

ESTUARINE FISH COMMUNITIES

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1. OVERVIEW

Estuarine fish are important parts of Narragansett Bay's food web, provide sustenance to humans, and serve as critical links between the estuary and the open ocean. While fishing, pollution, and habitat loss all cause changes in estuarine fish communities, warming of coastal waters—which has been documented over the last 60 years and is projected to continue into the future—is an increasingly important stressor. Because their composition responds to warming waters and other stressors, estuarine fish communities are considered to be excellent indicators of ecosystem change.

Two ways of measuring estuarine fish communities are by the ratio of pelagic (live in the water column) to demersal (live near the bottom) species (the P:D ratio) and by the abundance of species that prefer warm or cold water. Datasets from the University of Rhode Island Graduate School of Oceanography (GSO) fish trawl survey and the Rhode Island Department of Environmental Management (RIDEM) fish trawl survey provide information on estuarine fish communities since 1983 and 1959, respectively. For years prior to 1959, researchers rely on information from other sources, such as records of commercial fisheries landings. In addition to fish, this chapter includes findings related to lobster (*Homarus americanus*) and shellfish.

Since 1959, the estuarine fish community in Narragansett Bay has changed markedly. While year-to-year variability in fish communities is common and detectable in the data, a major regime shift occurred during the 1980s. Compared to the period before the 1980s, demersal species such as red hake (*Urophycis chuss*) and silver hake (*Merluccius bilinearis*) have become less numerous, warm-water species such as summer flounder (*Paralichthys dentatus*) and butterfish (*Peprilus triacanthus*) are more abundant, and cold-water species such as winter flounder (*Pseudopleuronectes americanus*) and American lobster may have reduced rates of survival (e.g., juvenile winter flounder, see Taylor and Collie 2003) and reproduction (Jeffries 1994, Jeffries and Johnson 1974). As Narragansett Bay and the adjacent coastal ocean water temperatures continue to warm, fish communities will be composed of fewer cold-water species and more warm-water species.

2. INTRODUCTION

Fish populations in Narragansett Bay are a vital ecological and economic resource. Fish are harvested commercially and recreationally, and they are important links in the estuarine food chain. Some fish in Narragansett Bay, such as menhaden (*Brevoortia tyrannus*), are consumed by birds, invertebrates, and larger fish, while others are top predators, such as striped bass (*Morone saxatilis*). Fish that spawn in rivers and migrate to the sea (e.g., herring species) represent the transport of nutrients between the upland portions of the watershed and the open ocean. The composition of fish populations, therefore, helps determine what ecosystem services are provided in an estuarine ecosystem and in what proportions.

In general, fish populations fluctuate on fine and broad temporal scales (inter-annual to millennial), influenced by a number of natural and anthropogenic factors. Relative to oceanic fish populations, those in estuaries are affected by more intense anthropogenic stressors that may alter their composition. For example, accessibility to fisheries, exposure to pollution, habitat loss, and introduced species are all stressors that are higher in Narragansett Bay and other estuaries than in the broader

Northwest Atlantic (Collie et al. 2008). In addition, water temperatures in Narragansett Bay have warmed faster than the surrounding Northwest Atlantic Ocean surface waters (Smith et al. 2010, Fulweiler et al. 2015). This trend is expected to continue, or even intensify, as model forecasts indicate that the Northwest Atlantic Ocean could warm three times as fast as the global average (Saba et al. 2016). Because many fish species in Narragansett Bay already live at the edge of their thermal tolerances (Smith et al. 2010), warming waters are an important stressor to consider (see “Temperature” chapter).

Rising water temperatures are a direct impact from climate change on the Narragansett Bay ecosystem. Warmer waters should favor warm-water species over cold-water species. Fish will move to more favorable habitats, and scientists are already seeing examples of this at the scale of the Northeast Shelf Large Marine Ecosystem. Nye et al. (2009) documented changes in abundance, pole-ward shifts, and shifts to deeper water for several fish species in the Northwest Atlantic between 1968 and 2007. In addition, cold-water species may be unable to reproduce successfully in warmer waters, further reducing their numbers (Jeffries 1994, Jeffries and Johnson 1974).

Indirect impacts of climate change will also affect Narragansett Bay fish communities. For example, warmer conditions increase the predation rates of sand shrimp (*Crangon septemspinosa*) on juvenile winter flounder, perhaps leading to local extinction (Taylor and Collie 2003). Warming waters are also disrupting the magnitude and timing of the winter-spring phytoplankton bloom in Narragansett Bay (Li and Smayda 1998, Nixon and Fulweiler 2007; see “Chlorophyll” chapter). Because phytoplankton are the major primary producers in Narragansett Bay, changes in primary productivity represent an indirect impact of climate change that will have implications for the entire food web, including fish. Notably, decreased phytoplankton biomass leads to lower quantities and quality of organic matter delivery to benthic invertebrates (Keller et al. 1999), altering the composition of benthic communities (see “Benthic Habitat” chapter). Changes in benthic communities over the past 20 years, resulting partly from changes in primary productivity, have the potential to impact fish species that rely on the benthos as a food source (Shumchenia et al. 2016).

Phytoplankton productivity and benthic productivity are also affected by the delivery of nutrients to the Bay. Nutrient input is another process affected by climate change that could represent an indirect impact on fish communities. In the nineteenth and twentieth centuries, nutrient inputs to the Bay rose as human population increased (Fulweiler and Nixon 2012). Increases in total precipitation and increases in extreme precipitation events due to climate change have facilitated the delivery of terrestrial-derived nutrients to the Bay (Smith et al. 2010). Only recently has nutrient pollution of the Bay decreased markedly through management actions such as improvements in wastewater treatment facilities (see “Nutrient Loading” chapter).

Other factors that have direct impacts on fish community composition in Narragansett Bay include harvesting and habitat loss. Both of these factors must be considered when interpreting trends in the context of climate change. From analysis of the earliest available quantitative fisheries data in the late 1800s, it was apparent that both habitat loss and harvesting had already altered fish community composition (Oviatt et al. 2003). Anadromous species, bay scallop (*Argopecten irradians*), and oyster (*Crassostrea virginica*) have all declined or nearly disappeared from the Narragansett Bay estuarine community as a result of habitat loss and exploitation, and overall fish abundance decreased 81 percent between 1898 and 1999 (Oviatt et al. 2003). In the case of bay scallop, habitat loss was due to nutrient enrichment. Beds of eelgrass (*Zostera marina*), a vital habitat for many fish species, were lost due to

nutrient inputs and shading from excessive phytoplankton blooms (Oviatt et al. 2003; see “Seagrasses” chapter).

Trends in the estuarine fish community detected in the available data likely resulted from a complex and cumulative combination of natural and anthropogenic stressors—one that has changed over time. Because the Bay has been fished intensively for hundreds of years, there were potentially significant changes to habitats and fish communities prior to the onset of the quantitative monitoring programs that began in 1959 at the University of Rhode Island Graduate School of Oceanography (GSO) and in 1979 at the Rhode Island Department of Environmental Management (RIDEM). Importantly, the fish communities characterized in the 1960s likely represented an already-shifted baseline (Oviatt et al. 2003). These two trawl surveys constitute the most continuous and comprehensive datasets on Narragansett Bay fish communities. The GSO trawl is one of the longest continuous records of fish and invertebrate relative abundance in the world (Taylor and Collie 2000).

Previous analyses of data from both surveys indicate that the abundance of demersal fish species has declined relative to pelagic species (Oviatt et al. 2003, Oviatt 2004, Collie et al. 2008). The ratio of pelagic to demersal fish species abundance—the P:D ratio—has therefore been used as an indicator of changing fish communities in Narragansett Bay and elsewhere (Collie et al. 2008). In Narragansett Bay, the P:D ratio is correlated with increasing sea surface temperatures (measured in situ during the trawls), declining chlorophyll-*a* concentrations, and the positive phase of the North Atlantic Oscillation (NAO) winter index (Collie et al. 2008). Spring/summer sea surface temperature, which increased 1.6°C (2.8°F) between 1959 and 2005, and a two-thirds reduction in chlorophyll-*a* concentrations are both linked with increased numbers of squids and pelagic fish, as well as the decline of demersal species such as winter flounder, red hake, and silver hake (Collie et al. 2008). The winter NAO is a basin-scale climate index that has been correlated to the abundance, growth, and migration timing of estuarine fish (Atrill and Power 2002) and is correlated with higher numbers of pelagic species in the Bay (Collie et al. 2008). The study by Collie and coauthors (2008) concluded that those patterns and the data from both GSO and RIDEM surveys reflect a regime shift in Narragansett Bay from demersal species to pelagic species occurring around 1980–1981.

Another trend reported by Collie and coauthors (2008) is the decline of boreal or cold-water species such as winter flounder, red hake, and silver hake, and the increase in seasonal migrants that are abundant in the summer months, such as butterfish, scup, summer flounder, and black sea bass. This trend has been reported at the regional scale as well (Pinsky et al. 2013) and is correlated to increasing temperatures and harvesting by fisheries in both cases. There has been a more recent (since the early 2000s) decline in American lobster populations in the Bay attributed to the onset of shell disease, extreme summer temperatures, and sharp declines in larval settlement (Wahle et al. 2015).

An “unnatural experiment” for helping to determine the potential effects of increased temperatures of fish stocks has taken place in Mount Hope Bay since the establishment of heated water discharge from the Brayton Point Power Station (BPPS) in Somerset, Massachusetts in 1963 (Rountree and MacDonald 2006). In 1984, a drastic decline in winter flounder populations was observed in Mount Hope Bay, and it was suggested that an increase in heated water discharged from the BPPS was responsible (Rountree and MacDonald 2006). Subsequently, there has been increased study of the cumulative stressors affecting Mount Hope Bay, including the effects of increased temperatures on fish. In addition to the GSO and RIDEM trawls, there are additional data collected (fish trawls) in Mount Hope Bay to monitor the effects of the BPPS by Marine Research, Inc. DeAlteris and colleagues (2006) compared trends within Mount Hope Bay with trends in wider Narragansett Bay,

using data from these three fish trawls, to determine if the BPPS is having a negative effect on winter flounder, windowpane, hogchoker, tautog, and scup. They found that there were no differences in abundance trends for these species between Mount Hope Bay and wider Narragansett Bay, and suggested that large-scale factors such as overfishing, climate change, and increased predator abundance are more important drivers of fish community change. It is the interaction of warming with one or more of these factors (e.g., increased predator abundance/activity) that is predicted to lead to further declines in cold-water species such as winter flounder in Narragansett Bay (Smith et al. 2010).

3. METHODS

Given the existing body of work characterizing trends in Narragansett Bay’s fish communities, the Narragansett Bay Estuary Program sought to update and distill the indicators already in use by GSO and RIDEM fish monitoring programs: the P:D ratio, the abundance of key cold-water species, and the abundance of key warm-water species.

Data sources for these indicators include annual mean abundance of fish species at all fixed and random Narragansett Bay stations from the RIDEM fish trawl between 1983–2012 (obtained from RIDEM Marine Fisheries) and annual mean abundance per trawl at the Fox Island (Middle-West Passage) station from the GSO fish trawl between 1959–2012 (obtained from www.gso.uri.edu/fishtrawl16) (Figure 1). Characteristics of each survey and major differences between them are important to note when considering the datasets (Table 1). A comparison by the Rhode Island Marine Fisheries Institute determined that the two surveys displayed similar trends for most species, but rates of catchability are different between trawls (RIMFI 2015). For example, it is apparent from comparing the mesh sizes in Table 1 that the RIDEM trawl catches higher abundances of smaller animals than the GSO trawl. Based on the tow duration and towing speed, it is also apparent that the GSO trawl samples along a slightly longer transect (1.15 miles, 1.85 kilometers) than the RIDEM trawl (0.96 mile, 1.54 kilometer).

Table 1. Characteristics of the two Narragansett Bay fish trawl surveys discussed in this report: the University of Rhode Island Graduate School of Oceanography (GSO) fish trawl and the Rhode Island Department of Environmental Management (RIDEM) fish trawl.

	GSO Fish Trawl	RIDEM Fish Trawl (Narragansett Bay stations only)
Temporal Coverage and Sampling Frequency	1959-present, weekly	<ul style="list-style-type: none"> • 1979-present: Stratified random stations, seasonal • 1988-present: Fixed stations, seasonal • 1990-present: Fixed stations, monthly
Number of Stations	2*	<ul style="list-style-type: none"> • Monthly, fixed: 12 • Seasonal, fixed: 12 • Seasonal, random: 14
Station Locations	Fox Island station (Middle West Passage) Whale Rock station (Mouth of Narragansett Bay)	Narragansett Bay including Mount Hope Bay and Sakonnet River, excluding Greenwich Bay and Providence River estuary

Trawl Methods	<ul style="list-style-type: none"> • 3” net mesh, 2” cod-end mesh • Steel otterboards • Tow duration: 30 minutes • Towing speed: 2 knots 	<ul style="list-style-type: none"> • Otter trawl with ¼” liner • Currently Thyboron Type II trawl doors (wooden Tomkiewicz flat otter trawl doors until 2012) • Tow duration: 20 minutes • Tow speed: 2.5 knots
Units Reported	Number of individuals (by species) per tow	Number of individuals (by species) per tow
Additional Variables Recorded	<ul style="list-style-type: none"> • Surface and bottom water temperature (since 1959) • Surface and bottom salinity (since 2006) • Surface and bottom dissolved oxygen (since 2006) 	<ul style="list-style-type: none"> • Wind speed and direction • Sea condition • Air temperature • Cloud cover • Surface and bottom water temperature • Net performance metrics

*Data from only 1 station—Fox Island—were included in the analyses reported in this chapter.

