A Summary of Landings, Legislative Actions, and Possible Climate-Induced Distribution Shifts in New England Fisheries

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A SUMMARY OF LANDINGS, LEGISLATIVE ACTIONS, AND POSSIBLE CLIMATE-INDUCED DISTRIBUTION SHIFTS IN NEW ENGLAND FISHERIES

by

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ABSTRACT

New England's fisheries produce millions of dollars annually, and monitoring and protecting these fisheries ensures the region's prosperity. There is evidence that the distributional centers of many fish species are shifting north so they remain within their optimal thermal range. Twenty species in New England's fisheries have been identified as being vulnerable to climate change and, for each of these species, landings data from New England and the Mid-Atlantic were analyzed for the years 1976 – 2015. Trends in landings data were compared to trends in temperature anomaly data. Major legislative events that may have impacted landings data, e.g., fishery closures and reductions in fishing effort, were also examined. The landings data of two out of the 20 species showed clear northward shifts. The remaining 18 species did not display clear trends linking distribution shifts to climate change. Longfin squid (*Doryteuthis pealeii*) demonstrated a well-defined distributional shift linked to climate change, and is likely to need immediate management action to account for the environmental effects of climate change. Ocean quahog (*Arctica islandica*), on the other hand, showed a similar landings trend that was not linked to climate change but instead correlated with landing trends in other fisheries. The equivocal nature of most of the results points to the necessity for further study using additional resources like fisheries independent survey data and more precise temperature data. This thesis serves as a background document summarizing the current status of New England fisheries and whether major legislative actions reflect the shifting environmental regime.

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INTRODUCTION

The Gulf of Maine is an important body of water for New England, providing economic value for nearby states through fishing and tourism. It is also the focus of much scientific research, as it contains myriad habitats that are at the base of an enormous fishing industry. It is a body of water that is subject to unique currents like the Gulf Stream and Labrador Current, and it has been argued that because of this it is one of the fastest warming bodies in the world (Townsend et al. 2006, Townsend et al. 2015, Pershing et al. 2015). Because of this assertion, the potential for change is of great concern to conservationists, fishery managers, and fishermen. Increased temperatures have been shown, for example, to increase egg mortality and affect the development of pelagic fish (Pepin 1991). In organisms with larval stages, increases in temperature have been shown to negatively impact the duration of the larval stages (MacKenzie 1988), affecting the distance that populations are dispersed (O'Connor et al. 2006). Many marine species along the eastern United States that prefer specific temperatures (like black sea bass and butterfish) are shifting their distribution ranges north (Hare et al. 2016, Kleisner et al 2017, Perry et al. 2005, Overholtz et al. 2011, Mills et al. 2013, Nye et al. 2009, Hare and Able 2007, Cheung et al. 2013, Lucey and Nye 2010).

Background on Major Legislation

To evaluate the relationship between fishery management and climate it is necessary to understand how fish are managed. To do this, federal legislation impacting and/or regulating fisheries in the northeast US should be consulted. The first modern day piece of legislation concerning fishery management in the United States was the

Magnuson-Stevens Fishery Conservation and Management Act (Magnuson-Stevens Act). The action was first signed into law in 1976 in response to foreign fishing fleet activities in waters off the coast of the United States, particularly in the 1960s and 1970s. In 1976, the Magnuson-Stevens Act established a 200 mile limit (also known as the Exclusive Economic Zone or EEZ) which effectively banned foreign fishing within those limits. Additionally, the Magnuson-Stevens Act established eight regional councils that are responsible for creating fishery management plans (FMPs). These councils consist of representatives from the federal government, state legislatures, and the fishery industry.

In 1996, the Sustainable Fisheries Act amended the original Magnuson-Stevens Act, adjusting the responsibilities of the fishery management councils. Since 1996, the councils have been required to define when a fish stock is overfished and when overfishing is occurring. In basic terms, overfished describes a fish population where too many individuals have already been taken out of the population, and overfishing describes the rate at which a fish population is declining due to fishing efforts. In addition to defining these parameters, since 1996 the councils have been responsible for developing plans that restore overfished species to acceptable population levels within 10 years of the species becoming overfished. This requirement has been met with success in some fisheries but not in others. Some of the species that are notorious for eluding efforts to rebuild them are species within the groundfish FMP like Atlantic cod (*Gadus morhua*) (Pershing et al. 2013). This legislation has defined modern fishery management under the federal fishery management councils.

The twenty species of fish and invertebrates examined during the course of this study are managed using fishery management plans (FMPs) developed by two of the eight regional councils. The New England Fishery Management Council (NEFMC) has jurisdiction over the Gulf of Maine, Georges Bank, and southern New England, while the Mid Atlantic Fishery Management Council (MAFMC) has jurisdiction over the Atlantic waters within the EEZ off of New York, New Jersey, Pennsylvania, Delaware, Maryland, Virginia, and North Carolina. The regional councils manage fish by controlling fishermen. This is done by using techniques such as limiting fishing effort (by controlling the number of vessels in a fishery or the number of days those vessels are allowed to be at sea), closing specific areas to fishing, and limiting catch (by metrics such as weight, size, and age that are based on the biology and ecology of the species in question).

New England Fisheries

The NEFMC established the Northeast Multispecies FMP to manage a suite of demersal fish, also known as the groundfish fishery. Groundfish are characterized by a tendency to live near the bottom of the water column or directly on the seafloor (the “ground”). The species in this fishery that were focused on here are Atlantic cod (*Gadus morhua*), haddock (*Melanogrammus aeglefinus*), yellowtail flounder (*Limanda ferruginea*), pollock (*Pollachius pollachius*), windowpane flounder (*Scophthalmus aquosus*), Atlantic halibut (*Hippoglossus hippoglossus*), and ocean pout (*Zoarces americanus*). The similarity of habitat used by these species and the fact that they are often targeted by fishermen together using the same gear, is why they are managed together under one FMP. All of the species from the Northeast Multispecies FMP covered in this study have a high probability to change their distributions due to climate change, with the exception of ocean pout which has a moderate probability to change their distribution due to climate (Hare et al. 2016).

The scallop (*Placopecten magellanicus*) fishery, managed by the NEFMC, is an invertebrate fishery for these bivalve (shellfish) mollusks. They live directly on the substrate, often forming “beds” that can be temporary or permanent. Areas of the Gulf of Maine and Georges Bank (which is a popular fishing ground) tend to have permanent beds. As a result, these areas and the scallops within are heavily regulated by the Scallop FMP as well as other FMPs. For example, the Northeast Multispecies FMP places restrictions on how and where yellowtail flounder can be fished on Georges Bank in order to protect Atlantic sea scallops. Atlantic sea scallops have a moderate probability to change their distributions due to climate (Hare et al. 2016).

The Atlantic Herring (*Clupea harengus*) FMP focuses on this pelagic forage species which spawns in estuaries, coastal waters, or offshore banks, and lives its adult life in the marine environment. Their diet consists mainly of phytoplankton and copepods, and as such form an important link between the primary producers lower on the food web and larger predators such as Atlantic cod. Atlantic herring are not currently overfished, and are managed primarily by a set of annual catch limits. Atlantic herring have a high probability to change their distributions due to climate (Hare et al. 2016).

The Small Mesh Multispecies FMP involves three species of hake: silver hake (*Merluccius bilinearis*), red hake (*Urophycis chuss*), and offshore hake (*Merluccius albidus*). This study focused on silver hake and red hake in the interest of keeping the total list of species to a manageable number. Originally under the umbrella of the Northeast Multispecies FMP, in 2000 the NEFMC deemed it necessary to manage hake under a separate FMP. They are fished using nets of a small mesh size (hence the FMP’s name) which distinguishes them from groundfish and requires specific management measures, mainly exceptions from requirements imposed by the Northeast Multispecies FMP and their own sets of annual catch limits. Silver hake and red hake both have a high probability of shifting their distributions due to climate (Hare et al. 2016).

Like scallops, spiny dogfish (*Squalus acanthias*) have their own FMP managed by NEFMC. These animals are a type of shark, and historically have been considered an undesirable species to catch. Relatively recently, European customers have acquired a taste for dogfish, and it has become a much larger fishery. The NEFMC manages the Spiny Dogfish FMP jointly with the MAFMC, as their distribution tends to lie between both jurisdictions. Spiny dogfish have a very high probability to change their distributions due to climate change (Hare et al. 2016).

The Atlantic Salmon (*Salmo salar*) FMP is a management measure to protect this anadromous fish. Specifically, it prohibits any possession of Atlantic salmon. The original implementation of the FMP in 1988 was in response to the salmon populations having been dangerously overfished. As an anadromous species, New England states manage the individual salmon populations within their own rivers and tributaries, and the Atlantic salmon FMP is meant to complement those efforts by preventing those state-managed salmon from being fished in federal waters where states hold no authority. To the present day, the NEFMC still does not allow fishing for or possession of Atlantic salmon. Atlantic salmon have been considered as having a moderate probability to change their distributions due to climate change (Hare et al. 2016).

Mid-Atlantic Fisheries

The Surfclams and Ocean Quahogs fishery is under management by the MAFMC. The ocean quahog (*Arctica islandica*) is a bivalve mollusk that burrows into the sediment at the bottom of the water column and filter feeds particles for food. Their eggs and larvae are carried by currents before they settle to the bottom where they mature into adults. The fishery is managed by an individual transferrable quota system. This means that a total allowable catch (TAC) is determined, and that number is divided into quotas for individual fishermen. Once allocated, each quota can be bought and sold, i.e., individual "transferrable" quotas. Ocean quahogs have been given a high probability of shifting their distributions in response to climate change (Hare et al. 2016).

The last FMP relevant to this study is the Mackerel (*Scomber scombrus*), Squid (longfin: *Doryteuthis pealeii* and shortfin: *Illex illecebrosus*) and Butterfish (*Peprilus triacanthus*) FMP which was created by the MAFMC. The species in this FMP used to be managed separately, but were eventually merged into one FMP. At the time they were merged, all the species within this FMP had a fishing season beginning in April, all were a bycatch in foreign fisheries, and the squid and butterfish species tended to be caught together. These common factors are why the species were merged into one FMP. Butterfish and shortfin squid are considered by Hare et al. (2016) as having a very high probability of experiencing a distribution shift, while longfin squid and Atlantic Mackerel were given a high probability.

Two of the species studied do not fall under the management of a regional council. Northern shrimp (*Pandalus borealis*) and American lobster (*Homarus americanus*) are both species that are instead managed by the Atlantic States Marine Fisheries Commission (ASMFC). The ASMFC has similar goals to the federal management councils, but operates under the authority of states rather than the federal government. Both American lobster and northern shrimp were predicted in Hare et al. (2016) as having a high probability of a climate-induced distribution shift.

All of these species were deemed vulnerable to a changing climate (Hare et al. 2016), and possibly subject to distribution range shifts. While they are all managed under fairly specific legislation, if a species is experiencing distribution shifts it can be unclear whether this shift is something that can be accounted for by management or a response to changing environmental conditions. This study examined landings trends in an attempt to determine if distribution range shifts were reflected in these data. If detected, shifting landings trends were compared to temperature anomalies and the major legislative events in each species' FMP to determine if those trends were related to climate change or to changes in fishery regulations. The hypothesis used to approach analyzing the data collected in this thesis was: Fisheries that had peak landings shifts from the Mid-Atlantic to New England are linked to climate change or changes in relevant regulations.

METHODS

Species Prioritization

The number of fisheries in New England and the Mid-Atlantic Bight are as varied as the natural biodiversity of the region, but not all these species are as necessarily sensitive to climate change. A recent comprehensive survey reported the vulnerability of various species to climate change on a case-by-case basis (Hare et al. 2016). This paper served as a template for determining the species of interest examined in this study. Each species was ranked in Hare et al. (2016) on their vulnerability to a potential climate-induced distribution shift, as well as whether such a distribution shift would be predicted to be positive or negative for each species. For this study, it was necessary to develop criteria narrowing the focus to species that are both commercially important and potentially impacted by climate change. A list of fish species was created using 1) the descriptions of all the New England Fisheries Management Council's list of FMPs and 2) species from the Atlantic Mackerel, Squid, and Butterfish fishery management plan and the Surfclam and Ocean Quahogs fishery management plan, which are managed by the Mid-Atlantic Fisheries Management Council. The MAFMC species were chosen primarily for their universal vulnerability to a species distribution change in Hare et al. (2016). The literature included descriptions of various facets of these fishing industries and their responses to climate change. This information, combined with the information from Hare et al. (2016), provided a more condensed list of species to focus this analysis (Table 1).

