The NMFS-SEFSC must account for climate change and inter-annual environmental variability in all South Atlantic stock assessments

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The NMFS-SEFSC must account for climate change and inter-annual environmental variability in all South Atlantic stock assessments

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Abstract

Climate change and inter-annual environmental variability is responsible for significant population shifts in most fisheries species in the northwestern Atlantic Ocean over the past 40 years. Large-scale climate change events, such as the Atlantic Multi-decadal Oscillation (AMO) and the North Atlantic Oscillation (NAO), rather than sea surface temperature, are the primary factors in "catchability" in some stock assessment models in the US northeast Atlantic coast, and may confound (by increasing or decreasing) "rebuilding" rates of exploited species. For coastal migratory pelagic (CMP) species, such as mackerels, stocks are responding to inter-annual climate cycles (e.g. + NAO) by changing over-wintering migration patterns, whereby affecting stock structure and fisheries "catchability." These phenomena have been documented in the mid and northeast Atlantic coast of the US, including species endemic to the south Atlantic US coast; hence climate change and inter-annual variability must be incorporated into all fishery stock assessments in the south Atlantic by the National Marine Fisheries Service (NMFS)-Southeast Fisheries Science Center (SEFSC), starting with the temperature sensitive CMP species in SEDAR 38- King Mackerel. The NMFS-SEFSC must assess which stock assessment models are capable of calculating inter-annual environmental and climate co-variance for future assessments.

Introduction

Fishery management plans (FMPs), based upon traditional stock assessment models, presume that environmental variability balances out over time, therefore making valid models dependant upon estimates of static spawner- recruitment, natural mortality, versus time-dependant fishery stock removal. In short, present fishery stock assessment models presume that environmental effects are the same in the present as they were in the past; we now know that static environmental conditions no longer exist over time (see Intergovernmental Panel on Climate Change, IPCC 2007).

Evidence is now available that inter-annual environmental variability and progressive climate change de-couples traditional fishery model indices of abundance. For example, recruitment, natural mortality, growth and maturity rates are all recognized to be affected by environmental variability (see Rothschild 1986, Hare et al. 2010). In light of well documented climate change driven regional-scale environmental variability in the western Atlantic, all stock assessment models designed to predict fishery stock structure and status must now account for this variability.

IPCC predictions for warming of the western Atlantic Ocean

Over the past 100 years the western north Atlantic ocean has warmed by nearly 1º C and may increase by another 2º C this century, based upon the most conservative model trajectories of increasing atmospheric CO_2 concentration (IPCC 2007).

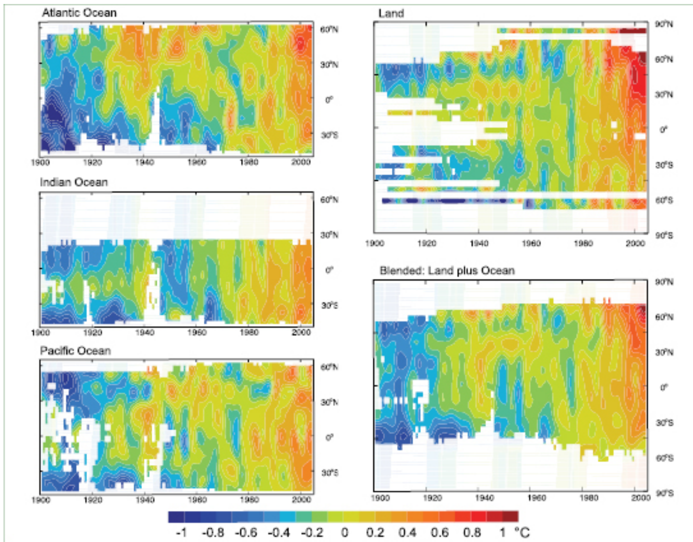

Figure 1. (Figure 3.5, Section 3.2.2.3, IPCC 2007)

Moreover, the IPCC estimates for a warming western Atlantic have implications beyond increases in sea surface temperature (SST); they also include increasing ocean acidification, changes in coastal runoff, and changes in wind patterns. Predicted atmospheric carbon dioxide concentrations over the next 100 years may be used in models to indicate biologically-relevant thresholds of water temperature expressed as absolute values or degree days (Hare et al. 2012).