The list of the 25 most-abundant species caught in the GSO trawl (Collie et al. 2008) was used as a starting point for this analysis. Four species on this list—all invertebrates—were not reported in the RIDEM data obtained by the Narragansett Bay Estuary Program (Table 2). Therefore, each trawl dataset was reduced to species in common, for a total of 21 species, and each species was categorized as having either pelagic or demersal habitat (Table 2).

To examine potential indirect impacts of climate change on the estuarine fish community, the P:D ratio was calculated for each year of available data for each trawl. Following Collie et al. (2008), the P:D ratio was calculated as the sum of individuals defined as pelagic species divided by the sum of individuals defined as demersal species. To examine potential direct impacts of climate change on the estuarine fish community, the abundance of four warm-water species (butterfish, long finned squid, scup, summer flounder; Table 2; based on Collie et al. [2008]) were plotted over time with in situ sea surface temperature recorded during the GSO trawls and bottom water temperature recorded during the RIDEM trawls. These four species are of interest because they are some of the most abundant species in the GSO trawl (see Table 2). The abundance of winter flounder and American lobster, both cold-water demersal species, were also plotted over time. Winter flounder and American lobster are of particular interest because they were historically abundant in the Bay (Collie et al. 2008), but have shown sharp declines in abundance recently.

The P:D ratio, species abundances, and water temperatures were plotted separately for each GSO and RIDEM survey, without applying any correction factors. Because the RIDEM data are summarized as annual mean abundance across all Narragansett Bay sites and the GSO data are summarized as annual mean abundance per trawl, the magnitudes of the abundances should not be directly compared between survey programs.

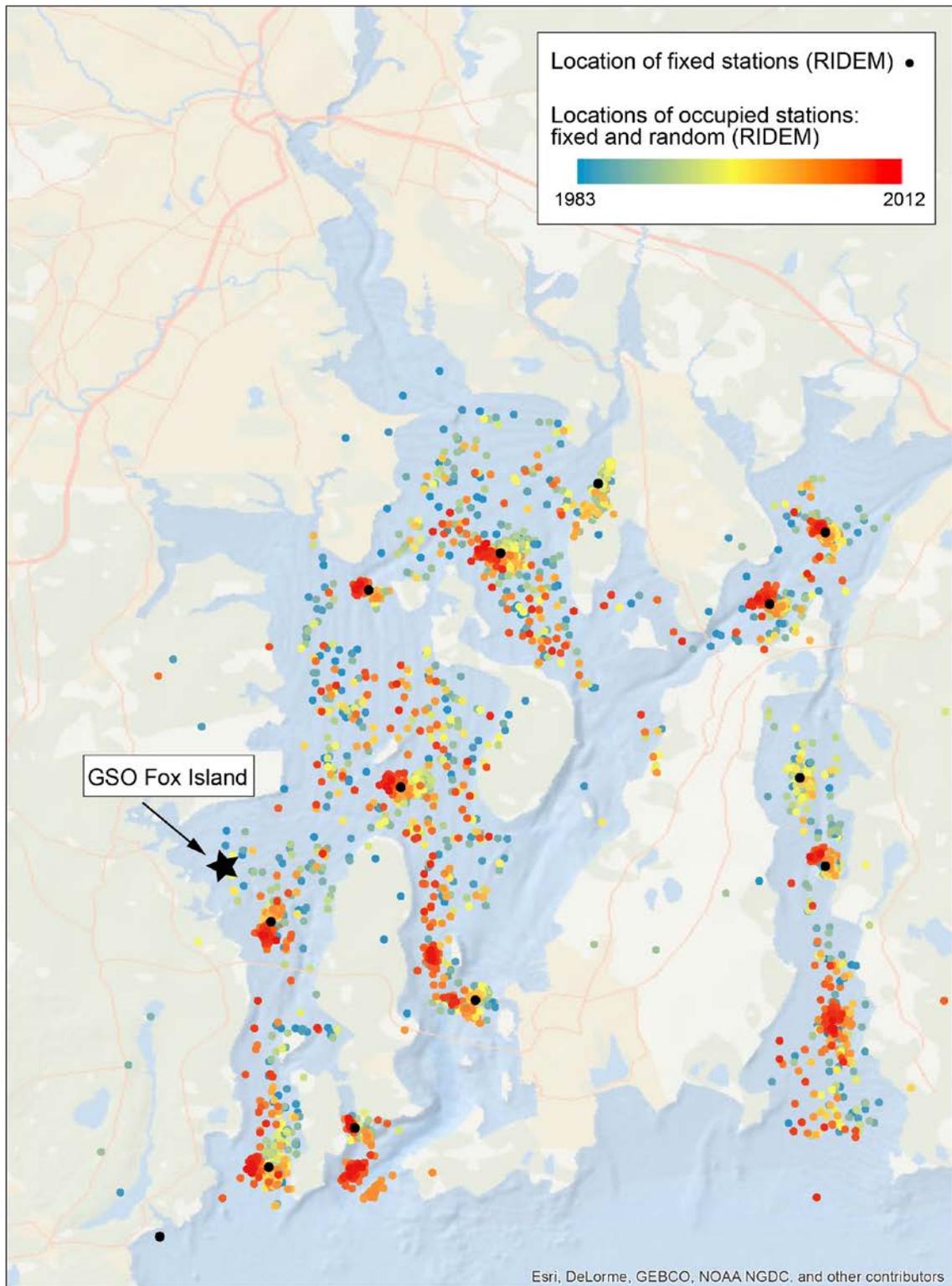


Figure 1. Locations of fish trawl stations from the University of Rhode Island Graduate School of Oceanography (GSO) and the Rhode Island Department of Environmental Management (RIDEM) fish trawl surveys that were used in the Narragansett Bay Estuary Program analysis of estuarine fish communities.

Table 2. Fish species caught in regular monitoring of Narragansett Bay by the University of Rhode Island Graduate School of Oceanography (1959–2012) and the Rhode Island Department of Environmental Management (1983–2012). Species are listed in order of greatest to least mean abundance per tow (1959–2005) from the GSO trawl.