Table 1: List of species studied and their corresponding fishery management plans. Left column lists fishery management plans and right column lists species scientific names as well as common names, except in the cases where the fishery management plan states the common name.

Fishery Management Plan	**Species Name**
Northeast Multispecies	Atlantic Cod (*Gadus morhua*)
	Haddock (*Melanogrammus aeglefinus*)
	Yellowtail Flounder (*Limanda ferruginea*)
	Pollock (*Pollachius pollachius*)
	Windowpane Flounder (*Scophthalmus aquosus*)
	Atlantic Halibut (*Hippoglossus hippoglossus*)
	Ocean Pout (*Zoarces americanus*)
Atlantic Sea Scallop	*Placopecten magellanicus*
Atlantic Herring	*Clupea harengus*
Small Mesh Multispecies	Silver Hake (*Merluccius bilinearis*)
	Red Hake (*Urophycis chuss*)
Spiny Dogfish	*Squalus acanthias*
Atlantic Salmon	*Salmo salar*
Surfclams and Ocean Quahogs	Ocean Quahogs (*Arctica islandica*)
Mackerel, Squid, and Butterfish	Atlantic Mackerel (*Scomber scombrus*)
	Longfin Squid (*Doryteuthis pealeii*)
	Illex Squid (*Illex illecebrosus*)
	Butterfish (*Peprilus triacanthus*)
Atlantic States Marine Fisheries Commission	Northern Shrimp (*Pandalus borealis*)
	American Lobster (*Homarus americanus*)

Distribution Data

Federal landings data from the NOAA Commercial Fisheries Statistics website were used to examine species distributions in the Mid-Atlantic and Gulf of Maine (New England) regions. Landings data were obtained for each species from 1976 – 2015 (https://www.st.nmfs.noaa.gov/commercial-fisheries/). Landings data were all in metric tonnes per year. The starting point was 1976 because that is when the Magnuson-Stevens Fishery Conservation and Management Act was enacted. The most recent year landings data was available from the NOAA Commercial Fisheries Statistics was 2015. Data was graphed as a time series as total landings grouped per year and compared for each species between the southern Mid-Atlantic region and the more northern New England region.

Temperature Data

Temperature data was retrieved from the Optimally Interpolated Satellite Sea Surface Temperature data (OISST) produced by the NOAA National Centers for Environmental Information, with a 0.25 degree spatial resolution. Originally, each data point was represented as SST anomalies over a region ("region" being the New England or the Mid-Atlantic Bight), averaged over a month. The first year satellite SST data was available was 1982. The data covered a time span of January 1982 – October 2016. For the purposes of comparing annual landings data to temperature trends, all the monthly values were averaged for each year, yielding an annual time series of average SST anomalies over each region, the Mid-Atlantic and New England. For this study, sea surface temperature is assumed to be representative of the full water column temperature trend since both regions extend out over the relatively shallow continental shelf.

Fishery Regulations

Information on the fishery regulations that may have influenced landings data was obtained from the species' FMPs. For the Northeast Multispecies, Sea Scallop, Atlantic Herring, Small Mesh Multispecies, Spiny Dogfish, and Atlantic Salmon fisheries, the New England Fishery Management Council's website (http://www.nefmc.org/) was used. For the Surfclams and Ocean Quahogs fishery and the Mackerel, Squid and Butterfish fishery, the Mid-Atlantic Fishery Management Council's website (http://www.mafmc.org/) was used. The Northern Shrimp and American Lobster regulations were obtained from the Atlantic States Marine Fisheries Commission's website (http://www.asmfc.org/). Each FMP's series of amendments and frameworks had a final rule that was used, and the most significant legislative events (such as closures and limits on fishing effort) were recorded.

RESULTS

Temperature Data

Throughout the 1982 to 2015 time period, Mid-Atlantic temperature anomalies remain fairly similar to New England temperature anomalies, with the main difference being a difference in magnitude for any given year. Prior to 1998, temperature anomalies for each year tend to stay between 0 and -1 (Figure 1). After 1998, temperature anomalies tend to stay between 0 and 1 with the exception of 2003 to 2005 where anomalies drop from 0 to -1 and then rise to 0 again. After 2005, temperature anomalies are almost exclusively above 0. The year 2012 stands out as a temperature anomaly with a magnitude of 2, greater than any other anomaly within the 1982 to 2015 time period. After 2012, temperature anomalies continue to stay above 0 at similar magnitudes to the years immediately preceding 2012.

Landings Data & Regulations

Northeast Multispecies Landings & Regulations

None of the chosen species managed by the Northeast Multispecies FMP show a change in the dominance between the New England region's landings and the Mid-Atlantic region's landings (Figures 2-8). In all cases landings for the Mid-Atlantic region were significantly lower (usually more than an order of magnitude, with the exception of Atlantic halibut, Figure 5) than landings for the New England region. In all cases, each species shows various peaks throughout the late 1970s and 1980s, before all entering a decline in the early 1990s. The only exception is an increase in 2015 for Atlantic halibut (Figure 5).

The legislation managing the Northeast Multispecies FMP is one of the most complex of all the FMPs (Table 2). There are over 50 framework adjustments and 16 amendments, and often multiple framework adjustments and amendments are established in a single year. Many of these focus on conserving groundfish populations, while some aim to conserve species not managed under the FMP (like harbor porpoises).

Table 2: Northeast Multispecies FMP regulations. Left column indicates date and title of each Amendment and Framework Adjustment to the FMP. Right column indicates regulations implemented by each corresponding Amendment or Framework Adjustment. Information obtained from www.nefmc.org/management-plans/

1987 – Amendment #1	• Southern New England closed area applies to dredge gear used for scallops to protect yellowtail flounder • Stricter gear requirements
1988 – Amendment #2	• Increase minimum size of yellowtail flounder and plaice
1990 – Amendment #4	• Stricter requirements on codend mesh sizes
1993 – Amendment #5	• Moratorium on issuing vessel permits during periods stock is rebuilding
1994 – Framework Adjustment #4	• 30-day closures for gillnets throughout GoM preventing harbor porpoise bycatch
1995 – Framework Adjustment #12	• Expand Mid-Coast porpoise closure area for gillnets, increase timing from 30 to 60 days
1996 – Amendment #7	• Establishes annual total allowable catch • Accelerates effort reduction in days at sea program • Adds new closed areas
1996 – Framework Adjustment #14	• Closure from end of March to early April for Mid-Coast porpoise closure area • Southern New England porpoise closure are added south of Cape cod for March
1996 – Framework Adjustment #15	• Mid-coast porpoise closure extended to September through December
1997 – Framework Adjustment #18	• Allow trawling for herring and mackerel in Multispecies Closed Areas if certain provisions met
1997 – Framework Adjustment #20	• cod and Haddock trip limits instituted
1997 – Framework Adjustment #23	• Closed right whale habitats to seasonally fixed gear
1997 – Framework Adjustment #24	• Adjusted cod trip limits
1998 – Framework Adjustment #25	• Established closed areas and trip limits for cod
1998 – Framework Adjustment #26	• Additional cod closures
1999 – Amendment 11	• Establishes essential fish habitats for regulated species
1999 – Framework Adjustment #27	• More closed areas, trip limits, gear restrictions imposed to reduce/maintain fishing
1999 – Framework Adjustment #28	• Again adjusted porpoise bycatch closures
2000 – Framework Adjustment #30	• Declared intent to reduce fishing mortality for Georges Bank cod by 22% from 1997/1998 levels
2000 – Framework Adjustment #31	• More strict management measures for GoM and Georges Bank cod
2003 – Amendment #13	• Stricter requirements to enter days-at-sea program • Stricter minimum fish sizes
2006 – Framework Adjustment #42	• Created rebuilding program for Georges Bank yellowtail flounder • Measures to reduce fishing mortality rates on 6 groundfish stocks
2009 – Amendment #16	• Establishes acceptable biological catch • Creates accountability measures for each fish stock in the FMP
2010 – Framework Adjustment #44	• Changed GoM cod and pollock trip limits • Delayed opening for trawling in Eastern US/Canada area • Trip limits for Georges Bank yellowtail flounder
2011 – Framework Adjustment #45	• GoM cod Spawning Protection Area established • Adjusted rebuilding program for yellowtail flounder
2014 – Framework Adjustment #51	• Catch limits for groundfish stocks • Adjusts rebuilding programs for cod and Plaice
2014 – Framework Adjustment #53	• Catch limits for groundfish stocks • Management intended to prevent overfishing, rebuild stocks, obtain optimum yield

Sea Scallop Landings & Regulations

Atlantic sea scallops (Figure 9) have two initial peaks during 1981 and 1990 for New England landings. The Mid Atlantic landings show similar trends. This was

1988 – Amendment #2	• Increase to the meat count standard

followed by two higher peaks in 2006 and 2012 for New England landings and 2004 and 2011 for Mid Atlantic landings. Generally landings increased since 1976 for both New England and the Mid Atlantic. Landings for the Mid Atlantic never exceed landings for New England.

The NEFMC regulates the Sea Scallop FMP relatively heavily (Table 3), similar to the Northeast Multispecies FMP. Every few years there is an amendment or framework adjustment, and most concern changes in standards for vessels or the implementation of major management measures, such as the creation of the area rotation management program in 2003. All of the legislation is aimed at regulating Atlantic sea scallops specifically, and sometimes manages other species at risk from sea scallop fishing activities (like sea turtles).

1994 – Amendment #4	• Switch from the meat count standard to an effort controlled fishery
1994 – Framework Adjustment #1	• Crews on limited access vessels restricted to 7 members
1995 – Framework Adjustment #4	• Continuation of 7-member limit in limited access fishery
1995 – Framework Adjustment #5	• Restrictions on gear types for limited access vessels in days-at-sea program
1996 – Framework Adjustment #7	• Continuation of 7-member limit in limited access fishery
1997 – Amendment #5	• Creates 9-mile^2 closure to support aquaculture research
1998 – Amendment #7	• Reduces fishing effort substantially for the time period 2000 to 2008
1998 – Framework Adjustment #10	• 18-month extension of experimental use area (closure) in Amendment #5
1999 – Amendment #9	• Defines essential fish habitat
1999 – Framework Adjustment #11	• Creates Seasonal Georges Bank Sea Scallop Exemption Area (allows scallop vessels into groundfish Closed Area II)
2000 – Framework Adjustment #13	• Creates 2000 Sea Scallop Exemption Program • Allows scallop vessels into groundfish closed areas if specific requirements are met
2003 – Amendment #10	• Creates an area rotation management program (closing and opening areas in specific seasons based on scallop stocks)
2004 – Amendment #11	• Creates limited access fishery with individual fishing quotas
2004 – Framework Adjustment #16	• Establishes Scallop Access Areas in groundfish closed areas for specific seasons
2006 – Framework Adjustment #18	• Seasonal closure created to prevent harm to sea turtles
2007 – Amendment #13	• Defines strict requirements for a fishery observer program
2010 – Framework Adjustment #21	• Adjustment to days at sea allocations • Adjustments to Scallop Access Area trip allocations
2011 – Amendment #15	• Defines annual catch limits • Defines accountability measures • Redefines overfishing • Redefines essential fish habitat closed areas
2011 – Framework Adjustment #22	• Creates annual catch limits • Creates accountability measures
2012 – Framework Adjustment #23	• Modifies gear by requiring a sea turtle deflector
2013 – Framework Adjustment #24	• Adjusts seasonal closures on Georges Bank
2014 – Framework Adjustment #25	• Establishes windowpane flounder accountability measures
2015 – Framework Adjustment #26	• Aligns sea turtle gear requirements with the Endangered Species Act

Table 3: Sea Scallop FMP regulations. Left column indicates date and title of each Amendment and Framework Adjustment to the FMP. Right column indicates regulations implemented by each corresponding Amendment or Framework Adjustment. Information obtained from www.nefmc.org/management-plans/

Atlantic Herring Landings & Regulations

Landings for Atlantic herring (Figure 10) are practically non-existent for the Mid-Atlantic from 1976 to 2015, with a few small peaks as exceptions. Landings for New England initially peak in 1980, followed by a sharp decline that ends in 1983. After 1983 landings follow a generally increasing trend with alternating and consistent variability year to year from 2000 to 2015. The notable exception is the years of 2004 and 2005, where landings in New England are almost entirely absent. Landings for the Mid Atlantic do not exceed landings for New England.

Atlantic herring has less regulations than the Northeast Multispecies FMP and the Sea Scallop FMP. This is due to a stock that is not overfished and a fishery where overfishing is not occurring. Most of the amendments and framework adjustments deal with defining requirements the fishery has to meet and defining the consequences for individuals who do not meet those requirements (Table 4).

Table 4: Atlantic Herring FMP regulations. Left column indicates date and title of each Amendment and Framework Adjustment to the FMP. Right column indicates regulations implemented by each corresponding Amendment or Framework Adjustment. Information obtained from www.nefmc.org/management-plans/

2002 – Framework Adjustment #1	• Caps landings during winter/spring for Management Area 1A
2007 – Amendment #1	• Establishes limited access program • Creates an area for only purse seine/fixed gear fishing
2010 – Amendment #4	• Defines fishery closure thresholds • Defines accountability measures
2013 – Amendment #5	• Stricter requirements for vessels to comply with observers sampling catch
2013 – Framework Adjustment #2	• NEFMC can split annual catch limits seasonally between the 4 management areas
2014 – Framework Adjustment #3	• Creates a process for setting caps on river herring and shad catch
2015 – Framework Adjustment #4	• Stricter reporting requirements of slippage (discarding catch before an observer samples) • Stricter slippage consequences

Hake Landings & Regulations

Silver hake landings (Figure 11) and red hake landings (Figure 12) show an overall decrease in landings as time progresses after the initial peaks in 1976 for New England and 1979 for the Mid-Atlantic. While there are peaks within that decreasing trend, they are always followed by a trough of similar (if not greater) magnitude. There is only one instance in 1979 when Mid-Atlantic landings were greater than New England landings for silver hake. The Small Mesh Multispecies FMP has amendments and framework adjustments that mostly concern gear types, fishing area definitions, and effort adjustments (Table 5).

Table 5: Small Mesh Multispecies FMP regulations. Left column indicates date and title of each Amendment and Framework Adjustment to the FMP. Right column indicates regulations implemented by each corresponding Amendment or Framework Adjustment. Information obtained from www.nefmc.org/management-plans/

	groundfish fishery

1997 – Amendment #1	• Limits winter whiting (hake) fishery to specific area • Acceptable by-catch of groundfish determined based on vessel's landings of shrimp and whiting
2000 – Amendment #12	• Establishes different silver hake and red hake possession limits based on the mesh size used to fish
2000 – Framework Adjustment #32	• Adjusts Northeast Multispecies FMP to manage hake species separately
2000 – Framework Adjustment #35	• Creates small mesh whiting (hake) fishery in the Gulf of Maine independent of groundfish fishery
2003 – Framework Adjustment #37	• Increased fishing effort due to rebuilt northern stock and no longer overfished southern stock
2003 – Framework Adjustment #38	• Created a small mesh silver hake fishery in inshore Gulf of Maine with specific gear requirements
2013 – Amendment #19	• Redefines overfishing for small mesh multispecies • Increases trip limits • Increases incidental possession limits

Spiny Dogfish Landings & Regulations

The spiny dogfish fishery (Figure 13) is characterized by relatively low landings, with the notable exception between 1990 to 1993 when there was a sharp increase in New England, immediately preceded and followed by exceedingly low landings. Before the 1990 to 1993 peak, there is a small uptick in New England landings in 1979. The Mid-Atlantic experienced a similarly small increase in landings in 1996. The only years that Mid-Atlantic landings are greater than New England landings were from 1994-1998. The majority of the legislation managing spiny dogfish is focused on how the legislation can be written for the fishery (as it is managed jointly between the NEFMC and the MAFMC) and defining effort controls like catch limits and quotas (Table 6).

Table 6: Spiny Dogfish FMP regulations. Left column indicates date and title of each Amendment and Framework Adjustment to the FMP. Right column indicates regulations implemented by each corresponding Amendment or Framework Adjustment. Information obtained from http://www.mafmc.org/dogfish/

Atlantic Salmon Landings & Regulations

Atlantic salmon landings (Figure 14) show that the fishery is for all intents and purposes a closed fishery, with a peak in 1978 of only 0.2 metric tonnes in New England landings.

There are no regulations for the Atlantic Salmon FMP that could affect landings other than the mandate stated in the original FMP that bans the possession of Atlantic salmon.

Ocean Quahog Landings & Regulations

Ocean quahog landings (Figure 15) show a trend where the Mid-Atlantic has greater landings initially and after 1991 New England usually had more landings, except for the specific years 2000, 2001, 2004, and 2011. The landings in New England during

2006 – Framework #1	• Allows the NEFMC and MAFMC to create commercial quotas for up to five years without having to review them annually
2009 – Framework #2	• Creates a method for more flexible determination of stock status • Maintains method for determining if stock is overfished • Allows peer-review to influence stock status determination if specific requirements are met
2011 – Amendment #2	• Defines annual catch limits • Defines accountability measures
2014 – Amendment #3	• Allows a portion of commercial quotas to be allocated to research • Redefines essential fish habitats • Changes allocation of federal commercial quotas to line up with allocation of state quotas

these specific years are a sharp contrast to the landings in the same region during the years immediately before and after them. In these years, landings in New England are almost at the lowest levels for the entire time period data was obtained for. After 1993, landings in New England increase by about 3000 metric tonnes, and the years thereafter (except for those mentioned above) are around the same number.

There are numerous regulations for the Surfclam and Ocean Quahog FMP, most of which concern the Atlantic surfclam specifically (Table 7). Many of these regulations include management measures such as size limits and fishing area definitions, effort controls like trip limits and closures, and maintaining a fishing fleet size by using a moratorium.

Table 7: Surfclam and Ocean Quahog FMP regulations. Left column indicates date and title of each Amendment and Framework Adjustment to the FMP. Right column indicates regulations implemented by each corresponding Amendment or Framework Adjustment. Information obtained from http://www.mafmc.org/surfclams-quahogs/

1979 – Amendment #1	• Continues measures like quarterly quota allocations defined in original FMP through 1979 • Continues moratorium on entry to the surfclam fishery from the original FMP through 1979
1979 – Amendment #2	• Continues original FMP measures through end of 1981 • Establishes two distinct areas for the surfclam fishery – New England and Mid-Atlantic • Continues moratorium in Mid-Atlantic area from vessels entering surfclam fishery, but moratorium lifted in New England area • Surf clam minimum size established
1981 – Amendment #3	• Continues measures stated in original FMP indefinitely • Increased minimum surfclam size in both NE and MA areas • Increased the surfclam fishing week in MA by one day
1984 – Amendment #4	• Sets trip limits based on vessel class • Unharvested portion of bimonthly quotas carry over to next bimonthly period

1985 – Amendment #5	• Size limit for surfclams in Mid-Atlantic also imposed on New England • Creates process that size limit on surfclams can be reviewed
1986 – Amendment #6	• New England area split into Nantucket Shoals and Georges Bank Areas • Bimonthly quotas instead become quarterly quotas • Ends landing limits on Nantucket Shoals • Vessels cannot fish in more than one area on each specific day
1987 – Amendment #7	• Georges Bank now has equal quarterly quotas • Adjusts the amount of quota that can "roll over" into the next quarter if too much or too little is fished in a specific quarter
1988 – Amendment #8	• Replaced fishing weeks with individual transferrable quotas for surfclams and ocean quahogs
1996 – Amendment #9	• Redefined overfishing definitions for surfclams and ocean quahogs
1998 – Amendment #12	• Implements a framework adjustment process
2003 – Amendment #13	• Establishes multi-year quotas
2007 – Framework #1	• Allowed for electronic reporting of vessel locations (vessel monitoring systems)
2011 – Amendment #16	• Created annual catch limits • Created accountability measures
2015 – Amendment #18	• Removed certain restrictions on upgrading vessels

<u>Atlantic Mackerel, Squid, Butterfish Landings & Regulations</u>

Atlantic mackerel landings (Figure 16) for the Mid-Atlantic and New England are extremely similar from 1976 up until 1998. After one of the lowest landing counts since 1976 occurred in New England in 2001, landings increased drastically until 2006, with the exception of 2005 where there was a drastic decline followed the next year by an equally dramatic increase. From 2006 to 2005, New England experienced a steady decline in Atlantic mackerel landings. The Mid-Atlantic experienced mostly the same trend as New England, but the increases in landings were much less steep after 2001, and the smaller peak had a similar decline to the New England landings. There is a brief period of time between 1998 and 2001 where landings in the Mid-Atlantic are greater than in New England.

Longfin squid landings (Figure 17) are initially greater in the Mid-Atlantic than New England landings, and starting in 1995 that begins to reverse. After 1995, New

England landings tend to be greater than Mid-Atlantic landings. This change corresponds to the beginnings of a shift in temperature anomalies from a majority of cold years in both regions to a majority of warm years in both regions (Figure 1). Prior to 1995, landings in New England for longfin squid were very minimal (with two exceptions in 1982 and 1988). Between 2012 and 2015, landings increased in New England and decreased in the Mid-Atlantic.

Northern shortfin squid landings (Figure 18) in the Mid-Atlantic are initially greater than New England landings. After 1995, both regions' landings follow a similar trend, but Mid-Atlantic peaks are greater in 1997, 2003, and 2009. In 2006, landings in New England experienced a peak but landings in the Mid-Atlantic were very low.

Butterfish landings in New England are significantly higher than Mid-Atlantic landings (Figure 19). Following progressively larger peaks that culminate in the largest during 1984, there is a sharp decrease in New England landings and landings do not increase again.

The Mackerel, Squid, Butterfish FMP has almost as many regulations as the Northeast Multispecies FMP and the Sea Scallop FMP (Table 8). After all the species were merged into one FMP, it became necessary to frequently update the FMP with amendments and framework adjustments to account for the four different species being managed under the same plan together. Many of the amendments mention some or all of the managed species, while most of the framework adjustments pertain only to one species. Most of the management measures are meant to prevent overfishing, for example by limiting the size of the shortfin squid fishery.

Table 8: Mackerel, Squid, Butterfish FMP regulations. Left column indicates date and title of each Amendment and Framework Adjustment to the FMP. Right column indicates regulations implemented by each corresponding Amendment or Framework Adjustment. Information obtained from http://www.mafmc.org/msb/

1983 – Merged FMP	• Atlantic Mackerel FMP, Atlantic Butterfish FMP, and Squid FMP merged into one FMP
1984 – Amendment #1	• Created method for Northeast Regional Director and MAFMC to adjust optimal yield for squid • Mackerel mortality rate re-evaluated
1986 – Amendment #2	• Created process for framework adjustments • Fishing permits expire annually rather than indefinitely
1991 – Amendment #3	• Defined overfishing for each species
1991 – Amendment #4	• Allows optimal yield for mackerel to be defined for 3 years or less
1996 – Amendment #5	• Longfin squid maximum sustainable yield changed • Ended targeted foreign fishing of squids and butterfish • Created limited access program for squids and butterfish • MAFMC expanded jurisdiction of FMP to all populations of the regulated species in the EEZ (not just the ones directly near the Mid-Atlantic)
1998 – Amendment #8	• Redefined overfishing for each species • Changed framework adjustment procedure
2001 – Framework #1	• A portion of annual quota is set aside for scientific research
2002 – Framework #2	• Continued a moratorium on entering the shortfin squid fishery • Management measures for longfin squid can be set for 3 years or

	less
2003 – Framework #3	• Continued moratorium on entering shortfin squid fishery
2004 – Framework #4	• Continued moratorium on entering shortfin squid fishery for additional 5 years
2008 – Amendment #9	• Allows all managed species to have specifications set for up to 3 years • Continued moratorium on entering shortfin squid fishery • Eggs of longfin squid have their essential fish habitat defined • Bottom trawls not allowed in Lydonia and Oceanographer Canyons to protect essential fish habitat
2008 – Amendment #10	• Creates butterfish rebuilding program • Increases minimum mesh size for longfin squid
2010 – Amendment #13	• Creates annual catch limits • Creates accountability measures
2011 – Amendment #11	• Establishes limited access fishery in mackerel fishery • Redefined all essential fish habitats

Northern Shrimp Landings & Regulations

Northern shrimp landings in the Mid-Atlantic were all reported as zero. New England landings increase from 1976 until a peak in 1987, then a large peak in 1996, followed by a decreasing trend. In 2009 and 2010 that decrease was reversed, but after the 2010 peak landings decrease steadily for three years.

