Exploring Species Range Shifts in the U.S. Mid Atlantic: Existing Literature, Web Portals, and Data

Report prepared for the Mid-Atlantic Regional Council on the Ocean (MARCO)

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Figures and Tables

1 Background

1.1 Scope

This report was prepared to address Task 5 under the Marine Life Data and Analysis Team (MDAT) contract to support Mid-Atlantic Ocean Planning in 2016 (MARCO Research Agreement with Duke University)

Task 5:
Develop maps that illustrate shifts in representative species observations over time (e.g. trends over past decades). Deliverables should be value added for utility in regional ocean planning and may include data and information from other ongoing and recently completed projects.

The work was also guided by input from members of the Mid-Atlantic Regional Planning Body (RPB) and the MARCO Ocean Data Portal team to focus on existing literature and to examine existing data portals with possible integration opportunities for the MARCO data portal. In addition, this guidance suggested the benefit of showing some example maps from the ongoing academic work of Sarah Roberts (Duke University MEM candidate) mapping regional fish distribution changes over time. That work is included in Section 4 (Roberts 2017 in prep).

1.2 Report Organization

To address MDAT 2016 Task 5 and the subsequent guidance from regional working groups, the report is organized into three broad sections.

Section 2: Existing Literature Review

Select literature on range shifts and distribution changes due to climate change were collected. Annotations by this report's authors and/or paper abstracts are presented. These references are organized by taxa, with any overview papers for each taxa presented first.

2.1 Overview Literature
2.2 Fish
2.3 Mammals
2.4 Seabirds
2.5 Invertebrates

Section 3: Existing Data Portal Review

Several existing data portals addressing range shifts and climate change were reviewed. A list of the species covered and data products presented is excerpted for each. A section on possible data integration possibilities with the MARCO Ocean Data Portal follows each portal review.

3.1 NEFSC Ecosystem Dynamics and Assessment Branch - Spatial Analyses portal
3.2 Ocean Adapt portal
3.3 Northeast Fish and Shellfish Climate Vulnerability Assessment portal

Section 4: Maps of Select Species of Interest

Using the Northeast Fisheries Science Center fall bottom trawl survey, maps were created for species managed by the Mid Atlantic Fishery Management Council or the Atlantic States Marine Fisheries Commission. Maps include the mean centroid of the entire spatial distribution of select species over 10-year aggregated time blocks.

4.1.1 Atlantic Croaker
4.1.2 Atlantic Mackerel
4.1.3 Black Sea Bass
4.1.4 Bluefish
4.1.5 Butterfish
4.1.6 Longfin Inshore Squid
4.1.7 Scup
4.1.8 Spiny Dogfish
4.1.9 Summer Flounder

In addition, maps for several species from the SEAMAP-SA bottom trawl surveys are included to highlight connections to regions south of the Mid-Atlantic Bight.

4.2.1 Atlantic Croaker
4.2.2 Black Sea Bass

2 Existing Literature Review

The literature collected below is intended to support a larger effort to better understand the state of knowledge on species range shifts in the Mid-Atlantic and bordering regions. Papers were included that discuss responses to climate change by all marine taxa generally, and for taxa in the Mid-Atlantic region specifically. The literature review focused on more recent papers where possible, given the emerging nature of these changes.

2.1 Overview Literature

Doney, S. C., Ruckelshaus, M., Duffy, J. E., Barry, J. P., Chan, F., English, C. A., ... Talley, L. D. (2012). Climate change impacts on marine ecosystems. *Annual Review of Marine Science*, *4*, 11–37. https://doi.org/10.1146/annurev-marine-041911-111611

Abstract:
“In marine ecosystems, rising atmospheric CO_2 and climate change are associated with concurrent shifts in temperature, circulation, stratification, nutrient input, oxygen content, and ocean acidification, with potentially wide-ranging biological effects. Population-level shifts are occurring because of physiological intolerance to new environments, altered dispersal patterns, and changes in species interactions. Together with local climate-driven invasion and extinction, these processes result in altered community structure and diversity, including possible emergence of novel ecosystems. Impacts are particularly striking for the poles and the tropics, because of the sensitivity of polar ecosystems to sea-ice retreat and poleward species migrations as well as the sensitivity of coral-algal symbiosis to minor increases in temperature. Midlatitude upwelling systems, like the California Current, exhibit strong linkages between climate and species distributions, phenology, and demography. Aggregated effects may modify energy and material flows as well as biogeochemical cycles, eventually impacting the overall ecosystem functioning and services upon which people and societies depend.”

Poloczanska, E. S., Burrows, M. T., Brown, C. J., García Molinos, J., Halpern, B. S., Hoegh-Guldberg, O., ... Sydeman, W. J. (2016). Responses of Marine Organisms to Climate Change across Oceans. *Frontiers in Marine Science*, *3*. https://doi.org/10.3389/fmars.2016.00062

Abstract:
“Climate change is driving changes in the physical and chemical properties of the ocean that have consequences for marine ecosystems. Here, we review evidence for the responses of marine life to recent climate change across ocean regions, from tropical seas to polar oceans. We consider observed changes in calcification rates, demography, abundance,

distribution, and phenology of marine species. We draw on a database of observed climate change impacts on marine species, supplemented with evidence in the Fifth Assessment Report of the Intergovernmental Panel on Climate Change. We discuss factors that limit or facilitate species' responses, such as fishing pressure, the availability of prey, habitat, light and other resources, and dispersal by ocean currents. We find that general trends in species' responses are consistent with expectations from climate change, including shifts in distribution to higher latitudes and to deeper locations, advances in spring phenology, declines in calcification, and increases in the abundance of warm-water species. The volume and type of evidence associated with species responses to climate change is variable across ocean regions and taxonomic groups, with predominance of evidence derived from the heavily-studied north Atlantic Ocean. Most investigations of the impact of climate change being associated with the impacts of changing temperature, with few observations of effects of changing oxygen, wave climate, precipitation (coastal waters), or ocean acidification. Observations of species responses that have been linked to anthropogenic climate change are widespread, but are still lacking for some taxonomic groups (e.g., phytoplankton, benthic invertebrates, marine mammals)."

2.2 Fish Literature

Cheung, W. W. L., Watson, R., & Pauly, D. (2013). Signature of ocean warming in global fisheries catch. *Nature*, *497*(7449), 365–368. https://doi.org/10.1038/nature12156

Researchers calculated a mean temperature of the catch (MTC) for 990 global species of fishes and invertebrates that are exploited, by taking the temperature preference of species, weighted by annual catch for 1970 to 2006. Data was obtained from the Sea Around Us project, and the temperature preference for each species was inferred from its distribution. The results conclude that changes in the MTC in 52 large marine ecosystems are significantly and positively related to regional changes in SST. Specifically, the Mid-Atlantic shows a general increase in MTC over the 3 decades.

Hare, J. A., Alexander, M. A., Fogarty, M. J., Williams, E. H., & Scott, J. D. (2010). Forecasting the dynamics of a coastal fishery species using a coupled climate–population model. *Ecological Applications*, *20*(2), 452–464. https://doi.org/10.1890/08-1863.1

In this predictive study, researchers developed a coupled-climate model for Atlantic Croaker that indicates that both exploitation and climate change will affect the abundance and future distribution of Atlantic Croaker. Data was obtained from the NEFCS fall bottom trawl survey, and ocean temperature forecasts were obtained from 14 general circulation models simulating three CO_2 emissions scenarios. The results indicate that recruitment in mid-Atlantic region is correlated to minimum air temperature – an increase in minimum winter temperatures will lead to higher recruitment and spawning stock biomass, and ultimately abundance. Additionally, warming temperatures will also cause the range of Atlantic croaker to shift northward.

Hare, J. A., & Able, K. W. (2007). Mechanistic links between climate and fisheries along the east coast of the United States: explaining population outbursts of Atlantic croaker (Micropogonias undulatus). ***Fisheries Oceanography*****,** ***16*****(1), 31–45. https://doi.org/10.1111/j.1365-2419.2006.00407.x**

Hare et al. (2007) determined that environmental factors (NAO, temperature) drive the large-scale variability in Atlantic croaker abundance and distribution, but fishing and habitat loss decrease the resiliency of the population to periods of poor environmental conditions and the subsequent weak year classes. The data included numerous fisheries independent surveys, focusing on the Mid-Atlantic. The results demonstrate that periods of high adult catch corresponded with periods of high minimum estimated winter water temperatures, adult catch was significantly correlated with winter NAO index, and high catch corresponded with positive NAO values. These relationships demonstrate a link between Atlantic croaker dynamics, thermal limited overwinter survival, and the large climate system of the North Atlantic.

Kleisner, K. M., Fogarty, M. J., McGee, S., Barnett, A., Fratantoni, P., Greene, J., … Pinsky, M. L. (2016). The Effects of Sub-Regional Climate Velocity on the Distribution and Spatial Extent of Marine Species Assemblages. ***PLOS ONE*****,** ***11*****(2), e0149220. https://doi.org/10.1371/journal.pone.0149220**

Kleisner et al. (2016) examined the relationship between observed shifts of species assemblages and regional climate velocity, or the rate and direction of change of temperature isotherms, using historical species presence data. The data was obtained from the NEFSC spring and fall bottom trawl surveys. The results demonstrate that species assemblages associated with warmer and shallower water on the broad, shallow continental shelf from the Mid-Atlantic Bight to Georges Bank shift strongly northeast along latitudinal gradients with little change in depth. Shifts in depth among the southern species associated with deeper and cooler waters are more variable, although predominantly shifts are toward deeper waters. In terms of rates of shift, species assemblages in the southern NES in the fall are shifting strongly northward and largely maintaining the same depths, with some species shifting as fast as 0.1°N per year. Their results suggest that along the Mid-Atlantic Bight, northward shifting distributions of traditionally harvested species will alter patterns of availability to local fishing communities, imposing economic impacts as a result of lost access to stocks managed with species-specific quotas, and rising fuel and travel costs.

Nye JA, Link JS, Hare JA, & Overholtz WJ. (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.**

Nye et al. (2009) analyzed temporal trends (bottom temperature, sea surface temperature, NAO and AMO) from 1968 to 2007 and distributional measures (the mean center of biomass, mean depth, mean temperature of occurrence, and area occupied) for 36 stocks using NEFSC Spring Bottom Trawl Data. The results demonstrate a poleward shift in the center of biomass which was much larger in the southern stocks, located in the Mid-Atlantic, than the northern stocks, located in the Gulf of Maine. Northern stocks shifted to deeper depths at larger magnitude than southern stocks. Large-scale temperature increase and changes in circulation, represented by the Atlantic Multi-Decadal Oscillation, was the most important factor associated with shifts in the mean center of biomass.

Pinsky, M. L., Worm, B., Fogarty, M. J., Sarmiento, J. L., & Levin, S. A. (2013). Marine Taxa Track Local Climate Velocities. ***Science*****,** ***341*****(6151), 1239–1242. https://doi.org/10.1126/science.1239352**

Pinsky et al. (2013) determined that climate velocity, or the rate and direction that climate shifts across the landscape, can explain species distribution shifts. They compiled a dataset across North America from 1968 to 2011, sampling 128 million individuals across 360 marine taxa. Their results determined that climate velocity explained the magnitude and direction of shifts in latitude and depth more effectively than species characteristics did. Ultimately, species closely track the complex local climate velocities. See http://oceanadapt.rutgers.edu/regional_data/

2.3 Mammal Literature

MacLeod, C.D., 2009: Global climate change, range changes and potential implications for the conservation of marine cetaceans: a review and synthesis. Endangered Species Research, 7, 125-136.

This paper is a synthesis of the presumed impacts of climate change on cetaceans. The paper categorizes marine mammals according to how vulnerable they are to increasing sea surface temperatures impacting their ranges and how detrimental a range shift will be for the species. The paper uses observed evidence of the sensitivity of cetaceans and determines that species that are restricted to polar and temperate waters and restricted to shelf waters are expected to do worse with climate change than species that are occur in tropical waters and all water depths. The following species have a High risk and unfavorable species conservation status as a result of climate change: Arnoux's beaked whale, Baird’s beaked whale, Northern bottlenose whale, Southern bottlenose whale, Hector’s beaked whale, True’s beaked whale, Sowerby’s beaked whale, Gray’s beaked whale, Andrew’s beaked whale, Hubb’s beaked whale, Stejneger’s beaked whale, strap-toothed beaked whale, Franciscana River dolphins, Beluga, Narwhal, Commerson's dolphin, Chilean dolphin, Heaviside's dolphin, Hector’s dolphin, White-beaked dolphin, Atlantic white-sided dolphin, Pacific white-sided dolphin, Dusky dolphin, Peale’s dolphin, Hourglass dolphin, Northern right whale dolphin, Southern right whale dolphin, Long-finned pilot whale, harbour porpoise, Vaquita, Burmeister’s porpoise, Spectacled porpoise, Dall’s porpoise, Bowhead whales, Northern right whale, Southern right whale.

Simmonds, M. P., & Isaac, S. J. (2007). The impacts of climate change on marine mammals: early signs of significant problems. *Oryx*, *41*(1), 19–26. https://doi.org/10.1017/S0030605307001524

This paper presents a large synthesis of the impacts of climate change on marine mammals in terms of their prey distribution shifts, sea ice changes, and breeding success. Although most of the paper focuses on mammals at the poles (where animals and prey depend on sea ice for survival), one section focuses on the impact of climate change on the breeding success of the North Atlantic right whale. In particular, researchers have found that a negative NAO leads to significantly decreased calving rates. An increase in climate variability through as a result of climate change may lead to swings in the NAO which could again negatively impact North Atlantic right whale calving rates and expedite this vulnerable species’ extinction.

Beaugrand, G., Reid, P. C., Ibañez, F., Lindley, J. A., & Edwards, M. (2002). Reorganization of North Atlantic Marine Copepod Biodiversity and Climate. *Science*, *296*(5573), 1692–1694. https://doi.org/10.1126/science.1071329

Many researchers predict that marine mammal ranges will shift as their prey species shift in response to climate change. This paper demonstrates this phenomenon and highlights the negative impacts of increased SST on copepod recruitment and abundance in eastern Canada. Researchers determined that growth, development, and egg production of this important copepod, which is the base for most of the North Atlantic food web.

Edwards, H. H. (2013). Potential impacts of climate change on warmwater megafauna: the Florida manatee example (*Trichechus manatus latirostris*). *Climatic Change*, *121*(4), 727–738. https://doi.org/10.1007/s10584-013-0921-2

This paper examines how the projected impacts of climate change on estuaries and nearshore areas in Florida will affect threats to manatees and their habitats, determining that threats may be exacerbated. For example, cold water stress, watercraft collision, and harmful algal blooms will likely increase with climate change, as well as degradations to their habitat. Several studies including Cummings et al. (2014) have demonstrated the presence of manatees in North Carolina and Virginia during the summer months. Thus, the impacts of climate change on manatees may be seen in North Carolina and Virginia as well as Florida (although the impacts in these areas specifically have not yet been studied)

Cummings, E. (2014). Spatial and Temporal Patterns of Habitat Use and Mortality of the Florida Manatee (*Trichechus manatus latirostris*) in the Mid-Atlantic States of North Carolina and Virginia from 1991 to 2012. *Aquatic Mammals*, *40*(2), 126–138. https://doi.org/10.1578/AM.40.2.2014.126

Abstract:
“Florida manatees (*Trichechus manatus latirostris*) are known to range north into the U.S. mid-Atlantic during warmer summer and fall months. However, rapid cooling of water temperatures in the fall can be detrimental to their survival in this region. This study reports upon all known manatee sightings (*n* = 211) and strandings (*n* = 9) from 1991 to 2012 in North Carolina and Virginia. The goals were to describe spatial and temporal patterns of manatee habitat use and mortality and relate those patterns to seasonal water temperatures, and to develop a finer-scale understanding of environmental temperatures across the region by deploying temperature data loggers at multiple sites throughout inland and coastal waterways. Although sightings were opportunistically gathered and, thus, not corrected for effort, they reveal a consistent picture of manatee presence in the mid-Atlantic. In both states, sightings were most common from June to October when water temperatures were above 20° C. Sightings in North Carolina were most common in the Intracoastal Waterway (27%), and in rivers and creeks (46%) in Virginia. Fine-scale temperature data collected throughout the region demonstrated highly variable, declining water temperatures in late fall, with temperatures dropping by as much as 1.35° C/d. Manatee sightings decreased precipitously with water temperature in November, while strandings increased. The results of this study demonstrate that manatees are predictably found in North Carolina and Virginia throughout the late spring, summer, and fall. These data can be used to plan future education and outreach, monitoring, regulatory actions, and habitat protection measures for this endangered species in this region.”

2.4 Seabird Literature

Grémillet D, & Boulinier T. (2009). Spatial ecology and conservation of seabirds facing global climate change: a review. *Marine Ecology Progress Series*, *391*, 121–137.

Abstract:
“In this review we detail the impact of climate change on marine productivity, on marine environmental stochasticity and cyclicity, and on the spatio-temporal match–mismatch of

seabirds and their prey. We thereby show that global warming has a profound bottom-up impact upon marine top-predators, but that such effects have to be studied in conjunction with the (top-down) impact of human fisheries upon seabird food resources. Further, we propose seabird ecological features, such as memory effects and social constraints, that make them particularly sensitive to rapid environmental change. We provide examples of how seabirds may nonetheless adapt when facing the consequences of climate change. We conclude that our understanding of the spatial ecology of seabirds facing environmental change is still rudimentary, despite its relevance for the conservation of these vulnerable organisms and for the management of marine ecosystems. We define the following research priorities. (1) Determine the factors affecting seabird distribution and movements at sea using biotelemetry, as well as colony dynamics on land. (2) Link seabird distribution patterns to those of their prey. (3) Determine further the role of historical and metapopulation processes in contributing to the dynamics of the spatial distribution of seabirds. (4) Assess phenotypic plasticity and the potential for microevolution within seabird spatial responses to climate change, since both will greatly affect the quality of modelling studies. (5) Adapt existing models to define and predict the impact of climate change onto seabird spatial dynamics. (6) Synthesize all gathered information to define marine protected areas and further conservation schemes, such as capacity reduction of fisheries. This research effort will require maintaining existing long-term monitoring programmes for seabirds, as well as developing new approaches to permit the integration of processes occurring at various scales, in order to be able to fully track the population responses of these long-lived vertebrates to environmental changes.”

Sydeman WJ, Thompson SA, & Kitaysky A. (2012). Seabirds and climate change: roadmap for the future. *Marine Ecology Progress Series*, *454*, 107–117.

Abstract:
“Based in part on a symposium held at the first World Seabird Conference in September, 2010 in Victoria, BC, Canada, we present a Theme Section (TS) on the topic of seabirds and climate change. We introduce this TS with a meta-analysis of key attributes of the current seabird−climate literature, based on 108 publications representing almost 3000 seabird−climate associations (mostly correlations) published up to 2011. Using the papers in this TS and our meta-analysis, a brief roadmap for the future of seabird−climate change research is presented. Seabird studies have contributed substantially to the literature on marine climate effects. To improve our understanding of climate change effects on seabirds at the global scale, however, additional low-latitude, mechanistic, and ‘end-to-end’ modeling studies, including integration of climatic, oceanographic, food web, and population dynamics models, should be conducted. This approach will enhance our understanding of the relationship between climate and population dynamics, and facilitate seabird conservation in a changing world.”

Veit, R., & Montevecchi, W. (2006). The influences of global climate change on marine birds. *Acta Zoologica Sinica*, *52*(Supplement), 165–168.

Abstract:
“Global climate fluctuates at several temporal scales. For the purposes of this review, we characterize these scales as “cycles”, “trends” and “regime shifts”, as exemplified by ENSO, Global Climate Change and the North Atlantic Oscillation respectively. We investigate whether seabird populations have experienced changes in abundance that correlate with climate variability at each of these scales. There are numerous examples of seabird populations responding to cyclic variation in climate, especially ENSO. Indications so far are that, by virtue of longevity, seabirds recover quickly from declines caused by El Niño. More recently, data have accumulated to demonstrate longer-term changes in populations that correlate with longterm (decadal or more) changes in oceanic climate. While there are clear examples of past regime shifts in the marine ecosystems of the North Pacific, North Atlantic and Antarctic Oceans, these shifts have not yet resulted in major changes in the structure of seabird communities.”

Montevecchi, W. A., & Myers, R. A. (1997). Centurial and decadal oceanographic influences on changes in northern gannet populations and diets in the north-west Atlantic: implications for climate change. *ICES Journal of Marine Science: Journal Du Conseil*, *54*(4), 608–614. https://doi.org/10.1006/jmsc.1997.0265

Abstract:
“Millennial and centurial changes in oceanography influence the distributions and movement patterns of fish and invertebrates. These changes, in turn, determine the availability of food resources for higher trophic levels and, hence, affect the distributions and abundances of marine birds. A century-long population trend of northern gannets (*Sula bassana*) is correlated with warming surface water conditions and increased mackerel (*Scomber scombrus*) availability. On a decadal scale, a major dietary change of breeding gannets from migratory warm-water pelagic fish and squids to cold-water fish is associated with cold-water perturbations in the north-west Atlantic during the 1990s. Cold-water influences appear to have inhibited migratory pelagic fish and squid from moving into the region in recent years, causing a major shift in pelagic food webs on the Newfoundland Shelf. Such findings imply that slight changes in oceanographic conditions, possibly associated with climate warming, could have large-scale and pervasive effects on seabird distributions, feeding ecology, reproductive success, and populations. Such changes might be detected initially near the limits of seabird ranges and the margins of oceanographic regions.”

Montevecchi, W. A., Hedd, A., McFarlane Tranquilla, L., Fifield, D. A., Burke, C. M., Regular, P. M., … Phillips, R. A. (2012). Tracking seabirds to identify ecologically important and high risk marine areas in the western North Atlantic. *Biological Conservation*, *156*, 62–71. https://doi.org/10.1016/j.biocon.2011.12.001

Abstract
"Protection of the marine environment lags far behind that of terrestrial domains. To help ameliorate this circumstance, top predators are being tracked to identify important ocean habitats, biodiversity hotspots and high risk areas and to assess effects of anthropogenic developments, pollution and environmental perturbations. We used GPS, Global Location Sensors (GLSs) and satellite platform terminal transmitters (PTTs) to track foraging and migrating thick-billed and common murres and northern gannets along with vessel surveys to identify potential Marine Protected Areas, to assess risk and to evaluate the consequences of the recent Gulf of Mexico oil disaster. Multi-year persistent sites of forage fishes generated multi-species predator aggregations. Species- and colony-specific winter inshore and offshore distributions of murres are associated with risks of climate change (ice), by-catch in fishing gear, hunting and oil extraction. Some thick-billed murres wintered in oceanic areas beyond the continental slope, and an area of high biological diversity was identified west of the Mid-Atlantic Ridge that, owing to its location beyond national jurisdictions, presents unique challenges for protection. Migration research indicated a substantial proportion of the North American gannet population wintering in the Gulf of Mexico near the *Deepwater Horizon* pollution area. Northern gannets incurred the highest incidence of oiling/recoveries and were the third-most oiled avian species; distributions and exit dates suggest that sub-adult birds suffered much, likely most, of this mortality. Environmental risk is being assessed by tracking combined with stable isotope and blood assays to probe trophic interactions, habitat relationships and to identify and protect biologically significant marine areas."

Veit, R. R., & Manne, L. L. (2015). Climate and changing winter distribution of alcids in the Northwest Atlantic. *Frontiers in Ecology and Evolution*, *3*. https://doi.org/10.3389/fevo.2015.00038

Abstract:
"Population level impacts upon seabirds from changing climate are increasingly evident, and include effects on phenology, migration, dispersal, annual survivorship, and reproduction. Most population data on seabirds derive from nesting colonies; documented climate impacts on winter ecology are scarce. We studied interannual variability in winter abundance of six species of alcids (Charadriiformes, Alcidae) from a 58-year time series of data collected in Massachusetts 1954–2011. We used counts of birds taken during fall and winter from coastal vantage points. Counts were made by amateur birders, but coverage was consistent in timing and location. We found significant association between winter abundance of all six species of alcids and climate, indexed by North Atlantic Oscillation (NAO), at two temporal scales: (1) significant linear trends at the 58-year scale of the time

series; and (2) shorter term fluctuations corresponding to the 5–8 year periodicity of NAO. Thus, variation in winter abundance of all six species of alcids was significantly related to the combined short-term and longer-term components of variation in NAO. Two low-Arctic species (Atlantic Puffin and Black Guillemot) peaked during NAO positive years, while two high Arctic species (Dovekie and Thick-billed Murre) peaked during NAO negative years. For Common Murres and Razorbills, southward shifts in winter distribution have been accompanied by southward expansion of breeding range, and increase within the core of the range. The proximate mechanism governing these changes is unclear, but, as for most other species of seabirds whose distributions have changed with climate, seems likely to be through their prey."

2.5 Invertebrate Literature

Hare, M. P., Weinberg, J., Peterfalvy, O., & Davidson, M. (2010). The "Southern" Surfclam (Spisula Solidissima Similis) Found North of Its Reported Range: A Commercially Harvested Population in Long Island Sound, New York. *Journal of Shellfish Research*, *29*(4), 799–807. https://doi.org/10.2983/035.029.0413

Abstract:
"The surfclam taxon *Spisula solidissima similis,* known as the "southern" surfclam and as Raveneli's surfclam, was recently shown to be reproductively isolated and genetically distinct from *S. s. solidissima,* the commercially harvested Atlantic surfclam, at the level of species. The reported distribution for *S. s. similis* includes shallow nearshore marine habitats south of Cape Hatteras as well as in the Gulf of Mexico. In contrast, *S. s. solidissima* is larger, has a longer life span, and is found in cooler waters north of Cape Hatteras both nearshore and offshore. The current study used molecular markers to test for *S. s. similis* in Long Island Sound (LIS), New York, at latitude 41°N, well north of its typical range. After analyzing a diagnostic mitochondrial DNA marker in 90 surfclam specimens from 3 locations in LIS, all samples were identified as *S. s. similis.* The LIS sample was also significantly different in both shell shape and in the shape of the cardinal tooth than comparably sized offshore *S. s. solidissima.* However, these shell differences are not adequate for differentiating between these taxa in the field. The documented history of *Spisula* in LIS is reviewed to address hypotheses about its origin there. In addition, the fishery management implications of our findings are discussed."

Hare, J. A., Morrison, W. E., Nelson, M. W., Stachura, M. M., Teeters, E. J., Griffis, R. B., … Griswold, C. A. (2016). A Vulnerability Assessment of Fish and Invertebrates to Climate Change on the Northeast U.S. Continental Shelf. *PLOS ONE*, *11*(2), e0146756. https://doi.org/10.1371/journal.pone.0146756

This paper evaluated climate change impacts on 82 species in the Northeast U.S. Continental Shelf Large Marine Ecosystem with existing data, including 18 invertebrate species (American lobster, Atlantic sea scallop, Atlantic surfclam, Bay scallop, Bloodworm, Blue crab, Blue mussel, Cancer crabs, Channeled whelk, Deep-sea red crab, Eastern oyster, Green sea urchin, Horseshoe crab, Knobbed whelk, Northern shrimp, Ocean quahog, Northern Quahog, Softshell clam), using the NMFS Climate Vulnerability Assessment Methodology (Morrison et al., 2015). They evaluated both exposure to and sensitivity to climate change and decadal variability stressors to obtain an overall vulnerability rating of very high, high, moderate, or low, with results including a potential positive, neutral, or negative directional effect. The paper includes expert opinion and is based on species profiles compiled from stock assessments, EFH documents, monographs, and peer-reviewed literature. The climate data used were from the IPCC AR5. Changes in population productivity and in species distribution are discussed.

Overall Results:

> As a functional group, benthic invertebrates are among the species that exhibit the greatest vulnerability, with the greatest number of species with very high + high vulnerability, and had the greatest proportion of species with estimated negative directional shifts (groundfish also). The climate factors with the largest expected change by 2055 (the study period) were ocean temperatures, shallow-water temperatures, and ocean acidification. Bay scallop fell in the very high climate exposure and very high biological sensitivity category; Eastern oyster, bloodworm, and Blue mussel have very high climate exposure and high biological sensitivity (whelks, softshell clam and blue crab as well, but with less certainty); Atlantic sea scallop, Atlantic surfclam, Northern shrimp, and Green sea urchin have high climate exposure and high biological sensitivity.

Morrison, W.E., M. W. Nelson, J. F. Howard, E. J. Teeters, J. A. Hare, R. B. Griffis, J.D. Scott, and M.A. Alexander (2015). Methodology for Assessing the Vulnerability of Marine Fish and Shellfish Species to a Changing Climate. U.S. Dept. of Commerce, NOAA. *NOAA Technical Memorandum NMFS-OSF-3*, 48 p.

Abstract:

"Climate change is already affecting fishery resources and the communities that depend on them. Climate change and multidecadal variability have been implicated in the shifting distributions, abundances, and phenology of fish and shellfish species in many marine ecosystems. These impacts are expected to intensify in the future, increasing the need to understand which species may be most vulnerable to climate-related environmental change. We have developed a vulnerability assessment that uses expert elicitation methods to quantify a species' exposure and sensitivity to expected climate change. Vulnerability, as used here, refers to a reduction in a species' productivity and or abundance associated with a changing climate, and includes both climate change and multidecadal climate variability. This methodology uses a vulnerability assessment framework, which is applicable across multiple species and provides a relative rank of vulnerability to climate change and variability as well as information about why a species may or may not be vulnerable. The results can help fishery managers and researchers identify highly vulnerable species and more effectively target research and assessment resources on species of highest concern."

Johnson, D. S. (2015). The savory swimmer swims north: a northern range extension of the blue crab Callinectes sapidus? *Journal of Crustacean Biology*, *35*(1), 105–110. https://doi.org/10.1163/1937240X-00002293

Abstract:
"Worldwide, climate-change is shifting species distributions poleward. Here I present recent (2012-2014) observations of the blue crab, *Callinectes sapidus* (Rathbun, 1896), in the Gulf of Maine (GoM), north of its historical range of Cape Cod, Massachusetts. To test the hypothesis of a climate-driven range expansion, I examined near-surface ocean temperatures. On average, ocean temperatures in the GoM in summer 2012 and 2013 were up to 1.3°C higher than the average of the previous decade, suggesting that warmer waters may have promoted the recruitment of C. sapidus to the GoM. Previous ephemeral populations of C. sapidus in the Gulf of Maine have been reported since the 1860s. Recent observations and continued warming in the northwest Atlantic may signal a permanent poleward expansion of C. sapidus into the GoM. If so, then a key goal for ecologists and managers will be to understand the effect of C. sapidus on GoM food-webs and fisheries."

Kimmel, D. G., & Newell, R. I. E. (2007). The influence of climate variation on eastern oyster (Crassostrea virginica) juvenile abundance in Chesapeake Bay. *Limnology and Oceanography*, *52*(3), 959–965. https://doi.org/10.4319/lo.2007.52.3.0959

Abstract:
"There has been a significant downward trend in the annual abundance (= spatfall) of 0-age eastern oysters (*Crassostrea virginica*) measured in the autumn since 1940 in the Maryland portion of Chesapeake Bay. We developed a multiple linear regression model to predict spatfall from environmental conditions and the magnitude of the previous year's oyster harvest. The model explained 57% of the variance in spatfall from 1940 through 1976. We used the model to predict spatfall using data from 1977 to 2004 and found poor fit for the years after 1985. We suggest that this predictive relation was lost because an epizootic of the protistan parasite *Haplosporidium nelsoni* in 1985 and 1986 killed large numbers of oysters in the Maryland portion of Chesapeake Bay. This event disrupted the tight relation

between oyster harvest and spatfall. Using the same variables as in our initial model, we constructed a second multiple linear regression model for all data after 1977. This new model explained 53% of the variance in spatfall, although there was a reduced relation between oyster harvest in the previous year and a strong relation between July salinity and spatfall. Hindcasting spatfall from 1940 to 1976, this model explained 49% of the variance. We suggest that the overall downward trend in oyster spatfall since records began in 1940 is driven by the loss of adult oysters in the spawning stock. Superimposed on this trend is large interannual variability in oyster spatfall that is strongly related to climate-driven changes in environmental conditions during the summer period of larval development and settlement."

Narváez, D. A., Munroe, D. M., Hofmann, E. E., Klinck, J. M., Powell, E. N., Mann, R., & Curchitser, E. (2015). Long-term dynamics in Atlantic surfclam (Spisula solidissima) populations: The role of bottom water temperature. *Journal of Marine Systems*, *141*, 136–148. https://doi.org/10.1016/j.jmarsys.2014.08.007

Abstract:
"The potential linkages between warming bottom temperatures and increased mortality and/or reduced growth of the Atlantic surfclam (*Spisula solidissima*) were investigated using a model that simulates the temperature-dependent growth of the post-settlement population at specific locations on the Middle Atlantic Bight (MAB) continental shelf. External forcing for the individual-based surfclam model is provided by a 50-year simulation (1958–2007) of bottom water temperature obtained from an implementation of the Regional Ocean Modeling System for the northwestern Atlantic. The simulations show that in years with above average bottom water temperature (> 2 °C above average), surfclam assimilation rate is significantly reduced as a result of thermal stress, which leads to starvation mortality and an overall decline in the surfclam population of 2–9%, mainly in the inner shelf regions. Years with warmer bottom water temperatures were preceded by warm winters, which produced an earlier and longer summer season. These results suggest that the long-term observed decline in Atlantic surfclam populations on the MAB is a response to episodic warm years rather than a gradual warming trend in bottom water temperature, as previously suggested. These temperature driven population declines can persist for several years and have the largest effect on older and larger animals, which are the target of the commercial fishery."

Wahle, R. A., Dellinger, L., Olszewski, S., & Jekielek, P. (2015). American lobster nurseries of southern New England receding in the face of climate change. *ICES Journal of Marine Science*, *72*(suppl_1), i69–i78. https://doi.org/10.1093/icesjms/fsv093

Abstract:
"Historically, southern New England has supported one of the most productive American lobster (*Homarus americanus*) fisheries of the northeast United States. Recently, the region has seen dramatic declines in lobster populations coincident with a trend of increasingly stressful summer warmth and shell disease. We report significant declines in the abundance, distribution, and size composition of juvenile lobsters that have accompanied the warming trend in Narragansett Bay, Rhode Island, since the first comprehensive survey of lobster nurseries conducted there in 1990. We used diver-based visual surveys and suction sampling in 1990, 2011, and 2012, supplemented by post-larval collectors in 2011 and 2012. In 1990, lobster nurseries extended from the outer coast into the mid-sections of the bay, but by 2011 and 2012 they were largely restricted to the outer coast and deeper water at the mouth of the bay. Among five new study sites selected by the lobster fishing industry for the 2011 and 2012 surveys, the deepest site on the outer coast (15–17 m depth) harboured some of the highest lobster densities in the survey. Separate fixed site hydrographic monitoring at 13 locations in the bay by the Rhode Island Division of Fish and Wildlife recorded an approximately 2.0°C increase in summer surface temperatures over the period, with 2012 being the warmest on record. Additional monitoring of bottom temperatures, dissolved oxygen and pH at our sampling sites in 2011 and 2012 indicated conditions falling below physiological optima for lobsters during summer. The invasion of the Asian shore crab, *Hemigrapsus sanguineus*, since the 1990s may also be contributing to declines of juvenile lobster shallow zones (<5 m) in this region. Because lobster populations appear increasingly restricted to deeper and outer coastal waters of southern New England, further monitoring of settlement and nursery habitat in deep water is warranted."

Weinberg, J. R. (2005). Bathymetric shift in the distribution of Atlantic surfclams: response to warmer ocean temperature. *ICES Journal of Marine Science*, *62*(7), 1444–1453. https://doi.org/10.1016/j.icesjms.2005.04.020

Abstract:
"Standard research vessel surveys during the 1980s and early 1990s demonstrated that Atlantic surfclams (*Spisula solidissima solidissima*) were common in the southern portion of their range (37–38°N) along the east coast of North America in the Delmarva region. Based on data from these surveys, the probability of capturing surfclams in shallow water (i.e. 20 m) tows of the Delmarva region was 75–85% in 1994 and 1997. In 1999 and 2002, this probability declined to 40–55%. The probability of capturing surfclams in survey tows from deeper waters (40–50 m) also declined, but this change was relatively small compared with that in shallower water. These changes were not the result of commercial clam fishing. Unusually warm water, which induces thermal stress in *S. s. solidissima*, was

prevalent within the period from 1999 to 2002 over the Delmarva continental shelf during fall when annual bottom temperature was peaking. The combined effects of poor physiological condition and thermal stress likely resulted in mortality of Atlantic surfclams in shallow water habitats in the Delmarva region. This resulted in a shift in the bathymetric distribution of the population to deeper water. Between 1982 and 1997, most of the surfclams in the Delmarva region occurred at depths between 25 and 35 m, whereas in 1999 and 2002, most of the Delmarva population occurred at 35–40 m."

3 Existing Data Portal Review

3.1 NEFSC Ecosystem Dynamics and Assessment Branch

3.1.1 Spatial Analyses section

Website: http://www.nefsc.noaa.gov/ecosys/spatial-analyses/

Abstract:
"Species on the U.S. NES have been shifting over time, possibly as a result of climate change, changes in preferred habitat, fishing pressure, or some combination of these factors. These shifts are visible in movies of the distribution of key species from the NEFSC bottom trawl survey from 1968 to 2014. The species distribution movies illustrate that for some species the bulk of their biomass has shifted northward, or towards areas with cooler temperatures. A recent study examining the shifts in the centers of biomass for more than 70 species were generally in a northeast direction along the Mid-Atlantic bight and in a southwest direction in the Gulf of Maine, possibly due to cooler bottom water temperatures. These shifts have important management implications. For species that are shifting out of traditional harvest areas, this will result in altered patterns of availability to local fishing communities, and possibly negative economic consequences as a result of lost access to stocks that are managed with species-specific quotas and rising fuel and travel costs. In some cases, fishers will need to adapt to altered marine community structures, and some subtropical-temperate species may replace those species that are lost. These shifts from one management jurisdiction to another will require more collaboration between fisheries managers in different regions. These shifts may also result in the concentration of targeted fish species increasing vulnerability to fishing activity. Atlantic cod, is one example of a species that may be experiencing this sort of concentration. Overall, shifts in species distributions may result in ecological, economic, and social challenges throughout the NES region."

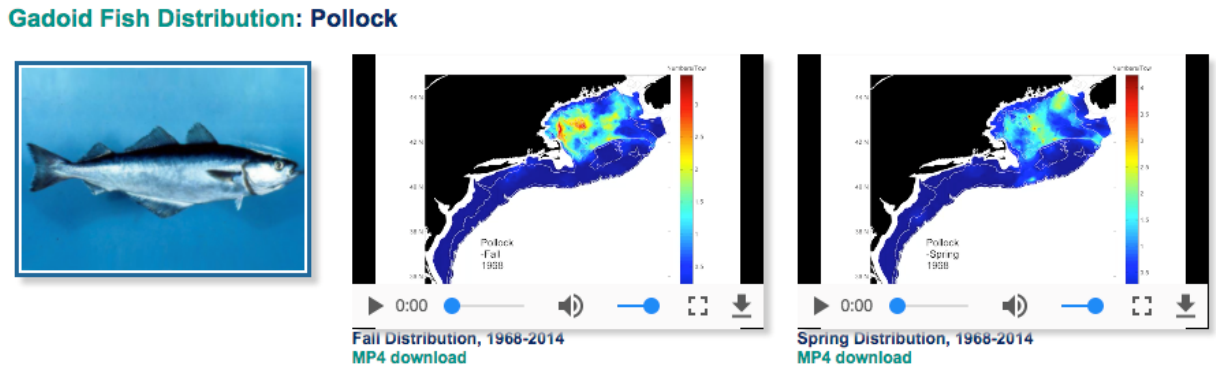


Figure 3.1.1-1 Map animations from the NEFSC data portal for Pollock

Gadoids	Other Demersals	Elasmobranchs	Flatfish
Atlantic Cod	Longhorn Sculpin	Atlantic Torpedo	American Plaice
Haddock	Monkfish	Barndoor Skate	Atlantic Halibut
Offshore Hake	Northern Puffer	Bluntnose Stingray	Fourspot Flounder
Pollock	Northern Sea Robin	Bullnose Stingray	Gulf Stream Flounder
Red Hake	Ocean Pout	Clearnose Skate	Summer Flounder
Silver Hake	Sea Raven	Little Skate	Windowpane Flounder
Spotted Hake	Striped Sea Robin	Rosette Skate	Winter Flounder
White Hake		Roughtail Stingray	Witch Flounder
		Sand Tiger Shark	Yellowtail Flounder
		Sharpnose Shark	
		Smooth Dogfish	
		Smooth Skate	
		Southern Stingray	
		Spiny Butterfly Ray	
		Spiny Dogfish	
		Thorny Skate	
		Winter Skate	

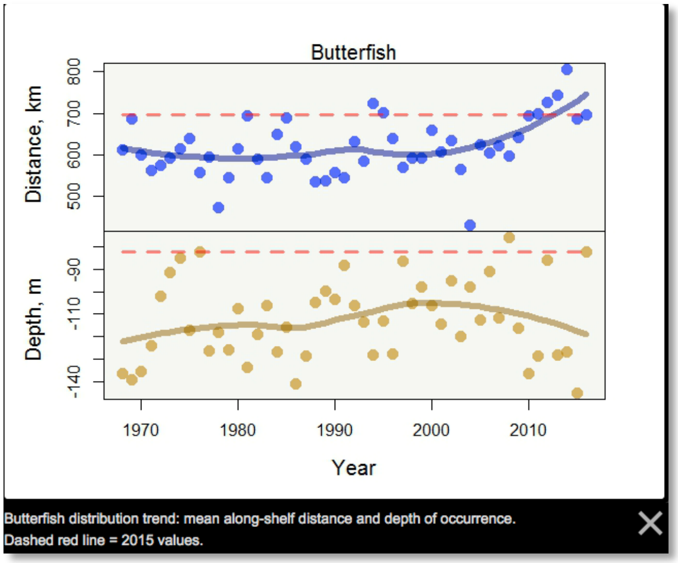
Invertebrates	Pelagic Fish	Other Fish
American Lobster	Alewife	Acadian Redfish
Jonah Crab	American Eel	Atlantic Croaker
Longfin Squid	American Shad	Banded Drum
Sea Scallop	Atlantic Herring	Black Sea Bass
Shortfin Squid	Atlantic Mackerel	Blackbelly Rosefish
	Atlantic Sturgeon	Cunner
	Blueback Herring	Cusk
	Bluefish	Pigfish
	Butterfish	Pinfish
	Northern Kingfish	Pipefish
		Sand Lance
		Scup
		Spot
		Striped Bass
		Tautog
		Tilefish
		Weakfish
		Wolffish

Table 3.1.1-2 Species included in the NEFSC data portal

3.1.2 Trends in Spring Species Distribution section

Website: http://www.nefsc.noaa.gov/ecosys/current-conditions/species-dist.html

Overview:
“The species of the Northeast Shelf ecosystem have shown changes in distribution over recent decades. Individual species have shifted distribution for a number of reasons and these shifts can be characterized in a number of different ways. Two metrics that have been used to characterize distribution on the NE Shelf include: 1) the position in the ecosystem along an axis oriented from the southwest to the northeast, referred to as the along shelf distance; and 2) the depth of occurrence. Along shelf distances range from 0 to 1360, which relates to positions along the axis from the origin in the southwest to the northeast in kilometer units. Depth ranges from 0 to -260, which relates to depth of occurrence in meters. The table below shows the species analyzed. The mean along shelf distance and depth of occurrence for all species by year are shown in the **two graphs**, with the 2016 values marked with a dashed red line. As a group, these species had an along shelf distance of approximately 790 km at the beginning of the time series. They now have a distance of over 880 km. There has been little change in the depth distribution of these species during the spring survey.”



Butterfish distribution trend: mean along-shelf distance and depth of occurrence.
Dashed red line = 2015 values.

Figure 3.1.2-1 Time series for Butterfish distribution depth and distance along-shelf

Click species name to see the along-shelf distance and depth distribution trends.

Acadian redfish	Alewife	American lobster
American plaice	American shad	Atlantic cod
Atlantic herring	Atlantic mackerel	Barndoor skate
Black sea bass	Blackbelly rosefish	Blueback herring
Butterfish	Clearnose skate	Cunner
Cusk	Fourspot flounder	Gulf Stream flounder
Haddock	Little skate	Longfin squid
Longhorn sculpin	Monkfish	Northern sea robin
Ocean pout	Pollock	Red hake
Sand lance	Scup	Sea raven
Sea scallop	Shortfin squid	Silver hake
Smooth dogfish	Smooth skate	Spiny dogfish
Spotted hake	Striped sea robin	Summer flounder
Thorny skate	White hake	Windowpane flounder
Rosette skate	Winter flounder	Winter skate
Witch flounder	Wolffish	Yellowtail flounder

Table 3.1.2-2 Species included in the NEFSC "Trends in Spring Species Distribution" graphs

3.1.3 MARCO Ocean Data Portal Integration Possibilities

The "Spatial Analyses" section of this portal distributes species-level map animations of the number of individuals per tow, at a yearly time step, for both the fall and spring NEFSC bottom trawl surveys. The current temporal range of the animations presented is 1968-2014. These animations can be downloaded and possibly linked into the MARCO Ocean Data Portal for species of regional interest.

The trawl data behind the fall map animations is already presented in the MARCO Ocean Data Portal via the MDAT collaboration with NEFSC, though the mapped units and time step presented are different. With appropriate explanatory text, these animations could make a nice complement to the existing MDAT fish data layers. Creating a location to embed or link to these animations on the MARCO Ocean Data Portal would require technical input from the portal team and development team.

The "Trends in Spring Species Distribution" section of this portal contains time series plots of the changes in mean along-shelf distance and depth of occurrence from 1968 to 2104. These plots would also make a nice addition to the MARCO portal, though they are not currently available for download via the NEFSC website. As with the map animations, creating a location to embed or link to these plots on the MARCO Ocean Data Portal would require technical input from the portal team and development team.

3.2 Ocean Adapt Portal

3.2.1 Overview

Website: http://oceanadapt.rutgers.edu

About:
"OceanAdapt is a collaboration between the Pinsky Lab of Rutgers University and the National Marine Fisheries Service (NMFS) to provide information about the impacts of changing climate and other factors on the distribution of marine life to the National Climate Assessment, fisheries communities, policymakers, and to others. This website hosts an annually updated database of scientific surveys in the United States and provides tools for exploring changes in marine fish and invertebrate distributions. We are continually working to expand the site with new data and visualization tools."

Details:
"The distributions of fish and invertebrate populations are routinely monitored by NMFS and other agencies during bottom trawl surveys on the continental shelves of North America. These surveys provide core information for use in fisheries management and extend back two to five decades. For the indicators displayed on this website, a mean location (the centroid) is calculated for each species in each year of each survey, after the surveys have been standardized to a consistent spatial footprint through time. The centroid is the mean latitude and mean depth of catch in the survey, weighted by biomass.

For the regional and national indices, the first year is standardized to a value of zero and changes are then averaged across species in a region. Only regions with consistent survey methods and without coastlines that would prevent poleward shifts in distribution are included in the national average (currently Eastern Bering Sea and Northeast U.S. Spring). Only species caught every year are analyzed to prevent changes in species composition from affecting the indicator. The indicator begins in the first year that data are available from the focal regions."

Methods are detailed in Pinksy et al. (2013):

> Pinsky, M. L., Worm, B., Fogarty, M. J., Sarmiento, J. L., & Levin, S. A. (2013). Marine Taxa Track Local Climate Velocities. *Science*, *341*(6151), 1239–1242. https://doi.org/10.1126/science.1239352

Data contributors to the website include:

- NOAA Northeast Fisheries Science Center Spring and Fall Bottom Trawl Surveys

- NOAA Northwest Fisheries Science Center U.S. West Coast Groundfish Bottom Trawl Survey
- NOAA Alaska Fisheries Science Center Groundfish Assessment Program surveys
- Gulf States Marine Fisheries Commission SEAMAP Groundfish Surveys
- Southeast Area Monitoring and Assessment Program - South Atlantic

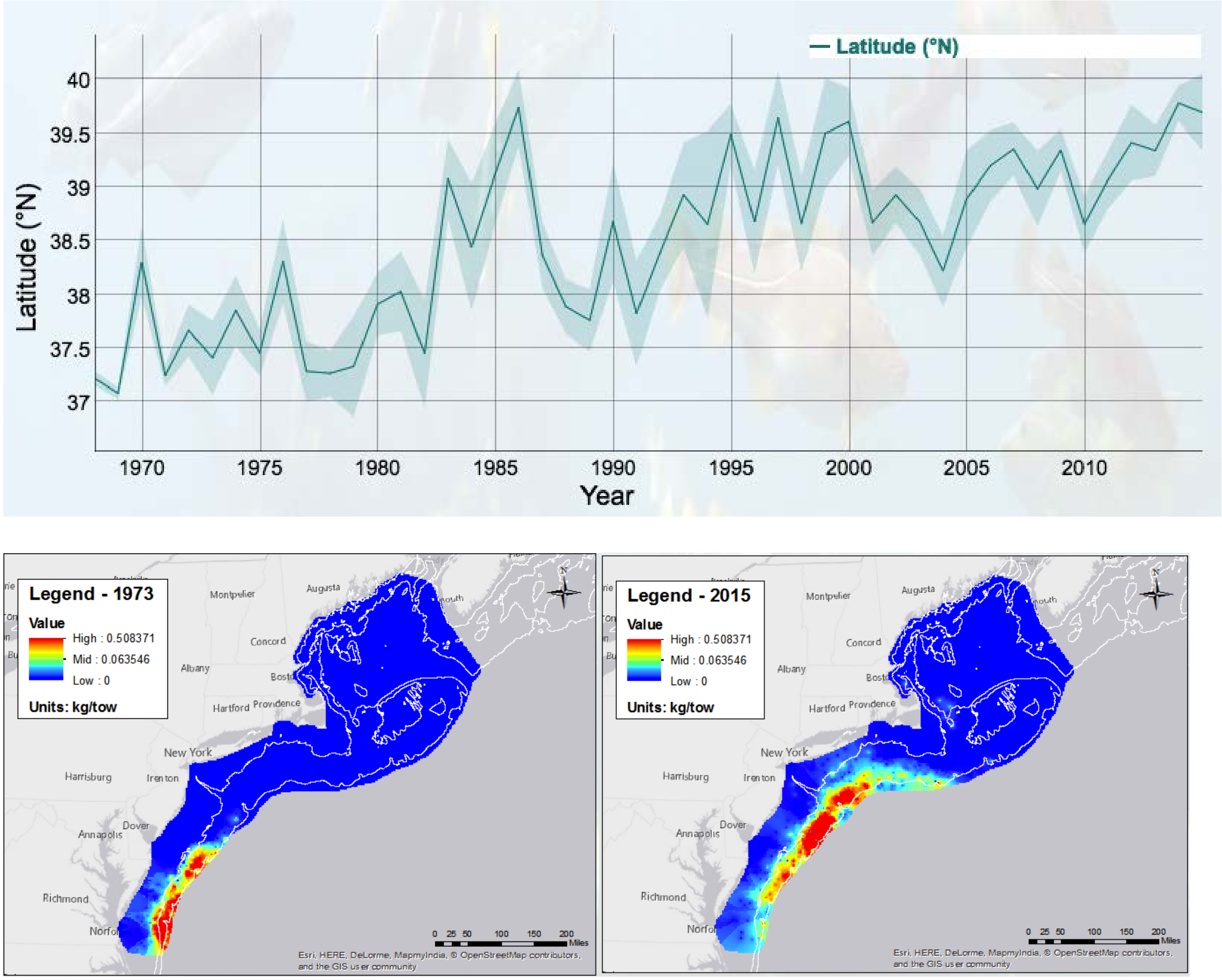


Figure 3.2.1-1 Graphics and Maps from the Ocean Adapt portal for Black Sea Bass

Acadian redfish
Alewife
American butterfish
American fourspot flounder
American lobster
American plaice
American shad
Armored searobin
Atlantic argentine
Atlantic cod
Atlantic croaker
Atlantic hagfish
Atlantic halibut
Atlantic herring
Atlantic mackerel
Atlantic rock crab
Atlantic wolffish
Barndoor skate
Big skate
Black sea bass
Blackbelly rosefish
Blueback herring
Bluefish
Butterfish
Chain catshark
Clearnose skate
Conger eel
Coursehand landy crab
Crustaceans
Cunner
Cusk
Fawn cusk-eel
Fourbeard rockling
Goosefish
Gulf Stream flounder
Haddock
Jonah crab
Lady crab
Little skate
Longfin hake
Longfin inshore squid
Longhorn sculpin
Lumpfish
Northern sand lance
Northern searobin
Northern shortfin squid
Ocean pout
Offshore hake
Pollock
Red hake
Rosette skate
Roughtail stingray
Round herring
Sand devil
Scup
Sea raven
Sea scallop
Silver hake
Smooth dogfish
Smooth skate
Spiny dogfish
Spot
Spotted hake
Starry skate
Striped searobin
Summer flounder
White hake
Windowpane
Winter flounder
Witch flounder wrymouth
Yellowtail flounder

Table 3.2.1-2 Northeast US Species included in the Ocean Adapt portal

Atlantic seabob
American butterfish
Anchovy
Atlantic brief squid
Atlantic bumper
Atlantic croaker
Atlantic cutlassfish
Atlantic menhaden
Atlantic moonfish
Atlantic sharpnose shark
Atlantic spadefish
Atlantic stingray
Atlantic thread herring
Banded drum
Bay whiff
Bighead searobin
Black drum
Black sea bass
Blackcheek tonguefish
Blackfin searobin
Blotched swimming crab
Blue crab
Blue runner
Bluefish
Bluntnose stingray
Bonnethead
Brown shrimp
Bullnose ray
Butterfish
Calico box crab
Clearnose skate
Cobia
Common octopus
Coursehand lady crab
Crownose ray
Crevalle jack
Devil ray
Dusky flounder
Florida pompano
Florida stone crab
Fringed flounder
Gafftopsail catfish
Gray hermit crab
Guaguanche
Gulf flounder
Gulf kingfish
Harhead catfish
Harvestfish
Hogchoer
Horseshoe crab
Inshore lizardfish
Iridescent swimming crab
King mackerel
Lady crab
Lane snapper
Leopard searobin
Lesser blue crab
Lesser mantis shrimp
Lined seahorse
Loggerhead sea turtle
Loligo squids
Lookdown
Mantis shrimp
Mojarras
Mottled purse crab
Northern kingfish
Northern puffer
Northern searobin
Ocellated flounder
Orange filefish
Pigfish
Pinfish
Pink shrimp
Planehead filefish
Rock sea bass
Roughtail stingray
Round scad
Sand perch
Scaled sardine
Scrawled cowfish
Sharksucker
Sheepshead
Shelf flounder
Shelligs
Silver perch
Silver seatrout
Smooth butterfly ray
Southern flounder
Southern kingfish
Southern stingray
Spanish mackerel
Spanish sardine
Speckled swimming crab
Spider crabs
Spineback hairy crab
Spiny butterfly ray
Spot
Spotted eagle ray
Spotted whiff
Star drum
Stenotomus porgies
Striped burrfish
Striped searobin
Summer flounder
Weakfish
White shrimp
Windowpane
Yellowfin menhaden

Table 3.2.1-3 Southeast US Species included in the Ocean Adapt portal

3.2.2 MARCO Ocean Data Portal Integration Possibilities

The Ocean Adapt web portal allows users to explore changes in the distribution of marine animals in the U.S. by region. Users can select individual species to plot the latitude and depth for the center of its distribution and show animated maps of their distribution over time (yearly time step). Users can select individual regions including Northeast US (include the Mid-Atlantic Bight) and Southeast US.

Users can also download data in CSV format. These data form the basis for the time series plots of changes in latitude and depth over time. An additional download is available with the raw survey data and R scripts to process the data into the derived products visualized on the Ocean Adapt website.

The MARCO Ocean Data Portal team would need to have detailed discussions with the Ocean Adapt web team about creating links into the Ocean Adapt website. Because the Ocean Adapt site is dynamic there are not readily available URL endpoints for the time series or maps animations. Creating a location to embed or link to these resources from the MARCO Ocean Data Portal would also require technical input from the portal team and development team.

3.3 Northeast Fish and Shellfish Climate Vulnerability Assessment portal

3.3.1 Overview

Website: http://www.st.nmfs.noaa.gov/ecosystems/climate/northeast-fish-and-shellfish-climate-vulnerability/NEVA_Overview

Abstract:

"The Northeast Fish Species Climate Vulnerability Assessment uses existing information on climate and ocean conditions, species distributions, and life history characteristics to assess relative vulnerability to changes in species abundance under projected future climate and ocean conditions. Multiple experts, using an agreed upon set of rules, scored each species as low, moderate, high or very high for its sensitivity to climate change (based on a specific set of life history attributes), its exposure to climate change (the overlap between expected change and its current distribution), and the overall expected directional effect (is the species expected to respond negatively, positively, or neutrally). Expert scores were then combined and later, in a workshop, the experts shared and discussed their scores before submitting final evaluations. For each species, there are three main results:

1. a vulnerability to shifts in productivity (based on exposure and sensitivity)
2. a propensity for shifting distribution (based on a subset of the sensitivity attributes)

3. an overall directional effect (do experts expect the species to respond positively or negatively to expected climate changes)”

Methods are detailed in Hare et al. (2016):

> Hare, J. A., Morrison, W. E., Nelson, M. W., Stachura, M. M., Teeters, E. J., Griffis, R. B., … Griswold, C. A. (2016). A Vulnerability Assessment of Fish and Invertebrates to Climate Change on the Northeast U.S. Continental Shelf. *PLOS ONE*, *11*(2), e0146756. https://doi.org/10.1371/journal.pone.0146756

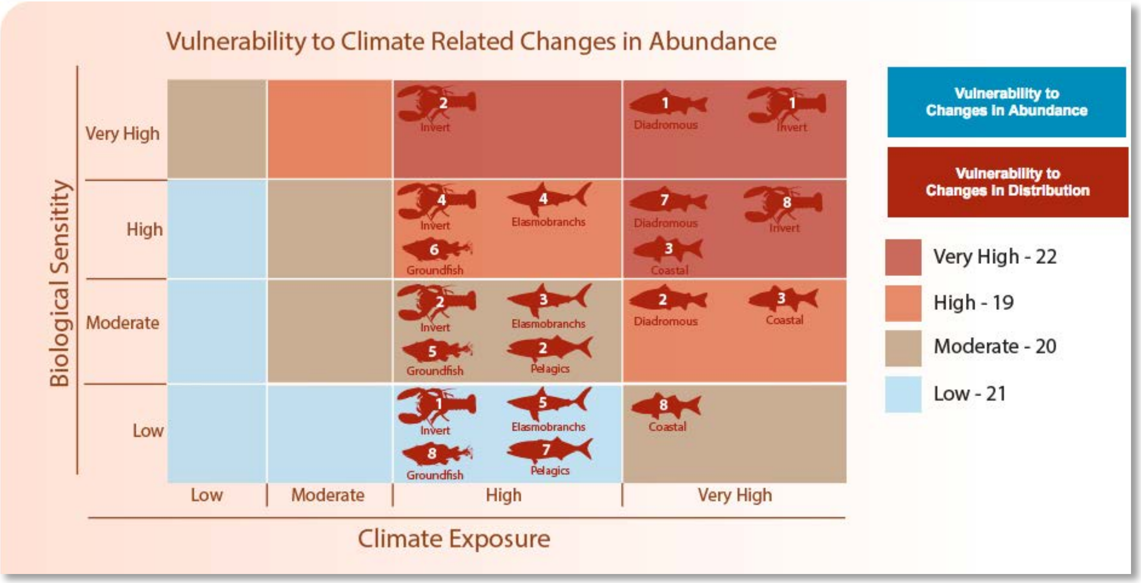


Figure 3.3.1-1 Graphic showing species vulnerability to climate related changes in abundance

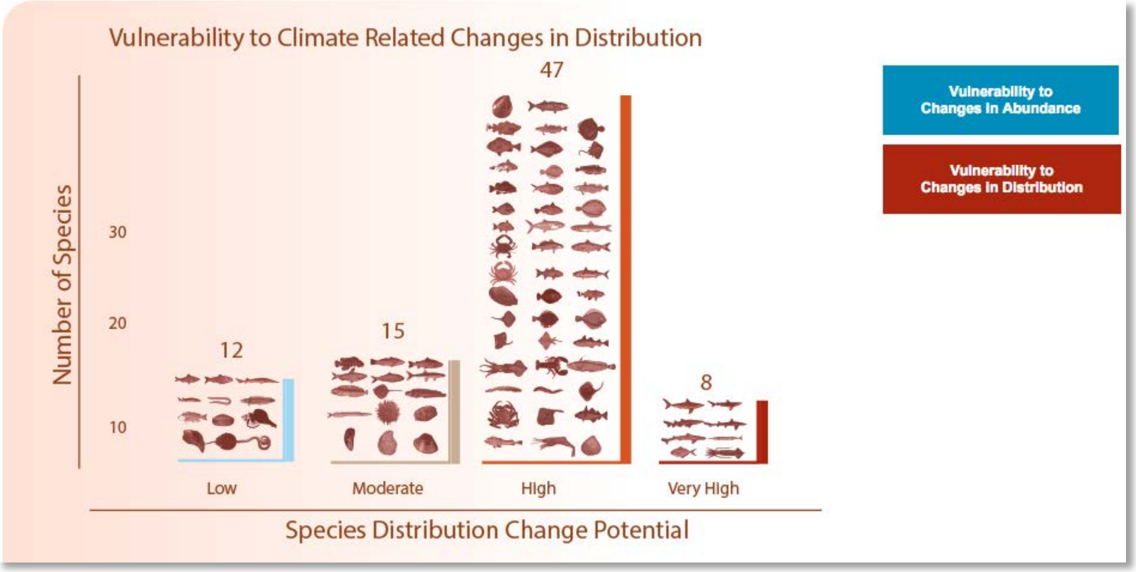


Figure 3.3.1-2 Graphic showing species vulnerability to climate related changes in distribution

Group	Common Name	Scientific Name
Coastal Fish	Atlantic Croaker	*Micropogonias undulates*
Coastal Fish	Atlantic Menhaden	*Brevoortia tyrannus*
Coastal Fish	Black Sea Bass	*Centropristis striata*
Coastal Fish	Northern Kingfish	*Menticirrhus saxatilis*
Coastal Fish	Red Drum	*Sciaenops ocellatus*
Coastal Fish	Scup	*Stenotomus chrysops*
Coastal Fish	Spanish Mackerel	*Scomberomorus maculatus*
Coastal Fish	Spot	*Leiostomus xanthurus*
Coastal Fish	Spotted Seatrout	*Cynoscion nebulosus*
Coastal Fish	Striped Bass	*Morone saxatilis*
Coastal Fish	Summer Flounder	*Paralichthys dentatus*
Coastal Fish	Tautog	*Tautoga onitis*
Coastal Fish	Weakfish	*Cynoscion regalis*
Coastal Fish	Winter Flounder	*Pseudopleuronectes americanus*
Diadromous Fish	Alewife	*Alosa pseudoharengus*
Diadromous Fish	Conger Eel	*Anguilla oceanica*
Diadromous Fish	American Eel	*Anguilla rostrata*
Diadromous Fish	American Shad	*Alosa sapidissima*
Diadromous Fish	Atlantic Salmon	*Salmo salar*
Diadromous Fish	Atlantic Sturgeon	*Acipenser oxyrhynchus*
Diadromous Fish	Blueback Herring	*Alosa aestivalis*
Diadromous Fish	Hickory Shad	*Alosa mediocris*
Diadromous Fish	Rainbow Smelt	*Osmerus mordax*
Diadromous Fish	Shortnose Sturgeon	*Acipenser brevirostrum*
Elasmobranchs	Barndoor Skate	*Dipturus laevis*
Elasmobranchs	Clearnose Skate	*Raja eglanteria*
Elasmobranchs	Dusky Shark	*Carcharhinus obscurus*
Elasmobranchs	Little Skate	*Leucoraja erinacea*
Elasmobranchs	Porbeagle	*Lamna nasus*
Elasmobranchs	Rosette Skate	*Leucoraja garmani*
Elasmobranchs	Sand Tiger	*Carcharias taurus*
Elasmobranchs	Smooth Dogfish	*Mustelus canis*
Elasmobranchs	Smooth Skate	*Malacoraja senta*
Elasmobranchs	Spiny Dogfish	*Squalus acanthias*
Elasmobranchs	Thorny Skate	*Amblyraja radiata*
Elasmobranchs	Winter Skate	*Leucoraja ocellata*
Groundfish	Acadian Redfish	*Sebastes fasciatus*
Groundfish	American Plaice	*Hippoglossoides platessoides*
Groundfish	Atlantic Cod	*Gadus morhua*
Groundfish	Atlantic Hagfish	*Myxine glutinosa*
Groundfish	Atlantic Halibut	*Hippoglossus hippoglossus*
Groundfish	Atlantic Wolffish	*Anarhichas lupus*
Groundfish	Cusk	*Brosme brosme*
Groundfish	Haddock	*Melanogrammus aeglefinus*
Groundfish	Monkfish (Goosefish)	*Lophius americanus*
Groundfish	Ocean Pout	*Zoarces americanus*
Groundfish	Offshore Hake	*Merluccius albidus*
Groundfish	Pollock	*Pollachius virens*
Groundfish	Red Hake	*Urophycis chuss*
Groundfish	Silver Hake	*Merluccius bilinearis*
Groundfish	Tilefish	*Lopholatilus chamaeleonticeps*
Groundfish	White Hake	*Urophycis tenuis*
Groundfish	Windowpane	*Scophthalmus aquosus*
Groundfish	Witch Flounder	*Glyptocephalus cynoglossus*
Groundfish	Yellowtail Flounder	*Limanda ferruginea*
Pelagic Fish and Cephalopods	Anchovies	*Anchoa hepsetus / Anchoa mitchilli*
Pelagic Fish and Cephalopods	Atlantic Herring	*Clupea harengus*
Pelagic Fish and Cephalopods	Atlantic Mackerel	*Scomber scombrus*
Pelagic Fish and Cephalopods	Atlantic Saury	*Scomberesox saurus*
Pelagic Fish and Cephalopods	Bluefish	*Pomatomus saltatrix*
Pelagic Fish and Cephalopods	Butterfish	*Peprilus triacanthus*
Pelagic Fish and Cephalopods	Longfin Inshore Squid	*Doryteuthis pealeii*
Pelagic Fish and Cephalopods	Sand Lances	*Ammodytes americanus & Ammodytes dubius*
Pelagic Fish and Cephalopods	Northern Shortfin Squid	*Illex illecebrosus*
Benthic Invertebrates	American Lobster	*Homarus americanus*
Benthic Invertebrates	Atlantic Sea Scallop	*Placopecten magellanicus*
Benthic Invertebrates	Atlantic Surfclam	*Spisula solidissima*
Benthic Invertebrates	Bay Scallop	*Argopecten irradians*
Benthic Invertebrates	Bloodworm	*Glycera dibranchiata*
Benthic Invertebrates	Blue Crab	*Callinectes sapidus*
Benthic Invertebrates	Blue Mussel	*Mytilus edulis*
Benthic Invertebrates	Cancer Crabs	*Cancer borealis / Cancer irroratus*
Benthic Invertebrates	Channeled Whelk	*Busycotypus canaliculatus*
Benthic Invertebrates	Deep-sea Red Crab	*Chaceon quinquedens*
Benthic Invertebrates	Eastern Oyster	*Crassostrea virginica*
Benthic Invertebrates	Green Sea Urchin	*Strongylocentrotus droebachiensis*
Benthic Invertebrates	Horseshoe Crab	*Limulus polyphemus*
Benthic Invertebrates	Knobbed Whelk	*Busycon carica*
Benthic Invertebrates	Northern Shrimp	*Pandalus borealis*
Benthic Invertebrates	Ocean Quahog	*Arctica islandica*
Benthic Invertebrates	Northern Quahog	*Mercenaria mercenaria*
Benthic Invertebrates	Softshell Clam	*Mya arenaria*

doi:10.1371/journal.pone.0146756.t001

Table 3.3.1-3 Species included in the Northeast Fisheries Climate Vulnerability Assessment

Table 1 from Hare et al. (2016)

3.3.2 MARCO Ocean Data Portal Integration Possibilities

The Northeast Fisheries Climate Vulnerability Assessment website enables access to detailed reports on the distribution and abundance climate vulnerability for 82 fish and invertebrate species in the Northeast region (include the Mid-Atlantic Bight). Each species-specific report contains the following information in a PDF file:

Scoring on Sensitivity criteria:

Stock Status
Other Stressors
Population Growth Rate
Spawning Cycle
Complexity in Reproduction
Early Life History Requirements
Sensitivity to Ocean Acidification
Prey Specialization
Habitat Specialization
Sensitivity to Temperature
Adult Mobility
Dispersal & Early Life History

Scoring on Exposure criteria:

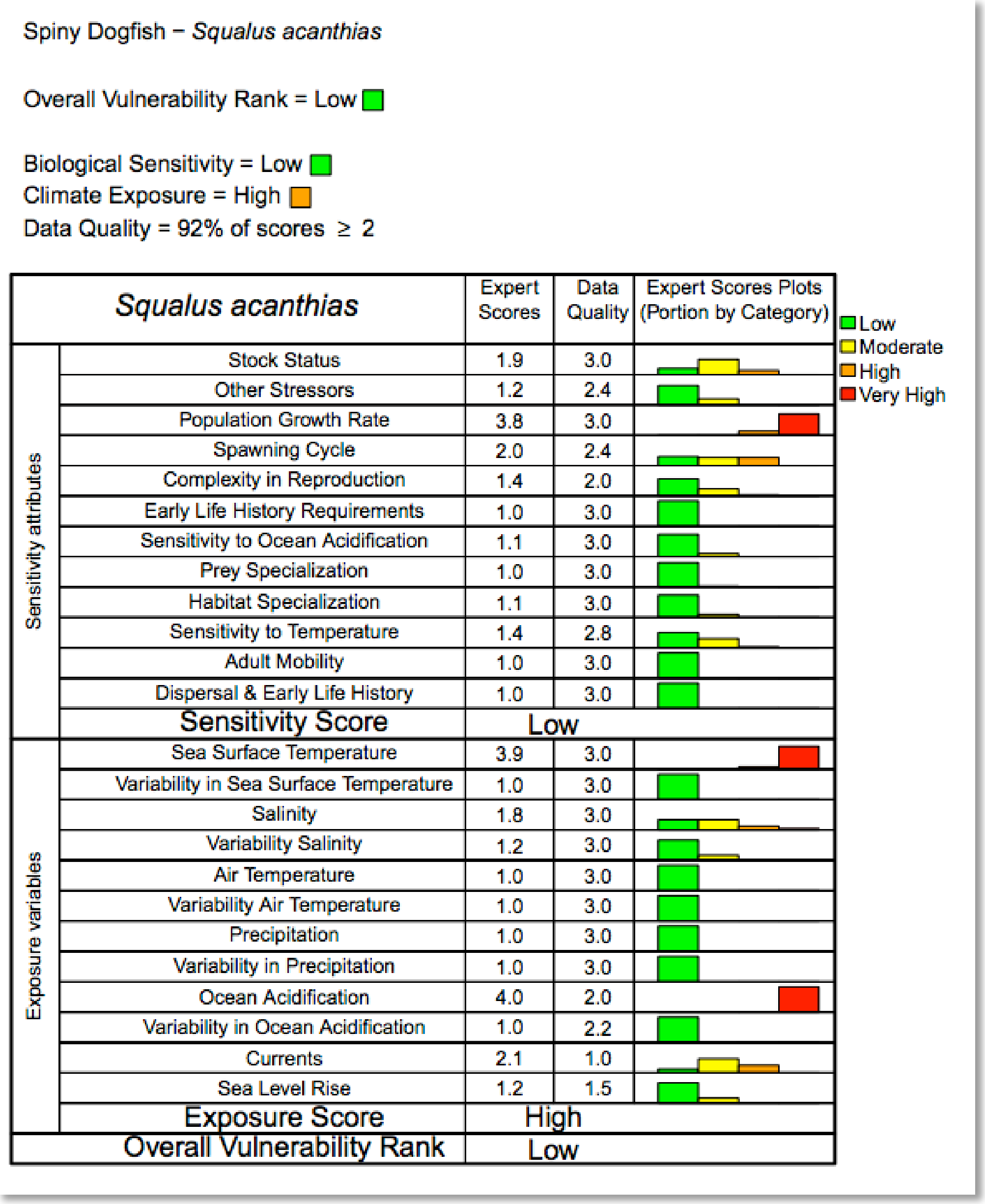
Sea Surface Temperature
Variability in Sea Surface Temperature
Salinity
Variability Salinity
Air Temperature
Variability Air Temperature
Precipitation
Variability in Precipitation
Ocean Acidification
Variability in Ocean Acidification
Currents
Sea Level Rise

Discussion Section:

Overall Climate Vulnerability Rank
Climate Exposure
Biological Sensitivity
Distributional Vulnerability Rank
Directional Effect in the Northeast U.S. Shelf:
Data Quality:
Climate Effects on Abundance and Distribution:
Life History Synopsis
Literature Cited

These reports would make a nice addition to the MARCO Ocean Data Portal as a supplement to any species-specific map layers. The PDFs are available for download on a per-species basis, but do not appear to be available for external linking. In addition, the results summarized in these per-species PDFs are also available within the supplemental material for the Hare et al. (2016) paper.

Some effort would need to be allocated to working with the NOAA Northeast Fisheries Climate Vulnerability Assessment team to pull together or link to these materials. Creating a location to embed or link to these species PDFs on the MARCO Ocean Data Portal would require technical input from the portal team and development team.



Spiny Dogfish – *Squalus acanthias*

Overall Vulnerability Rank = Low 🟩

Biological Sensitivity = Low 🟩
Climate Exposure = High 🟧
Data Quality = 92% of scores ≥ 2

	Squalus acanthias	Expert Scores	Data Quality	Expert Scores Plots (Portion by Category)
Sensitivity attributes	Stock Status	1.9	3.0	
	Other Stressors	1.2	2.4	
	Population Growth Rate	3.8	3.0	
	Spawning Cycle	2.0	2.4	
	Complexity in Reproduction	1.4	2.0	
	Early Life History Requirements	1.0	3.0	
	Sensitivity to Ocean Acidification	1.1	3.0	
	Prey Specialization	1.0	3.0	
	Habitat Specialization	1.1	3.0	
	Sensitivity to Temperature	1.4	2.8	
	Adult Mobility	1.0	3.0	
	Dispersal & Early Life History	1.0	3.0	
	Sensitivity Score	Low		
Exposure variables	Sea Surface Temperature	3.9	3.0	
	Variability in Sea Surface Temperature	1.0	3.0	
	Salinity	1.8	3.0	
	Variability Salinity	1.2	3.0	
	Air Temperature	1.0	3.0	
	Variability Air Temperature	1.0	3.0	
	Precipitation	1.0	3.0	
	Variability in Precipitation	1.0	3.0	
	Ocean Acidification	4.0	2.0	
	Variability in Ocean Acidification	1.0	2.2	
	Currents	2.1	1.0	
	Sea Level Rise	1.2	1.5	
	Exposure Score	High		
	Overall Vulnerability Rank	Low		

Figure 3.3.2-1 Summary page for the Spiny Dogfish climate vulnerability report

4 Maps of Select Species of Interest

4.1 NOAA NEFSC Bottom Trawl Maps

NEFSC Autumn Bottom Trawl surveys can be downloaded through the OBIS data download portal (NOAA NEFSC 2005, at iobis.org). This fishery-independent survey uses a stratified random sampling design for unbiased estimates of fish abundance from Cape Hatteras, North Carolina to Nova Scotia. Surveys were collected between 1963 and 2008, but the most consistently sampled and standardized surveys occurred between 1972 and 2008 in inshore strata. Each tow is separated into species, each species weighted (to the nearest .1kg) and measured (to the nearest cm). Geographic location, depth, and hydrographic data are also recorded collected.

Using the Northeast Fisheries Science Center fall bottom trawl surveys, the following maps were created for species managed by the Mid Atlantic Fishery Management Council or the Atlantic States Marine Fisheries Commission. These maps document the mean centroid and smoothed raster of the entire spatial distribution of the following species over 10-year aggregated time blocks. The mean center diagrams were calculated for strata consistently sampled throughout the entire range of dates and adjusted by tows per year (1972-2008). Due to less available datasets, interpolated rasters were developed for all strata and adjusted by tows per year.

These maps represent exploratory work as part of a Duke University Master's Thesis (Roberts 2017, in prep) and should not be treated as a finalized data product.

- Atlantic croaker
- Atlantic mackerel
- Black sea bass
- Bluefish
- Butterfish
- Atlantic Mackerel
- Longfin inshore squid
- Scup
- Spiny dogfish
- Summer flounder

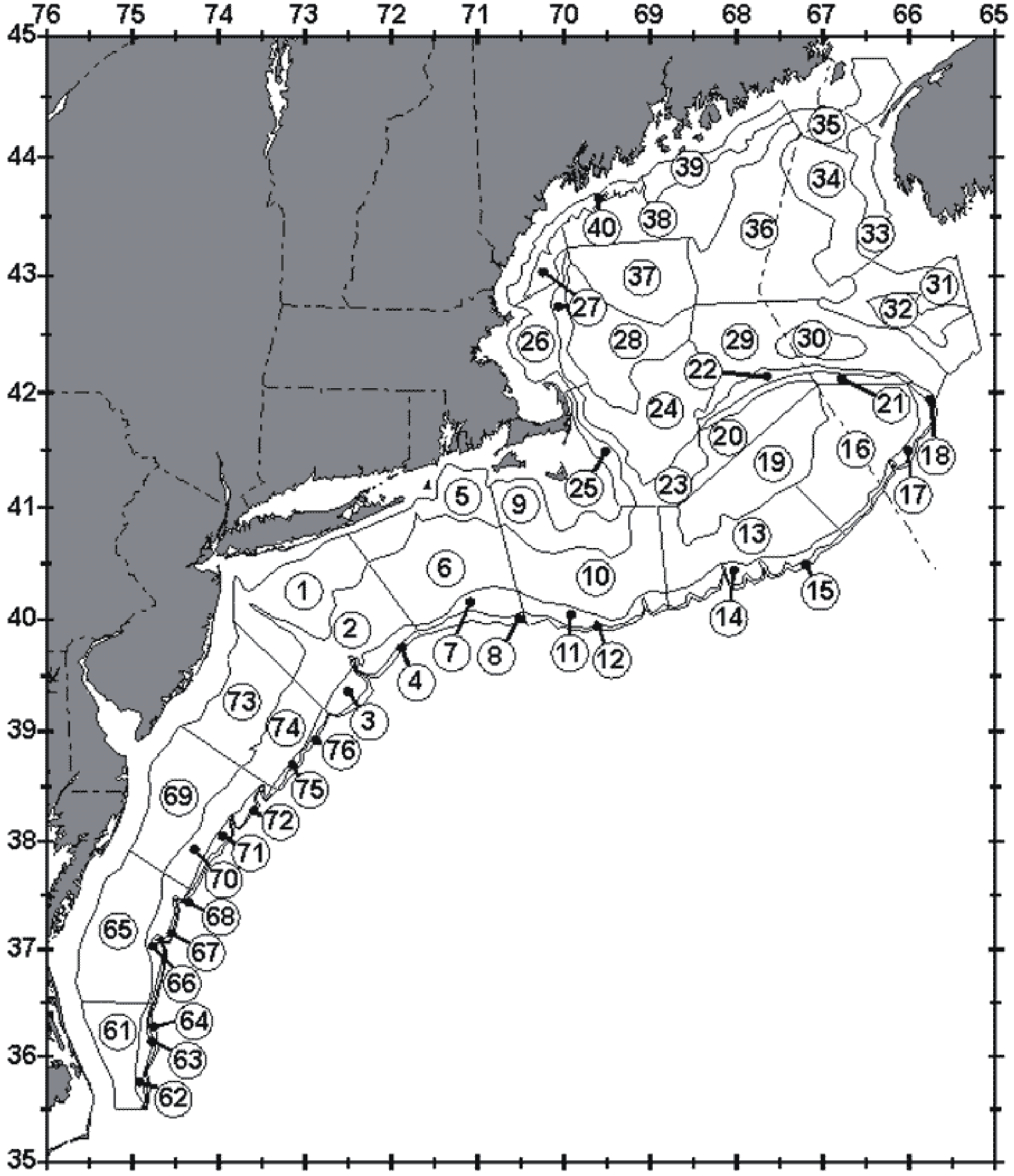


Figure 1. Strata sampled on NEFSC offshore bottom trawl surveys. Depths range from 27 to > 200 meters.

Figure 4.1-1 Map of the NEFSC offshore bottom trawl survey strata

Figure 1 from Sosebee and Cadrin (2006)

4.1.1 Atlantic croaker

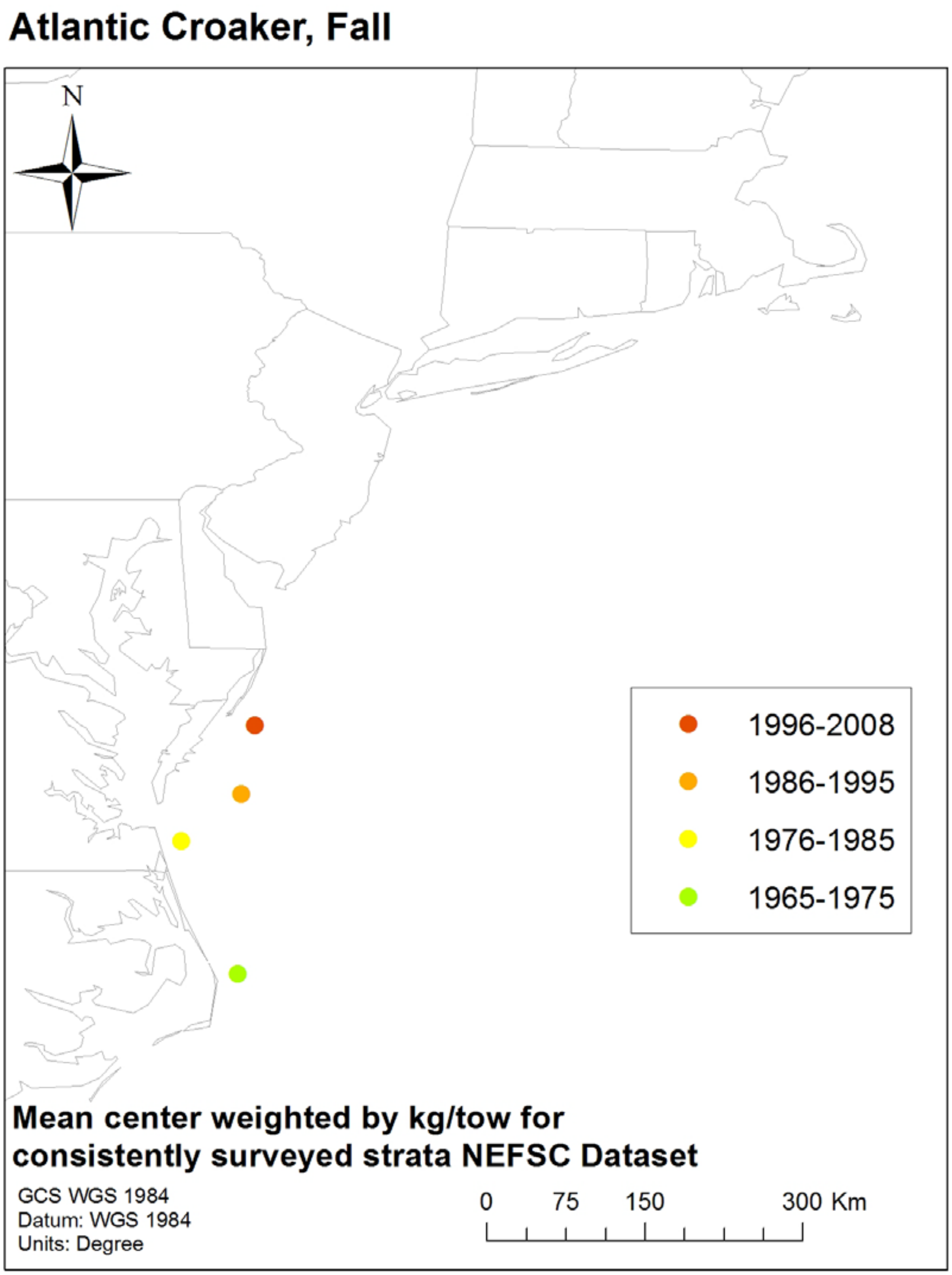


Figure 4.1.1-1 Atlantic Croaker: Weighted mean center

4.1.2 Atlantic Mackerel

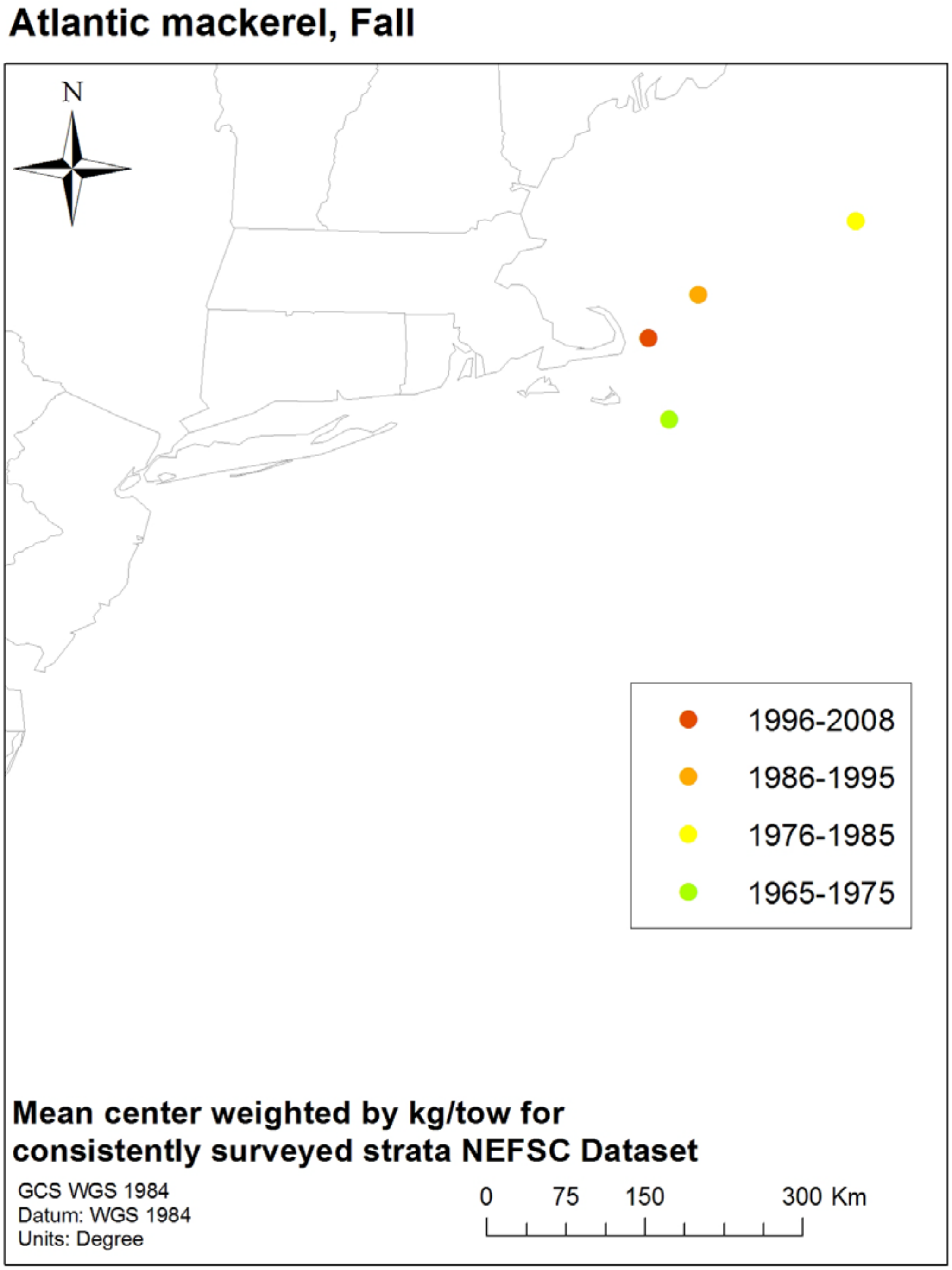


Figure 4.1.2-1 Atlantic Mackerel: Weighted mean center

4.1.3 Black Sea Bass

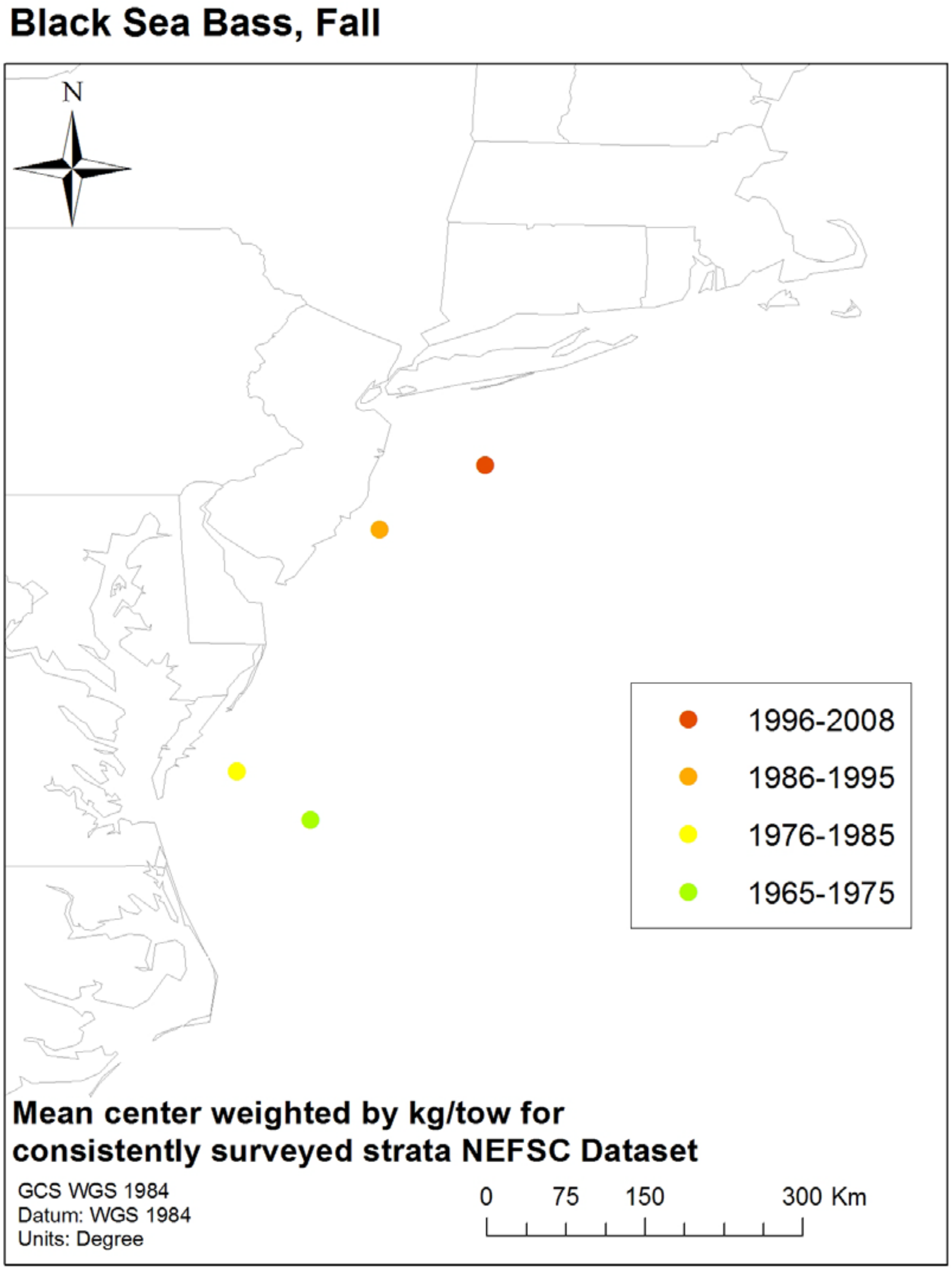


Figure 4.1.3-1 Black Sea Bass: Weighted mean center

4.1.4 Bluefish

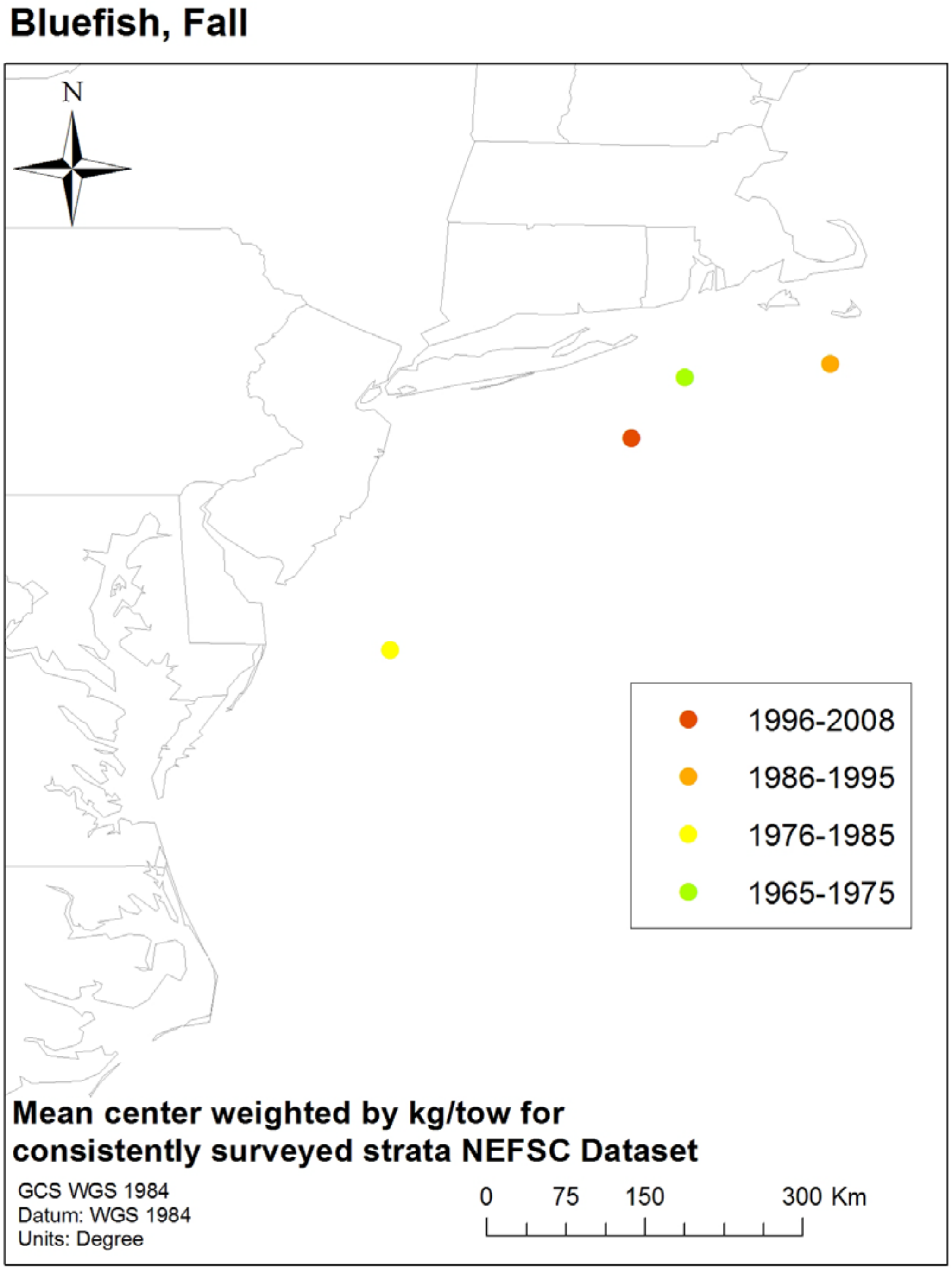


Figure 4.1.4-1 Bluefish: Weighted mean center

4.1.5 Butterfish

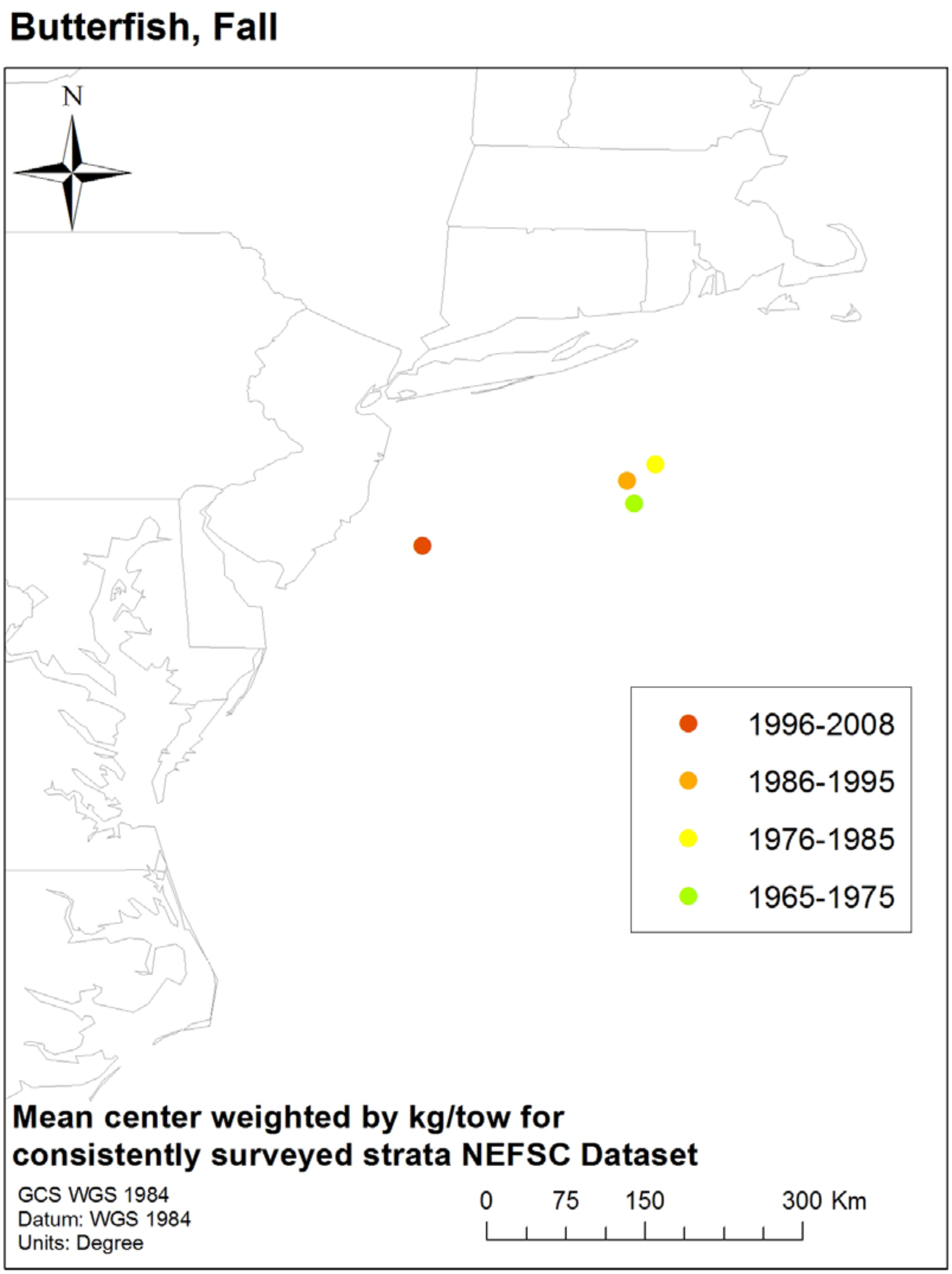


Figure 4.1.5-1 Butterfish: Weighted mean center

4.1.6 Longfin Inshore Squid

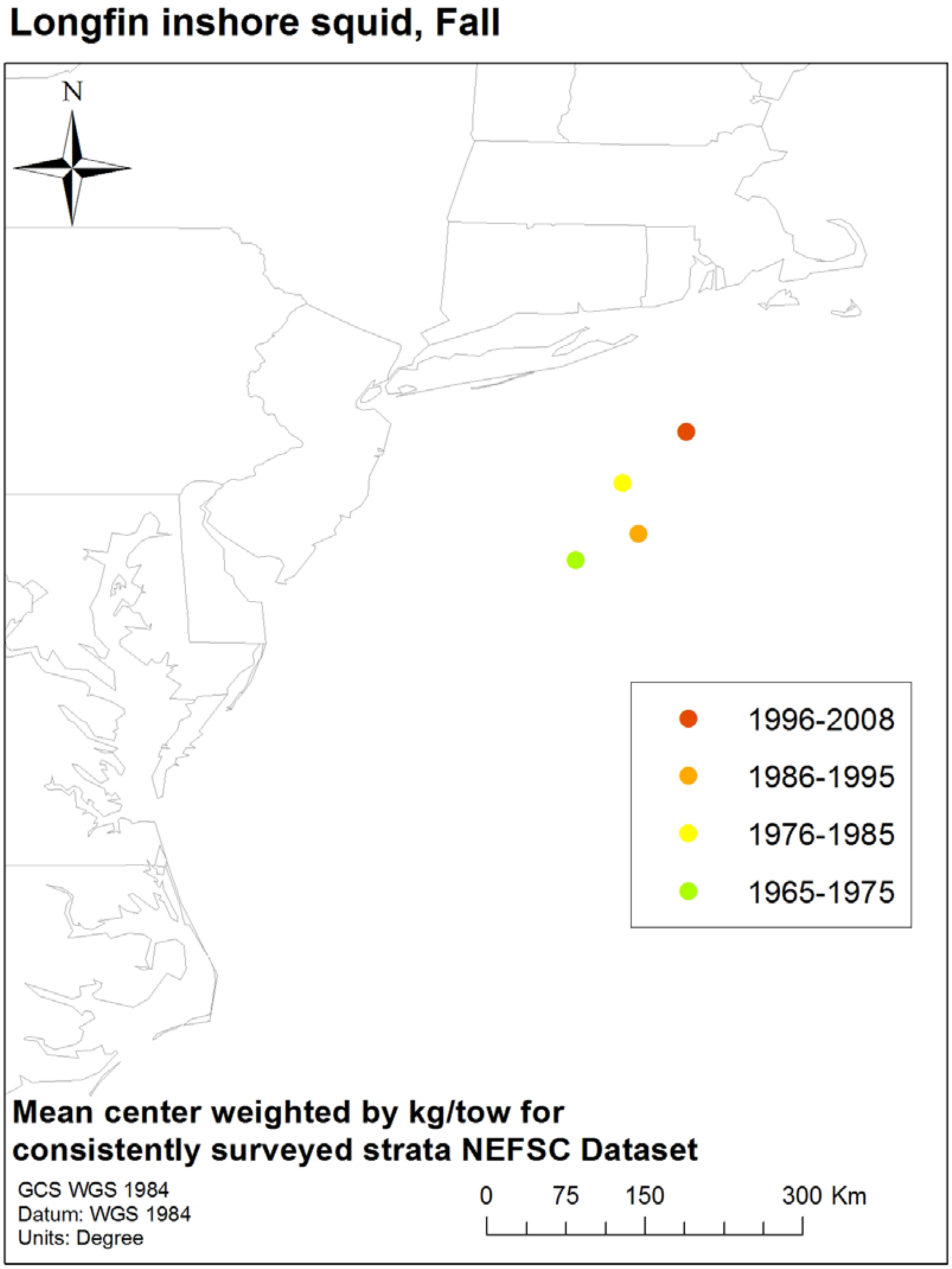


Figure 4.1.6-1 Longfin Inshore Squid: Weighted mean center

4.1.7 Scup

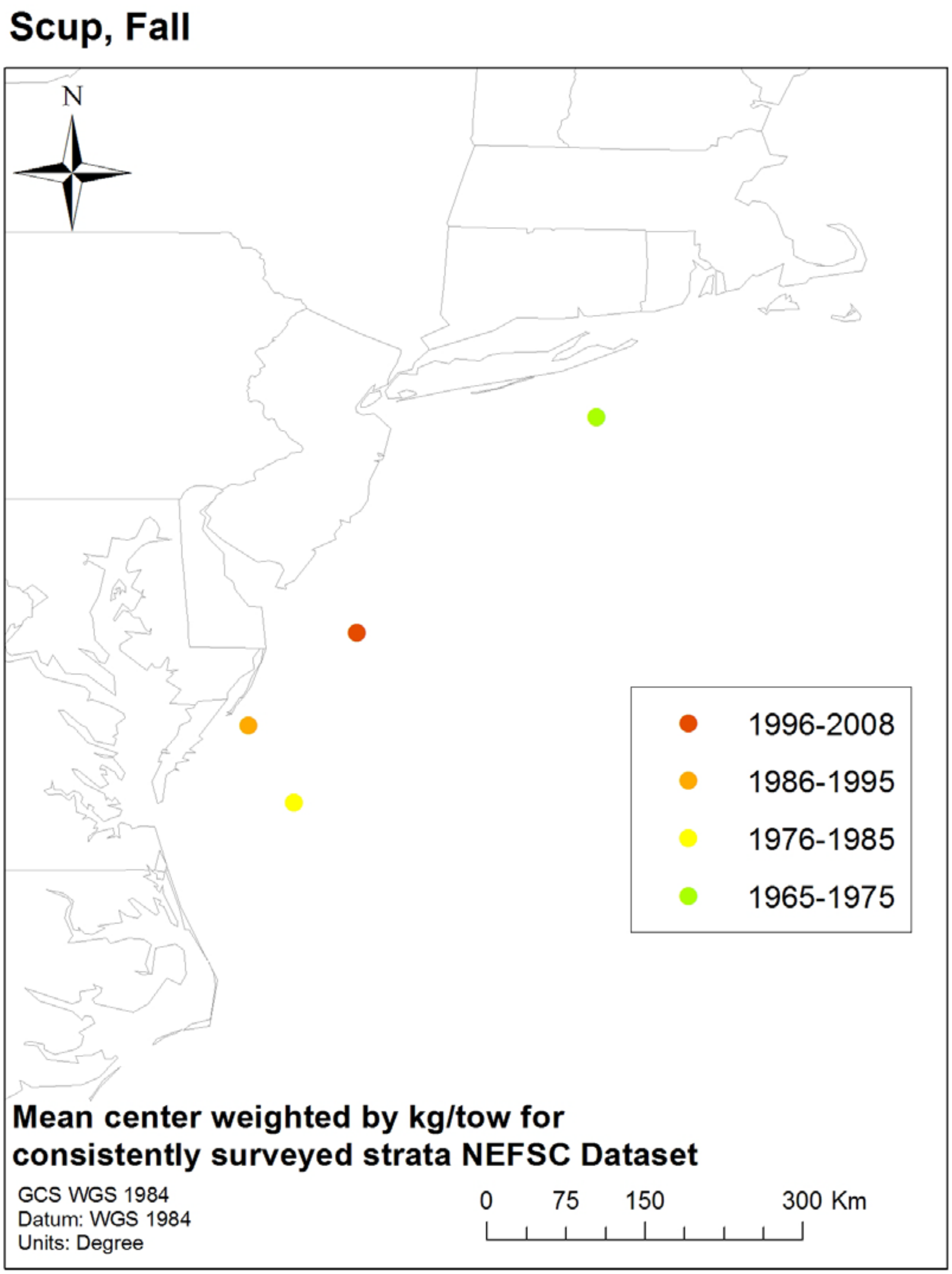


Figure 4.1.7-1 Scup: Weighted mean center

4.1.8 Spiny Dogfish

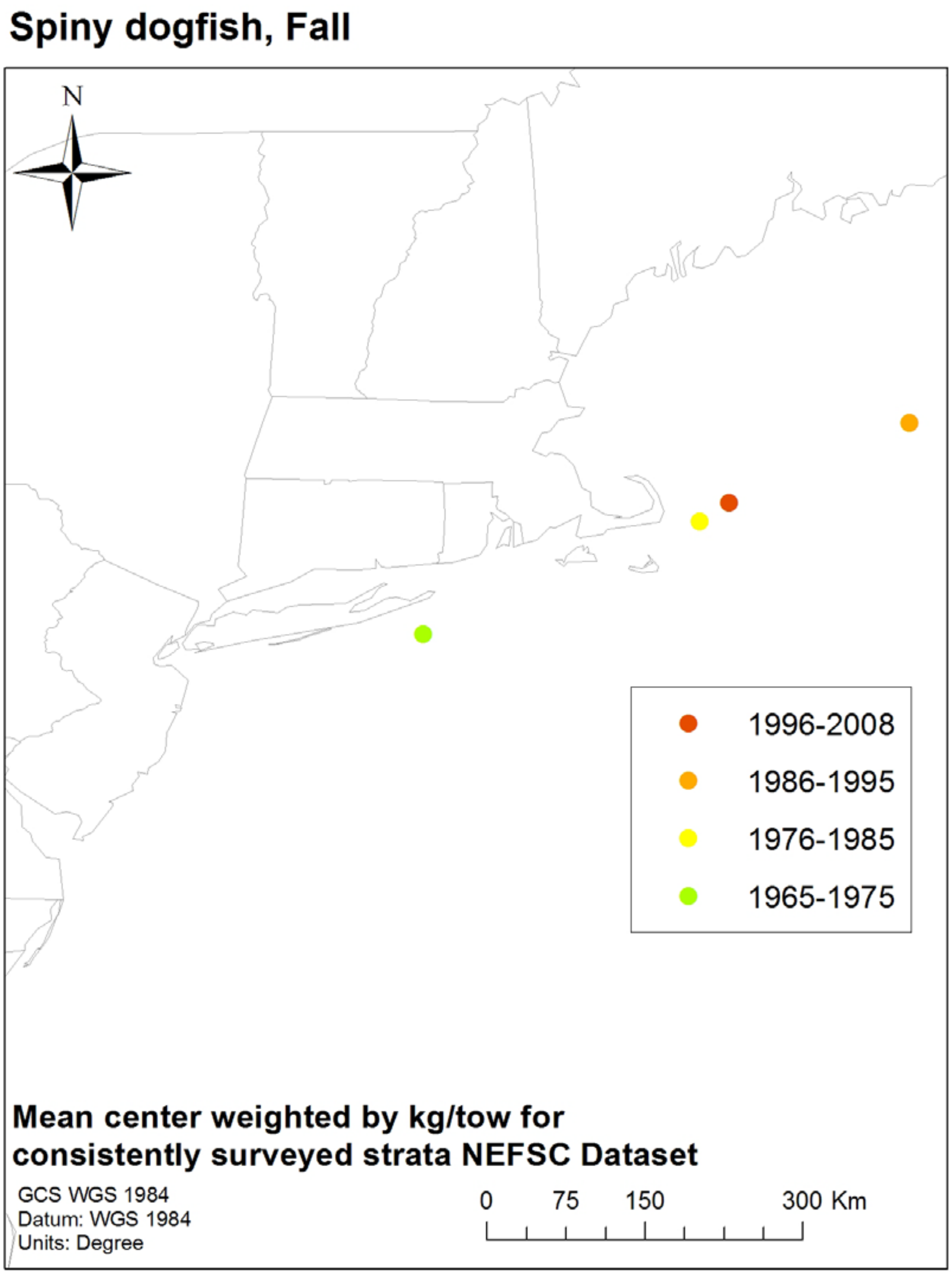


Figure 4.1.8-1 Spiny Dogfish: Weighted mean center

4.1.9 Summer Flounder

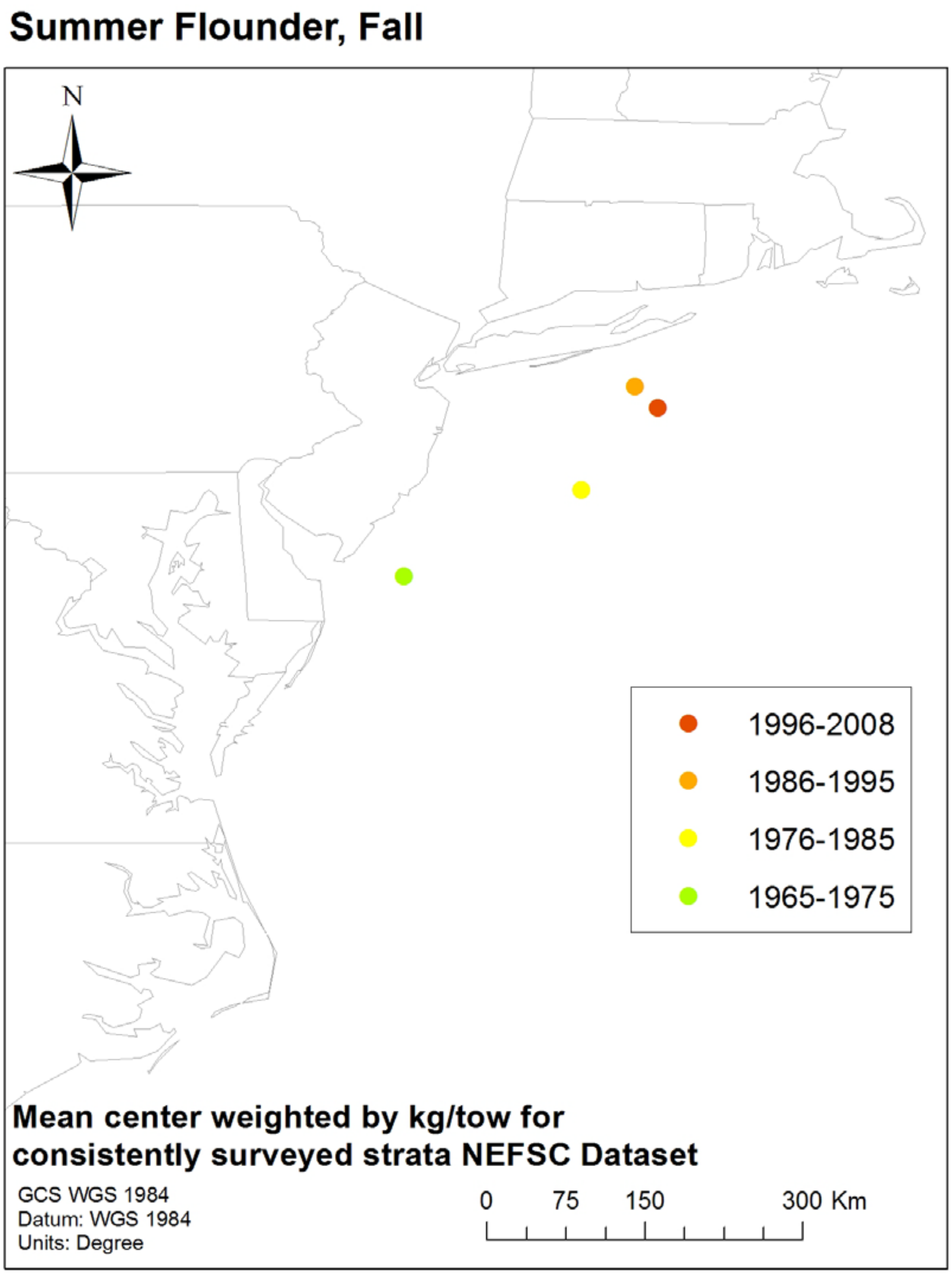


Figure 4.1.9-1 Summer Flounder: Weighted mean center

4.2 SEAMAP-SA Bottom Trawl Maps

The Southeast Area Monitoring and Assessment Program-South Atlantic (SEAMAP-SA) is an NMFS sponsored survey conducted by the South Carolina Department of Natural Resources, Marine Resources Division (SCMRD). Data can be downloaded through seamap.org. Data were available from trawl surveys of coastal habitats between Cape Hatteras, North Carolina and Cape Canaveral, Florida beginning in 1986, but standardized in 1990, and ending in 2014. Collections were made at randomly selected sites in predefined strata, for inshore (4.6-9.1m depth) and offshore strata (9.1-18.2), but inshore strata was most consistently sampled, and is therefore used in the following analysis. Fish collected were counted, measured to the nearest cm, and weighed by species to the nearest gram (except for very large catches, which were subsampled). Catch-per-tow was defined as the combined catch from both paired nets. Surface and bottom temperature, salinity and sampling depth were recorded at each station. Effort data was also recorded.

The following maps were created for the species listed below. Ellipses were also added to figures, and both mean centroids and ellipses were weighted by CPUE (species counts/effort). This dataset is confined to only the nearshore strata.

- Atlantic croaker
- Atlantic mackerel
- Black sea bass
- Bluefish
- Butterfish
- Atlantic Mackerel
- Longfin inshore squid
- Scup
- Spiny dogfish
- Summer flounder

The Atlantic Croaker and Black Sea Bass maps are included below to demonstrate the need for examining changes outside of the Mid-Atlantic Region that may impact the region in the future.

4.2.1 Atlantic Croaker

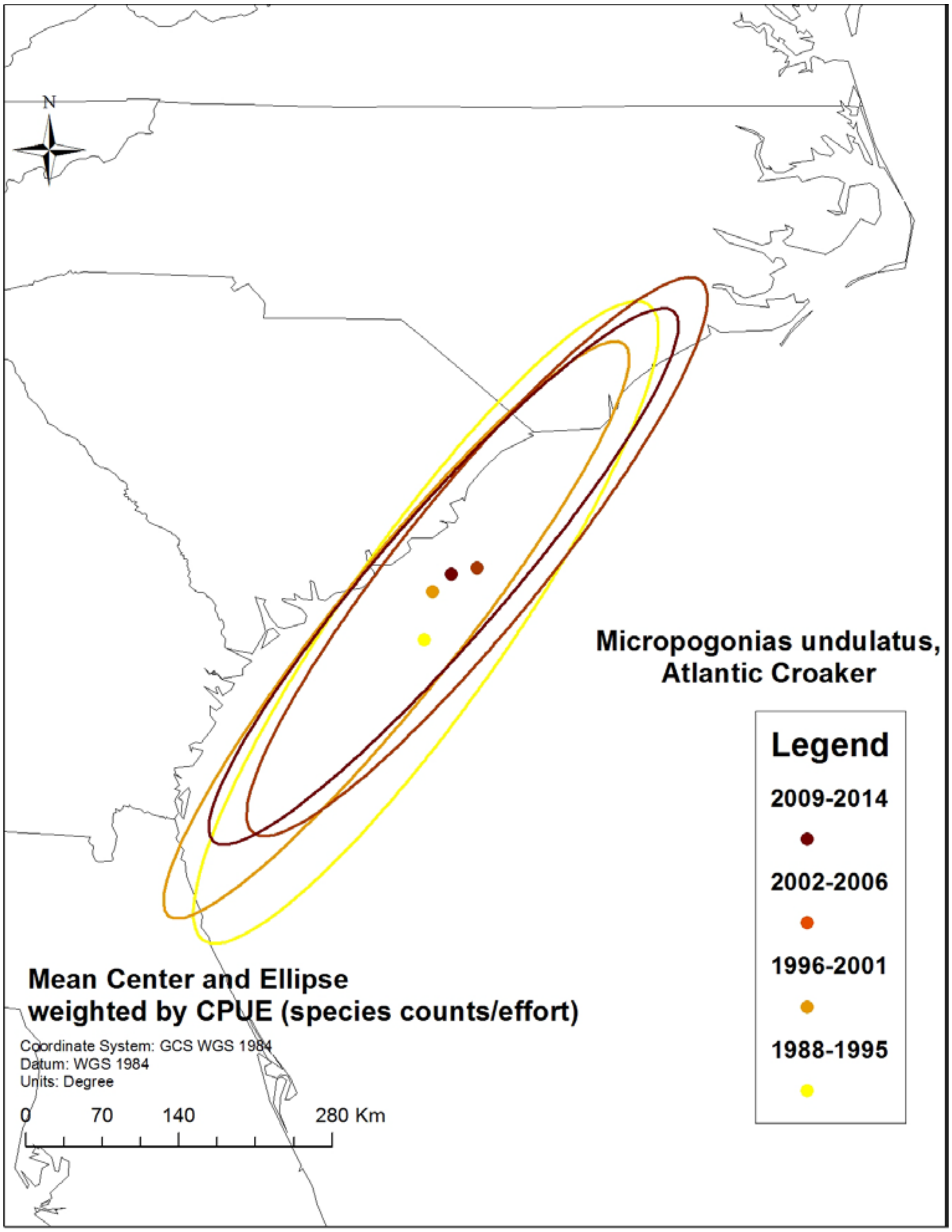


Figure 4.2.1-1 Atlantic Croaker: Weighted mean center

4.2.2 Black Sea Bass

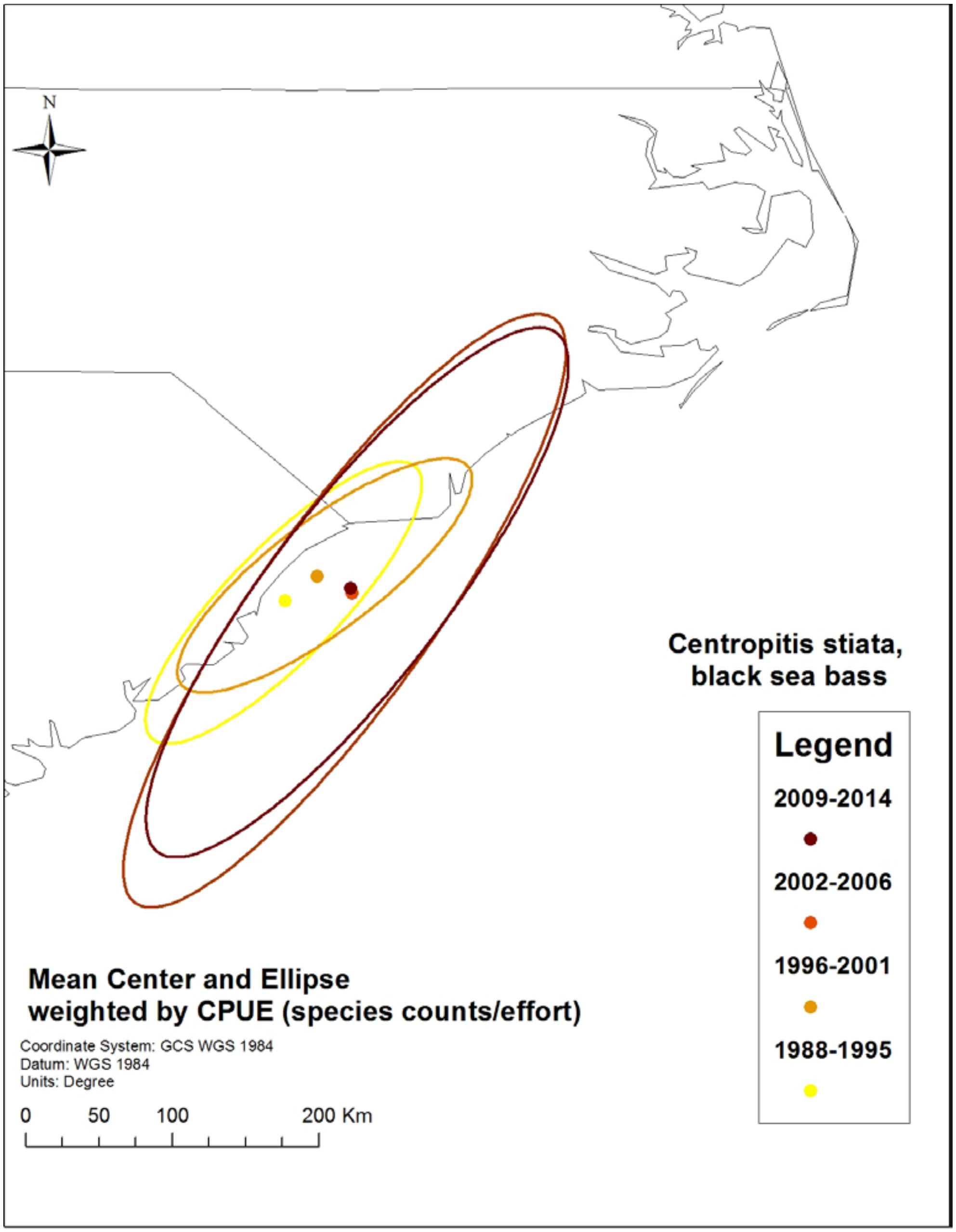


Figure 4.2.2-1 Black Sea Bass: Weighted mean center

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