Species Common Name	Species Scientific Name	Habitat	Used in this report
Scup	<i>Stenotomus chrysops</i>	Demersal	Yes
Winter flounder	<i>Pseudopleuronectes americanus</i>	Demersal	Yes
Cancer crab	<i>Cancer irroratus</i> and <i>Cancer borealis</i>	Demersal	No
Butterfish	<i>Peprilus triacanthus</i>	Pelagic	Yes
Silver hake	<i>Merluccius bilinearis</i>	Demersal	Yes
Long finned squid	<i>Loligo pealeii</i>	Pelagic	Yes
American lobster	<i>Homarus americanus</i>	Demersal	Yes
Little skate	<i>Leucoraja erinacea</i>	Demersal	Yes
Windowpane	<i>Scophthalmus aquosus</i>	Demersal	Yes
Red hake	<i>Urophycis chuss</i>	Demersal	Yes
Spider crab	<i>Libinia emarginata</i>	Demersal	No
Atlantic herring	<i>Clupea harengus</i>	Pelagic	Yes
Northern sea robin	<i>Prionotus carolinus</i>	Demersal	Yes
Sea star	<i>Asterias forbesi</i>	Demersal	No
Longhorned sculpin	<i>Myoxocephalus octodecemspinosus</i>	Demersal	Yes
Fourspot flounder	<i>Paralichthys oblongus</i>	Demersal	Yes
River herring*	<i>Alosa</i> spp.	Pelagic	Yes
Cunner	<i>Tautoglabrus adspersus</i>	Demersal	Yes
Summer flounder	<i>Paralichthys dentatus</i>	Demersal	Yes
Lady crab	<i>Ovalipes ocellatus</i>	Demersal	No
Horseshoe crab	<i>Limulus polyphemus</i>	Demersal	Yes
Bluefish	<i>Pomatomus saltatrix</i>	Pelagic	Yes
Striped searobin	<i>Prionotus evolans</i>	Demersal	Yes
Tautog	<i>Tautoga onitis</i>	Demersal	Yes
Weakfish	<i>Cynoscion regalis</i>	Pelagic	Yes

* includes alewife (*Alosa pseudoharengus*) and blueback herring (*Alosa aestivalis*)

4. STATUS AND TRENDS

The P:D ratio for Narragansett Bay was variable over time but generally increased between 1959 and 2012, suggesting that increasing temperatures, eutrophication, and harvesting were continuing to affect fish community composition (Figure 2). The longer time period of data provided by the GSO survey revealed the major shift in fish community composition that occurred in the 1980s (Figure 2). While P:D ratios varied within the two periods—before (1959–1980) and after (1981–2012) the shift—the average magnitude of the ratio differed greatly between the two periods. There also appears to have been a declining trend beginning in the mid-1990s. In the RIDEM survey, which began in 1983, P:D ratios were variable, but with an increasing trend for the duration of the data series. The RIDEM trawl data had higher P:D ratios than the GSO trawl data. This may be attributable to any of the differences between trawl methods noted in Table 1, including the smaller mesh size used by the RIDEM trawl and the greater number of stations over a wider area represented by the RIDEM data.

The abundance of warm-water species increased slightly since 1959, according to the results of both trawl surveys (Figures 3a and 3c). Both datasets showed large increases in the variability in their respective metrics since the beginning of each time series, suggesting that factors other than increasing temperatures (Figures 3b and 3d) were influencing fish species abundance.

American lobster and winter flounder abundance data showed different trends (Figure 4). Lobster abundance was low from the 1960s through the 1980s, increased in the mid- to late 1990s, and then abruptly declined from the early 2000s to 2012. This recent decline corresponds with trends reported in stock assessment reports (ASMFC 2015) and studies of American lobster nurseries in Narragansett Bay (Wahle et al. 2015). Winter flounder, on the other hand, were most abundant in the earliest segment of the time series and declined since the 1980s. This decline is consistent with previous findings that winter flounder abundances have decreased 90 percent since 1980 in Narragansett Bay (Oviatt 2004), linked to warmer winter water temperatures (Jefferies 1994, Jefferies and Johnson 1974, Taylor and Collie 2003).

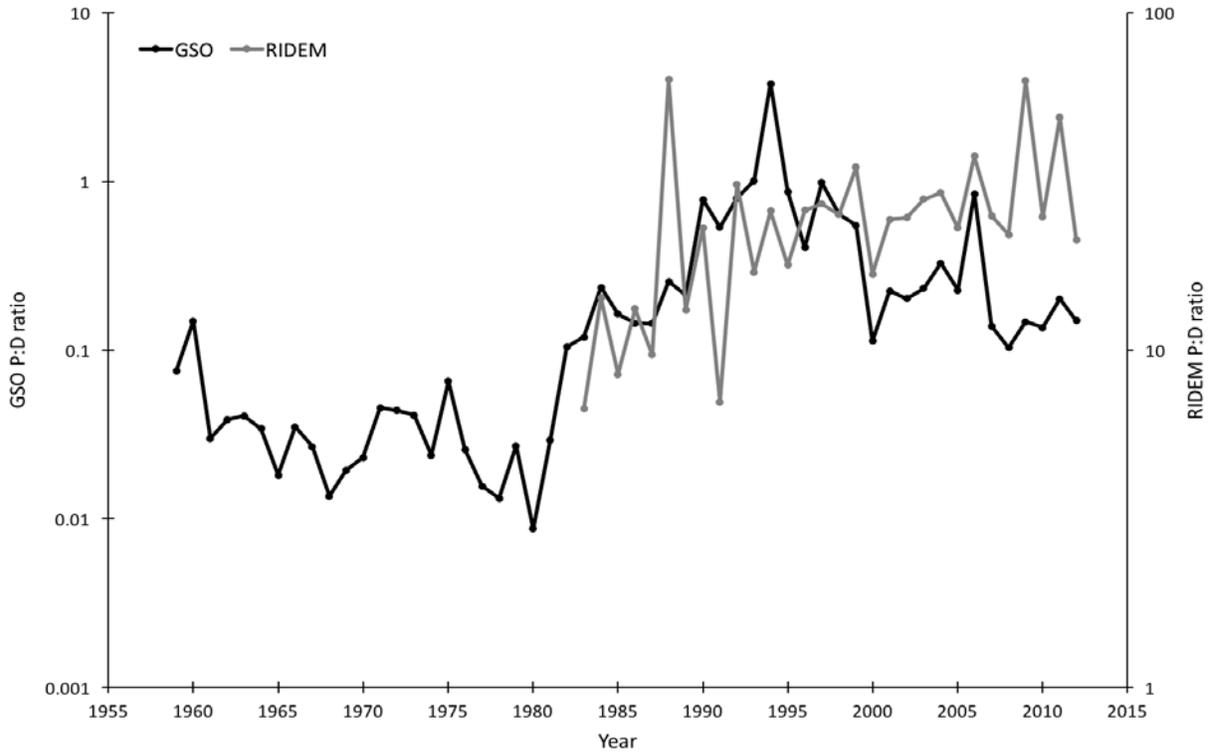


Figure 2. Narragansett Bay pelagic-to-demersal (P:D) ratio for the fish community calculated from abundance-per-tow data for GSO (black line) and mean annual abundance data for RIDEM (grey line) trawl surveys. GSO = University of Rhode Island Graduate School of Oceanography. RIDEM = Rhode Island Department of Environmental Management.

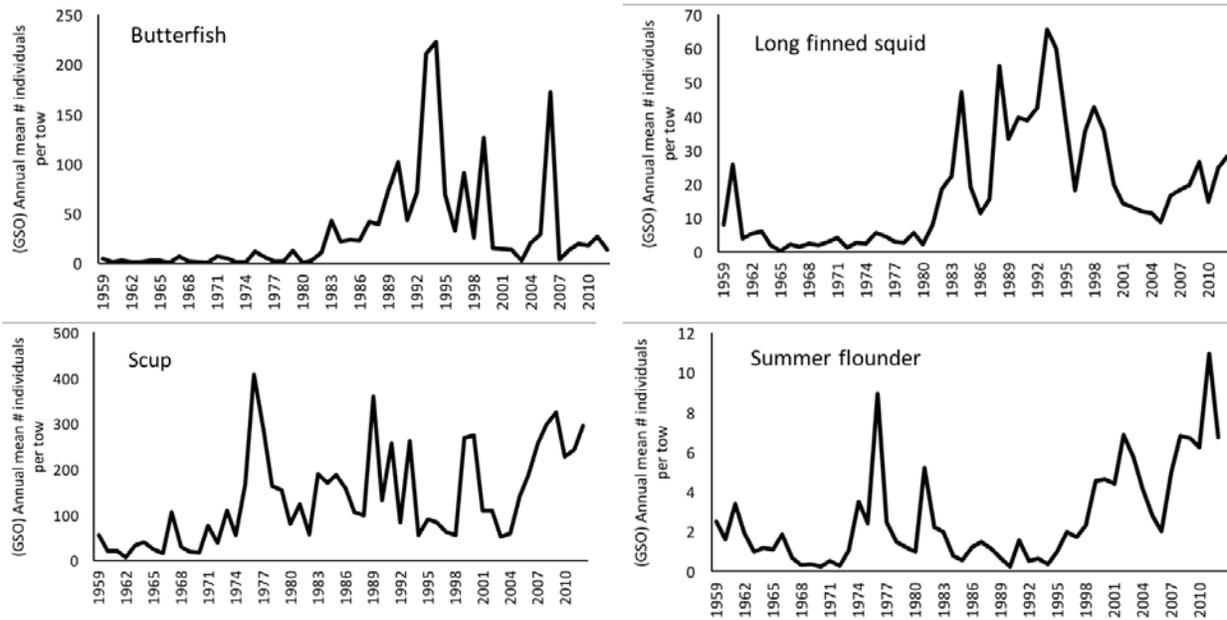


Figure 3a. Mean annual number of individuals per tow for four warm-water fish species caught at the Fox Island (Middle West Passage) station of the University of Rhode Island Graduate School of

Oceanography (GSO) trawl survey. *Clockwise from top left:* Butterfish, long finned squid, scup, and summer flounder.

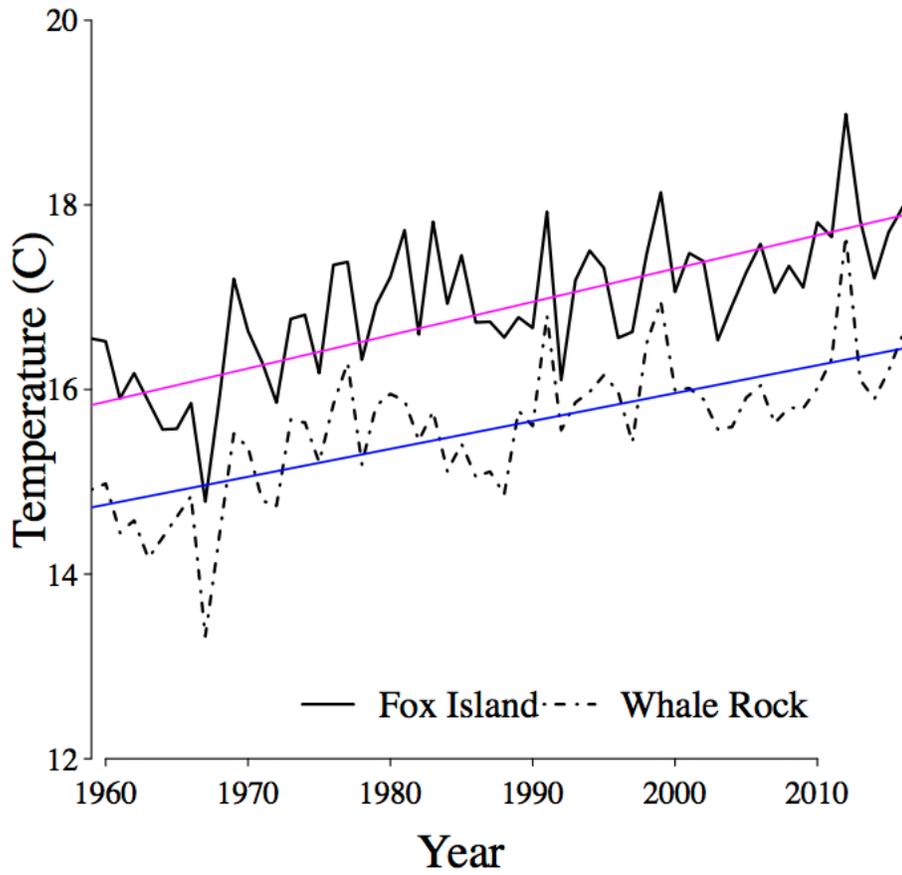


Figure 3b. In-situ mean annual sea surface temperature from the GSO trawl survey (<https://www.gso.uri.edu/fishtrawl16/>).