Regional climatological forcing

Anthropogenically-driven climate change is also evident in alterations in regional climatological forcing. For example, four of the five most intense El Nino/ La Nina (ENSO) events of the past century occurred after 1980. With respect to the coastal south Atlantic Bight (SAB) region, El Nino winters tend to be colder, wetter and more stormy; whereas, La Nina winters tend to be warmer, drier and calmer (Ropelewski and Halpert 1986). Sun and Furbish (1997) reported that El Nino and La Nina are responsible for up to 40% of the annual precipitation variation and up to 30% of the river discharge variations in Florida. During the 1997–1998 El Nino event, rainfall was heavy throughout the south Atlantic region from December through March. Florida and the coastal zone of the Carolinas received over 200% of normal precipitation for this period, while inland areas received 150% of normal precipitation. These climate change-related physical conditions all have implications, either directly or indirectly, on fisheries productivity in the SAB.

Changes in dominant regional climatology may already be altering coastal oceanographic conditions in the south Atlantic Bight (SAB). For example, Hyun and He (2010) report that a persistent wind-shear event was a primary driver in a historically significant upwelling event in the SAB in the summer of 2003. Evidence from historical summer sea surface temperature data suggest an increase in the magnitude and frequency of these summer upwelling events along the east coast of Florida (see Barile 2013-SEDAR38 DW-07). These climatological conditions have obvious implications for species whose population dynamics are regulated by temperature resulting in changes in the catchability. The commercial fishing industry has observed depressed finfish (e.g. King mackerel) and shellfish (e.g. rock shrimp) landings associated with periods of cold (< 70º F) water temperatures during summer months. As a testable hypothesis, cold upwelling events in the SAB should be analyzed as a co-varying factor in catchability of fishery species.

Other climatological forcing, such as the Atlantic Multi-decadal Oscillation (AMO) may be six to eight decades in duration, and may simulate long-term climate warming scenarios on marine populations (see Nye et al. 2009). Alternatively, abrupt changes in regional climate change cycles, such as the North Atlantic Oscillation (NAO, see Figure 2.) may result in extreme inter-annual temperature regimes on western Atlantic shelf environments (see Overholtz et al. 2011). Strength of the NAO causes significant difference in the winter climatology of the US Atlantic coast (see Figure 3). Based on knowledge of temperature regimes on adult behavior (e.g. migrations) and early life history stages (thermal tolerances) associated with these climatological events, responses of fishery stocks have been predicted with high statistical precision, and are reviewed below.