Most of the regulations managing northern shrimp are relatively recent (Table 9). Many of the regulations are focused on learning more about the stock and determining the best measures to effectively regulate the species.

Table 9: Northern shrimp ASMFC regulations. Left column indicates date and title of each Amendment and Amendment Addendum to the original FMP. Right column indicates regulations implemented by each corresponding Amendment or Amendment Addendum. Information obtained from http://www.asmfc.org/species/northern-shrimp

2004 – Amendment #1	• Implemented measures to improve knowledge of the shrimp stock populations dynamics, life stages, distributions and biology • Created two options for managing shrimp: season lengths and gear

	limitations
2011 – Amendment #2	• Clarifies fishing mortality reference points • Creates a more efficient reporting system • Adds options for managing shrimp: allows for implementation of trip limits, trap limits, and days on the water spent fishing shrimp
2012 – Addendum I to Amendment #2	• Clarifies annual specification process • Allows a portion of catch to be set aside for scientific research • Allocates total allowable catch based on historical landings by gear type

<u>American Lobster Landings & Regulations</u>

American lobster has experienced a steady increase in landings in New England since 1976 (Figure 21). Unlike all other species studied, lobster does not have significant decreases in landings, only increases every year since 1976. Some years alternate between a peak and a trough briefly between 2000 and 2007, but the increasing landings is one of the strongest trends in the 20 species studied. In the Mid-Atlantic, lobster landings are relatively low, with a fairly insignificant peak from about 1995 to 2000.

The American lobster fishery is regulated mainly by measures such as size limits and management areas (Table 10). It also makes use of some unique management techniques like v-notching egg-bearing females.

Table 10: American lobster ASMFC regulations. Left column indicates date and title of each Amendment and Amendment Addendum to the original FMP. Right column indicates regulations implemented by each corresponding Amendment or Amendment Addendum. Information obtained from http://www.asmfc.org/species/american-lobster

1997 to 2009 – Amendment #3 and Addenda I-XXIV	• Creates 7 lobster conservation and management areas • Each area has a management team • Fishery managed with minimum/maximum size limits, trap limits, and v-notching of egg-bearing females
2009 to 2013 - Addenda XVII-XXII to Amendment #3	• Added to v-notching program • Reduced trap numbers • Added closed seasons for specific areas

DISCUSSION

While most of the species examined did not display trends in landings data indicative of a northward distribution shift it was still remarkable to find evidence for two that did and could be related to climate change or legislative changes. The Northeast Multispecies FMP species (Figures 2 through 8) show peaks in landings in the mid-1970s and 1980s that decline rapidly in the following decades. While some species like Atlantic halibut (Figure 5) have landings increases in recent years, most of the species within the Northeast Multispecies FMP do not experience recent landings increases. This FMP is quite complex because it attempts to manage so many species together under one plan (Table 2). The decreasing landings trends characteristic of the groundfish species is most likely due to the increasingly strict regulations imposed on these species to try and save the stocks from depletion. As a result, these downward trends likely mask any indications that these species might be shifting their distributions northward.

While the Northeast Multispecies FMP is an example of a FMP that struggles to balance conservation and the economic viability of the fishery, the Sea Scallop FMP

(Figure 9) is an example of a FMP that has managed to properly balance these two influences. Landings decreased to their lowest levels in the 1990s, but within the last decade landings have reached their highest peaks. Innovations in management (Table 3) like the rotating seasonal closures instituted in 2003 most likely contributed to the health of the scallop stocks while allowing fishermen to still profit from them as a natural resource. Despite these indications that the FMP is well-managed, it is still unclear from the landings data if Atlantic sea scallop are experiencing any kind of distribution shift. Atlantic sea scallops were characterized as having a moderate probability that they will change their distribution due to climate (Hare et al. 2016), but these results do not provide information that can verify or discredit that prediction. Like the Northeast Multispecies FMP, the trends in landings data for the Sea Scallop FMP appear to be responses to regulations and not to climate-induced distribution range shifts.

Longfin squid (Figure 17) is the species that most clearly shows a trend in landings that may be related to a climate-induced distribution range shift from southern Mid-Atlantic waters to northern New England waters. From 1983 to 1995, longfin squid landings are greater in the Mid-Atlantic than in New England, and after 1995 that trend reverses. Temperature anomalies in both regions experienced a colder than normal year in 1995. However, the Mid-Atlantic had a less drastic cold year than New England during 1995. Following 1995, temperature anomalies that indicate a warmer than normal year become much more common than previous to the 1990s. This is the same time period that longfin squid shows landings that are greater in New England than in the Mid-Atlantic. This is possible evidence of a northern distribution shift. Longfin squid is a species that is seasonally migratory, and it migrates based on changes in water temperature (Jacobson

2005). If water temperatures continue a warming trend, it stands to reason that longfin squid will continually migrate north until their southern distribution range is no longer within the Mid-Atlantic. These landings data suggest that this might already be happening. If so, this has enormous significance for management. If longfin squid are shifting their distributions out of Mid-Atlantic waters and into New England waters, the MAFMC may eventually no longer be effective in managing a species that moves further and further north.

Another species that displays a landings trend that might indicate a climate-induced shift is ocean quahog (Figure 15). While at first this trend appears to suggest a climate-induced distribution shift, it is more likely due to more indirect effects of other fisheries and the biology of their species. Prior to 1991, ocean quahog landings were relatively low (when compared to more recent landings), and landings were higher in the Mid-Atlantic than New England. After 1991, New England landings for ocean quahog begin to increase rapidly while Mid-Atlantic landings remain at relatively similar levels. From 1994 to 2014, landings remain at this elevated level with the exception of specific years (2000, 2001, 2004, and 2011). The landings appear at first glance as if related to specific events such as closures, but it is unclear after reviewing Amendments and Frameworks modifying the Surfclams and Ocean Quahog FMP why those specific years had landings lower than the surrounding years. The Amendments and Frameworks for the years prior to and during these events do not specifically mention events like closures. When comparing Figure 15 to Figure 1, it can be seen that when New England landings become greater than Mid-Atlantic landings in 1993, shortly after a trend of increasing temperature anomalies is apparent. While these factors might suggest that a distribution shift occurred that can be linked to climate change, it is likely this is not the case. Landings of ocean quahog have historically been related to the success of the surfclam fishery.

In years when the surfclam fishery declined, ocean quahog landings increased allowing fishermen to supplement their earnings. It is likely that the rapid increase in landings after 1991 may have been due to a closure or reduction in effort within the surfclam fishery or Atlantic sea scallop fishery, and the subsequent decreases in landings of ocean quahog in 2000, 2001, 2004, and 2011 were all due to increased success in the surfclam or Atlantic sea scallop fishery. Additionally, ocean quahog is a sedentary species that does not have the capacity to migrate within an individual's life cycle, which can last for hundreds of years (Ridgway and Richardson 2011). Its distribution would change over longer periods of time due to settlement patterns of their larvae. Therefore, due to legislative actions and the life cycle of the organism, it is unlikely that this landings trend represents a rapid distribution shift in ocean quahog due to climate.

The ocean quahog fishery is an example of the relative value of fishery dependent data and fishery independent data when trying to evaluate climate related changes in distribution, rather than relying solely on one type of data, such as bottom trawl surveys (Lucey and Nye 2010). As with the example of the ocean quahog, it is difficult to predict how a closure or reduction of effort in one fishery might affect the landings of another. It is therefore clear that the findings of the current study are best described as preliminary, as a result of relying solely on fishery dependent data. With that being said, fisheries dependent data does have advantages other data sets might not. Landings data reflects what species are valued more commercially, as well as providing links between the ways human behavior affects species. Traditional techniques for collecting fisheries independent data include methods like bottom trawl surveys, which cover very large geographic areas to evaluate populations and determine their overall distributions, but they do not necessarily reflect the temporal and spatial scales of a species targeted for harvest. Fisheries dependent data may better represent species concentrations that more rapidly reflect trends in distribution, which could be the result of accelerating climate change.

The longfin squid could be an example of how a species' landings data may be representative of a climate driven distributional shift. Using fishery dependent data, a trend was apparent that correlates with changing water temperatures. Fishermen go where the fish are, so utilizing fishery dependent data gives a reasonable look at the current state of species' distributions. To confirm that such a trend is real however, it is important to also consider relevant fishery independent data like stock assessments and population abundance surveys as part of a more quantitative examination of how these species are reacting to climate change. In the past for example, longfin squid has been studied with the intent of identifying links between climate variability, oceanography and changing distributions (Dawe et al. 2007) near the northern end of its geographic range in Newfoundland. Longfin squid, off the US east coast, is characterized by Hare et al. (2016) as having a high probability of a distribution shift due to climate change, and this current study corroborates that finding.

This study describes a link between fisheries dependent data (landings) and climate for longfin squid as an example of how its distribution may be changing. Other species, like the ocean quahog, did not have similarly obvious links. Fisheries dependent data may describe a possible distribution shift for longfin squid that has a relatively short, varied and mobile life cycle, but may be insufficient for species like the ocean quahog with a long and sedentary life cycle. A species like ocean quahog would most likely require supplemental information (like fisheries independent data) to form similar conclusions.

The longfin squid example may be an indicator of climate driven change, or the proverbial canary in the coal mine, suggesting that many more (if not all) of these species are experiencing distributional range shifts as suggested by Hare et al. 2016. Additionally, ocean quahog is also characterized as having a high probability of a climate-induced distribution shift, but as discussed it is sometimes difficult to link changes in fisheries dependent data to climate without supplementing those findings with other information sources. These climate-induced shifts are simply not revealed in a careful examination of the landings data alone. The inherent value of this study is the compilation of information describing fishery management practices and relating these to landings data, and observing major shifts in these data compared to the known temperature anomalies. This has resulted in a preliminary summary and examination of the relationships between landings data, temperature trends, and fishery management measures within New England fisheries, which is relevant to a world experiencing rapid climate change.

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APPENDIX: FIGURES

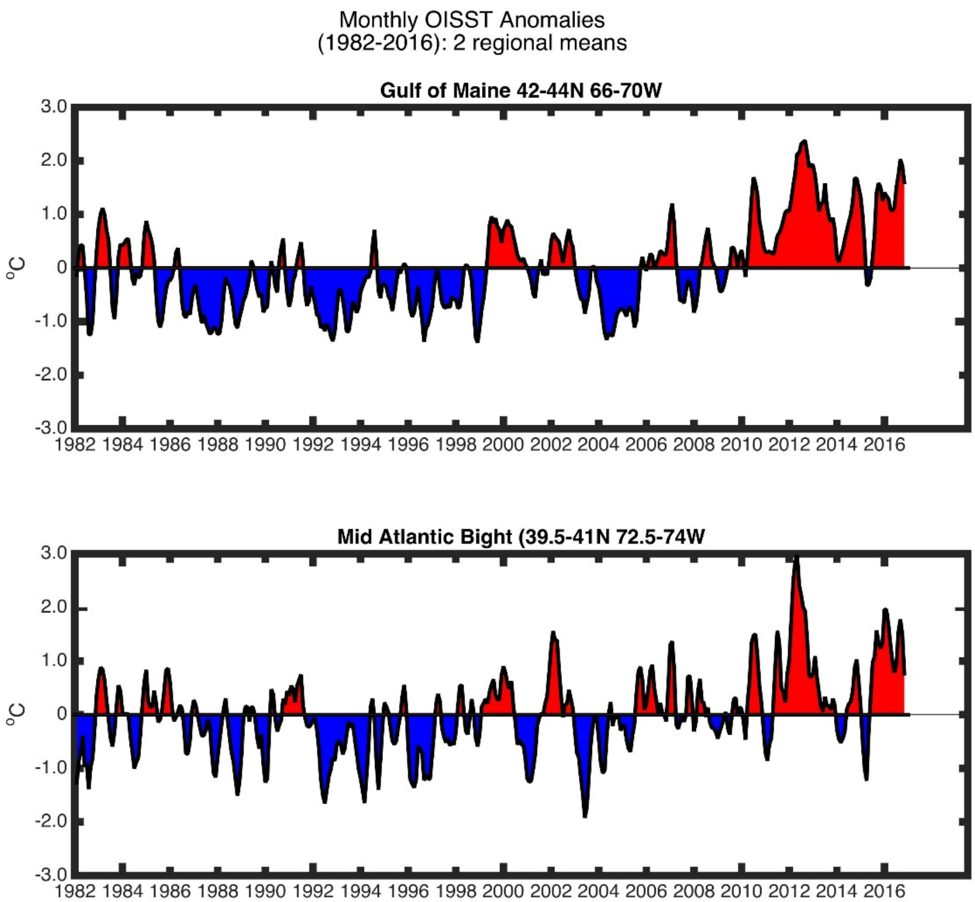

Figure 1: Annual average temperature anomalies from 1982 to 2015. Temperatures are a spatial average of sea surface temperature (SST) anomalies over the regions of New England and the Mid Atlantic. Data obtained from Dr. Andrew Thomas of the University of Maine School of Marine Sciences as Optimally Interpolated Satellite Sea Surface Temperature (OISST), originally produced by NOAA NCEI at 0.25 degree spatial resolution.

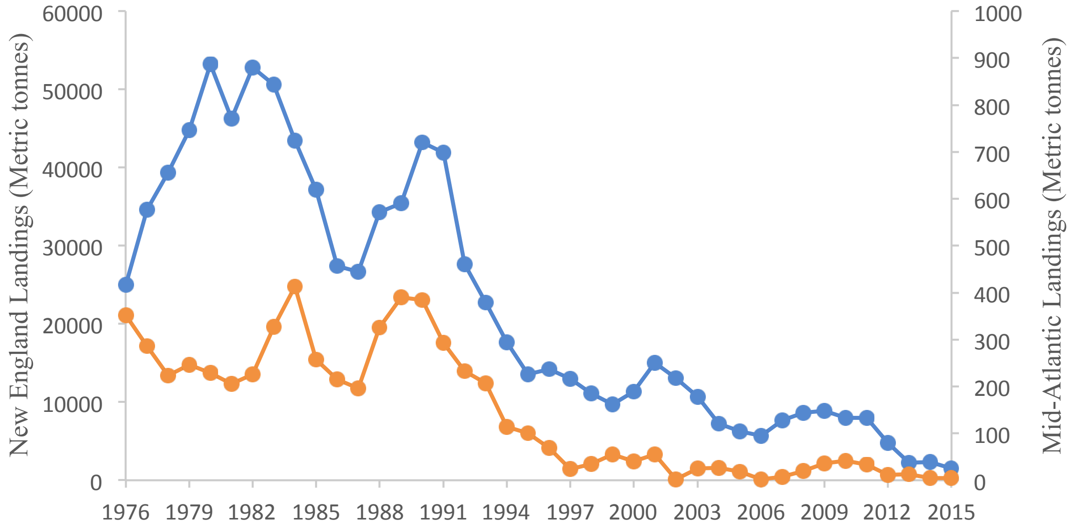

Figure 2: Annual landings data for Atlantic cod (*Gadhus morha*) from 1976 to 2015. Landings displayed in metric tonnes. The blue line denotes landings from New England and the orange line denotes landings from the Mid Atlantic. The left y-axis corresponds to New England landings and the right y-axis corresponds to Mid Atlantic landings. Landings data obtained from NOAA Commercial Fishery Statistics.

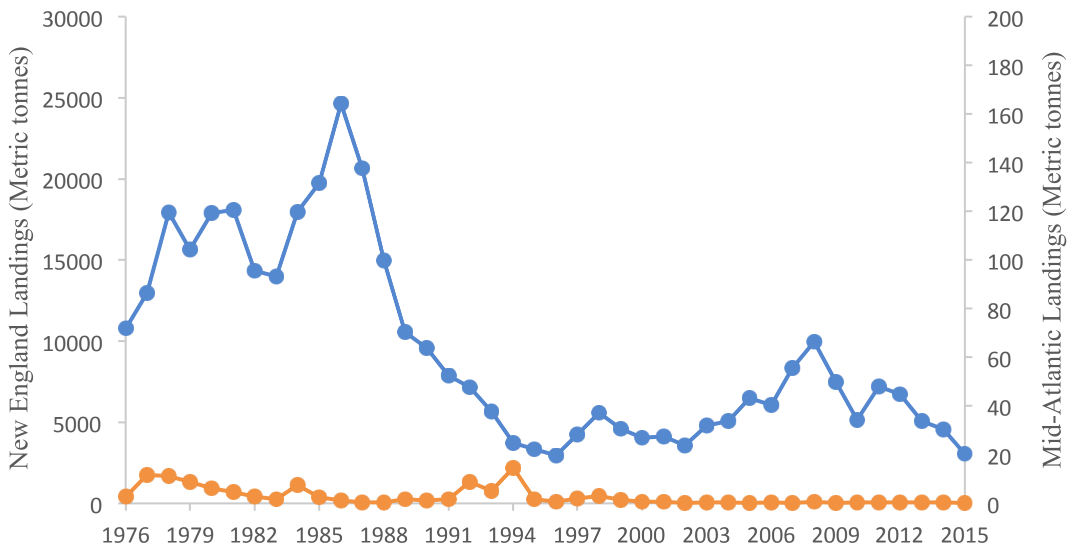

Figure 3: Annual landings data for pollock (*Pollachius pollachius*) from 1976 to 2015. Landings displayed in metric tonnes. The blue line denotes landings from New England and the orange line denotes landings from the Mid Atlantic. The left y-axis corresponds to New England landings and the right y-axis corresponds to Mid Atlantic landings. Landings data obtained from NOAA Commercial Fisheries Statistics.

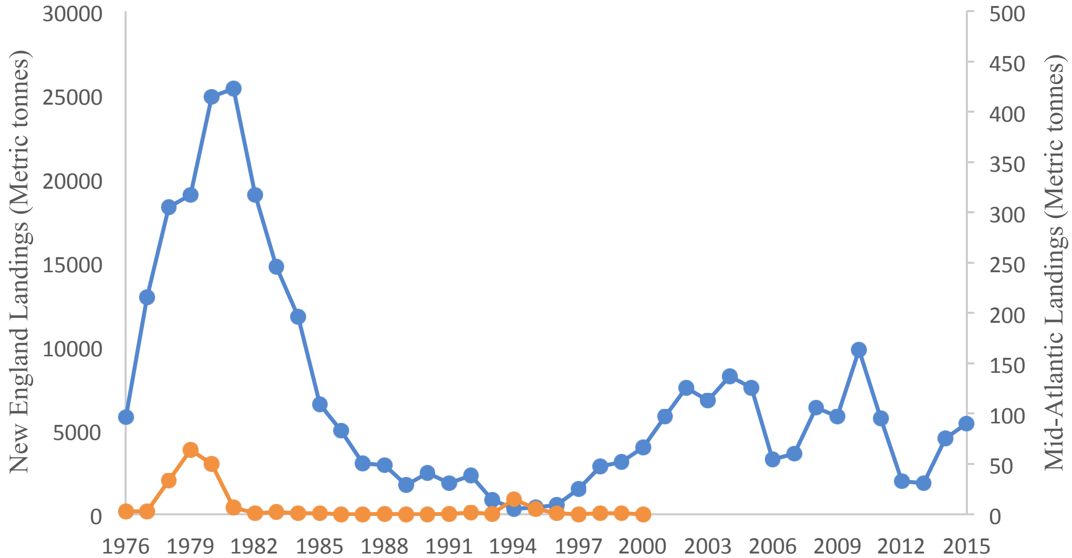

Figure 4: Annual landings data for haddock (*Melanogrammus aeglefinus*) from 1976 to 2015. Landings displayed in metric tonnes. The blue line denotes landings from New England and the orange line denotes landings from the Mid Atlantic. The left y-axis corresponds to New England landings and the right y-axis corresponds to Mid Atlantic landings. Landings data obtained from NOAA Commercial Fishery Statistics.

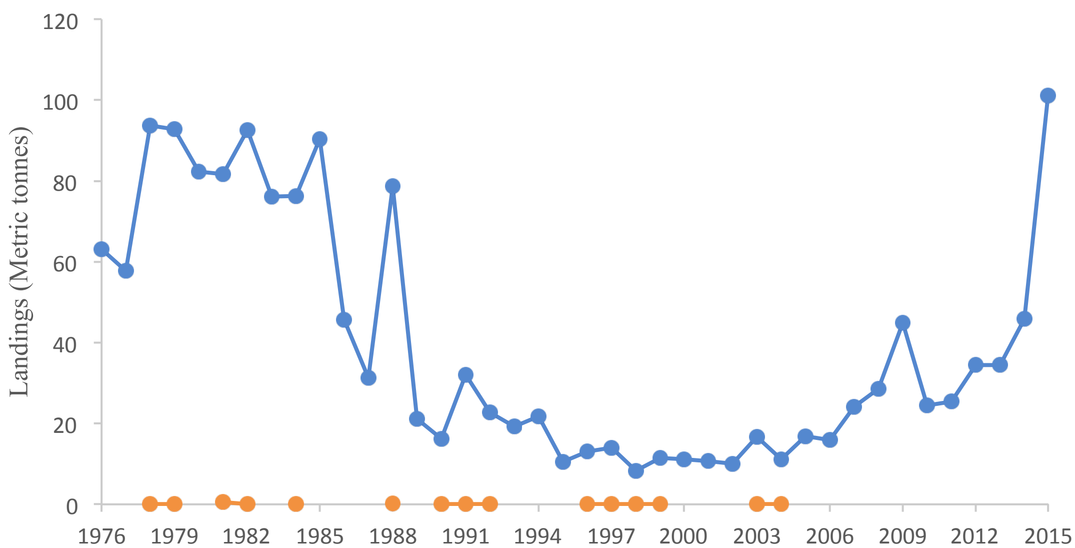

Figure 5: Annual landings data for Atlantic halibut (*Hippoglossus hippoglossus*) from 1976 to 2015. Landings displayed in metric tonnes. The blue line denotes landings from New England and the orange line denotes landings from the Mid Atlantic. The single y-axis corresponds to both New England and Mid Atlantic landings. Landings data obtained from NOAA Commercial Fishery Statistics.

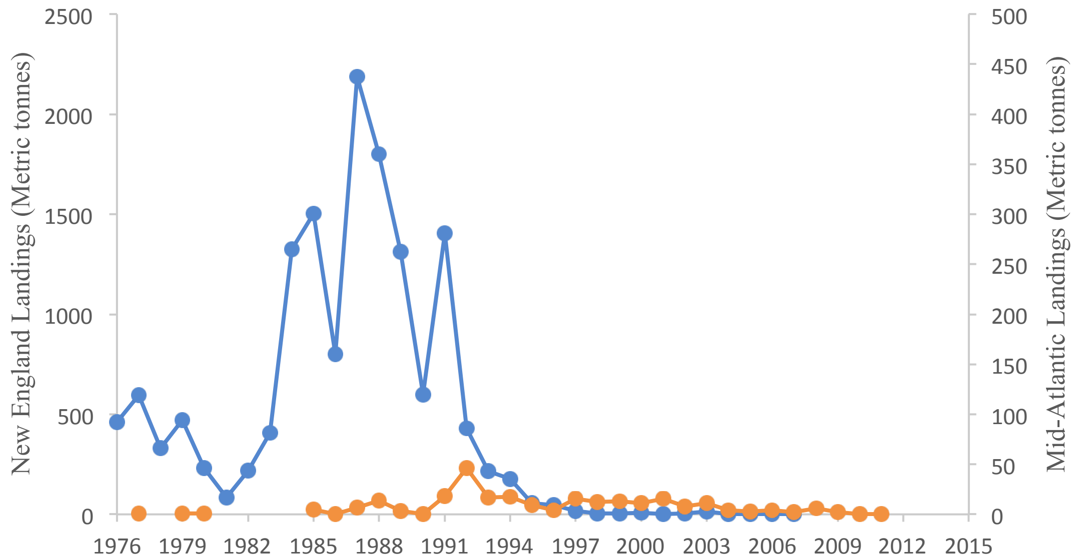

Figure 6: Annual landings data for ocean pout (*Zoarces americanus*) from 1976 to 2015. Landings displayed in metric tonnes. The blue line denotes landings from New England and the orange line denotes landings from the Mid Atlantic. The left y-axis corresponds to New England landings and the right y-axis corresponds to Mid Atlantic landings. Landings data obtained from NOAA Commercial Fishery Statistics.

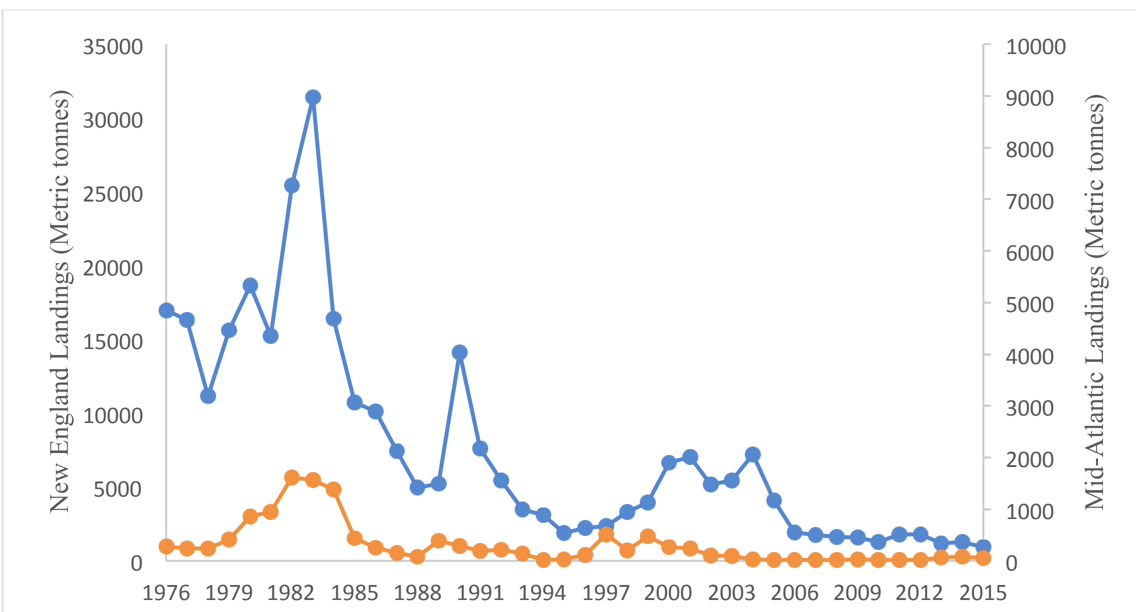

Figure 7: Annual landings data for yellowtail flounder (*Limanda ferruginea*) from 1976 to 2015. Landings displayed in metric tonnes. The blue line denotes landings from New England and the orange line denotes landings from the Mid Atlantic. The left y-axis corresponds to New England landings and the right y-axis corresponds to Mid Atlantic landings. Landings data obtained from NOAA Commercial Fishery Statistics.

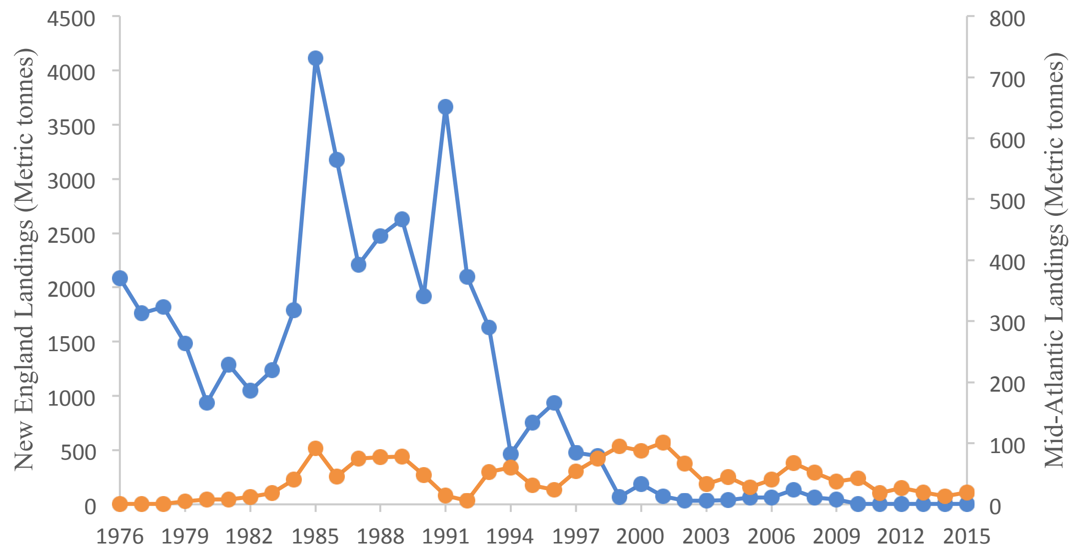

Figure 8: Annual landings data for windowpane flounder (*Scophthalmus aquosus*) from 1976 to 2015. Landings data displayed in metric tonnes. The blue line denotes landings from New England and the orange line denotes landings from the Mid Atlantic. The left y-axis corresponds to New England landings and the right y-axis corresponds to Mid Atlantic landings. Landings data obtained from NOAA Commercial Fishery Statistics.

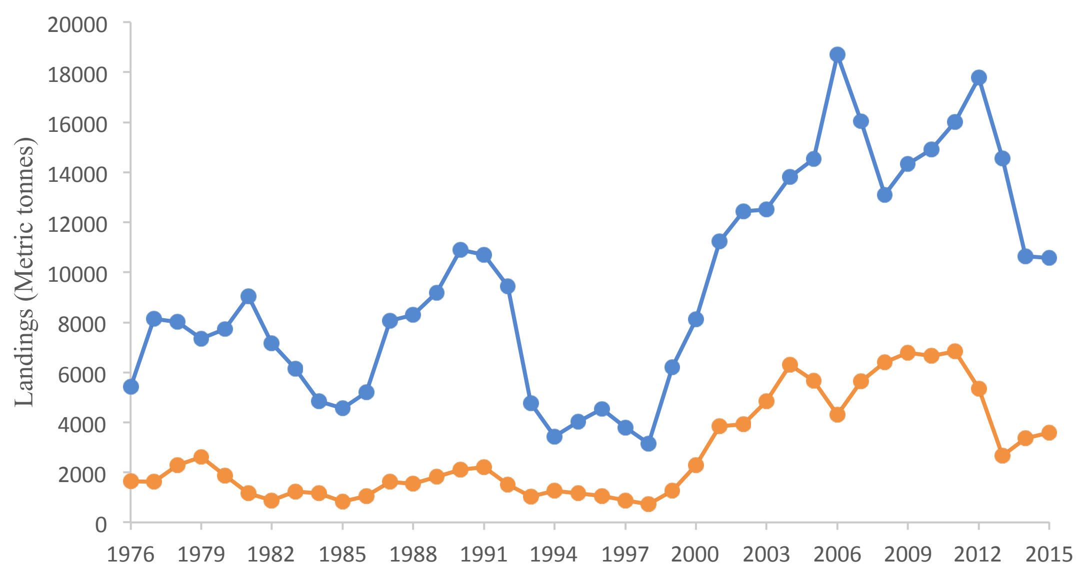

Figure 9: Annual landings data for Atlantic sea scallop (*Placopecten magellanicus*) from 1976 to 2015. Landings data displayed in metric tonnes. The blue line denotes landings from New England and the orange line denotes landings from the Mid Atlantic. The single y-axis corresponds to both New England and Mid Atlantic landings. Landings data obtained from NOAA Commercial Fishery Statistics.

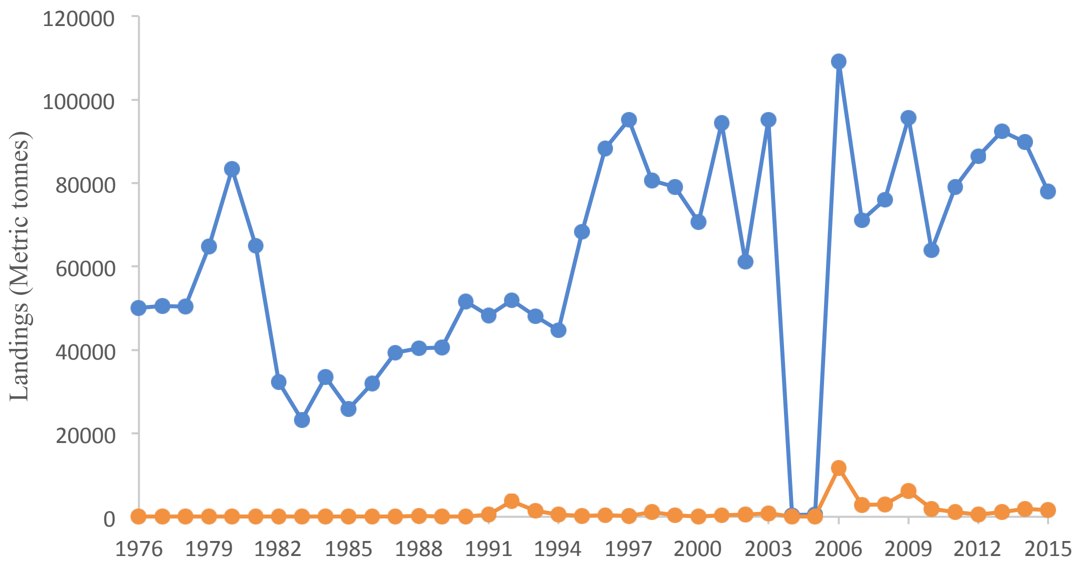

Figure 10: Annual landings data for Atlantic herring (*Clupea harengus*) from 1976 to 2015. Landings data displayed in metric tonnes. The blue line denotes landings from New England and the orange line denotes landings from the Mid Atlantic. The single y-axis corresponds to both New England and Mid-Atlantic landings. Landings data obtained from NOAA Commercial Fishery Statistics.

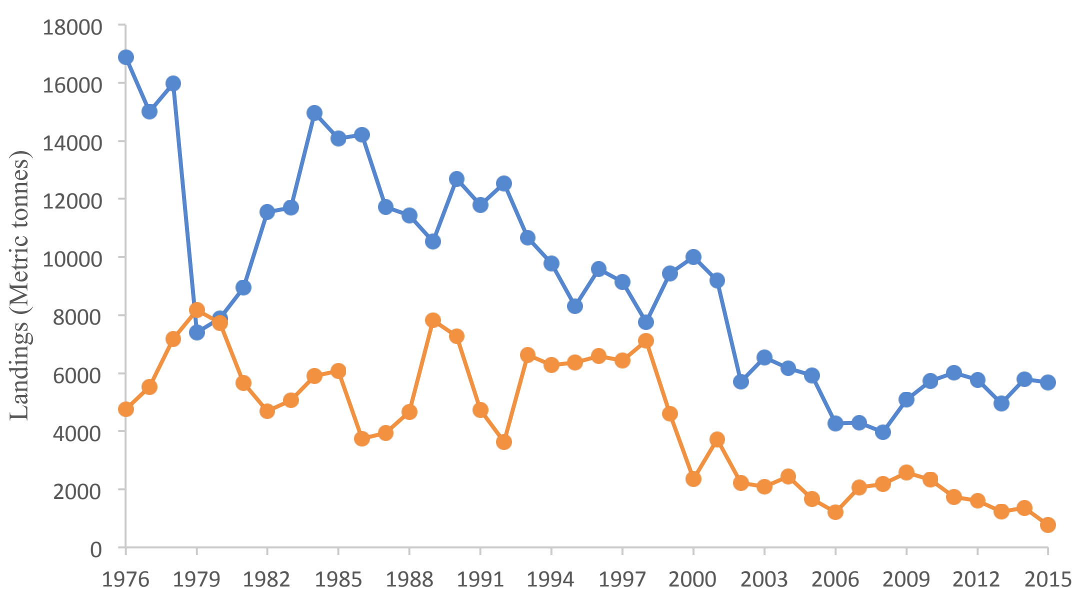

Figure 11: Annual landings data for silver hake (*Merluccius bilinearis*) from 1976 to 2015. Landings data displayed in metric tonnes. The blue line denotes landings from New England and the orange line denotes landings from the Mid Atlantic. The single y-axis corresponds to both New England and Mid Atlantic landings. Landings data obtained from NOAA Commercial Fishery Statistics.

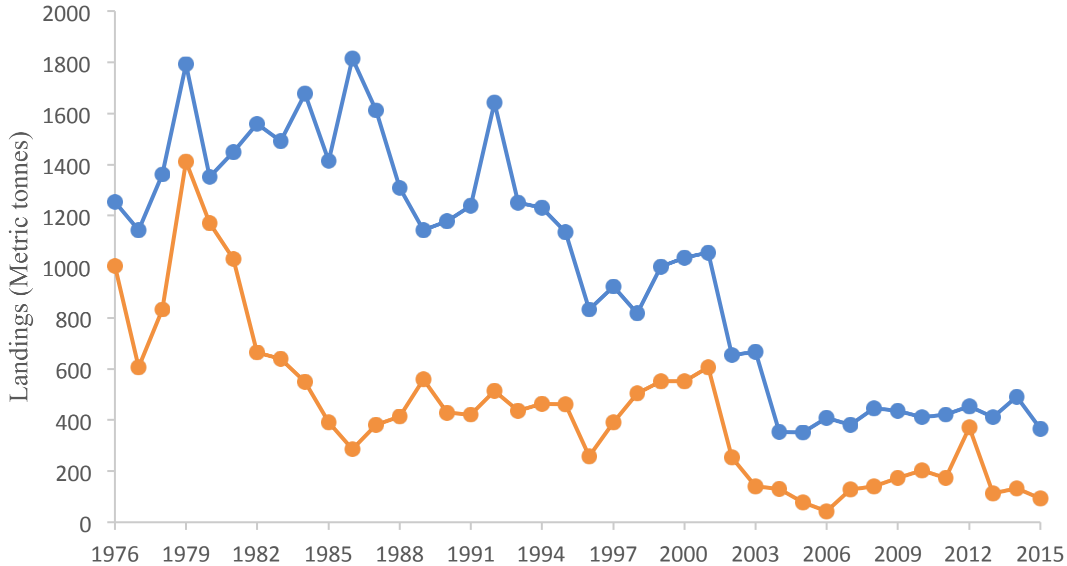

Figure 12: Annual landings data for red hake (*Urophycis chuss*) from 1976 to 2015. Landings data displayed in metric tonnes. The blue line denotes landings from New England and the orange line denotes landings from the Mid Atlantic. The single y-axis corresponds to both New England and Mid Atlantic landings. Landings data obtained from NOAA Commercial Fishery Statistics.

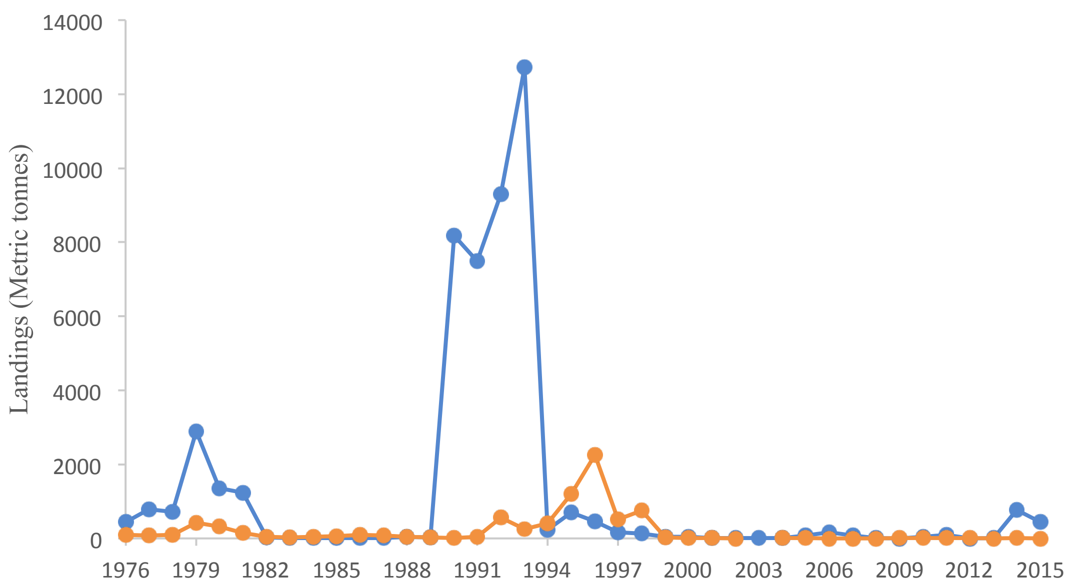

Figure 13: Annual landings data for spiny dogfish (*Squalus acanthias*) from 1976 to 2015. Landings data displayed in metric tonnes. The blue line denotes landings from New England and the orange line denotes landings from the Mid Atlantic. The single y-axis corresponds to both New England and Mid Atlantic landings. Landings data obtained from NOAA Commercial Fisheries Statistics.

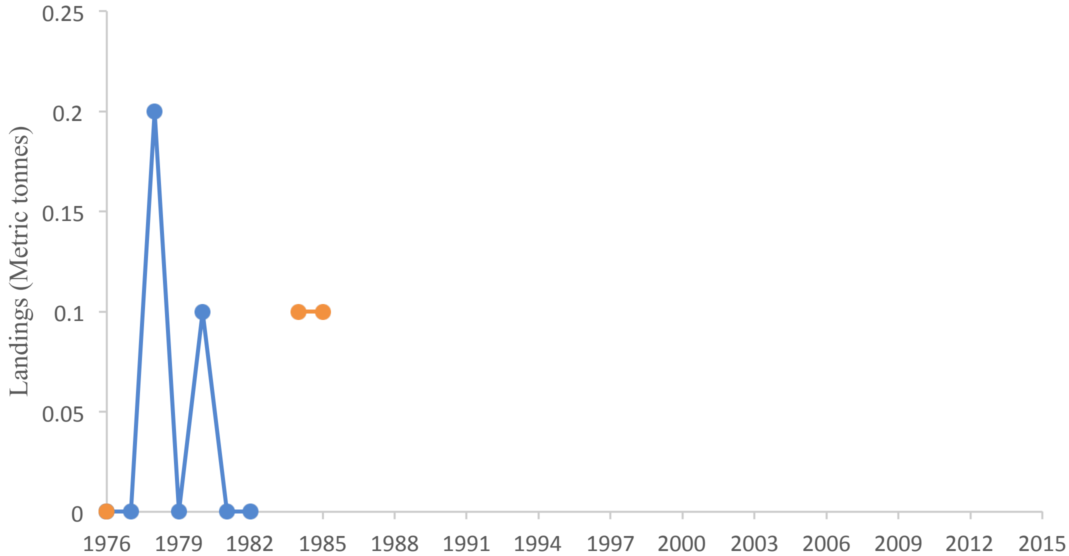

Figure 14: Annual landings data for Atlantic salmon (*Salmo salar*) from 1976 to 2015. Landings data displayed in metric tonnes. The blue line denotes landings from New England and the orange line denotes landings from the Mid Atlantic. The single y-axis corresponds to both New England and Mid Atlantic landings. Landings data obtained from NOAA Commercial Fisheries Statistics.

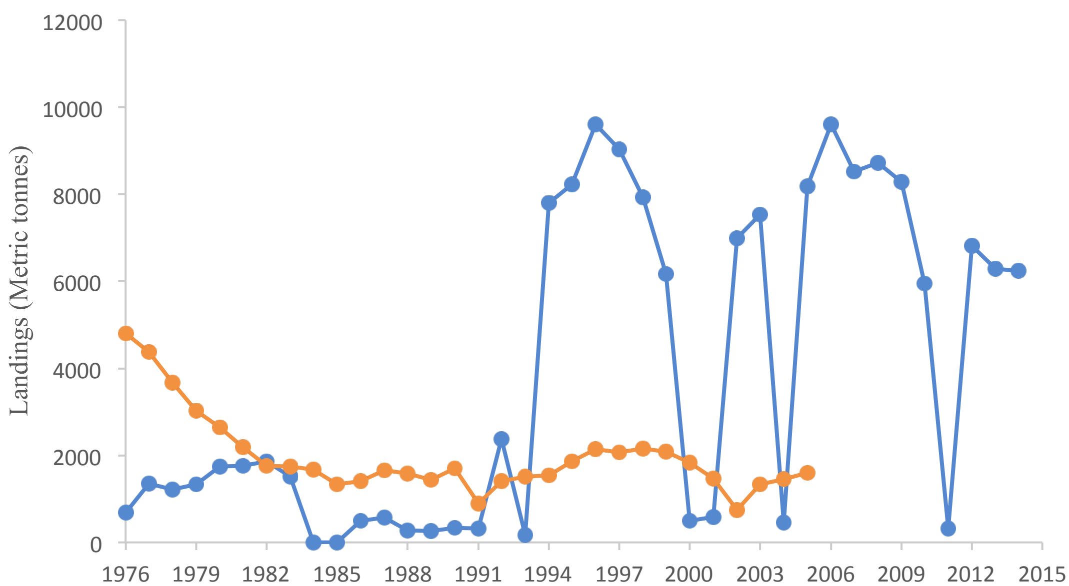

Figure 15: Annual landings data for ocean quahog (*Arctica islandica*) from 1976 to 2015. Landings data displayed in metric tonnes. The blue line denotes landings from New England and the orange line denotes landings from the Mid Atlantic. The single y-axis corresponds to both New England and Mid Atlantic landings. Landings data obtained from NOAA Commercial Fisheries Statistics.

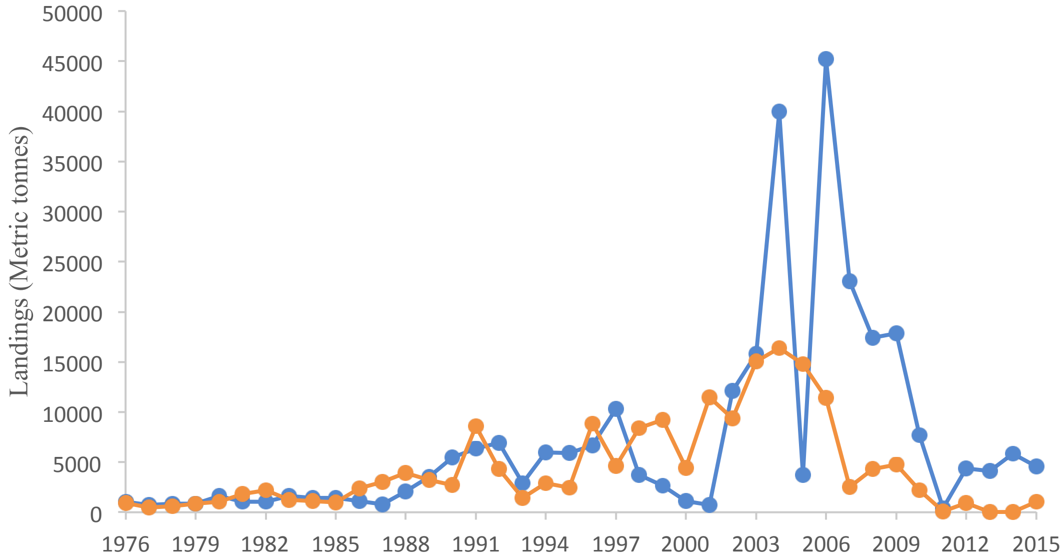

Figure 16: Annual landings data for Atlantic mackerel (*Scomber scombrus*) from 1976 to 2015. Landings data displayed in metric tonnes. The blue line denotes landings from New England and the orange line denotes landings from the Mid Atlantic. The single y-axis corresponds to both New England and Mid Atlantic landings. Landings data obtained from NOAA Commercial Fisheries Statistics.

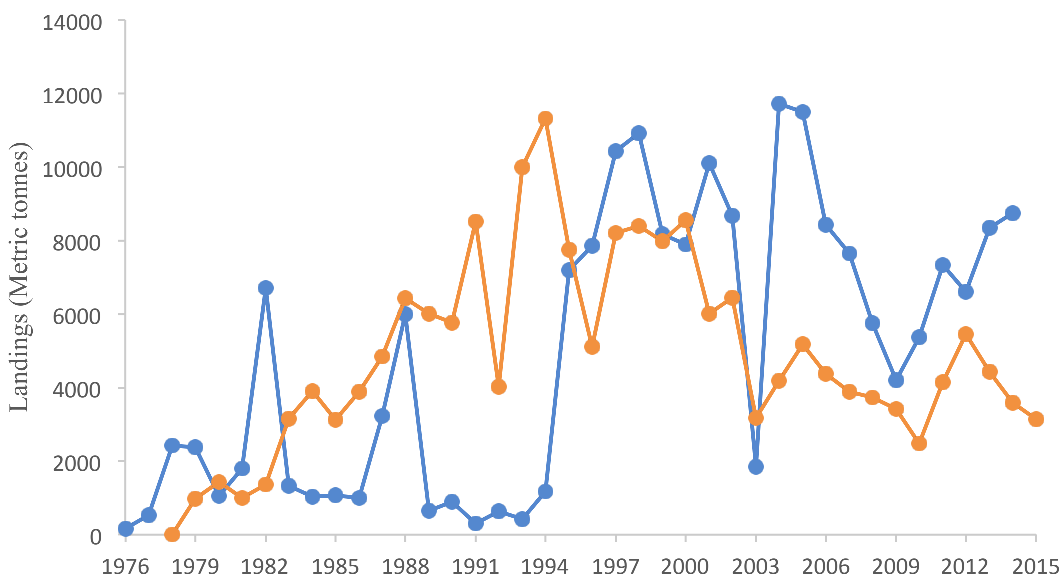

Figure 17: Annual landings data for longfin squid (*Doryteuthis pealeii*) from 1976 to 2015. Landings data displayed in metric tonnes. The blue line denotes landings from New England and the orange line denotes landings from the Mid Atlantic. The single y-axis corresponds to both New England and the Mid Atlantic landings. Landings data obtained from NOAA Commercial Fisheries Statistics.

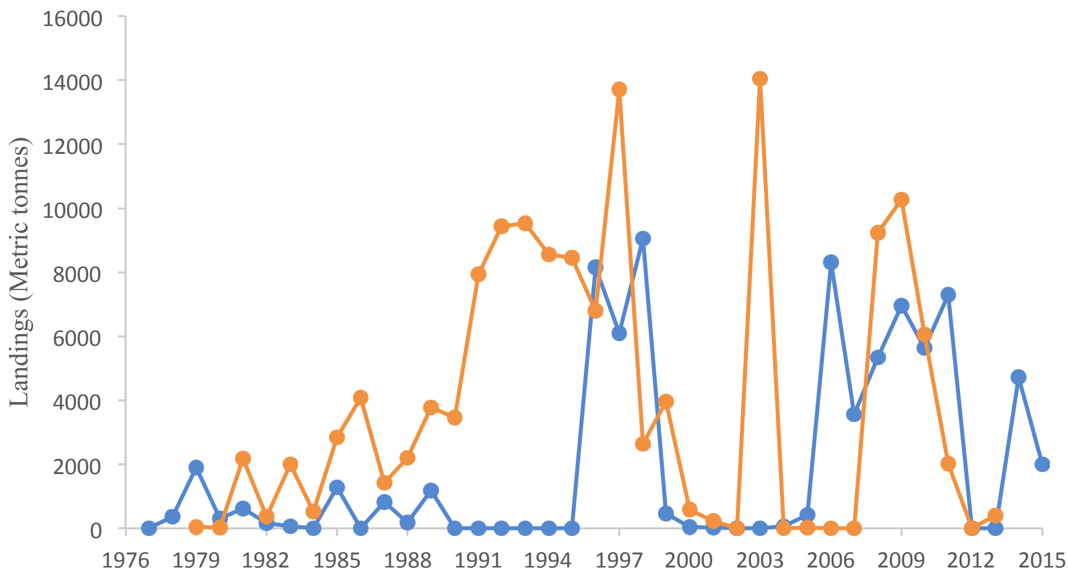

Figure 18: Annual landings data for northern shortfin squid (*Illex illecebrosus*) from 1976 to 2015. Landings data displayed in metric tonnes. The blue line denotes landings from New England and the orange line denotes landings from the Mid Atlantic. The single y-axis corresponds to both New England and Mid Atlantic landings. Landings data obtained from NOAA Commercial Fisheries Statistics.

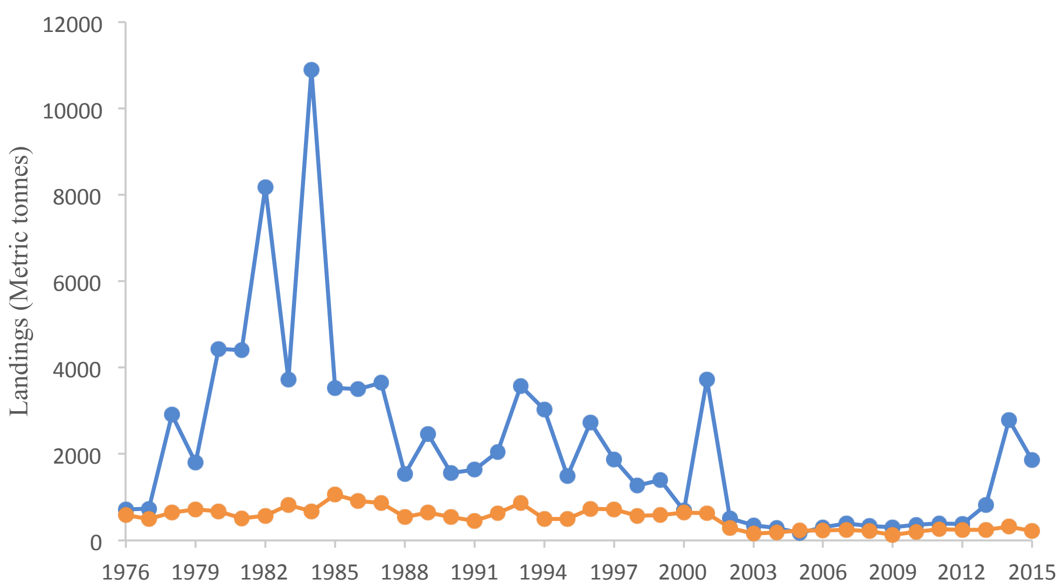

Figure 19: Annual landings data for butterfish (*Peprilus triacanthus*) from 1976 to 2015. Landings data displayed in metric tonnes. The blue line denotes landings from New England and the orange line denotes landings from the Mid Atlantic. The single y-axis corresponds to both New England and Mid Atlantic landings. Landings data obtained from NOAA Commercial Fisheries Statistics.

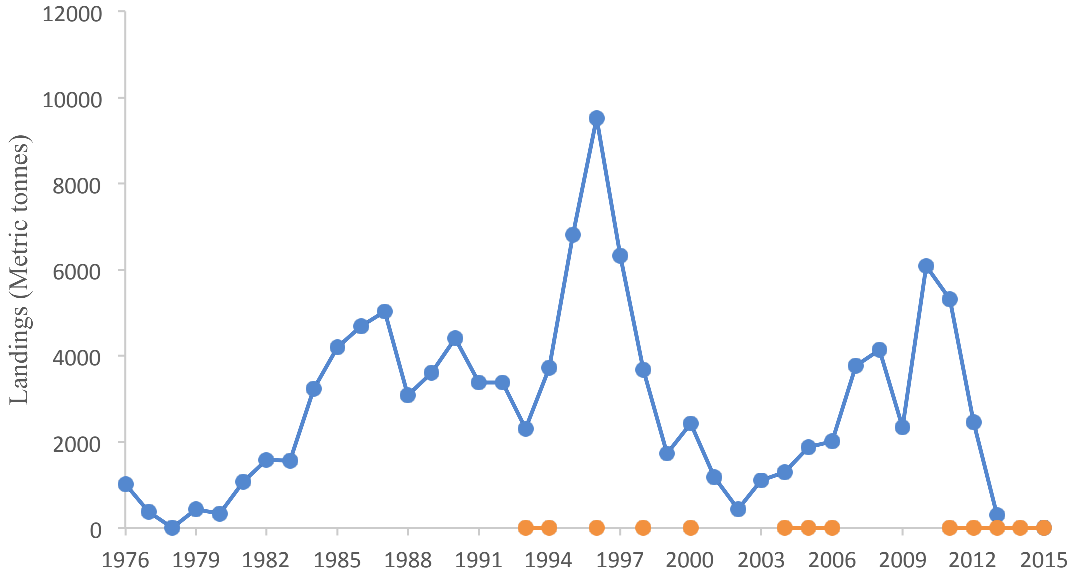

Figure 20: Annual landings data for northern shrimp (*Pandalus borealis*) from 1976 to 2015. Landings data displayed in metric tonnes. The blue line denotes landings from New England and the orange line denotes landings from the Mid Atlantic. The single y-axis corresponds to both New England and Mid Atlantic landings. Landings data obtained from NOAA Commercial Fishery Statistics.

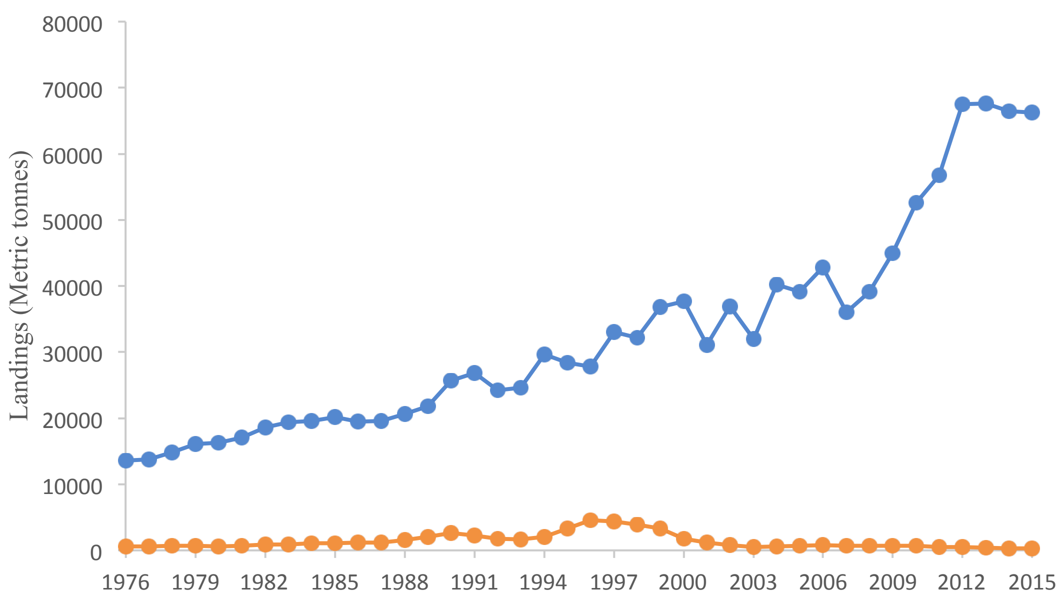

Figure 21: Annual landings data for American lobster (*Homarus americanus*) from 1976 to 2015. Landings data displayed in metric tonnes. The blue line denotes landings from New England and the orange line denotes landings from the Mid Atlantic. The single y-axis corresponds to both New England and Mid Atlantic landings. Landings data obtained from NOAA Commercial Fishery Statistics.

AUTHOR'S BIOGRAPHY

Dylan T. Trueblood was born in Silver Spring, Maryland. He grew up in Durham, New Hampshire and graduated from Oyster River High School in 2013. Dylan is majoring in Marine Science with a concentration in Marine Biology and graduating after four years at the University of Maine in May 2017. He spent spring semester of 2016 abroad in Australia at Deakin University in Warrnambool, VIC. He also participated in the Semester by the Sea program during the fall semester of 2016 at the Darling Marine Center in Walpole, ME. He is a member of Phi Beta Kappa.

After Graduating, Dylan will be working at Fat Dog Shellfish, an oyster aquaculture center in Great Bay, NH for the summer and possibly fall of 2017. He tentatively plans to pursue an advanced degree by applying to graduate programs during the year following his graduation. Meanwhile, he plans to continue working within the scientific field of marine science.