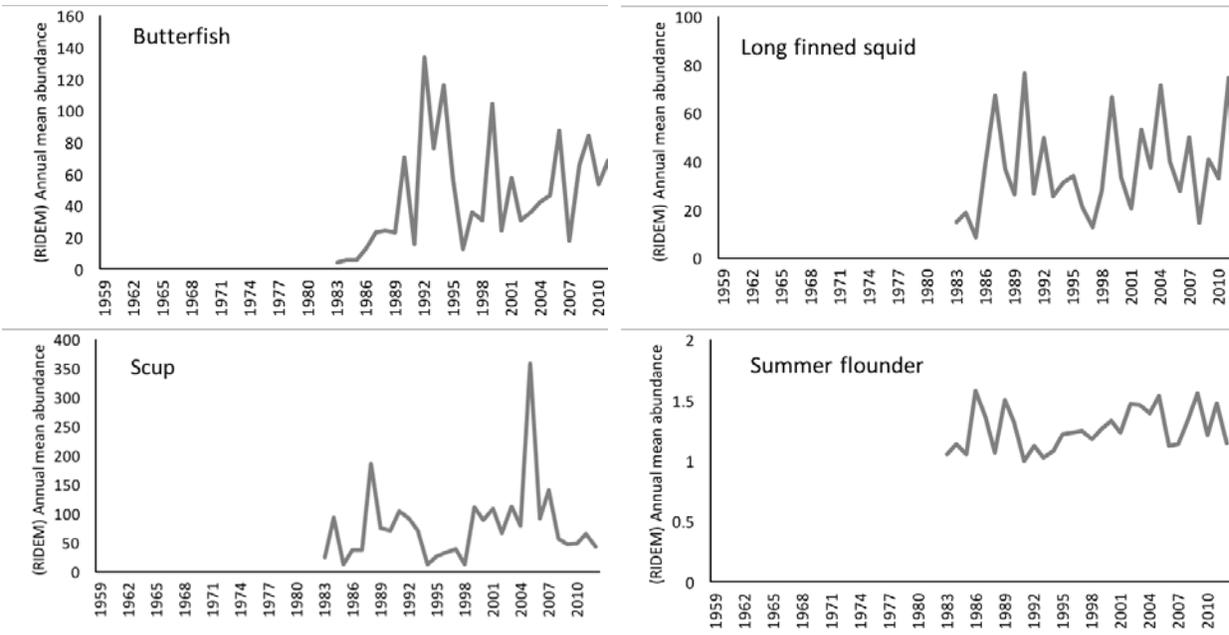


Figure 3c. Mean annual abundance for four warm-water fish species caught in the Rhode Island Department of Environmental Management (RIDEM) trawl survey. *Clockwise from top left:* Butterfish, long finned squid, scup, and summer flounder.

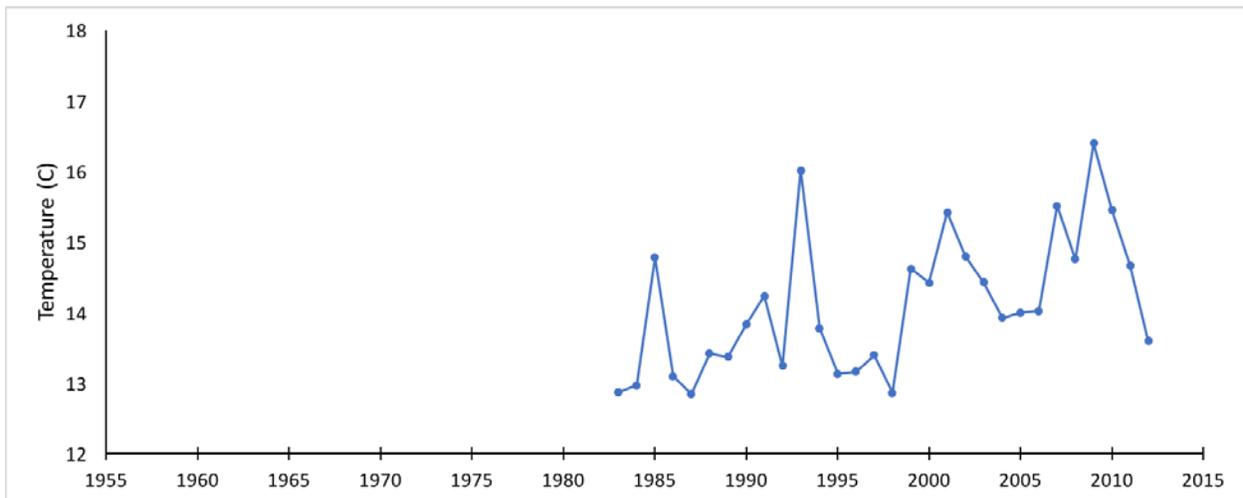


Figure 3d. In-situ mean annual bottom-water temperature from the RIDEM trawl survey.

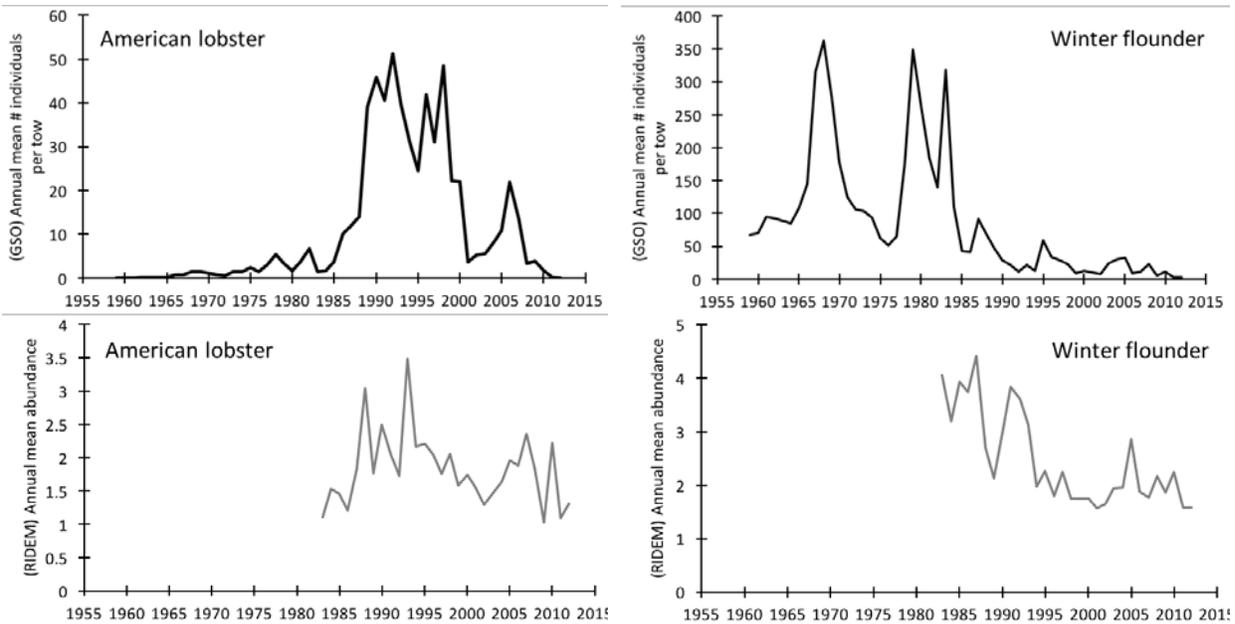


Figure 4. Mean annual number of individuals per tow (GSO trawl, top row) and mean annual abundance (RIDEM trawl, bottom row) for American lobster (left column) and winter flounder (right column). GSO = University of Rhode Island Graduate School of Oceanography. RIDEM = Rhode Island Department of Environmental Management.

5. DISCUSSION

In previous studies, increases in the P:D ratio of fish communities were correlated with nutrient enrichment and fishing pressure on demersal species. However, Collie et al. (2008) found that the P:D ratio from 1959–2005 was correlated with warming temperatures. The temperature increase was correlated with declines in winter flounder, red hake, and silver hake—demersal species that reside in Narragansett Bay in the winter months—and increases in butterfish and scup—warm-water species that migrate into the Bay in summer. These results suggest that opportunistic seasonal migrant species have displaced the demersal resident species in the Bay, partly due to increasing temperatures. All of these changes have altered the character of the Narragansett Bay fish community from a typical southern New England temperate estuarine community to one that is tending toward a Mid-Atlantic estuarine community (Collie et al. 2008).

In recent years, lobster abundance has declined markedly, likely due to a combination of factors. American lobster is emblematic of a species subject to cumulative stressors, exacerbated by climate change. The southern New England lobster stock was reported to be in a depleted condition in 2006 (ASMFC 2015). At that time, managers developed a “rebuilding timeline,” but assessments in 2009 showed continued declines. To address the decline, managers implemented a 10 percent reduction in exploitation of the stock (ASMFC 2015). In 2012, further management actions were taken to reduce traps allocated inshore by 50 percent and offshore by 25 percent over 5 years. However, the lobster stock reached a record low in 2013, and the inshore portion was classified as “collapsed” (ASMFC 2015). As the inshore population has declined, fishing pressure has increased on the offshore population (ASMFC 2015). It is important to note that although this stock is depleted, overfishing is not occurring—indicating that there are ecological factors at play (i.e., recruitment failure due to

increasing temperatures). Because the inshore lobster population (including nursery habitats in Narragansett Bay) is critical to sustaining both the inshore and offshore populations, measures were taken to reduce fishing pressure in both areas (ASMFC 2015). As previously noted, juvenile or young-of-the-year American lobsters have declined in abundance throughout Narragansett Bay based on a comparison of findings from 1990 and 2011/2012 (Wahle et al. 2015). Juvenile lobsters, once occurring throughout the mid and lower Bay, are now mostly restricted to deeper waters at the mouth of the Bay and offshore (Wahle et al. 2015). The optimal temperature range throughout the American lobster life history is 12–18°C (53.6–64.4°F). With portions of the inshore southern New England lobster stock recently experiencing prolonged periods above 20°C (68°F), these habitats have become extremely stressful to lobster and are likely contributing to the lack of recruitment (Fogarty et al. 2007, ASMFC 2015).

Shell disease, another stressor for the southern New England lobster population, is not directly linked to increased water temperatures, but shell disease susceptibility does appear to be associated with environmental stressors in general such as temperature, salinity, and oxygen conditions (ASMFC 2015). Studying shell disease in Massachusetts, Glenn and Pugh (2006) reported a much higher incidence in Buzzards Bay lobsters, compared to other regions of the state, and suggested warm waters as a prime factor contributing to shell disease. Prevalence of shell disease in southern New England has increased since the late 1990s and is a contributing factor to the status of the stock observed today.

Winter flounder face a similar combination of stressors: population effects from fishing mortality and the effects of warming waters (Oviatt et al. 2003, Collie et al. 2008, Smith et al. 2010). Fisheries yield for winter flounder is estimated to have declined by a factor of more than 6 between 1900 and 1999 (Oviatt et al. 2003). Winter flounder lay their eggs in winter, when predators such as sand shrimp are either absent or dormant (Oviatt 2004). As winter water temperatures have increased over the past several decades, sand shrimp have remained active during winter and can therefore prey on winter flounder larvae (Whitehouse 1994, Taylor and Collie 2003). In addition, water temperatures in winter may have increased beyond the optimal temperature for winter flounder egg health (Keller and Klein-MacPhee 2000). All of these factors contribute to low winter flounder reproductive success and present some possible explanations for the observed declines.

Oviatt et al. (2003) suggest that warming waters, an increase in available estuarine space from fish populations reduced by harvesting, and temperature stress have all facilitated the observed increase in warm-water species in Narragansett Bay. Aside from changes to the ecology of the Bay, these shifts will likely cause a change in fishing practices as “new” species establish in Bay waters. The results of fish population research, like those described here, are just beginning to inform the adaptation of new policies and fishery management schemes to climate change. For example, the Gulf of Maine Research Institute has developed the report *Preparing for Emerging Fisheries: An Overview of Mid-Atlantic Stocks on the Move* by Hudson and Peros (2013). This report discusses trends and management options for warm-water species that are increasingly common in the Gulf of Maine (as well as Narragansett Bay) including butterfish, black sea bass, summer flounder, squid, and scup. Recommendations include opening new fisheries and changing quotas for existing fisheries.

6. DATA GAPS AND RESEARCH NEEDS

A significant data gap in this report is geographic—the data summarized here do not represent status and trends within the Providence River estuary, Greenwich Bay, Narrow River, Little Narragansett

Bay, or the coastal ponds. Some of these areas are likely subject to the highest magnitude of anthropogenic stressors (e.g., Providence River estuary and Greenwich Bay) and are also likely important juvenile fish habitat due to their shallow depths and sheltered configuration. This data gap could be partially addressed by integrating information from the RIDEM beach seine surveys conducted since 1981 within upper Narragansett Bay and since 1994 within several coastal ponds, Little Narragansett Bay, and Narrow River. These surveys sample juvenile finfish populations and are particularly useful for tracking juvenile winter flounder and several other recreationally important species.

An important research need is to determine an approach to synthesize fish abundance data for Narragansett Bay from multiple sources. First, it may be desirable to continue exploring ways to quantitatively compare and/or combine data from the GSO and RIDEM trawls. Research to determine similarities and differences between surveys and the magnitude of catches has been conducted through the Rhode Island Marine Fisheries Institute (a URI-RIDEM partnership), and it concluded that the surveys are highly correlated (RIMFI, 2015). Developing a calibration factor is one way that these trawl datasets could be integrated into a single time series of information.

Future work could expand the analysis reported here to include a weighted-mean preferred temperature approach. Between 1959 and 2006, mean preferred temperature of the fish community captured in the GSO trawl increased by 2°C (Collie et al. 2008). The weighted mean preferred temperature approach uses the temperature preference of each species (available in the Collie et al. 2008 study) weighted by its annual mean abundance. Further research needs to be done to determine the temperature preferences of the fish species in the RIDEM trawl that are not in the top 25 most abundant species in the GSO trawl. Once this research is complete and reviewed by partners, the preferred temperature trend analysis can be completed for both datasets. Completing this analysis would add mean preferred temperature data to the existing 1959-2006 time series for the most recent decade, and if applied to the RIDEM data, would expand the geographic scope of this metric beyond the two stations monitored by the GSO trawl. The mean preferred temperature approach provides another metric by which to confirm trends in estuarine fish communities.

Given the rapidly shifting environmental conditions and fluctuations in fish community composition, it would be beneficial to convene experts to provide input on future analyses of these large fish trawl datasets. For example, which of the available metrics are most desirable: abundance or biomass? In addition, future trends analyses would benefit from consensus on which warm-water species and cold-water species are essential to track. There was also at least one difference in the way researchers classified fish species' habitat—Collie et al. (2008) included scup in the demersal group (replicated here), whereas Oviatt (2004) considered it in the pelagic group. This classification difference is particularly important because scup is a dominant species in each of the Narragansett Bay trawl datasets, is considered a warm-water species, and has increased in abundance over time.

7. ACKNOWLEDGEMENTS

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8. REFERENCES

- ASMFC (Atlantic States Marine Fisheries Commission). 2015. American lobster stock assessment peer review report. Prepared by the ASMFC American Lobster Stock Assessment Review Panel. Woods Hole, MA. 493 pp.
- Attrill, M.J., and M. Power. 2002. Climatic influence on a marine fish assemblage. *Nature* 417:275–278.
- Collie, J. S., A.D. Wood, and H.P. Jeffries. 2008. Long-term shifts in the species composition of a coastal fish community. *Canadian Journal of Fisheries and Aquatic Sciences* 65(7):1352–1365.
- DeAlteris, J.T., T.L. Englert, and J.A.D. Burnett. 2006. Trends in fish abundance in Mount Hope Bay: Is the Brayton Point Power Station affecting fish stocks? *Northeastern Naturalist* 13(Special Issue 4):95–116.
- Fogarty, M., L. Incze, R. Wahle, D. Mountain, A. Robinson, A. Pershing, K. Hayhoe, A. Richards, and J. Manning. 2007. Potential climate change impacts on marine resources of the Northeastern United States. Union of Concerned Scientists Technical Report Series/Northeast Climate Impact Assessment. 33pp.
http://www.ucsusa.org/sites/default/files/legacy/assets/documents/global_warming/pdf/miti/fogarty_et_al.pdf
- Fulweiler, R.W., and S.W. Nixon. 2009. Responses of benthic-pelagic coupling to climate change in a temperate estuary. *Hydrobiologia* 629:147–156.
- Fulweiler, R.W., A.J. Oczkowski, K.M. Miller, C.A. Oviatt, and M.E.Q. Pilson. 2015. Whole truths vs. half truths – And a search for clarity in long-term water temperature records. *Estuarine, Coastal Shelf Science* 157:A1–A6.
- Glenn, R.P., and T.L. Pugh. 2006. Epizootic shell disease in American Lobster (*Homarus americanus*) in Massachusetts coastal waters: interactions of temperature, maturity, and intermolt duration. *J. Crustacean Biol.* 26:639–645.
- Hudson, M., and J. Peros. 2013. Preparing for emerging fisheries: An overview of Mid-Atlantic stocks on the move. Gulf of Maine Research Institute, Portland, ME. 15pp.
- Jefferies, H.P. 1994. The impacts of warming climate on fish populations. *Maritimes* 37:12–15.
- Jefferies, H.P., and W.C. Johnson. 1974. Seasonal distributions of bottom fishes in Narragansett Bay area: seven-year variations in the abundance of winter flounder (*Pseudopleuronectes americanus*). *Journal Fisheries Research Board of Canada* 31:1057–1066.
- Keller, A., and G. Klein-MacPhee. 2000. Impact of elevated temperature on the growth, survival, and trophic dynamics of winter flounder larvae: A mesocosm study. *Canadian Journal of Fisheries and Aquatic Sciences* 57:2382–2392.

- Li, Y., and T. Smayda. 1998. Temporal variability of chlorophyll in Narragansett Bay 1973–1990. *ICES Journal of Marine Science* 55:661–667.
- Nye, J.A., J.S. Link, J.A. Hare, and W.J. Overholtz. 2009. Changing spatial distribution of fish stocks in relation to climate and population size on the Northeast United States continental shelf. *Marine Ecology Progress Series* 393:111–129.
- Oviatt, C.A. 2004. The changing ecology of temperate coastal waters during a warming trend. *Estuaries* 27(6):895–904.
- Oviatt, C.A., S. Olsen, M. Andrews, J. Collie, T. Lynch, and K. Raposa. 2003. A century of fishing and fish fluctuations in Narragansett Bay. *Reviews in Fisheries Science* 11(3):221–242.
- Pinsky, M.L., B. Worm, M.J. Fogarty, J.L. Sarmiento, and S.A. Levin. 2013. Marine taxa track local climate velocities. *Science* 341:1239–1242.
- RIFMI (Rhode Island Marine Fisheries Institute). 2015. Comparison of Trawl Survey Information for Four Important Marine Species – University of Rhode Island Fish Trawl and the RIDEM Division of Fish and Wildlife Coastal Trawl.
- Rountree, R.A., and D.G. MacDonald. 2006. Introduction to the Special Issue: Natural and anthropogenic influences on the Mount Hope Bay ecosystem. *Northeastern Naturalist* 13(Special Issue 4):1–26.
- Saba, V.S., S.M. Griffies, W.G. Anderson, M. Winton, M.A. Alexander, T.L. Delworth, J.A. Hare, M.J. Harrison, A. Rosati, G.A. Vecchi, and R. Zhang. 2016. Enhanced warming of the Northwest Atlantic Ocean under climate change. *Journal of Geophysical Research: Oceans* 121(1):118–132.
- Shumchenia, E.J., M.L. Guarinello, and J.W. King. 2016. A Re-assessment of Narragansett Bay Benthic Habitat Quality Between 1988 and 2008. *Estuaries and Coasts* doi:10.1007/s12237-016-0095-z.
- Smith, L.M., S. Whitehouse, and C.A. Oviatt. 2010. Impacts of climate change on Narragansett Bay. *Northeastern Naturalist* 17(1):77–90.
- Taylor, D.L. and J.S. Collie. 2000. Sampling the Bay Over the Long Term. *Maritimes* 42(4):7–9.
- Taylor, D.L. and J.S. Collie. 2003. Effect of temperature on the functional response and foraging behavior of the sand shrimp *Crangon septemspinosa* preying on juvenile winter flounder *Pseudopleuronectes americanus*. *Marine Ecology Progress Series* 263:217–234.
- Wahle, R.A., L. Dellinger, S. Olszewski, and P. Jekielek. 2015. American lobster nurseries of southern New England receding in the face of climate change. *ICES Journal of Marine Science* 72:i69–i78.
- Whitehouse, S.T. 1994. The abundance and distribution of *Crangon septemspinosa* in Narragansett Bay. Ph.D. Dissertation. University of Rhode Island, Kingston, RI. 189 pp.

Wood, A.J.M., J.S. Collie, and J.A. Hare. 2009. A comparison between warm-water fish assemblages of Narragansett Bay and those of Long Island Sound waters. *Fishery Bulletin* 107(1):89–100.