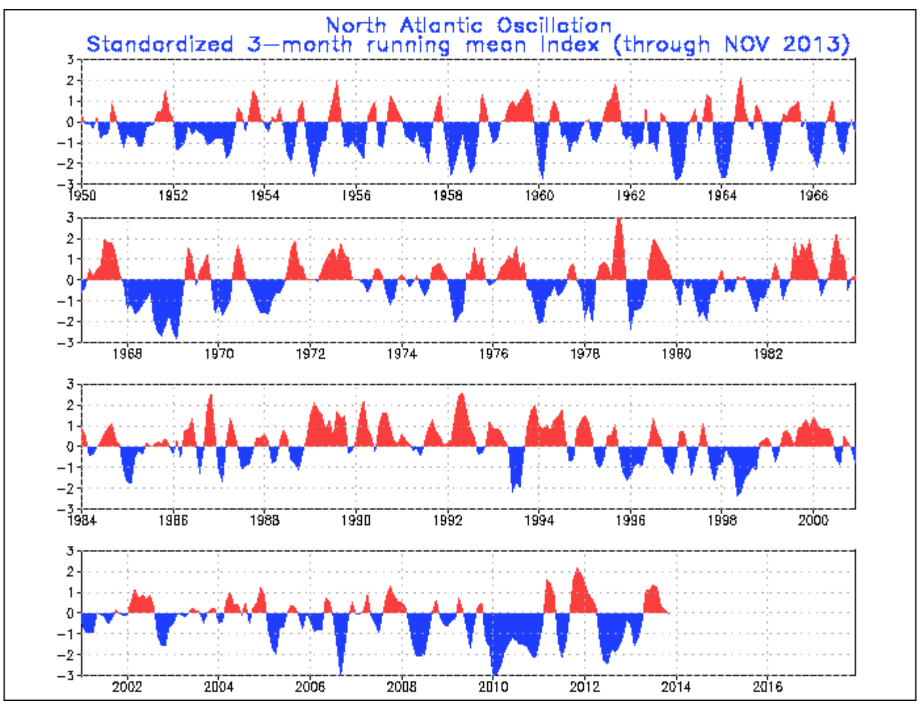

Figure 2. Historical record (1950-2013) of North Atlantic Oscillation climate forcing event. From NOAA-National Climate Data Center.

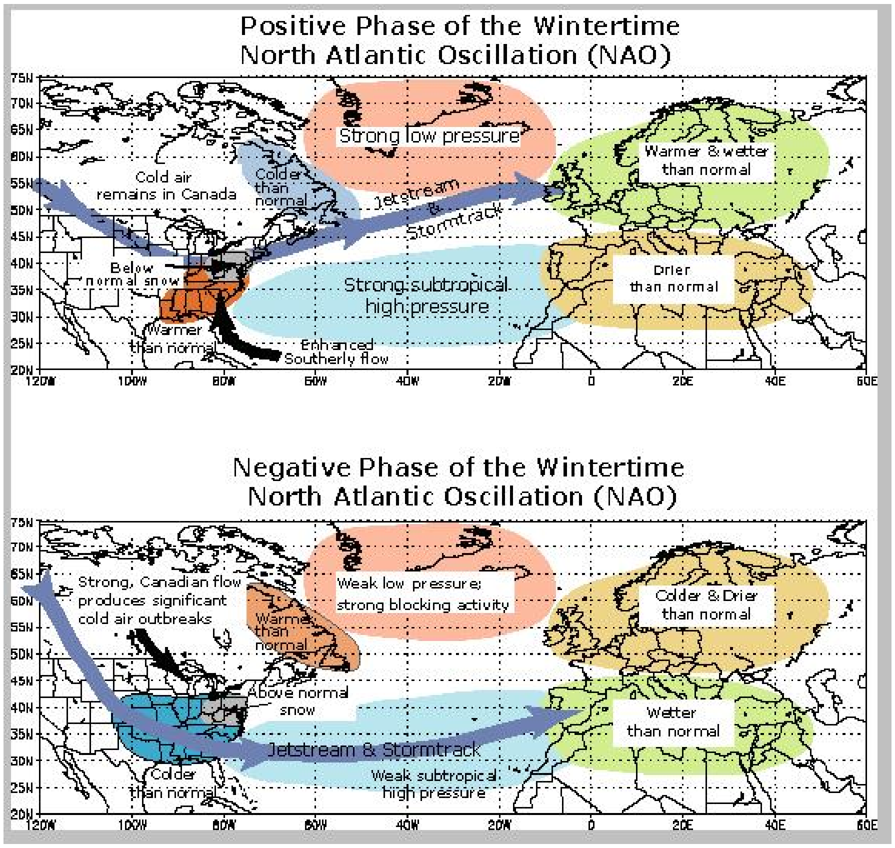

Figure 3. Schematic of positive and negative phases of the North Atlantic Oscillation climate forcing event. From NOAA-National Climate Data Center.

Evidence from western Atlantic fisheries

Climate velocities A series of reports on changes in population centers of fishery species along the US coast, including the mid and north Atlantic coast, have documented significant latitudinal and longitudinal population shifts as a result of long-term changes in water temperature (see Fig. 4). For these species, “climate velocities” are the name given to the climate change driven rate and direction of temperature “isotherm” changes in the coastal ocean that result in shifts in population centers of abundance (see Pinsky et al. 2013, NOAA/ NMFS 2013).

A now five year old study by Nye et al. (2009) indicates that over the past 40 years: 1) most of the 36 fish stocks evaluated in the northwest Atlantic Ocean experienced spatial population shifts, 2) 50% of the species, many of them commercially valuable, shifted northward over the last four decades, with 3) some stocks nearly disappearing from U.S. waters as they move farther offshore. Many of these species have experienced historical exploitation, (e.g. the Atlantic cod), bringing to light climate change as a confounding factor in accounting for the “rebuilding” of over-exploited stocks.

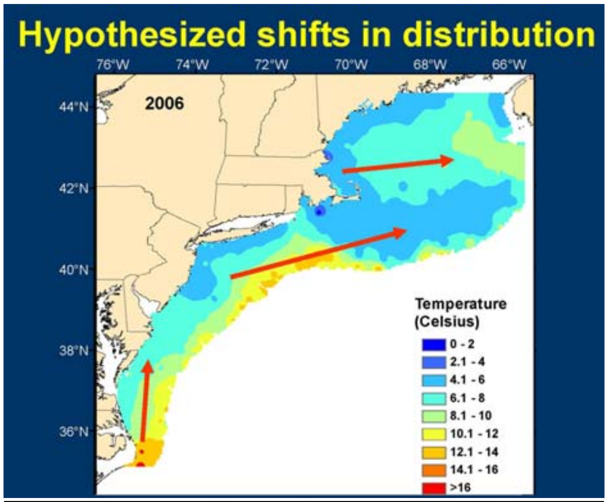

Figure 4. Climate velocities and changing fisheries distributions. From Nye et al. 2009, NMFS/ NEFSC

As the result of several mechanisms, temperature is an important regulator of marine fish at scales from the individual to population level (Hurst 2007). Obviously, most juvenile and adults have preferred temperature ranges resulting in both temporary and permanent migratory behavior. For example, the scombrids (mackerels) are widely recognized to undergo seasonal migrations of significant latitudinal magnitude, while other species guilds may undergo longitudinal (inshore-offshore) migrations that also coincide with spawning behavior. Alternatively, seasonal temperature regimes that dictate survivability of early life history stages, may affect the significance of recruitment events, particularly at the margins of population distributions (Hare and Able 2007).

For species, such at the Atlantic croaker (*Micropogonias undulatus*), climate-induced winter water temperature anomalies associated with the North Atlantic Oscillation (+NAO) in the mid-Atlantic have created “thermal openings” that allow “recruitment bursts” and a 165% increase in thermally suitable habitat conditions, which result in markedly successful recruitment events (see Hare and Able 2007). These successful recruitment events, at the northerly margins of the mid-Atlantic croaker population distribution, not only result in large year classes, but are involved with northerly range extensions into New Jersey. Stock assessment models that include climate variability suggest that (+) NAO events are a more significant driver of stock biomass than that of fishing and bycatch removal. For this stock of Atlantic croaker, climate change is predicted to increase spawning stock biomass by 60 to 100% and maximum sustainable yield by 30 to 100% over the next 80 years (Hare et al. 2010).

A similar model of decreasing over-wintering mortality of Gray snapper (*Lutjanus griseus*) recruits, likewise, suggests a climate velocity of increasing population range extension into mid-Atlantic coastal waters. This model was calibrated using the three most plausible climate change (atmospheric CO_2 concentration) scenarios as they relate to the predicted number of lethal over-wintering temperature degree-days (i.e.<17º C) in mid-Atlantic estuaries (Hare et al. 2012).

Mackerel Populations and Fisheries are sensitive to Climate/ Env. change

Coastal migratory pelagic species, such as the scombrids (mackerels), are known to be temperature sensitive, and undergo significant seasonal migrations to reside in preferred isothermic conditions. For example, the Atlantic mackerel (*Scomber scombrus*) prefers water temperature greater than 5º C. