reason, ground truthing using stakeholder interviews was a more suitable choice. If ground-truthing revealed strong agreement between stakeholders and social media data, it would indicate that social media can supply accurate insights as to the state of the industry during a disruption. In addition, these interviews further elucidated both the impacts of, and responses to, the pandemic.

The formal interviews involved an interview questionnaire which was first reviewed and approved by the University of Maine's Institutional Review Board for the Protection of Human Subjects (IRB). Stakeholders with in-depth knowledge of issues facing the LSC were the target population for this study, including actors from each level of the supply chain from the U.S. and Canada. Stakeholders from both countries were included in the target population as there was reason to believe that perceptions would differ dramatically across the U.S.-Canada border as the fishing seasons and handling practices in the two countries vary. Each segment of the supply

chain may also respond to disruptions with different coping and adaptation mechanisms to address accompanying challenges. Participants were recruited and interviews conducted until a point of thematic saturation was reached in terms of novel topics (impacts and responses) broached during interviews (method as described by Bernard et al., 2016; Guest et al., 2006). However, interviews could carry on past this point to continue data collection. Utilizing this point of saturation methodology ensured that research was done until interviews yielded no new information for the construction of the analysis framework (Mason, 2010; Weller et al., 2018).

The first participants involved were invited due to their engagement with the lobster industry and their professional affiliation with the research institution. Snowball sampling was used to procure further study participants (at least 18 years of age) and interview packets were digitally distributed to participants via email (snowball sampling as described by (Parker et al., 2019). Due to the travel and interactive restrictions stemming from the COVID-19 pandemic, interviews were held over the video conferencing platform Zoom or through phone calls. These interviews followed an IRB-approved script (with the exception of open-ended questions), and included timeline, pile-sorting, and ranking exercises, as well as a brief survey (Appendices C-H). Participants were counted demographically for all segments of the supply chain they are a part of, for example, they were counted as a harvester and also as a member of a cooperative if they are involved in both. The supply chain segment of each participant was determined by both the participant's particular position and workplace. Although some categories may be similar in terms of their practices and membership, for example, associations and cooperatives, participants were labeled on the basis of their self-reported involvement in the industry and with certain organizations.

After the interviews, transcriptions were coded thematically using the program NVivo. This software allows researchers to more efficiently and effectively analyze large quantities of qualitative data, including (but not limited to) interview transcripts, surveys, and publications (AlYahmady & Al Abri, 2013). Each interview's contents were analyzed such that the manifest content (or "meaning unit," i.e. what is said in the interview) could be categorized and ultimately understood at a higher level of abstraction to gather all overarching themes discussed (such as the methodology described by (Erlingsson & Brysiewicz, 2017)). Like the Twitter dataset, the interview dataset underwent two passes of analysis. The coding tree can be viewed in Appendix I. The categories were based on the chronological phases of the Tendall et al. (2015) food system resilience action cycle (absorb, react, restore, and learn or build robustness). Percent coverage for figures was found via queries in NVivo, and indicates how much of the source material – in this case, all interviews – was coded for a given topic.

The ranking exercises, in which participants were asked to rank disruption responses on the basis of their importance and duration, were also analyzed. Data resulting from these exercises were first reviewed and divided into "rule breakers" and "rule followers" depending on whether participants had followed the exercise instructions. Rule breaking included not providing clear values for a response, or in the case of the duration ranking exercise, labeling responses only as short-term or long-term (rather than ranking a response's duration in comparison to other responses). These results from rule breakers were analyzed further such that they may be included when reasonable, for example, when values could be gleaned from a participant's comparative descriptions of responses. On the rare occasion that data had to be excluded, it was because the participant misunderstood the exercise and thus provided unreliable results. As participants could add in or remove responses during the ranking exercise, the number

of total responses reported in their results varied. To standardize these results so that they might be compared to one another, Z-scores were used. In addition to the groupings of all, American, and Canadian participants, the groups "clumpers" and "splitters" were also included. While "splitters" were those participants who ranked the responses as expected (one after the next, with each response getting its own unique number value), "clumpers" were those who grouped responses together or gave them equal values in the rankings. Chi tests were performed to check for significant differences between groups. Out of the 13 responses offered up to interview participants for ranking, two were ultimately combined for analysis: government assistance and bailout funds. This was because the two were almost always either grouped by participants, ranked equally or next to each other, or interpreted as one item: these instances occurred in 20 out of 27 interviews. In three other interviews, only one of these responses was discussed. In two other interviews, neither response was included. Only two interview participants ranked these responses apart from one another.

The average Z-scores for each response were utilized as coordinates to create scatter plots showing each response's overall impact. The responses in Quadrant I of these scatter plots are those which were "most impactful" as they have the highest Z-score averages in terms of both importance and duration. Those in Quadrant III were least impactful, as they have the lowest importance and duration Z-score averages. Responses shown in Quadrant II were ranked as important, but not long-lasting, while responses in Quadrant IV were ranked as long-lasting but of lower importance.

3.3. Results

3.3.1 Comparing data sources

Twitter data and interviews both provided insight into the impacts of and responses to the pandemic disruption, but at different scales. Twitter data had a greater focus on international trade and how it had been affected by the shock: observing the most frequently utilized codes (top 10%), international trade was the most frequently discussed topic, followed by sales/demand and lobster price (Figure 3.2). Twitter data also indicated a greater number of countries as having been involved in the ongoing disruption: China is the country most often discussed in posts (71.2% of posts mentioned China), followed by the U.S. (46%), Australia (30.9%), and then Canada (30 %). 23 other countries were mentioned (Figure 3.3A). The interview dataset most often addressed the U.S. (2.9%), Canada (2.2%), and China (1.2%), and only 8 other countries were mentioned (Figure 3.3B). Topics which occurred less frequently in the Twitter data, such as the issue of right whales, were emphasized in the interview data. In this way, the interview data had greater focus on regional challenges than did the Twitter data.

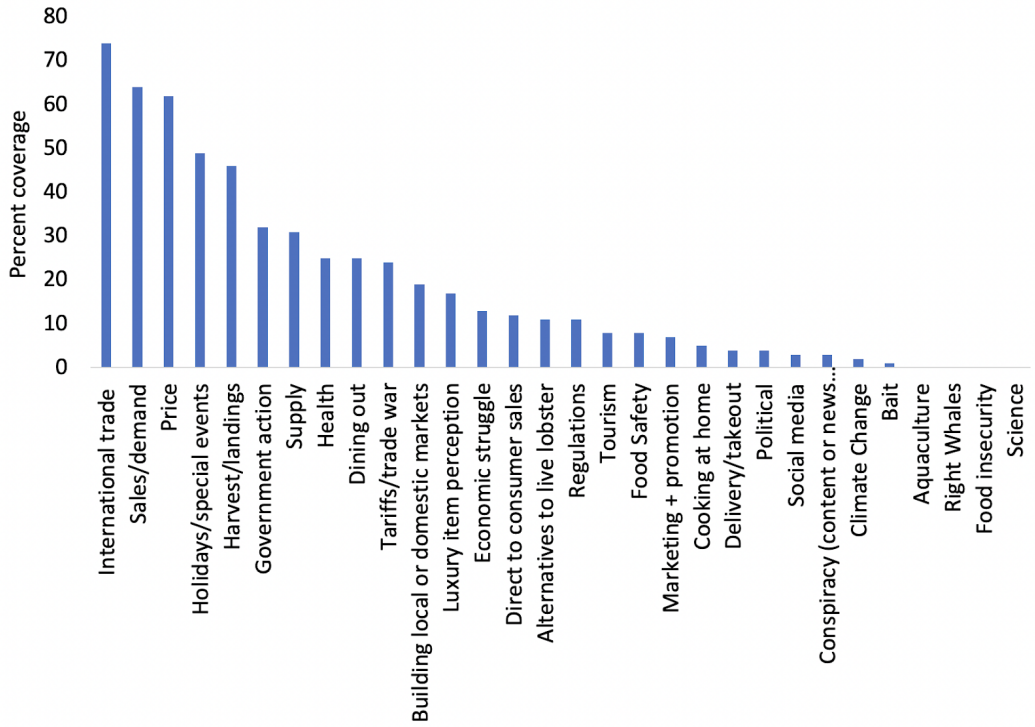

Figure 3.2. Percent coverage of topics found in Twitter dataset. Percent coverage of topics found in 719 "lobsters" and "coronavirus" related Tweets from October 2019 through June 26, 2020.

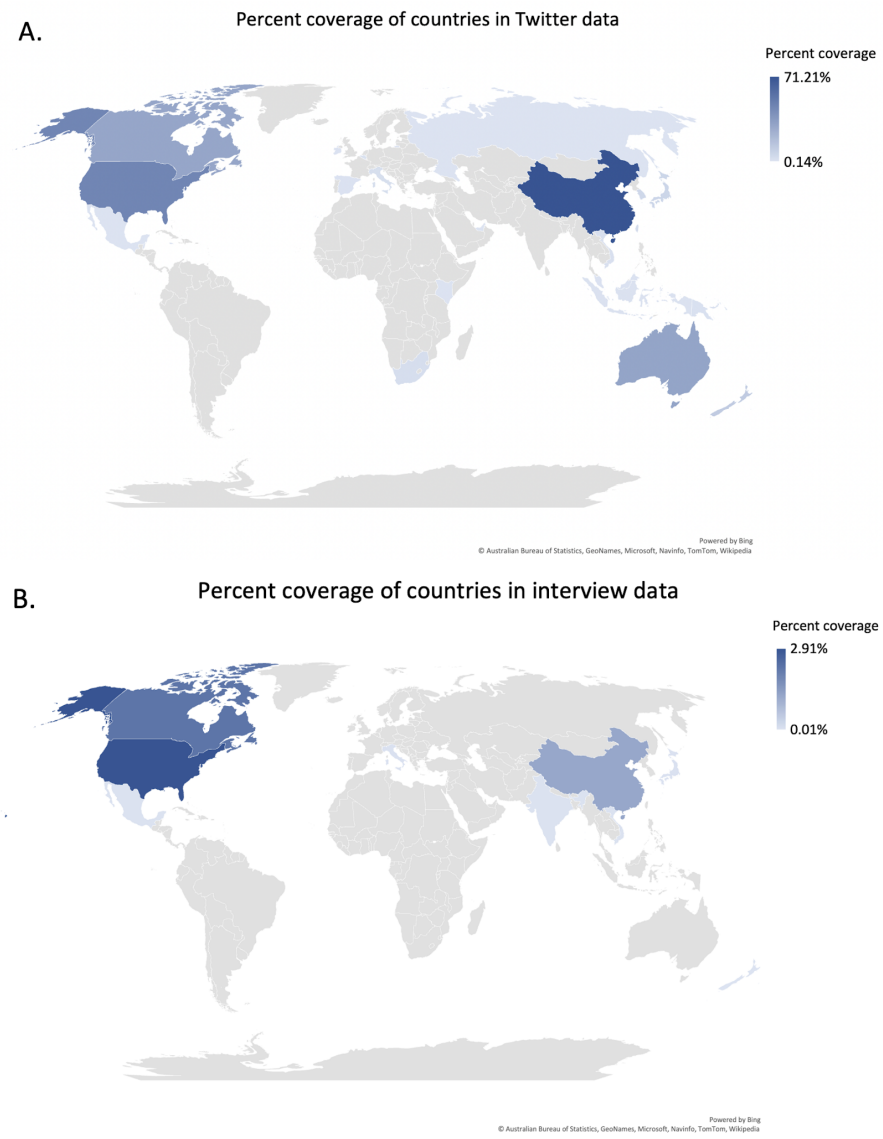

Figure 3.3. Global distribution of Twitter and interview datasets. **A.** Percent coverage of countries found in Twitter dataset. **B.** Percent coverage of countries found in interview dataset.

Twitter posts successfully recreated the food system resilience action cycle (Tendall et al., 2015; Figure 3.1) for the American lobster industry's response to the COVID-19 pandemic (Figure 3.4). The responses of industry members to the disruption are represented in the absorb, react, and restore sections of the cycle. The Twitter dataset showed 13 main responses by stakeholders to the COVID-19 disruption: more lobsters frozen/processed, harvesting less when the market is down, lobstermen joining other fisheries, government assistance and bailout funds

(later combined), regulatory changes, a shift in consumer interface, consumers cooking at home, direct to consumer sales, an increased use of social media for sales and marketing, a shift to local markets, diversifying buyers, and marketing to countries other than China (Figure 3.4). These responses were placed into the food system resilience action cycle on the basis of how soon they occurred after the disruption began – whether there was an immediate shift to the response, or the response took longer to precipitate. Although the Twitter dataset could supply information about which responses happened, questions regarding the duration of responses remained.

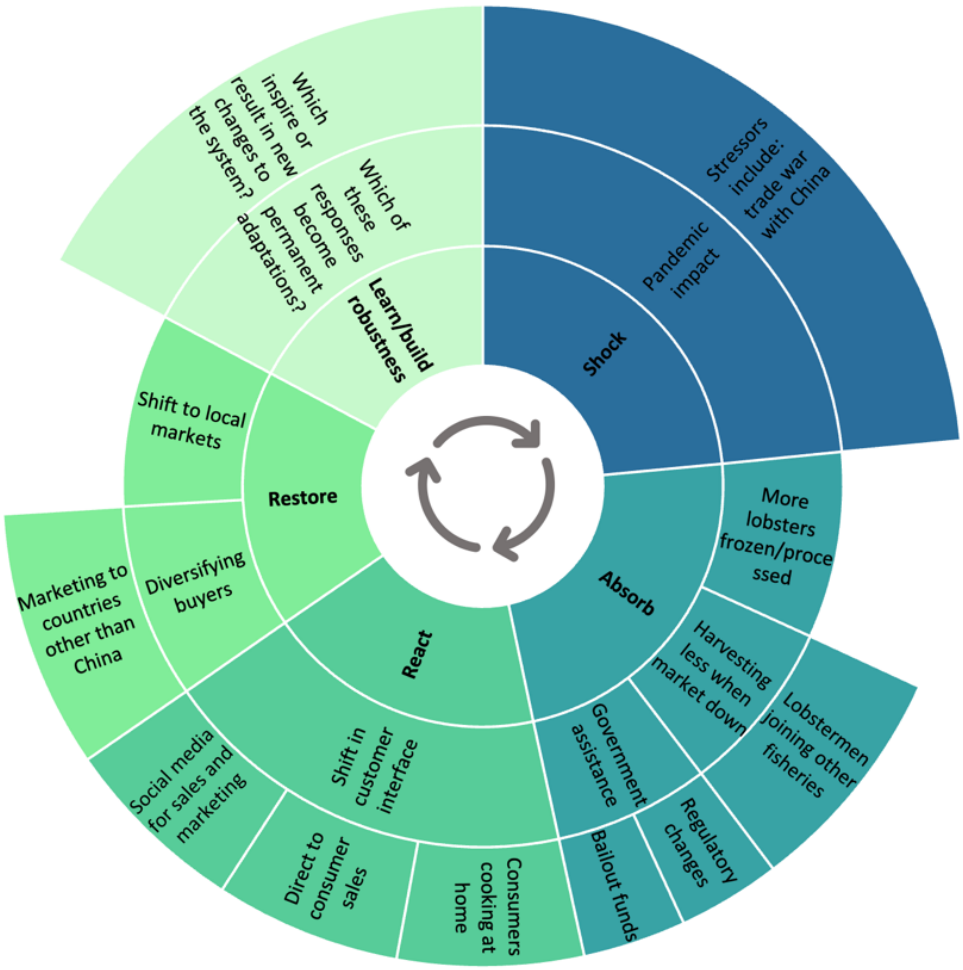

Figure 3.4. Twitter dataset food system resilience action cycle. A food system resilience action cycle adapted from the original action cycle (Tendall et al. 2015) which illustrates the responses of the American lobster industry to the COVID-19 pandemic disruption. The coping and adaptation mechanisms shown in this figure were derived through the analysis of the social media (Twitter) dataset.

Twitter analysis and stakeholder interviews produced similar food system resilience action cycles for the LSC (Figures 3.4 and 3.5). Although participants sometimes removed responses and stated that they were not applicable, the addition of new responses was rare. Six new responses were added during the interviews, including expanding markets past the U.S.-Canada partnership (originally posited as marketing to countries other than China and the U.S.), diversifying lobster value added products, maintaining existing buyers (as a complement to diversifying buyers), COVID protocols, working together with representatives in the legislature, and lobstermen joining other industries (Figure 3.5). The results from the interview dataset show that diversifying buyers, shift to local markets, marketing to countries other than China, using social media for sales and marketing, consumers cooking at home, and more lobsters frozen or processed were all deemed as an adaptation by a majority of >50% of the participants. The only response to be deemed as a coping strategy with the same level of agreement was government assistance and bailout funds, which most participants agreed was a short-term response. Harvesting less when the market is down was also seen as a short term response, but by a smaller margin (a relative majority, <50%). The regulatory changes response was ranked equally as a coping and adaptation strategy, with 18.5% stating that it was a coping strategy and 18.5% stating that it was an adaptation strategy.

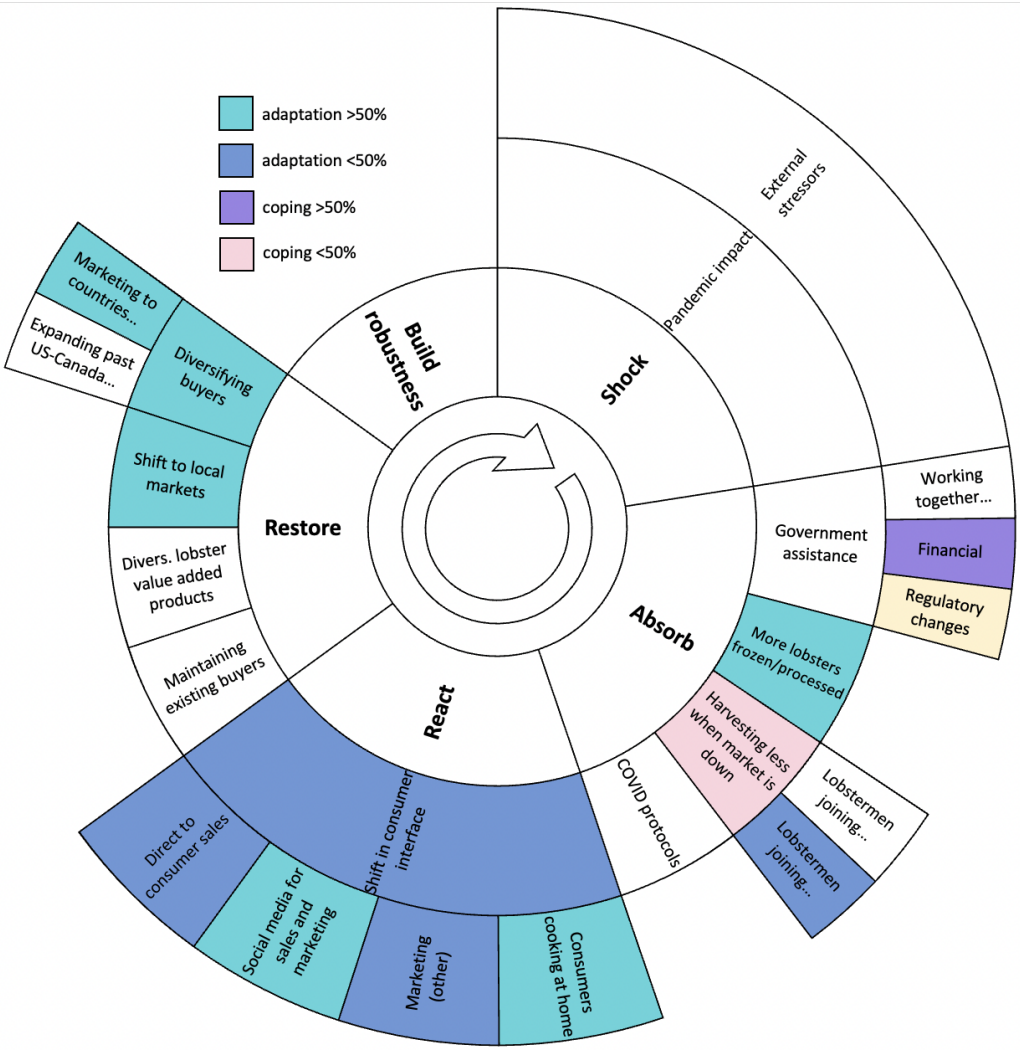

Figure 3.5. Interview dataset food system resilience action cycle. Interview-derived food system resilience action cycle of the American lobster fishery supply chain to the COVID-19 pandemic disruption. Teal are responses which were deemed adaptations by the majority of interviewees (>50%), purple are coping responses as deemed by the majority of interviewees (>50%). Blue are responses deemed adaptations by a relative majority of the participants (<50%), and pink are the same type of majority, but for coping responses.

3.3.2. Interview participants

109 individuals were contacted about participation in this study, and 27 from across the lobster industry participated in an interview. The most-represented supply chain segment was association members, followed by harvesters, then dealers/wholesalers/exporters and cooperative members (Figure 3.6A). Members of nonprofits, government, and fisheries management had the

lowest levels of representation in this study. Breakdown of supply chain segment involvement from both the U.S. and Canada is available in Table 2. Nearly half of the participants in this study were from Maine, 18% were from Nova Scotia, 15% were from PEI, 11% were from New Brunswick, and only 4% of participants were from each New Hampshire and Massachusetts (Figure 3.6B). The sample population of this study is not intended to be representative, but rather aimed to cover a wide cross section of geographies and segments of the LSC.

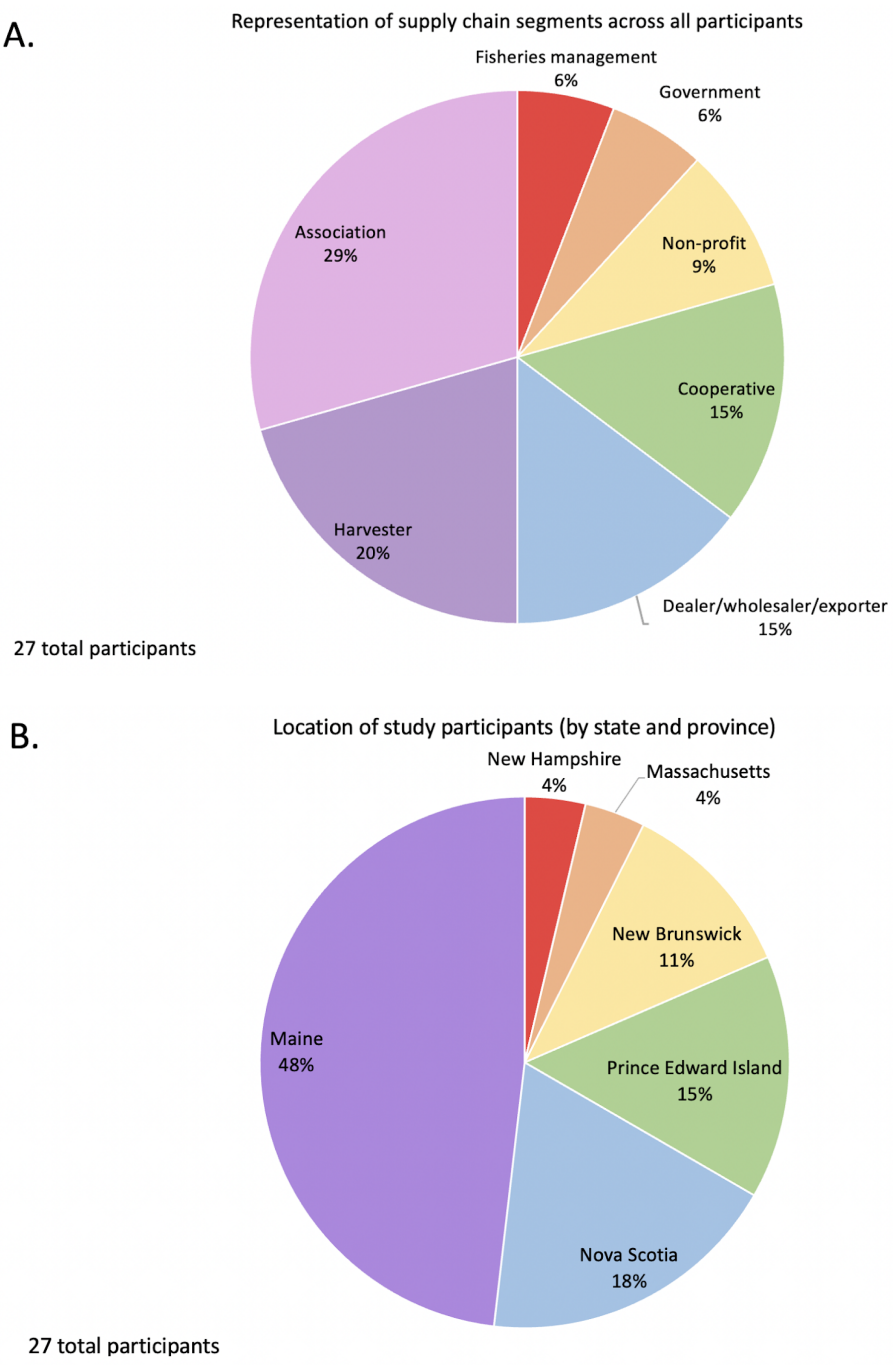

Figure 3.6. Demographic information of interview participants. **A.** Interview participants' (n=27) involvement in the lobster supply chain. **B.** Interview participants' geographic locations.

Table 3.2. Breakdown of interview participants' involvement in the supply chain. American interview participants' (n=15) and Canadian interview participants' (n=12) involvement in the supply chain in relation to supply chain segment (percentage of participants involved in each segment).

Segment of supply chain	**% U.S.**	**% Canada**
Association	18	50
Harvester	27	9
Cooperative	23	0
Dealer/wholesaler/exporter	18	8
Fisheries management	0	17
Non-profit	9	8
Government	5	8

3.3.3. Local support and diversified product pathways

A pivot from old markets which had been shut down to new, local and domestic markets played a key role in the LSC weathering the disruption. Multiple responses contributed in conjunction with one another to make for this successful shift. To begin with, interviewees identified consumers cooking from home as the most important response to the disruption, giving it the highest mean score. As one respondent explained:

> Because everybody was home, there was all of a sudden this big boon in cooking at home and people trying different things, the recipes and seafood and so a lot of retail chains zeroed in on that and that really helped our inventory situation, in that typically product that would have gone to Europe was absorbed by the U.S. and that really helped.

Following consumers cooking at home, participants deemed diversifying buyers as second most important, followed by a shift to local markets and more lobsters frozen/processed. One industry participant elaborated on the positive effects of buyer diversification:

> The stat everybody says is that 70% of seafood generally is eaten in restaurants, the number is probably higher for lobster. You really have to replace all of this restaurant and food service buyers with other people and still sell. I guess it wound up being maybe 15% down on the catch, so that means finding new grocers that are willing to pick up lobster products that weren't selling lobster products before. It means finding ways to reach consumers directly to buy the product, that's the direct to consumer online. But really I think 70% of the buyers that were out there vanished so [if] you didn't diversify, then you went away.

In particular, participants pointed to the role of dealers in the transition to more diverse buyers and markets, and the lasting benefits that resulted from this shift. As one participated noted:

> The dealers I think did an amazing job. I don't know how they did it but they developed markets that we didn't have I think before that […] my impression is that they were able to develop markets like grocery stores, to make up for the restaurants and the cruise ships that were just basically at zero, at least for a couple months. And I think that's probably… part of why we're enjoying such a high price now that they developed markets during COVID in 2020 that didn't go away… That when things started coming back online in 2021, when restaurants started buying lobsters again, processors came back online, but

> those grocery stores or those newer markets didn't go away, and so there was more demand than there was supply […]

Diversifying buyers was the response with the highest mean score in terms of duration (Figure 3.7B). In terms of duration, this response was followed by more lobsters frozen/processed and then by marketing to countries other than China. One participant noted the likely longevity of the diversifying buyers response, after saying that the addition of new markets has helped the price of lobster to remain high (as mentioned in another quote above):

> Diversifying buyers, still at the top. That's forever I think, even though some of the other buyers are back we're holding onto the new buyers that we found.

The diversification of buyers also provided access to previously untapped markets, especially in conjunction with a shift to local markets:

> Shifting to local markets, I actually wish we would lean into that a little bit heavier. I think we have so much potential in the United States, and we have potential in Maine specifically because we have such a high, new population of people in the state. [...] And people are traveling more within the country, within New England, you know we have a shifting population that could take advantage of our seafood and I don't necessarily think we do a good job marketing. And I think the pandemic highlighted that they are a better potential market than we perhaps gave them credit for in the past.

Participants also noted that these potential markets could extend from local to domestic:

> For me, local means the United States, and maybe even Canada versus worldwide. [...] My company, like I said, has shipped to more than 30 different countries on a regular basis. But we are finding our best customers, especially for some of the processed goods, tends to be right here in the United States, so that's what I mean by shift to local markets, and I think when you add in, whether it's politics, regulations, many other things that complicate international trade, when you pull it all back and look at it as a whole, it does make a lot of sense to keep things local.

Due to the complications that can accompany international trade, finding local or domestic markets does more than just increase the number of potential customers. It also provides product pathways which are more resilient to disruption:

> I think logistics will continue to be more difficult, there's more and more goods being traded, which is surprising in a time where it's more difficult to transport those goods around the world. I think that is going to drive more local consumption, and I think that's going to drive more manufacturing in the US […]

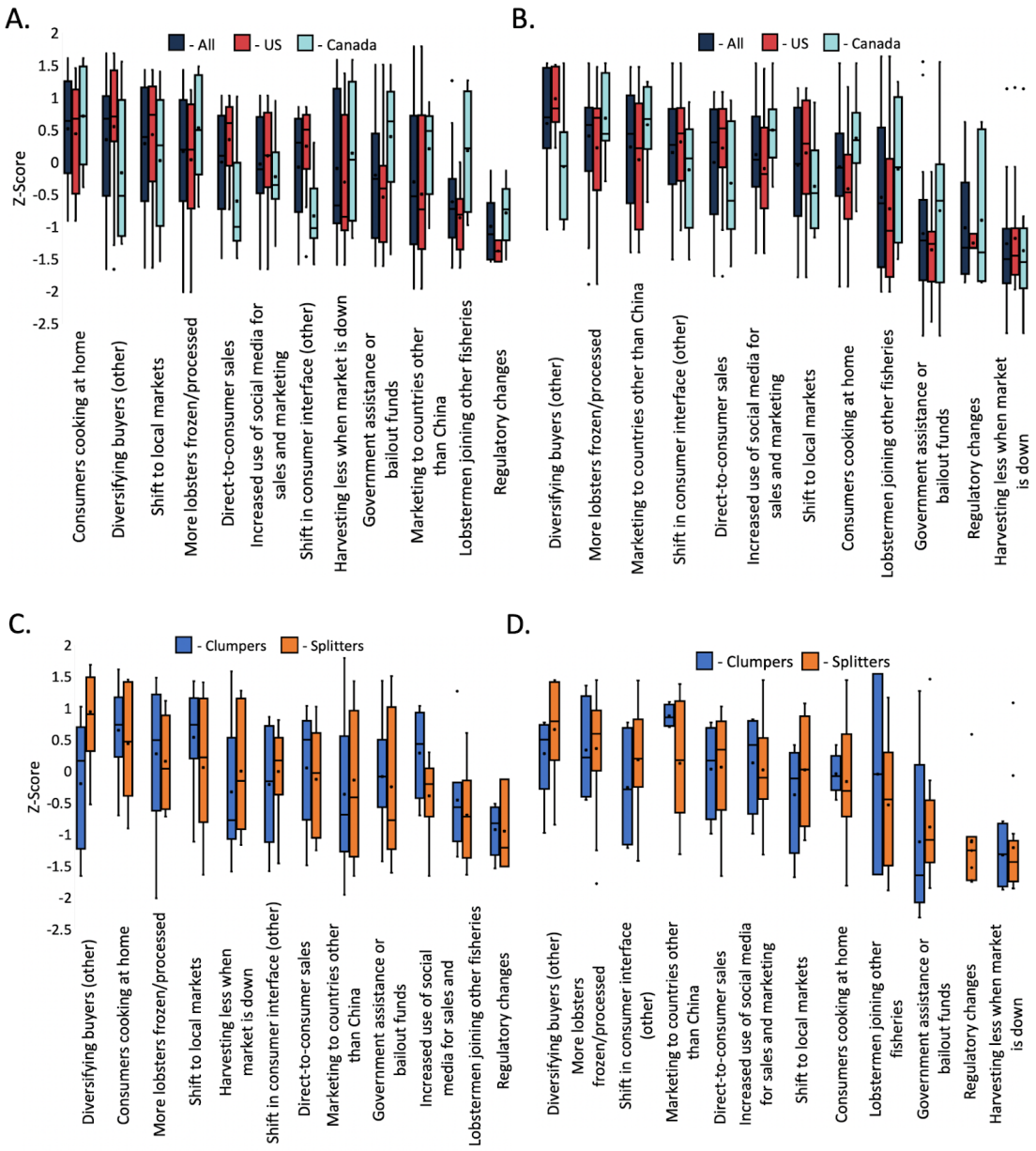

Figure 3.7. Comparative importance and duration of industry responses. **A.** Box plot showing normalized Z-score ratings (n=26) for each response in terms of its importance in carrying the industry through the pandemic disruption. Dark blue shows the average ratings among all interview participants, red shows the average ratings from American participants, and light blue shows the average ratings from Canadian participants. **B.** Box plot showing the Z-score rankings for each response in terms of its duration during the pandemic disruption. Colors as utilized in Figure 3.7.A. **C.** Box plot showing the Z-score rankings for each response in terms of its importance during the pandemic disruption. Blue shows the average ratings between interview participants who "clumped" or grouped responses together, while orange shows the average ratings from participants who "split" the responses, ranking them one after the other with none sharing the same rating. **D.** Box plot showing the Z-score rankings for each response in terms of its duration in carrying the industry through the pandemic disruption. Colors as utilized in Figure 3.7.C.

Along with a shift in end markets came a shift in the type of lobster product that was being sold. Participants pointed out that frozen or processed lobster products are suitable for unpredictable market conditions, in part because you don't have to worry about a limited shelf life:

> More lobster is probably going to be processed. That's because we're coming into a time of global uncertainty and economic uncertainty. By processing a product and freezing it, it gives you a long longer window of speculation. My live lobster I've got- if it's good quality I've got two or three months. If it's bad quality I've got a week. Maybe four days. But if that product can be processed and then those processors have probably a year to speculate. Before we have to unload the product. And even after that it's got six months shelf life and the buyer- anybody buying it will want that.

Processing lobster also leads to greater convenience when it comes to cooking, and translates to greater accessibility for consumers who have not previously handled lobster:

> More and more lobsters have been frozen and processed from when I first started shipping. In the early 90s, everybody wanted just a live lobster. When I quit, when I stopped 23 years later, people were looking for processed, they wanted meat, they didn't want to cook it in their house, they just wanted to microwave it or thaw it out or do whatever, so I think social media, shift in consumer interface how this is all translated to them and giving them an opportunity to buy in, I think those are all here to stay.

Although marketing to countries other than China had a relatively high mean score in terms of duration, it had the third-lowest mean score in terms of importance. It also had the highest variability in terms of importance (SD=1.1). Some participants noted that overseas markets (including but not limited to China) lacked viability during the pandemic:

> And what made me bring up Europe was I saw the marketing to countries other than China, but I feel like we lost the entire global option list during this pandemic so kind of have that as least important because we just didn't have any place to really go.

3.3.4. Lobstermen staying in the fishery

Lobstermen joining other fisheries was deemed as the second least important response by mean Z-score. Participants noted that this is a response which was already occurring before the pandemic:

> Lobstermen joining other fisheries, because I think that that's something that's just changing and going to be changing. But again, not necessarily the result specifically of the pandemic, but a better understanding that it's very difficult to be resilient if you're dependent on a single species.

They noted that this response may be important in the future, but would not be utilized much while the industry is strong:

> Then I have lobstermen joining other fisheries. That might be important to them in the future, and I think growing other fisheries and establishing other fisheries in Maine where we're not just so reliant upon lobster is probably going to be a good thing. But the lobstermen themselves shifting focus while the fishery is strong and while the demand's robust, I don't think that's very important.

In addition, licensing regulations mean that joining other fisheries is not always easy or efficient, making this response one which is not most suitable for a relatively short-term disruption:

> In terms of lobstermen joining other fisheries… it's pretty, how can I say- it doesn't really happen in Canada it, you know. Because of the way the license systems work, they are already pretty much all filled, so you don't really have an opportunity to go into other species, aside from the species that you already have a license for.

3.3.5. Contention: a symptom of maladaptive responses

Several responses to the COVID-19 pandemic were identified as contentious by the interviewees. The most contentious response to the pandemic was government assistance and bailout funds, followed by harvesting less when the market is down and regulatory changes (Figure 8). In terms of government assistance, interview participants sometimes expressed disdain:

> People don't like any kind of government assistance. You know, keeps people in the industry, maybe questionables, that wouldn't survive type of thing. A lot of that- there's a lot of animosity towards any kind of disaster money.

In the following two quotes, participants cited dissatisfaction that their own segment of the supply chain did not receive sufficient financial assistance when compared with other segments:

> There was definitely a fair amount of resentment on the part of everybody in the industry that wasn't a harvester that we were passed over for support when it came to bail out funds. Not so much begrudging money going to lobstermen, but wondering why there was none for the folks who are actually really hurting at a time when lobstermen were getting at or above their average price.

> I think this is going to sound super [expletive] and petty but I think the dealers were able to take better advantage of COVID funding and tariff funding- that doesn't have anything to do with it, but I think they were better positioned to take advantage of how best to access that type of funding. And that is via PPP programs, COVID relief funding or grants in a way that fishermen were unable to.

Harvesting less when the market is down had the lowest mean score in terms of duration, with regulatory changes scored as second shortest-lasting, and government assistance and bailout funds as third shortest-lasting. Participants generally expressed regret that there had been less harvesting when the market was down:

> So we move on now to harvesting less when the market's down. That was certainly a big part of the conversation. In hindsight it would have been better for the entire market to have fished and harvested the same way it had in the past. That pause in fishing turned into not enough product when the demand came back on strong. And while that might have forced inflation up faster, and prices back up faster, it disrupted other parts of the industry, like the ability to maintain the customer base, the ability to maintain enough work in the facilities that were built to handle a certain amount of volume. So, looking back, I would rather the fishery not be paused, it will naturally fish harder when prices are stronger.

Regulatory changes had the lowest mean score in terms of importance. This response does not refer to regulatory issues unrelated to the pandemic disruption, such as right whale regulations or area closures. Instead, it refers to actions taken in response to the pandemic in particular (e.g. fishing season delays). However, regulatory changes were interpreted in multiple ways by participants, namely as changes to the fishing season or quotas (but those imposed by stakeholders rather than government) and regulatory changes implemented by other countries (e.g. China) with regards to international trade. These interpretations are what is represented in the ranking exercise results for this response. There was also a great deal of concern about regulatory changes in relation to right whales or offshore wind; these concerns are not examined here but instead are reflected in Figure 3.11. Participants noted that fishing seasons should only be delayed for biological or safety reasons:

> I, to this day, objected strongly to DFO [(Fisheries and Oceans Canada)]. DFO should only be- what should impact the start of the season, there's only two things: biology and safety. One would be if we've got ice and they can't get out or we have high winds, the season is delayed. That makes a lot of sense. [...] I don't think DFO should ever get involved when it comes to economic decisions and they did.

As discussed in the following two quotes, some stakeholders were better prepared than others to weather lowered profits:

> I can admit now that there was quite a bit of tension within the industry, I mean a lot of people were you know, we kind of had two camps, the camps that said that we need to go fishing to pay the bills, I would argue that in that period, probably the new entrants into the fishery, the guys with the most debt were the guys that were pushing to go out pretty hard. Right? And so it's sort of divided the fleet along generational lines, I would say. Really. A lot of the older guys would say, well, listen, we'll flood the market so on, but that's an easy position when your fishing enterprise is paid for or largely paid for. And you're not so worried about paying debts.

> So this part I found really interesting. We ended up having a vote, like a formal vote of our membership to decide whether or not we wanted the season to open on March 31st given all of the stuff we were hearing. And the vote ended up being I think like 80% of people were in favor of delaying the season opening, but there were really two camps of people. There was one camp of people who had higher operational costs, you know like

ran a bigger boat, and had this debt load and more costs of operating their business that were like I can't afford to go lobster fishing when lobster is only $5 a pound or $4 a pound. And then there was this other group of people who had smaller boats, who haven't upgraded their capital assets, the way other people have, you know they've had their boat, they've had the same boat for a long time, and they're not in debt. And they said, well, I want the season to open, because I can make money on a $4 lobster. That guy might not be able to, but I can, and so I want the season to open.

Figure 3.8. Responses deemed as contentious. The percentage of interviews which deemed each given response contentious (that some members of the industry liked them more than others).

3.3.6. Differences between participant groups

Overall, results showed no significant difference in importance rankings between American and Canadian participant responses when excluding ($p=0.74$) or including rule

breakers (p=0.41). However, while Canadians ranked consumers cooking at home as the most important response, Americans found diversifying buyers to be most important, followed by consumers cooking at home. Other differences were found between American and Canadian participants: Canadians tended to view diversifying buyers, direct-to-consumer sales, increased use of social media for sales and marketing, and a shift in consumer interface (other) as less important than Americans. Canadian participants also found government assistance and bailout funds, lobstermen joining other fisheries, and regulatory changes as more important than did American participants. There was low variability amongst participants in terms of regulatory changes; most asserted that this response was not important in terms of weathering the pandemic disruption (Figure 3.7.A). There was high variability within Canadian participants in terms of their responses regarding lobstermen joining other fisheries.

While completing the ranking exercises, some participants had a tendency to rank multiple responses as the same value. This action was not considered rule breaking, but did lead to a need for standardization between the ranked results via normalized Z-scores. Splitters tended to rank diversifying buyers at a higher value than clumpers. A shift to local markets and increased use of social media for sales and marketing were both ranked higher by clumpers than they were by splitters. In terms of the importance ranking, there was no significant difference between clumpers and splitters excluding (p=0.40) or including rule breakers (p=0.075), likely due in part to there being only one replicate difference between these two groups. In the importance ranking exercise, there were only 2 participants who did not follow the rules. The answers of one of these participants could reasonably be included in these results (Figure 3.7.A). Because of this, there was little difference between the average response ratings of importance

between all participants including rule breakers and all participants excluding rule breakers (since the difference between these subsets of data was only 1 replicate).

American and Canadian participants disagreed on the duration of diversifying buyers: while Americans scored it as the longest-lasting response, Canadians scored more lobsters frozen/processed as longest-lasting. When including rule breakers, there was no significant difference found between the American and Canadian subsets of data in terms of duration ratings ($p=0.77$). There was high variability in Canadian participants' rankings of lobstermen joining other fisheries, government assistance and bailout funds, and regulatory changes. On the other hand, there was very low variability with regards to American participants' rankings of the regulatory change response.

In terms of duration, clumpers tended to rank marketing to countries other than China higher than splitters. Greater variability was exhibited by the clumpers' ranked responses regarding lobstermen joining other fisheries and government assistance and bailout funds. None of the clumpers listed regulatory changes as a response in the duration exercise, and so that particular data is absent from Figure 3.7.D. There was no significant difference in duration scores between all participants including rule breakers and all participants excluding rule breakers ($p=0.99$). All of the rule breakers in the duration ranking exercise that could be reasonably included (of which there were 5) sorted their responses in a binary manner: short-term versus long-term. All of these binary scores were placed into the clumper category when included in the results, as multiple responses were ranked with the same value (Figure 3.7.D).

The combination of importance and duration Z-scores of the LSC responses to COVID-19 identified the most impactful factors contributing to this industry's resilience during the pandemic. Diversifying buyers, consumers cooking at home, shift to local markets, and more

lobsters frozen/processed were the most impactful across all respondents while harvesting less when the market is down, government assistance and bailout funds, lobstermen joining other fisheries, and regulatory changes were the least impactful (Figure 3.9.A). The responses which were most impactful ranged across all phases of the food system resilience action cycle while the least impactful responses were all from the absorb section of the cycle. American participants placed diversifying buyers, a shift to local markets, direct-to-consumer sales, a shift in consumer interface (other), more lobsters frozen/processed, and an increased use of social media for sales and marketing as most impactful and identified that harvesting less when the market is down, government assistance and bailout funds, lobstermen joining other fisheries, and regulatory changes were the least impactful responses (Figure 3.9.B). Canadian participants identified consumers cooking at home, more lobsters frozen/processed, lobstermen joining other fisheries, and marketing to countries other than China as most impactful and ranked regulatory changes and direct-to-consumer sales as least impactful (Figure 3.9.C).

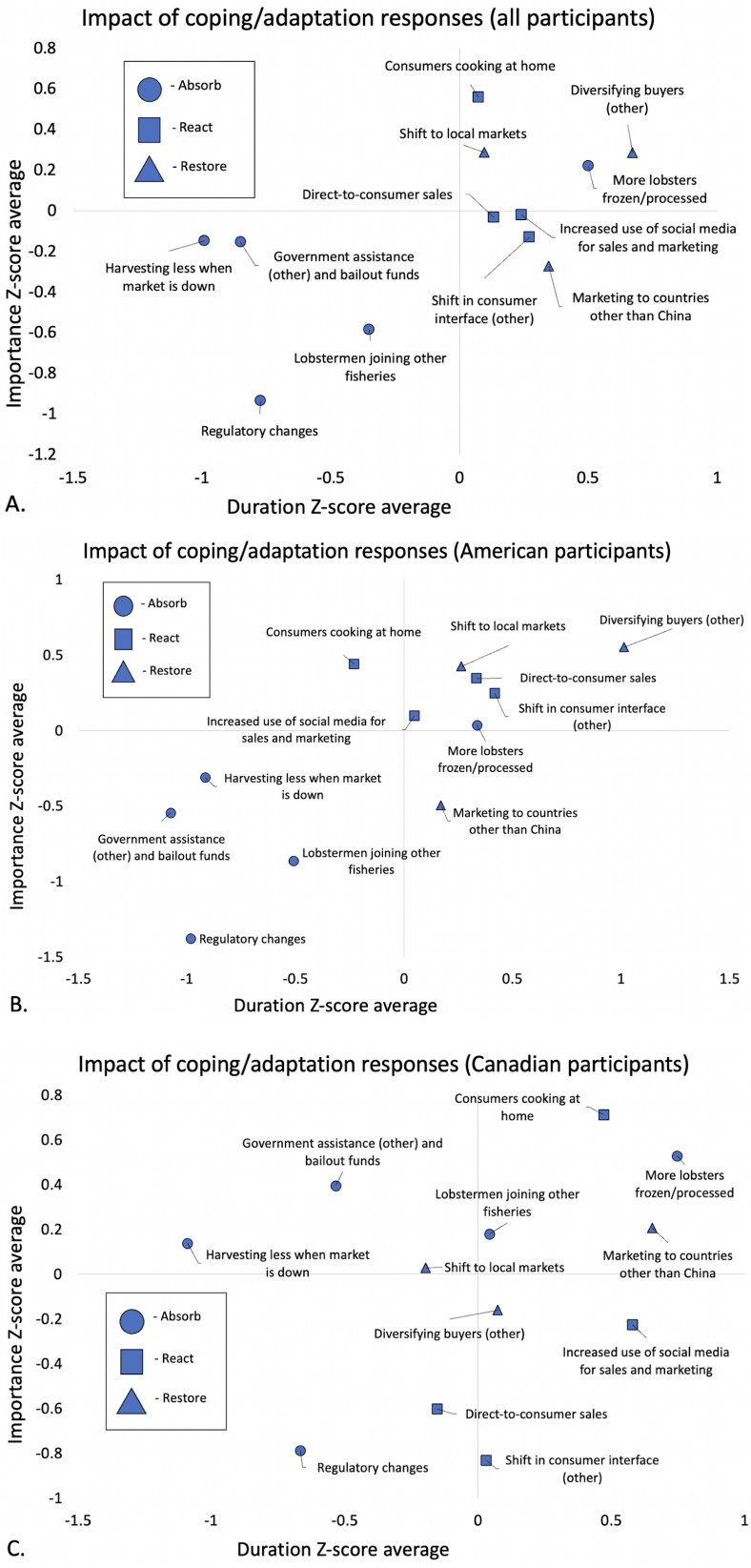

Figure 3.9. Overall impact of industry responses. Average Z-score ranking of the importance and duration of responses by the lobster supply chain to the COVID-19 pandemic. **A.** Responses from American and Canadian participants. **B.** Responses from American participants. **C.** Responses from Canadian participants.

3.3.7. Sources of uncertainty and compounding stressors

The pandemic disruption caused much temporary uncertainty, especially within the first year of the pandemic (Figure 3.10):

> I mean you remember being home during that time period, it's crazy, it was nuts, that was something that… I don't know anybody who has experienced anything like that, at least in their lifetime, that was unique. The whole world shut down. And when the whole world shuts down- that level of uncertainty was scary. We were all scared, are we going to be a business in two weeks, where the hell are our lobsters going to go, what am I going to do with all my traps, what am I going to do with my boat, what am I going to do with my house and my family, for that matter, like that was a scary, scary time and to see what's come out of that for our industry has been encouraging.

Although there is also some ongoing uncertainty due to the pandemic disruption, interviewees placed slightly more emphasis on ongoing uncertainty in the industry which is a result of non-pandemic issues. Non-pandemic issues included climate change, regulatory changes as a result of right whale entanglements and offshore wind projects, concerns about the future of the lobster stock, bait issues, and more (Figure 3.10).

Stressors are also a key part of the original food system resilience action cycle. In addition to the pandemic disruption, the industry also had to contend with external stressors (stressors unrelated to the pandemic disruption; Figure 3.11). The most commonly cited non-pandemic related stressor was right whale regulations with approximately 67% of interviews

mentioning it, followed by offshore wind at 48%, the trade war between the U.S. and China at 41%, and climate change at 37%.

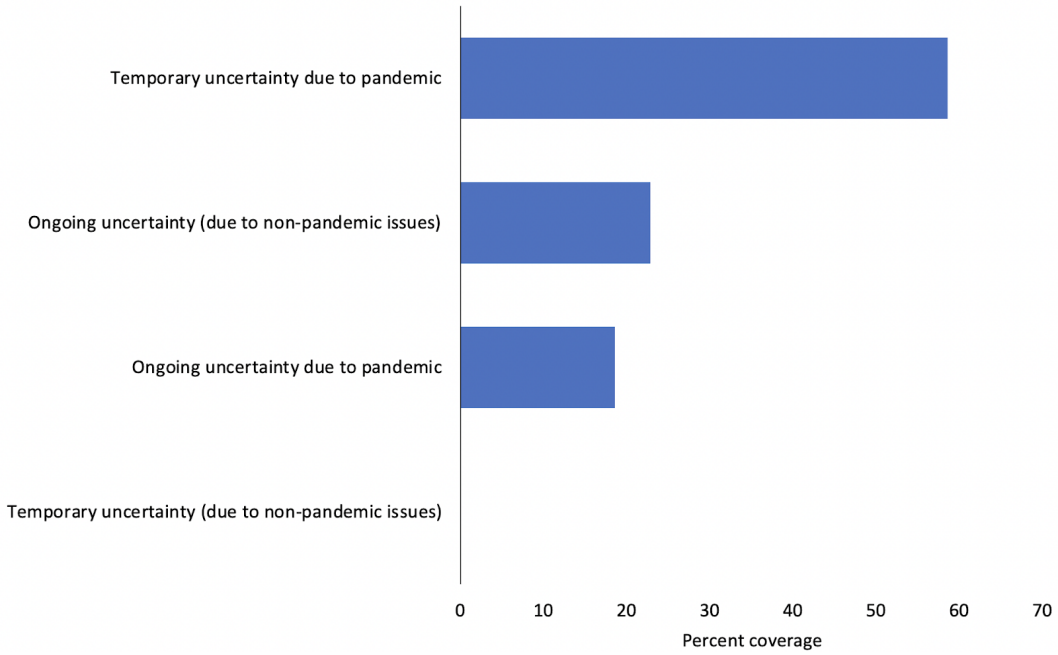

Figure 3.10. Sources of uncertainty for the industry. Prevalence of sources of uncertainty across all interviews (by percent coverage). Sources of uncertainty were categorized as either pandemic-related or non-pandemic issues.

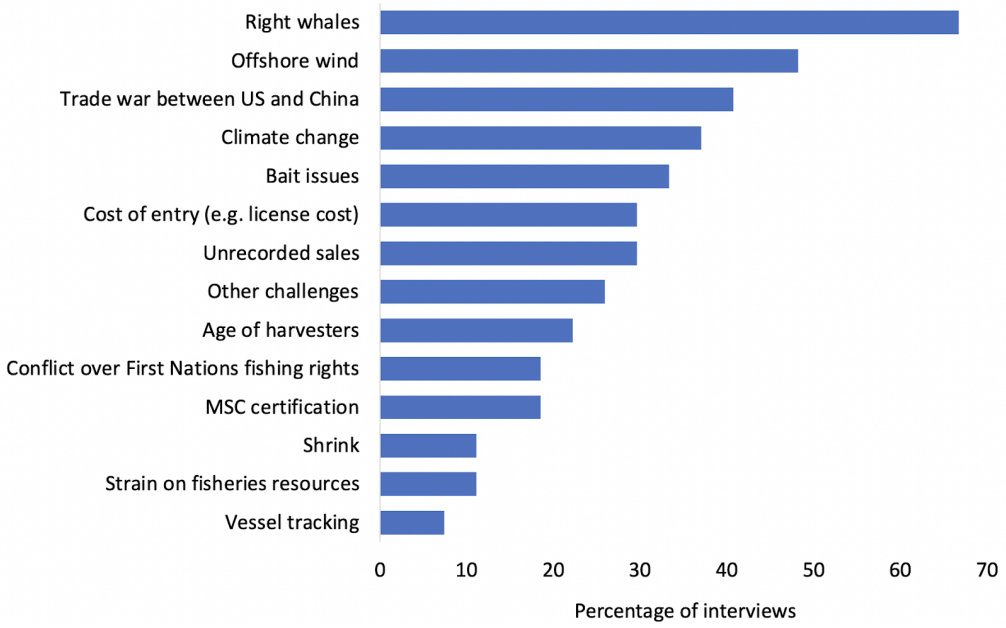

Figure 3.11. External sources of stress. The prevalence of external stressors (not pandemic-related) in the interview dataset sorted by percentage of interviews which mentioned each stressor.

3.3.8. Building resilience through disruptions

Although the pandemic was a source of challenges and uncertainty for the LSC, there were some positive outcomes from this disruption. These included an increase in stakeholder collaboration within the industry, opening of new markets for lobster products, and an increased awareness of, and demand for, local lobster. In the following two quotes, interview participants discuss strengthened relationships with other stakeholders which resulted from the pandemic disruption:

> I think, out of times of uncertainty like this, it certainly has strengthened relationships with a lot of our partners and our customers and they don't thrive if we don't thrive and vice versa, and I think just these challenging times really emphasize that.

> But generally it all worked out very well, I mean to me overall it showed that the sector works well in crisis and the sector came together and worked together, like I've never seen it. I think we learned a lot about each other. And I think those types of things are very good for the long term viability of a sector, to show that in crisis, we can work together when we have to. And it helps us work together better now, I feel like there's a much, much more collegial and collaborative environment in our sector today.

In addition to answering questions about the impacts of and responses to the pandemic disruption, formal interview participants were also asked about what resilience meant to them. Interview participants' views on the meaning of resilience can be found in Appendix J. In the next two quotes, participants discuss the ways in which disruptions have ultimately made the

LSC more resilient due to stakeholders being forced to find new outlets for lobster product, diversifying their markets:

> I think COVID in a lot of ways has been challenging for our industry, but our industry has done a good job of combating those challenges and finding the opportunities that are always present during challenging times and up until a couple months ago we were saying COVID has been the best thing that has happened to our industry because it forced us to do things differently. You know the same way the financial crash of 2008 did, the same way the ocean heat wave of 2012 did, but certainly COVID did that under much more extreme circumstances. We were forced to find new markets for our product, and then, when things turned around last summer, old markets came back and the new markets on top of that resulted in a huge amount of demand for our product which helped harvesters in the form of boat price almost doubling and just increasing the market for different lobster products.

> I guess the positive is the fact that retail- the retail market- it's a new- it's an expanded market. And I'll give you just an example of say this spring, where we had China that normally buys a lot of whole cooks right, China said well you know, pandemic's still here, we should be able to get a really good price, so they were negotiating very low prices and first thing you know, no problem, the U.S. just picked up the whole cooks. And one processor was telling me that my Chinese customer came back, said I want to buy now wherever the price is, and he said I'm sorry I've signed contracts, it's all promised. So just- the retail has been the big surprise and now what's happening is as the

food service industry is coming back, the market has expanded, which has caused prices to go up sky high.

The pandemic also resulted in increased consumer awareness about the availability of local seafood:

> There is still an awareness among the public, but is there an urgency? No. But at least we're not where we started in January of 2020 where people really on a whole, overall, are not looking into where their seafood is coming from nationally. Or regionally. [...] but COVID changed that. It changed that- if even 10% more people are thinking about where they're getting their seafood I'll take it. So COVID really did that for people.

3.4 Discussion

3.4.1 Multimethod approach

This work used a novel combination of deductive and inductive approaches: the coding method was shaped both deductively by theory and literature (mainly the food system resilience action cycle from Tendall et al. 2015) and inductively through the interviews themselves. Social media data analysis helped inform the questions posed to stakeholders in informal interviews. These processes along with the framework of the food system resilience action cycle cumulatively shaped the analysis methodology for the formal interviews. As the second pass through the Twitter data was occurring at the same time as formal interviews, these interviews further informed the methods of social media data analysis.

3.4.2. A comparison of data sources

Both datasets provided insights into the impacts of the pandemic disruption, but at different scales. The social media dataset was international in focus, and thus included mention of a greater number of trade partnerships than the interviews. Posts from the social media dataset generally focussed on the disruption of international trade over the course of the first year of the pandemic. The top several countries noted in the two datasets are generally the same, with a great amount of focus on the U.S., Canada, and China, though the social media dataset included Australia whereas the interview dataset did not. This is in part a result of the keywords used in TWINT, as they did not specify American lobster, but instead included any lobster species, such as spiny lobster. The high prevalence of China in the Twitter dataset is not just due to its being an important trade partner for the American lobster industry, but also because Chinese New Year was when impacts of the disruption were first felt by industry members. The interview dataset speaks to a finer scale of examination due to the focus of the interview questionnaire and background of participants. Although the calculations of percent coverage for the Twitter and interview datasets differ (as the former simply notes whether a topic was addressed in a given post, rather than the proportion of source content in each post), the difference in number of countries represented in each dataset still indicates a dissimilarity in geographic scope. The two datasets focused on different portions of the supply chain as well: the Twitter dataset put a greater focus on international consumers, such as China, whereas the interview dataset focused on the U.S. and Canada through the actions of harvesters, cooperatives, and dealers. Participants were not asked specifically about international trade partnerships (though some participants discussed this topic). The complementary spatial scopes of these two datasets indicate that this type of multimethod approach can more fully encapsulate the impacts of a disruption, as

globalization means that shocks do not just ripple across supply chain segments, but across borders as well.

The Twitter dataset could supplement the interview dataset with more information on the given topic of study, and could with some accuracy depict the responses of the industry to the pandemic disruption: the two datasets showed a great deal of agreement in terms of what responses to the pandemic disruption occurred within the lobster industry. It was rare for responses to be added by interview participants. However, the Twitter dataset could not as readily fill in the blanks regarding how long these responses may last and what other effects these responses may have on the industry. Industry stakeholders could address these issues in interviews, as well as what agreement or disagreement ensued over these responses between industry members. The learn/build robustness section of the food system resilience action cycle posits questions that are not answered by the Twitter dataset, but can be partially answered by interview participants: which of these responses may become permanent adaptations, and which responses inspire or result in new changes to the system.

3.4.3. Local support and diversified product pathways

The most impactful responses across all participants (as determined by the results of both the importance and duration ranking exercises) were diversifying buyers, consumers cooking at home, a shift to local markets, and more lobsters frozen/processed. Over 50% of participants agreed that these responses as well as marketing to countries other than China and using social media for sales and marketing were adaptations (long-term responses). These responses and others often occurred in conjunction with one another: as the pandemic caused an aversion to eating at restaurants, there was a shift to consumers cooking at home, ordering takeout, and

eating in the privacy of their own homes for the sake of their health. Instead of being channeled through restaurants, lobsters were sold through retail to reach these consumers. In the same vein as the ever-growing farm to table movement, lobster was marketed locally using social media and sold directly to consumers for them to cook at home (Iacono, 2013). More lobsters were also frozen or processed to meet this form of consumer demand, and overall, the way in which those selling lobsters engaged with those buying lobsters shifted (i.e. a shift in consumer interface).

Different segments of the LSC were linked via these grouped responses to the disruption. In this way, the strongest responses to the pandemic were those bred from collaboration amongst industry stakeholders. In response to the disruption, there was support for, and amongst, stakeholders at a local level as evidenced by increased marketing of lobster products, local demand, and direct-to-consumer sales. There was also a reliance on supportive business relationships, with one interview participant pointing out the importance of maintaining business partnerships (in addition to building new relationships). Closer collaboration is a means of building resilience which will also help avoid contentious responses, or maladaptations, to future disruptions. For example, increased collaborative involvement by industry members in influencing policy will lead to legislation that is perceived as beneficial by a greater number of stakeholders (Arnstein, 1969; Trachtenberg & Focht, 2005). Agreements or at least compromises can be reached amongst industry members in terms of best paths forward, for instance, in terms of government financial assistance and disbursement.

In addition to increasing collaboration, another important theme found in both datasets is diversifying into new markets in the face of disruptions. Diversifying buyers was a response done out of urgency and necessity in the height of the pandemic disruption. But the staying

power of these new markets has meant that with the return of other markets (such as restaurants) the price of lobster has remained high as the number of sales pathways has increased.

Participants were often concerned that local or domestic demand could not support the high volume of lobsters harvested in New England and Atlantic Canada. While this may always be the case, many of the responses discussed in this study can feed into each other and help build local or domestic demand for lobster products: more lobsters frozen/processed translates to products which are more accessible for the average consumer, and make it easier for consumers to continue the trend of cooking at home. Increased marketing, especially via social media, helps to build demand for new products and establish new product pathways. These responses together can make the LSC more robust, as a greater number of product pathways will aid in preventing industry shutdown in the face of future global disruptions like the COVID-19 pandemic (Hertel et al., 2021; Lim-Camacho et al., 2017; Pizzol, 2015). Even those responses which were short term may be utilized once again should the need arise.

3.4.4. Lobstermen staying in the fishery

Lobstermen joining other fisheries was viewed as the second least important response across all participants. Although this response was one which some participants noted may come in handy in the future and could increase resilience, it was not as applicable to the pandemic as a short-term disruption. One of the reasons for this is due to restrictions which prevent a quick pivot into another fishery. Some lobstermen are also honing their skills in other trades to serve as a fallback in case of troubled times in the lobster industry – this is represented in the added response of lobstermen joining other industries. However, this response, like lobstermen joining other fisheries, is not looked upon favorably when the industry is profitable with a high shore

price. If "lobster is king" as one participant so aptly asserted, there is no need to earn an income with other jobs, whether they're in other fisheries or other industries. High costs for entry, boats, and gear also mean a great investment into the industry which could also make a shift away from the fishery more difficult (Barnett et al., 2017; Johnson & Mazur, 2018).

3.4.5. Contention: a symptom of maladaptive responses

One question asked during interviews was whether any of the responses were contentious (whether some members of the supply chain liked them more than others). Although the responses which were contentious could still have been effective in some ways, the fact that they caused disagreement and conflict between stakeholders meant that they were also a maladaptation, as stakeholders working together through hardship plays a key role in the resilience of the industry. Tendall et al. emphasized that in order to build resilience within a system, the different segments of the system and their interactions must be well-understood (a "whole system perspective") (2015). To achieve this, stakeholders throughout the LSC must be involved and must collaborate with one another. As they were a hindrance to collaboration, contentious responses were shown to have the potential to be more harmful than helpful.

Government assistance and bailout funds was ranked as third shortest-lasting, and was viewed as a response that was inherently temporary as many of the financial assistance programs were designed to help stakeholders and industries only when they were in dire straits at the height of the pandemic disruption. Most participants didn't like the idea of government support, and often viewed it as unnecessary. There were participants that thought that their segment of the supply chain did not get the support it deserved, especially in comparison to another segment of the supply chain. This perspective, however, was not unique to any one segment of the supply

chain. Other types of financial assistance such as the PPP, the CARES Act, and unemployment were also noted to be contentious in addition to non-specified government financial assistance (which was found to be most contentious). This only emphasizes the controversial nature of financial assistance of any kind. Other issues also contributed to this response's low ranking: even those that did appreciate government assistance took issue with the amount provided or the slow timing of its disbursement. The overall dissatisfaction with government assistance as expressed by interview participants indicates an opportunity for improvement in the way in which assistance is provided to the industry during disruptions.

Harvesting less when the market was down or even delaying the season was contentious as some thought that changes to the season should only be made when it came to biological concerns about the lobster stock. In addition to that, some participants had financial concerns about a pause in fishing – they needed the income – whereas others could afford to wait to fish. This is where the cost of entry comes into play as a stressor: recent entrants to the fishery who had debt hanging over their heads were under more pressure to fish. Harvesting less when the market is down is a short-term response by its nature, as its necessity dissipates as long as the market is performing at a high enough level. It is also a response which is easy to implement, as it does not rely on changes in infrastructure and logistics, and only relies on the actions of one segment of the supply chain. The simple reapplication of this response in the face of disruption may be why less than half of the participants deemed it a coping response (seeing it instead as omnipresent and used whenever necessary).

The regulatory change response was ranked as second shortest-lasting amongst all participants, and is linked to harvesting less when the market is down via delays (i.e. these three codes were often used together to describe discussion around lobster fishing season delays).

Regulatory changes were ranked equally as a coping strategy and an adaptation strategy. This is likely due to the variability of how it was perceived: for example, some participants perceived it as a delay in the season (even if that decision came directly from fishery participants rather than members of the government), but some interpreted it as changes in international trade regulations, such as those which China may put into place. Generally, stakeholders wanted fewer regulatory changes in terms of fishing seasons and practices, and preferred changes only to be made to protect the lobster resource.

3.4.6. Differences between participant groups

Differences were found in the scoring between groups (Americans and Canadians, clumpers and splitters). None of these differences were significant, and the sample size of this study was low enough for results to not be representative of any given demographic. However, themes that arose within and between groups should be considered in future research with a larger sample size. Differences in both importance and duration of some responses were found between American and Canadian participants: the difference in scoring between direct to consumer sales, increased use of social media for sales and marketing, and a shift in consumer interface are likely because Canadian participants tended to see less opportunity in lobstermen selling directly to the consumer than American participants did. They didn't believe that their local demand, especially given a lower population in Atlantic Canada, could put a dent in what was being caught. That is also reflected in the data regarding the shift to local markets response. Although American participants ranked diversifying buyers as the longest-lasting response, Canadian participants ranked more lobsters frozen/processed as longest-lasting. This is likely due

to Canada's strong processing sector, which has historically had a greater capacity than its U.S. counterpart (Henry & Johnson, 2015).

Canadian participants found government assistance and bailout funds, lobstermen joining other fisheries, and regulatory changes to be more important than American participants did. However, high variability was also evident in the ranking of these responses by Canadian participants. The delays which occurred in Canada (e.g. 2 weeks in LFAs 23, 24 and 26 and 1 month in LFAs 36 and 37) are reflected in Canadian participants' slightly higher rating of that response and the regulatory change response (*Lobster Fishers, Processors Call for Delay of Spring Season | Globalnews.Ca*, n.d.; *Spring Lobster Season Delayed 2 Weeks Due to COVID-19 Concerns | Globalnews.Ca*, n.d.). American participants showed very low variability when it came to the low ranking of the regulatory change response. This may have been because season delays were more pertinent on the Canadian side of the border, while there was no comparable response for most stakeholders on the American side. There was low variability amongst participants in terms of regulatory changes; across all participants, scores indicated that these were not important in terms of responding to the pandemic disruption. This is likely because most participants either said that regulatory changes did not occur in response to the pandemic disruption or that any that occurred were ultimately unnecessary (e.g. fishing season delays). For those that found harvesting less when the market is down of little importance, it is likely because harvesters suspended fishing or fished less, but then in hindsight (due to the swiftly rising price of lobster) realized that they could have still gone fishing as usual. In addition, some participants said that at the time, there was nothing else to do but fish – harvesting less when the market is down was not a universal response by harvesters to the disruption, and was likely not necessary.

However, there was too much uncertainty at the time for stakeholders to have known that this would be the case.

Ranking orders also differed between the groups of splitters and clumpers. Splitters ranked diversifying buyers as more important than clumpers did, whereas clumpers ranked a shift to local markets and the increased use of social media for sales and marketing higher than splitters did. Clumpers also ranked marketing to countries other than China as having a higher duration than splitters did. The clumpers' ranking of lobstermen joining other fisheries and government assistance and bailout funds showed a high level of variability when compared with the splitters' ranking of these responses. The differences observed between clumpers and splitters are likely a result of the value of a given response increasing or decreasing on the basis of what it is being grouped with. As clumpers rated responses at the same level, it's possible that the level of importance of individual responses were influenced as a function of that practice. For example, clumpers ranked a shift to local markets and increased use of social media for sales and marketing higher than splitters; these responses were closely linked in their value to the industry as discussed above. The lack of inclusion of the regulatory change response by clumpers within the duration exercise is likely a result of the overall rarity of the response's inclusion by participants.

3.4.7. Sources of uncertainty and compounding stressors

In terms of sources of uncertainty, it's noteworthy that even though these interviews were geared towards the pandemic disruption in particular, non-pandemic issues often arose as topics of interest. The highest level of uncertainty (as determined by percent coverage of the formal interviews) arose temporarily from the pandemic, as the shutdown of markets and COVID

precautions meant a dearth of lobster product pathways. Despite the consternation caused by the pandemic (especially in its first year), non-pandemic issues ever so slightly outpaced the pandemic in terms of a source of uncertainty moving forward. This emphasizes that the pandemic disruption is a short-term shock (at least in comparison to other ongoing or future challenges which the LSC will have to face). Interviewees discussed external stressors which were causing strain on themselves and the supply chain as a whole. Some of these external stressors were the same issues which were noted as causing ongoing uncertainty in the industry: climate change and regulatory changes related to right whales and offshore wind were major concerns for participants.The trade war between the U.S. and China was also addressed as an external stressor, though it was not seen as negative by all stakeholders: while it was problematic for American stakeholders as some lost their customers in China, Canadian stakeholders were able to adopt those customers when the trade war occurred.

3.4.8. Building resilience through disruptions

Despite the ongoing problems caused by the pandemic, disruptions can lead to the overall strengthening of the industry. Solutions to temporary issues caused by the disruption can lead to a supply chain which is more prepared for the next shock, as infrastructure (both logistical and social) is built to allow for an increased number of lobster product pathways. The COVID-19 pandemic resulted in a diversification of markets as well as heightened demand for American lobster both locally and domestically. Although many of these new outlets for lobster cannot distribute the high volume which is normally harvested and handled by the LSC, they allow responses (e.g. direct-to-consumer sales) which can be put into play whenever a disruption

occurs. In addition, beyond marketing to build awareness amongst consumers, creating new value-added products will increase consumer exposure to lobster as a protein source.

The American lobster industry has demonstrated resilience time and time again, and therefore, understanding its responses to the pandemic can assist stakeholders in finding the best pathway forward in the face of future disruptions. This study observed which responses to the pandemic were most important and long-lasting in the eyes of the LSC stakeholders, and also noted similarities and differences in findings between social media and interview datasets. Results of the study fit smoothly into the template of the food system resilience action cycle suggested by Tendall et al. (2015). However, this study also indicates that maladaptations could be included in that theoretical framework. The original food system resilience action cycle does note the existence of internal stressors, but does not further address maladaptations, or responses that ultimately undermine the resilience of a given food system. These maladaptations cause a problem described by Carpenter et al.: "resilience […] achieved in one time period at the expense of resilience in a succeeding period" (2001). One such maladaptation that occurred during (and also outside of the pandemic disruption) is unreported sales. These types of sales inhibit the ability to understand the value of the industry and where lobster product is going. The shift to remote engagement between stakeholders and their representatives was also problematic for some industry members; while some could more easily engage with those who were far away, others found it more difficult to contribute their perspectives to the policy-making process and to access government officials.

The culture of secrecy that exists within the industry (and which was referenced in the scoping interviews) also means that there is a limited public understanding of how the supply chain operates once lobsters are transported beyond the dock. Attempting to overcome the

culture of secrecy which exists in the LSC will lead to a more unified and effective industry. Instead of a simple step in a linear supply chain, dealers seem to be a multi-purpose and centralized hub (they may be buyers, exporters, and processors) that require more comprehensive knowledge of the entire supply chain in order to function. Not all participants have this level of knowledge about the supply chain beyond the segment of which they themselves are a part – for example, cooperative members and harvesters don't need to be concerned with the final destination of their lobster products. But a culture of secrecy and division between segments of the supply chain can cause tension and diminish learning opportunities which could otherwise lead to greater robustness in the system. Stakeholders' hesitation to speak with researchers due to concerns about resultant regulatory changes can also make it difficult to conduct research on the LSC. Stemming the flow of information diminishes learning, which is an integral part of the food system resilience action cycle: the learning stage of the cycle fortifies food systems against future disruptions, and its absence reduces opportunities for increased resilience.

Due to the dependency of New England and Atlantic Canada on the LSC, continued research on its resilience in the face of shocks is essential (Steneck et al., 2011). Although some responses to the disruption may become permanent fixtures in the industry, many of the impacts of the pandemic were temporary. In comparison to other challenges such as climate change and regulatory changes related to right whales or offshore wind energy, the COVID-19 pandemic disruption may be viewed as a short-term, albeit far-reaching, disruption. This disruption is nonetheless a useful case study for the observation of the resilience of the LSC.

3.4.9. Study limitations

As this study was designed and carried out during the COVID-19 pandemic, initial plans to travel for in-person interviews were altered to safeguard the health of the participants and the interviewer. Although meeting over Zoom can make interviews more streamlined and efficient, this format may make the study less accessible to some potential participants. For example, if those potential participants are not active online, and are not easily reached via email – the main mode of communication used to connect with participants – then it would be more difficult to include them in the study. In addition, the potential participant's schedule may not be conducive to engaging in a lengthy interview during normal work hours. When possible, engagement with stakeholders in-person would aid in creating a greater pool of participants, as those with a limited online presence could engage with the researcher and also recommend others, further bolstering the snowball sampling technique.

Participants were not found from each segment of the supply chain as was originally the goal. Future studies would benefit from inclusion of stakeholders from more segments of the supply chain, including those involved in grocery and restaurants. This study also had a relatively small pool of interviewees, such that results may be suggestive of a given demographic but further data collection would need to be done to ascertain their validity for a given population.

Another limitation of this study is the usage of only the keywords "lobsters" and "coronavirus" during the social media datascraping phase. Further queries with other keywords would have collected a wider range of results pertaining to this disruption. Notably, more terms could have been used (e.g. "COVID-19" or "pandemic" instead of "coronavirus," and "seafood"

instead of “lobsters”). Future research with social media datasets should take more search terms into account for a more thorough exploration of a given topic.

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APPENDICES

APPENDIX A: ANOVA TABLES FOR TEMPERATURE AND ION SUPPLEMENTATION TREATMENTS

Table A.1.A. ANOVA table for the effect of temperature and calcium concentration on individual lobster weight change over the course of trials 2-11.

Source	DF	Sum of Squares	Mean Square	F Ratio	Prob > F
Temperature	1	145.17		1.89	0.17
Calcium conc	1	1438.30		18.70	0.0001*
Temperature*Calcium conc	1	212.50		2.76	0.099
Model	3	1790.09	596.7	7.7594	
Error	135	10381.44	76.9		
Total	138	12171.53			<.0001*

Table A.1.B. ANOVA table for the effect of temperature and calcium concentration on lobster weight (tank average) over the course of trials 2-11.

Source	DF	Sum of Squares	Mean Square	F Ratio	Prob > F
Temperature	1	22.76		0.50	0.48
Calcium conc	1	334.69		7.43	0.010*
Temperature*Calcium conc	1	65.94		1.46	0.23
Model	3	435.75	145.25	3.2235	
Error	34	1532.05	45.06		
Total	37	1967.80			0.035*

Table A.2.A. ANOVA table for the effect of temperature and calcium concentration on individual lobster soft spot average over the course of trials 2-11.

Source	DF	Sum of Squares	Mean Square	F Ratio	Prob > F
Temperature	1	222.39		4.61	0.034*
Calcium conc	1	8.57		0.18	0.67
Temperature*Calcium conc	1	92.02		1.91	0.17
Model	3	313.29	104.43	2.16	
Error	129	6228.71	48.29		
Total	132	6542.00			0.096

Table A.2.B. ANOVA table for the effect of temperature and calcium concentration on lobster soft spot average (tank average) over the course of trials 2-11.

Source	DF	Sum of Squares	Mean Square	F Ratio	Prob > F
Temperature	1	60.61		3.62	0.066
Calcium conc	1	1.34		0.08	0.78
Temperature*Calcium conc	1	19.44		1.16	0.29
Model	3	80.46	26.82	1.60	
Error	34	568.73	16.73		
Total	37	649.19			0.21

Table A.3.A. ANOVA table for the effect of temperature and calcium concentration on difference in number of behavioral indicators expressed by individual lobsters over the course of trials 2-11.

Source	DF	Sum of Squares	Mean Square	F Ratio	Prob > F
Temperature	1	2.00		1.14	0.29
Calcium conc	1	2.86		1.63	0.20
Temperature*Calcium conc	1	0.40		0.23	0.63
Model	3	4.90	1.63	0.93	
Error	135	236.22	1.75		
Total	138	241.12			0.43

Table A.3.B. ANOVA table for the effect of temperature and calcium concentration on difference in number of behavioral indicators expressed by lobsters (tank average) over the course of trials 2-11.

Source	DF	Sum of Squares	Mean Square	F Ratio	Prob > F
Temperature	1	0.49		0.81	0.37
Calcium conc	1	1.13		1.88	0.18
Temperature*Calcium conc	1	0.12		0.20	0.66
Model	3	1.56	0.52	0.87	
Error	34	20.40	0.60		
Total	37	21.97			0.47

Table A.4.A. ANOVA table for the effect of temperature and calcium concentration on individual lobster Brix measurement.

Source	DF	Sum of Squares	Mean Square	F Ratio	Prob > F
Temperature	1	0.24		0.42	0.52
Calcium conc	1	1.44		2.57	0.11
Temperature*Calcium conc	1	0.17		0.30	0.59
Model	3	1.84	0.61	1.09	
Error	108	60.52	0.56		
Total	111	62.36			0.36

Table A.4.B. ANOVA table for the effect of temperature and calcium concentration on Brix measurement (tank average).

Source	DF	Sum of Squares	Mean Square	F Ratio	Prob > F
Temperature	1	0.052		0.23	0.64
Calcium conc	1	0.31		1.35	0.25
Temperature*Calcium conc	1	0.062		0.27	0.61
Model	3	0.44	0.15	0.63	
Error	27	6.24	0.23		
Total	30	6.68			0.60

Table A.5. ANOVA table for the effect of temperature and calcium concentration on change in Brix measurement over the course of simulated transportation trials.

Source	DF	Sum of Squares	Mean Square	F Ratio	Prob > F
Temperature	1	0.22		1.10	0.32
Calcium conc	1	0.0010		0.0050	0.94
Temperature*Calcium conc	1	0.13		0.66	0.43
Model	3	0.96	0.32	1.59	
Error	11	2.23	0.20		
Total	14	3.19			0.25

APPENDIX B: TWITTER DATASET CODING TREE AND RULES

Table B.1. Categories used for Twitter dataset coding.

Segment of the LSC	Lobster Type	Location	Topics	Relevance*	Relevance Type
Harvester	American	City**	Price	Tweet	Impact
Co-op	European	Region/area**	International Trade	Article	Coping
Dealer/wholesalers**	Spiny/rock	State/Province**	Tariffs/trade war**		Adaptation
Processor	Other/unknown	Country	Political		
Distribution/exporters**		Continent	Government action		
Retail			Sales/demand		
Consumer			Bait**		
Marine supplier**			Regulations		
			Food Safety		
			Health		
			Science		
			Harvest/landings		
			Supply		
			Holidays/special events**		
			Dining out**		
			Tourism**		
			Climate Change		
			Marketing/promotion		
			Right whales		
			Food insecurity		
			Economic struggle		
			Aquaculture		
			Social Media		
			Alternatives to live lobster		
			Building local or domestic markets**		
			Direct to consumer sales**		
			Cooking at home		
			Delivery/takeout**		
			Conspiracy (content or news source)**		
			Luxury item perception**		

*Marked if unrelated
**Marked if added or modified in second pass

Table B.2. Twitter dataset coding rules.

Harvester	Any mention of a harvester or lobsterman
Co-op	Any mention of a lobstering cooperative
Dealer	Any mention of a dealer or wholesaler
Processor	Any mention of a processor
Distribution/exporter	Any mention of lobster product transport (e.g. plane or truck), exporters
Retail	Any mention of lobster sales (grocery or restaurants)
Consumer	Any mention of those who buy lobster products (at the end of the supply chain, final consumer (the ones eating the product))
Marine supplier	Any mention of marine suppliers (e.g. boat builders)
Lobster types	Types of lobster described, including American, rock lobster, European, or unknown (unidentified in post)
Location categories	Split up by city, state/province, etc. Countries are also included for each smaller location mentioned, such that a graphic of countries included could be created.
Location - region	Other types of areas (other than cities, states/provinces, etc.), e.g. bays
Location - countries	All countries mentioned in relation to the lobster industry
Price	Any mention of lobster or lobster product price
International trade	Any mention of international trade
Tariffs/trade war	Any mention of the US/China trade war which began in 2018
Political	Political commentary - e.g. criticism of a given politician
Sales/demand	Any mention of lobster sales, demand for lobster
Bait	Any mention of bait (e.g. the “bait crisis”)
Regulations	Any mention of regulations or regulatory changes
Food safety	Any mention of food safety or concerns about food safety
Health	Any mention of health issues (e.g. measures taken to curb the spread of COVID-19, reach of the virus)
Science	Any mention of scientific study
Harvest/landings	Any mention of harvesting or amount of landings
Supply	Any mention of the supply of lobsters (e.g. a glut)
Recreation - Holidays/special events	Any mention of holidays (e.g. Chinese New Year) or special events during which lobster is enjoyed (e.g. anniversaries)
Recreation - dining out	Any mention of dining out/eating at restaurants
Recreation - tourism	Any mention of tourism
Climate change	Any mention of climate change
Marketing + promotion	Any mention of marketing and promotion of lobsters

Table B.2 Continued

Right whales	Any mention of right whales or right whale regulations
Food insecurity	Any mention of food insecurity (e.g. a fisherman not able to feed his family)
Economic struggle	Any mention of economic struggle. Includes economic hardship and turning to other sources of income
Aquaculture	Any mention of aquaculture
Social media	Any mention of the usage of social media to promote lobster sales, or an actual post on social media promoting lobster sales
Alternatives to live lobster	Any mention of alternatives to selling lobster live, e.g. lobster frozen or otherwise processed
Building local or domestic markets	Any mention of building local or domestic markets
Direct to consumer sales	Any mention of selling lobster directly to consumers (e.g. a lobsterman selling to consumers in a parking lot or off of a boat) but also includes other shortcuts in the supply chain
Cooking at home	Any mention of consumers cooking lobster at home
Delivery	Any mention of delivery from a restaurant
Conspiracy (content or news source)	Either conspiracy content or content from a conspiracy source
Luxury item perception	Any mention of lobster as a luxury item, lobster being treated as a luxury
Unrelated	Checked if content is unrelated to the topic of this study
Impact	Mention of impact of the pandemic on the lobster industry
Coping	Short-term changes by those involved with the industry in response to the pandemic
Adaptation	Long-term changes by those involved with the industry in response to the pandemic
Description	Includes notes about post, quotes from news article (sometimes entirety of article)
Original news source vs who posted it	Original news source that produced the article, vs. another news source that reposted it

APPENDIX C: LETTER TO PARTICIPANTS

Letter to participants

Hello,

Thank you for agreeing to participate in this study regarding the effects of the COVID-19 pandemic on the American lobster supply chain. My name is Nicole Orminski—I am a graduate student at the University of Maine and I will serve as the principal investigator in this study, and will be conducting interviews and analyzing the data as a part of the thesis work for my Dual Master's program in Marine Biology and Marine Policy. The faculty sponsor who will be supervising my research is Dr Joshua Stoll. He is an Assistant Research Professor of Marine Policy at the School of Marine Sciences (University of Maine) who has worked on multiple projects involving human subjects, including ongoing projects related to coastal community sustainability, adaptive capacity among fishers, and ecosystem-based fisheries management. We are aiming to complete these stakeholder interviews by the end of January 2022. Each interview should take 1.5-2 hours to complete.

In this packet you will find materials which will be used throughout the interview, including a blank timeline that will be filled out in the first part of the interview, an envelope with two pre-made timelines, and an envelope of notecards with different coping/adaptation strategies from the data as well as extra notecards for other responses which will be utilized in an exercise in the second part of the interview. A printed version of the survey questions has also been included, as well as an informed consent form.

We are interested in learning about the ways in which the American lobster supply chain has been impacted by the COVID-19 pandemic as well as the ways in which it has responded, both through short- and long- term methods (coping and adaptation mechanisms, respectively). You do not need to complete any part of this questionnaire on your own—all parts of the interview will be conducted under the guidance of the principal investigator. Participating in the interview, sorting/ranking exercises, and survey indicates consent.

For more information about the study please see the attached consent form. If you have any questions, please feel to contact us. Your interview time and date are listed below. If that time no longer works, please let us know as soon as possible.

Thank you very much for your time and for sharing your knowledge with us. Sincerely,

Nicole Orminski

Umaine Graduate Student Researcher (248)238-6289 nicole.orminski@maine.edu

Interview Time & Date:_____

APPENDIX D: SURVEY QUESTIONS

Survey questions

Questions 1-6 will be asked at the start of the interview. Questions 7-8 will be asked at the end. You will discuss these questions with the principal investigator during the interview—there is no need to write down your responses on this page.

Table D.1. Survey questions

ID	Question	Type	Demographic	To evaluate perspective on the state of the fishing industry and its role in different regions of the state.
1	How are you involved (either directly or indirectly) in the lobster industry?	Multiple choice	1	
	Harvester			
	Family relationship			
	Researcher			
	Technical assistance provider			
	Association / Trade organization / Lobbyist			
	Manager / Policy maker			
	Non-profit			
2	How many year(s) that you have been involved in the lobster industry?	Short	1	
	Where do you have the most knowledge about the lobster industry?	Multiple choice	1	1
	Eastern, Maine			
	Midcoast, Maine			
	Western, Maine			
	Statewide			
	Other (Please specify)			
	Is your knowledge of the lobster fishery based on experiences:			

Table D.1 Continued

	Inshore			
	Offshore			
	Both			
3	What THREE words best describes how you feel things are going in the lobster industry right now?	Short		1
	Why?	Long		
4	On a scale from 1 to 10, with 1 being the best you can remember and 10 being the worst, how would you score the overall state of the lobster industry right now?	Rank		1
5	On a scale from 1 to 10, with 1 being the best you can remember and 10 being the worst, how would you score the future of the lobster industry in 5 to 10 years?	Rank		1
6	What does resilience in the lobster industry mean to you?	Long		1
7	Is there anything else that you would like to add?			
8	Are there other people who you would recommend that we interview?			

APPENDIX E: INFORMED CONSENT FORM

Informed Consent Form for Participation in a Research Study

You are invited to participate in a research project being conducted by Nicole Orminski, a graduate student at the University of Maine advised by Joshua Stoll, faculty at the University of Maine School of Marine Sciences.

The purpose of the research is to:

• Understand the effects of the COVID-19 pandemic on the American lobster supply chain

• Understand the responses to the disruption by stakeholders

• Establish a better understanding of the resilience of the lobster industry and its ability to cope with, adapt to, and learn from disruptions

You were identified for this study by your engagement in the American lobster industry. You must be at least 18 years old to participate.

What Will You Be Asked to Do? If you decide to participate, you will be asked to participate in an interview which includes timeline and pile sorting exercises, open-ended questions, and a survey. The interview will take approximately 1 to 2 hours. You will receive an information packet which will include the following: a blank timeline that will be filled out in the first part of the interview, an envelope with two pre-made timelines, an envelope of notecards with different coping/adaptation strategies from the data, and extra notecards for other responses which will be utilized in an exercise in the second part of the interview. A printed version of the survey questions has also been included, as well as an informed consent form.

Interview:

- Please take digital photos of your timeline figures and sorted/ranked piles at the end of your interview using your cell phone camera. You can text the photos to 248-238-6289 or email them to nicole.orminski@maine.edu .
- The interview will take place over the phone or via Zoom and with your permission will be audio recorded.

Sample questions—amongst others, you will be asked questions like the following:

1. What were the impacts of the pandemic on the industry? How did they change through time?
2. How did the fishermen, dealers, policymakers, and others respond to the impacts?

3. Which adaptations have lasted into 2021? What if any impacts do you still see today?

Risks: Except for your time and inconvenience, there are no risks to you from participating in this study.

Benefits: There are no direct benefits to you for participating in the mapping study. However, this research will contribute to a greater understanding of the resilience of the American lobster supply chain. This information is integral as the industry continues to face both short- and long-term challenges.

Confidentiality: All of your responses will be kept confidential. Digital data (audio recordings, pictures of interview figures, transcripts) will be kept on a password-protected laptop. Audio recordings of the interview will be downloaded to the password-protected laptop and then deleted off of Zoom (if Zoom is the platform through which you are interviewed). Recordings will be deleted from Zoom and the handheld recorder within 48 hours. Recordings and pictures will be kept on the principal investigator's computer for up to three months after the interview (until the end of March 2022 at latest). Contact information will also be stored on the password protected laptop and will be deleted by the end of March 2022. The transcripts will be kept indefinitely and be part of the faculty sponsor's long-term archive of social-ecological system change in the Gulf of Maine. Your name or other identifying information will not be reported in any publications.

Voluntary: Participation is voluntary. If you choose to take part in this study, you may stop at any time. You may skip any questions you do not wish to answer.

Contact Information: If you have any questions about this study, please contact Nicole Orminski at nicole.orminski@maine.edu or 248-238-6289. You may reach the project's faculty advisor at the University of Maine, Joshua Stoll at Joshua.stoll@maine.edu or at (207)581-4307. If you have any questions about your rights as a research participant, please contact the Office of Research Compliance at the University of Maine at 207-581-2657 (or email umric@maine.edu).

APPENDIX F: INTERVIEW CONTENTS

Interview contents

Introductory script for interview

Hello [NAME],

Thank you again for participating in our study to help us learn about the effects of the COVID-19 pandemic on the American lobster industry. My name is Nicole Orminski, I am a graduate student at the University of Maine and the principal investigator in this study, and will be conducting interviews and analyzing the data as a part of my thesis work for my Dual Master's program in Marine Biology and Marine Policy. My faculty sponsor, who will be supervising my research, is Dr. Joshua Stoll, an Assistant Research Professor of Marine Policy, School of Marine Sciences at the University of Maine, who has worked on multiple research projects involving human subjects, including ongoing projects related to coastal community sustainability, adaptive capacity among fishers, and ecosystem-based fisheries management.

We have a few things we need to go over before we get started. First, your responses will be kept confidential. Your name or other identifying information will not be reported in any publications.

Before we begin, please take a moment to go to a private and quiet space if you have not already done so. To protect confidentiality, please do not take screenshots or record this session on your own device.

Second, do you give us permission to record this interview? I will delete the recording off of Zoom but will retain the audio from the interview on my own password-protected computer.

Before we begin, please feel free to open up your interview packet to view its contents if you have not already done so. However, please do not open the envelope marked "timelines" until I ask you to do so later in the interview. This interview will begin with six questions from the survey page included with your interview packet. Following the discussion of those questions, you will be invited to construct a timeline of the significant events in the lobster industry since the start of the COVID-19 pandemic. Upon completion of the timeline, I will ask you to describe how you constructed and organized your timeline, and will then ask you a series of questions about this time period, using both your timeline and ones of my own making.

Next, we will use pile sorting and ranking exercises to rank the importance of different industry adaptation strategies. You will use notecards with different coping/adaptation strategies from the data (these have been provided in the interview packet). I will ask you to rank these mechanisms from most to least important. We will then repeat this experience by asking you to rank the coping/adaptations strategies based on how long they lasted during the pandemic disruption period. I will then ask you to walk me through your ranking process and results. Finally, I will ask you a series of open-ended questions related to these industry responses.

The interview will conclude with a couple more survey questions. You do not have to write these answers down—I will take note of your responses on my computer.

Do you have any questions?

We will start recording now and move on to the interview.

Interview
Part 1: Respondent generated timeline

Instructions: You are invited to construct a timeline of the significant events in the lobster industry since the start of the COVID-19 pandemic. If you ask for further clarification about the structure and content of the timeline, I will restate the general instructions without offering specific guidance to avoid influencing your timeline.

Materials: You will be supplied with a blank timeline (this will be included in your interview packet) and given 15-20 minutes to complete the task.

Questions: Upon completion of the timeline, I will ask you to describe how you constructed and organized your timeline. As part of this line of questions, I will ask you to respond to the following questions:

1. When did you first hear about COVID-19? Was there a specific moment when you realized that the pandemic would have an impact on the industry?
2. What were the impacts of the pandemic on the industry? How did they change through time?
3. How did the fishermen, dealers, policymakers, and others respond to the impacts?
4. Which adaptations have lasted into 2021? What if any impacts do you still see today?

After we review your timeline, you will open the envelope containing two timelines which I developed using Twitter data from the first ten months of the pandemic. One timeline will reflect U.S. events, the other will represent Canadian events (see sample figures below).

You will be asked the following questions:

1. What stands out to you as being similar or different about this timeline and the one you created?
2. Is there anything on this timeline that you think doesn't belong or is out of place? Why?
3. Are there any additional events which you remember happening during this time frame which should be included?
4. Ex-vessel price is charted behind the timeline. Are there other events (unrelated to the pandemic disruption) that had an impact on price during this time period?

Part 2: Resilience action cycle (pile sort/ranking exercises and open-ended questions)

Instructions: You will use pile sorting to rank the importance of industry adaptation strategies.

Materials: You will use notecards with different coping/adaptation strategies from the data (these have been provided in the interview packet). Please rank these mechanisms from most to least important. You can remove any that you do not think occurred. There will also be extra notecards for you to write other responses which you might think of that aren't already included. Finally, I will ask you to walk me through your ranking process and results.

We will repeat this experience by asking you to rank the coping/adaptations strategies based on how long they lasted during the pandemic disruption period. Again, I will ask you to walk me through your ranking process and results. We will also discuss the following open-ended questions:

Open-ended questions:

1. Which responses haven't been represented here?
2. Which of these responses (if any) do you expect to become a permanent part of the way the industry works?
3. Which responses were contentious (some members of the industry liked them more than others)?

IF harvester:

1. When this disruption occurred, did you take part of any of these listed strategies (e.g. direct to consumers)? Or any others?
2. If you did adopt new strategies, which will you be continuing to use moving forward?

IF dealer/exporter:

1. How did your company's operations change over the course of the disruption? E.g. were there shutdowns, layoffs? Were any of the changes made permanent, or were they temporary? What impacts are you still seeing on your day-to-day operations, if any?
2. Some lobstermen shifted to new strategies (e.g. selling direct to consumers) during the disruption period. To what extent did this impact your operations? Did you have to make changes due to lobstermen's (or other stakeholders') new methods of sales?

IF grocers/restaurants:

1. How did the variety of lobster products offered in your establishment change over the course of the disruption? Are there any products that you have since stopped selling, or any that you have newly added?
2. Were any of the business relationships you have with your vendors disrupted over the course of the pandemic? How so?
3. How did your company's operations change over the course of the disruption? E.g. were there shutdowns, layoffs? Were any of the changes made permanent, or were they all temporary? What impacts are you still seeing on your day-to-day operations? (same question asked to dealers/exporters)

IF government:

1. During this time period, countries around the world temporarily altered fisheries regulations to shield stakeholders from the worst effects of the disruption. Which regulatory changes or government actions do you think worked best?
2. Are there government actions or regulatory changes that you think should be implemented moving forward to make the supply chain more resilient? Or were temporary measures sufficient (e.g. easy enough to implement and effective enough to help stakeholders) such that permanent changes are not necessary?

At this time, please take pictures of your completed timelines and sorted/ranked piles and send them to me at my phone number (248)238-6289 or my email address Nicole.orminski@maine.edu. These pictures will be saved on the researcher's computer for up to three months (until the end of March 2022 at latest).

APPENDIX G: AMERICAN AND CANADIAN TIMELINES

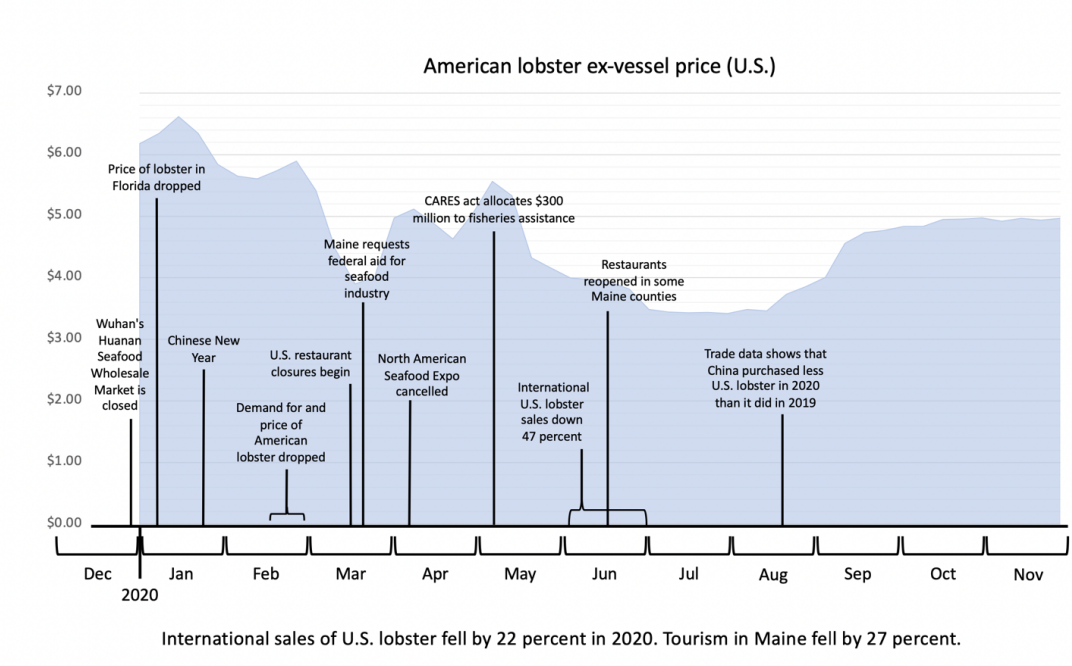

Figure G.1. American timeline.

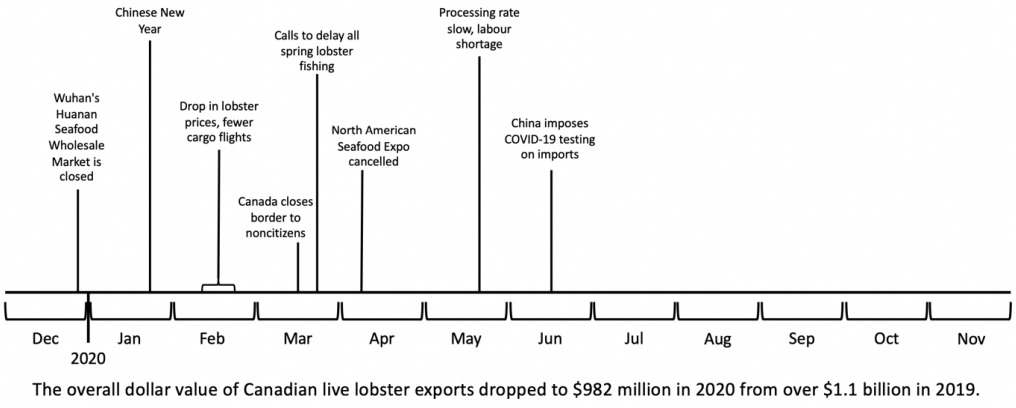

Figure G.2. Canadian timeline.

APPENDIX H: LIST OF RESPONSES TO PANDEMIC DISRUPTION

These responses were provided on separate notecards (one response per notecard) to be ranked by interview participants. Participants were also provided with 13 blank notecards such that they may write in responses note included in this list. Interview materials were initially mailed in a packet to participants, but were later sent digitally through e-mail due to slow mailing times.

1. More lobsters frozen/processed
2. Harvesting less when market is down
3. Lobstermen joining other fisheries
4. Government assistance (other)
5. Regulatory changes
6. Bailout funds
7. Consumers cooking at home
8. Direct-to-consumer sales
9. Increased use of social media for sales and marketing
10. Shift in consumer interface (other)
11. Marketing to countries other than China
12. Shift to local markets
13. Diversifying buyers (other)

APPENDIX I: INTERVIEW DATASET CODING TREE (IN LIST FORMAT)

Codes

Shock
- Access to markets
- Demand
    - Domestic
    - Falling
    - High
    - International
    - Local
    - Low
    - Rising
- Economic struggle and impacts on operations
    - Effects on shipping
    - Inflation of operating costs
        - Bait
        - Gas
        - Gear
        - Packing materials
    - Labor shortage
        - Temporary foreign workers
    - Layoffs
    - Shortage of materials
    - Shutdowns (not as a COVID precaution)
    - Wages
        - Decreasing wages
        - Increasing wages
- Ongoing uncertainty due to pandemic
- Temporary uncertainty due to pandemic

Absorb
- Change in product pathway
    - More lobsters frozen or processed
- Government assistance during pandemic
    - CARES Act
    - Extra money on the pound for lobster (given to lobstermen)
    - Other (financial)
    - Other (non-financial)
    - PPP
    - Unemployment
- Harvest
    - Fishing effort (other)
    - Harvesting less when market is down

- Harvester occupation
    - Lobstermen already participating in other fisheries
    - Lobstermen downsizing
    - Lobstermen joining other fisheries
    - Lobstermen joining other industries
    - Lobstermen leaving the fishery
- Landings
    - Higher catch or volume
    - Lower catch or volume
- Regulatory changes
- Seasonality
    - Delay

React

- Shift in consumer interface
    - Consumers cooking at home
    - Direct to consumer sales
    - Marketing (other)
    - Marketing to countries other than China
    - Social media for sales and marketing

Restore

- Change in product pathway
    - Diversifying buyers or markets
    - Maintaining existing buyers or markets
    - New products
        - Other species
    - Shift to local or domestic markets
        - Talk of untapped markets
- End markets
    - Africa
    - Asia
        - China
            - Chinese New Year
        - India
        - Japan
        - Korea
        - Singapore
        - Vietnam
    - Casinos
    - Cruise ships
    - E-commerce
    - Europe
        - Italy
    - Mexico
    - Middle East

- New Zealand
- North America
    - Canada
        - New Brunswick
        - Nova Scotia
        - PEI
    - US
        - Maine
        - Massachusetts
        - New Hampshire
- Restaurants
    - Take-out or delivery
- Retail (grocery)
- South America

Learn or build robustness

- Adaptation strategy or long-term
- Build resilience
    - Increase in storage capacity
- Coping strategy or short-term

State of the industry

- Business as usual
- Canary in the coal mine
- Co-op membership
- COVID-related topics
    - COVID precautions (e.g. masking, shutdowns, social distancing)
    - How the industry fared overall
    - New variant
    - Number of COVID cases
    - Positive outcomes of pandemic
    - Shift to remote
        - Access to government officials
        - Accessibility (internet)
    - Vaccines
- Effect of politics
    - On international trade issues
    - On pandemic response
- Live vs. processed pathway comparison
- Lobster stock
    - Quality of lobster
- Luxury item perception
- Mental health of industry participants
- Price of lobster
    - Falling
    - High

        - Low
        - Rising
- Province or state relationship or comparison
- Recreation or holiday
- Scientific sampling or reporting
- Stakeholder collaboration
    - Stakeholders working together
    - Stakeholders' involvement in legislation
- State of lobster environment
- Supply
    - Glut or high supply
    - Shortage or low supply
    - Stranded lobster
- Supply chain segment relationship or comparison
    - Culture of secrecy
- Tourism
- US-Canada relationship or comparison
- What comes next (predictions)

Stressors

- Cost of entry (e.g. license cost)
- Ongoing uncertainty (due to non-pandemic issues)
- Other challenges
    - Age of harvesters
    - Bait crisis
    - Climate change
    - Conflict over First Nations fishing rights
    - MSC certification
    - Offshore wind
    - Right whales
    - Shrink
    - Strain on fisheries resources
    - Trade war between US and China
    - Vessel tracking
- Temporary uncertainty (due to non-pandemic issues)
- Unrecorded sales

Survey questions

- Contentious
- Geographic knowledge
- Inshore, offshore, or both
- Involvement in the industry
- Meaning of resilience
- State of the industry 5-10 years
- State of the industry present

- Three words
- Years in the industry

APPENDIX J: DEFINITIONS OF RESILIENCE BY INTERVIEW PARTICIPANTS

Table J.1. Interview participants' responses to the question, "What does resilience in the lobster industry mean to you?"

"It's an honest transparent view towards what's actually happening in the fishery and what might happen in the future, and then proactive adaptation with an open mind to whatever innovation might be necessary to overcome those challenges and move towards a fishery that works in the future."
"Resilience is such a good word. I always thought that we shouldn't say that seafood is sustainable, that we should say that this is an industry and a product that's resilient and adaptable because it's a wild product we can't continue to harvest it in the same way, all the time forever. Fishermen know that too: you can't catch the same amount of cod, year after year after year and think that it's not going to change, it has to be adaptable. And I think a resilient industry is one that can both create solutions that allow for that adaptability and mitigation, as well as to be able to thrive after those solutions happen."
"Okay, we've had a lot of conversations about what resiliency is [...] but talking about the lobster population so resiliency in the fishery, I think, is how the people that are involved in the fishery respond to change. And that they're able to- I guess it might be kind of resistance to change, but not so much that they're unwilling to change because I think when it comes down to it, they do change, they do adapt, they do make it work for themselves, as long as there are lobsters to catch. So I think it's linked to adaptability and being able to sustain their livelihoods."
Being able to adapt to what's going on and being involved in conservation of the resource. It's a generational thing, family to family, concerned about the future and preserving the resource. The fishermen of up until today are very conservatively minded and they want to continue into the future. The mentality is not to catch everything you can now. *not a direct quote as the audio recorder was not working at this point of the interview.
"Same thing as being stubborn. You know you just have to have a mindset, I mean I… Whatever happens, you just deal with it, whether it's- in the past sometimes it's been bait, sometimes it's been low prices, sometimes it's been weather, you know I mean when I… I looked at- I found a box of my old records, from when I started, and a lot of years when I first started I'd get out 2, 3, 4 days the first week in December and then I'd get out 2 more times the rest of the month, because it was 35 mile an hour and 20 degrees. Nowadays, in December, probably since you were born it's just- the weather's gotten milder and milder and milder, we have nasty storms, but between the storms it's milder and milder. I mean it was about 60 degrees the other day. We never had that. So resilience is the ability to adapt to whatever's tossed at you."

Table J.1 Continued

"It's one of my favorite words. It's certainly a word that I think that I followed and practiced through my career. I've seen it being practiced in the industry as a whole, the fishermen, and I know they're challenged right now with potential new rules with the right whales, but we've had those challenges in the past and the fishermen, although they might be stubborn about it and move slowly, eventually, they do what they have to do to continue the industry, and I think that resilience will show that moving forward."
"Resilience means taking the punches and fighting back accordingly with those daily problems or like the whale entanglement issue that's kind of been all over the news lately, dealing with various events like that and doing it as gracefully as possible. With the understanding that these animals aren't going to be at these quotas forever and resilience then would mean that these fishermen and these various lobster companies start pivoting now to have some sort of other alternative infrastructures in alternative products lined up prior to the fishery collapse."
"I think we need to be realistic to what you know… we have to be able to be safe, the fishermen need to be safe, be realistic to what actually is the issues on the water, all fishermen want to be clean fisherman they don't want to harm any marine mammals or they'll do what they need to do to work with regulators, it just comes to a point where, you know, when is enough enough? We give up so much and we don't always get in return what we work for, and you know it's hard to always keep giving up a little more to please you know risk reductions and such but it's… you know, we need to stand strong as an industry. You know, meaning we need to stand together and agree that we need to fight the battle for the industry and for the future, you know. There's a lot at stake here."
"Resilience. I mean to me, and I could be probably wrong on this, but to me it just means flexibility and how they can adjust to things. They're very resilient in the fact that they're survivors. […] Of all the challenges. If there's a challenge, and you know we get them all the time, but they don't tend to ignore them, they tend to deal with them."
"Well resilience is what the industry has experienced in its, you know, forever. The lobster sector is extremely resilient. Being able to weather things like a pandemic, like 911, like the SARS outbreak, like mad cow, like the great recession, I could go on and on, when we've had major downturns in the market and the sector has always responded, one way or another. Generally in Canada, with very strong support of our governments. But the industry is resilient and, more recently, with lots of consolidation happening, but the sector is very resilient, we have good policies in place that help, the owner operator policy that keeps the harvesting- the fishing industry from consolidating has been very good for keeping us resilient and small but nimble, and the fleet separation policy that keeps plants from being able to buy fishing licenses has also, I think, contributed to the consistent resiliency of the sector, so I would say yeah. That's what it means."

Table J.1 Continued

"Resilience to me just means the ability to adapt to change. And like I said, change is something that is constant in this industry, since I've been in it, I think the major challenges that we have faced as an industry have been- obviously, when 911 happened that was a big wrench in the wheel for markets and flights and getting product all around the world. The financial crash of 2008 was another example of that. 2012, and I think you're probably pretty familiar with this, but 2012 we had a really warm winter and spring and [...] that was kind of the first run of lobsters we saw those soft shell lobsters that we were catching right around late June early July in 2012 those lobsters came—May. You know, mid to late May, and that timing of a high volume of catch in Maine overlapped with a high volume in one of the Canadian lobster fishing area seasons. And that volume of lobsters at that time of year overwhelmed processors, overwhelmed live markets and there was just not enough demand to take care of that supply and move that supply through the supply chain, out of that came, you know [dealer's] processing capacity and a number of other processors here in Maine. And really led to the growth of our business and others as well, and that led to developing new products, developing new markets and… and that is resiliency, in my mind, is taking on challenges that always will be popping up and instead of you know, throwing your hands up in the air and saying why me, you look for the opportunities in those challenges, and I think with COVID obviously that was probably the biggest challenge our industry has ever faced and out of that challenge we found markets for live lobster, we found new markets for frozen lobster tails, we found new markets for cooked and picked lobster meat–you think back to 2020, and everything getting shut down, spring coming along, everyone being locked down and being itchy to get out and go out and see other humans all along the eastern seaboard lobster stock provided a really good opportunity for people to do outdoor dining, socially distanced and get out of their house and enjoy a nice meal. And so we really thrived during that thankfully. And that's one of the reasons right there. So working with our partners, and working with restaurants, to make them see that potential was huge, you know developing new markets, online retailers thrived while people were stuck at home and people didn't want to go out to the grocery store and risk their health, so a lot of people were just ordering food by clicking on a box on their computer so there's plenty of online retailers that sell steak and pork and chicken. And so, seeking those outlets out and opening their eyes up to the opportunity to offer lobster through those same channels was something that we were successful with and that- like I said we think of ourselves as a big deal here in Maine, but as far as protein go we're just a small amount, and our eyes were opened to how much volume outlets like that can move. And so resilience to me is just the ability to adapt to change and that's something we've done well as an industry historically, and I would say something we've done really well during the pandemic."
"It means everything. Everything we do requires on ourselves as a company being resilient, our suppliers being resilient, our clients around the world being resilient, with a live product that varies in quality, cost and availability on a daily basis, you know it's three variables that we're juggling every single day, the price can go up or down, the quality can go up or down, or the supply can go up or down, you had better be resilient to have a meaningful role in this industry, so it's one of the key descriptors of our industry that all the players learn over time to be resilient, otherwise they don't survive."

Table J.1 Continued

"I think resilience would be having a really robust management plan that takes into consideration that we really don't want the stock to decline at all. Right now in Canada, the stock is considered to be in the healthy zone. Actually we're way way up in the healthy zone, because the biomass increased hugely from the 1980s. So we're considered to be very healthy. But I think that's a dangerous way to manage the stock, because so many people are reliant on that biomass staying really high so even if it declines a little bit, it's going to be a problem, so. Yeah I feel like we're not being proactive enough in our approach with that. I'd say… other aspects of resilience are really going to need to incorporate like how we're going to- like a rationalization of the fleet essentially, we've got lobster licenses where the value is extremely high. It really prevents… it's going to prevent our owner-operator fleet from continuing to be successful the way it has in the past, because people are being priced out of the fishery. So there needs to be- you know something done to address that if we're going to have a resilient lobster fishery. And I would say, those are my- those are the two big categories of things that I think we need to be resilient."
"To be able to survive the whale rule. I know that they want to eliminate vertical lines. And do things like ropeless fishing. But we need to be able to survive and fish traditionally to the best of our ability."
"Well, it means adapting to- I think the industry's incredibly resilient and it means adapting to different situations, whether it's on the water, in the plant, processing plants or dealers facilities, finding new customers, finding new ways to fish, different areas to fish, all that kind of thing but… you know, with a full shutdown it's- it doesn't leave any room for- I mean resilience would have to be for the dealers and processors finding other products to carry but for the- you know for the fisherman finding other jobs, but if the fishery itself doesn't exist, I think that kind of eliminates opportunities for resilience."
"You know, like to me, it's a good question, because if you look at resiliency to me means the ability of the industry to adjust if it has to, right. And you know if you look at COVID in terms of how we bounced back, and I think it was- in many ways, is it was the relationship piece, I know that sounds kind of strange, but how we work with our fishers of the in-processors, fishers, government work together when COVID first hit to kind of work through this so. You know resiliency to me means you know you work together and you bounce back, and they did bounce back, now, in some cases it has a lot to do with the kind of product you have and how consumers, right because you can say we can all work together and handle every issue, but we've got to remember pretty well everything we catch is exported, and a lot of it is exported to the US so. To me it's really the ability to bounce back, and this industry has been resilient, I mean if I tell you my brothers had to take a truck driving course because it looked like they were done, there were some fishers that sold out for you know I don't know what they sold out for, but a lot less than $1.3 million you know 10, 15 years ago. So there's been great resiliency in the industry, and I think we do that with relationships and I think we do that, where we work on common problems together like labor you know looking hard now at automation things like that so it's a traditional industry but in a lot of cases it's ever-changing."

Table J.1 Continued

“I guess it’s fishermen’s capacity to adapt, I mean and we’ve seen it in the last couple of years, you know it’s been ironic, the context is probably the most difficult in which we’ve operated, yet we’re having the best years that we could possibly imagine so. Yeah resilience is a- I don’t know if you know any fishermen but they’re a pretty tough breed, put it that way they’re pretty resilient.”
“I think- I mean the lobsters are incredible, they’re resilient, I mean they- look at the amount of pressure that’s on that resource, not going to lie, the amount of traps that are in the water, the amount of the lobsters that we catch, especially when we’re going hard in the fall, day after day after day. It’s incredible. They really have so few natural predators. But still. They- so yeah, they’re very resilient. And lobster fishermen, of course, we’re super resourceful, we’re smart, we’re not ignorant rednecks like people think but- you know people can only take so much. There’s a point where things don’t make sense anymore, we’re not there yet, but we could be at some point.”
“Resilience is that the fishermen are going to adjust and make changes to keep on being able to fish. And not change their careers and go do something else. I mean it’s resilience because of the fisherman, and also the processors, so like when they lost different markets overseas, they went and found new markets, you know they- you know they made changes to adjust. For example, for us, we were losing our lobstering so we ended up starting to sell fish. Which we didn’t do before, so we have to adjust and make changes to make the money that we’re missing in the lobsters.”
“To me it just means being able to weather the downs, there’s lots of ups and downs in this industry and the business in general but just being able to kind of manage those, to weather that.”
“The ability to reinvent itself and be better prepared for the challenges ahead.”
“I suppose adaptability and being able to cope through the hard times.”
“Lobster fishing- the inshore lobster fishery is not exempt from all the other issues that other fisheries have seen as well. It’s just the last few years it’s been a lot, but so far we’ve been able to manage a lot of these issues, but right now it’s all of them coming together at once. Whereas before we may have only had to deal with one issue at a time, then there would be another, so the resiliency is there, but I would say it is fading and it’s fading quickly.”
“The catch holding its own or getting better. When we started here like 5000 pounds was a big season for 50 days, in the 70s, and now if you don’t have 30,000 pounds you’re some kind of a loser.”

Table J.1 Continued

"Oh, I think you know, adaptability and I think what you're doing your thesis on is a prime example- that an industry that literally we were- [laughs] well at least in our spring fishery, which is our large fish on the island, starting off right literally the throes of COVID with a lot of uncertainty. You don't know international flights going on all kinds of things. And one of the positives I see and I'm sure we'll get into it in a little bit, but was that the industry, I think pulled together like it never has before it's been fairly splintered and adversarial and everyone just said, come on that's how we're going to make this thing work, and I think there was definitely some positives that came out of that type of interaction."
"Markets that are consistent, and a supply base that is consistent. So in any fishery, despite what anybody tells- well. How can I put it. In the past, in all fisheries, there's been boom or bust cycles, but really for any sensible operator, all they want is consistent landings. The price is the price on the market, there's not a lot that they can do about that, because it's commodity based product. But if you have consistent landings, then you- that's your best opportunity to ensure profitability for the future. So consistent landings are a direct result from having a very sustainable, healthy biomass. So any larger seafood company or any company that's professional, will say long term sustainability guarantees long- well, helps support long term profitability, the two go hand in hand. It's when you have independent harvesters or harvesters that only care about short term gains, they're the ones that are upsetting the applecart. Anybody that just wants consistent success and consistent sustainability they absolutely do care about biomass. And they're taking care of it."
"Resilience means that as a group of fishermen, they stand together- resilience to me means exactly what the Maine Coast Fishermen's Association is doing. Getting boats together, doing boat protests of the offshore wind implementation. So resilience is exactly what Ben Martens and Monique Coombs are doing, and what I'm trying to build […], where… we go to public hearings with regulators, the reason they do stakeholder hearings and input is because they want to hear from the industry, and we just keep banding together and advocate for each other. Fishermen are notoriously resilient."

BIOGRAPHY OF THE AUTHOR

Nicole Danielle Orminski was born in Bowmanville, Ontario on March 21, 1995. She was raised in Clarkston, Michigan and graduated from Clarkston High School's International Baccalaureate Programme in 2013. She attended the Honors College and Lyman Briggs College at Michigan State University and graduated in 2017 with one bachelor's degree in Biochemistry and Molecular Biology and another in German. During this time she taught self-defense and worked in research laboratories in the fields of plant molecular biology, forestry, and entomology. She attended the University of Waterloo and the Universität Mannheim and graduated in 2020 with a joint master's degree in Intercultural German Studies. In the summer of 2019 she moved to Maine to intern with the Wahle Lab at the Darling Marine Center before starting the dual masters program. Nicole is a candidate for a Dual Master of Science Degree in Marine Biology and Marine Policy from the University of Maine in December 2022.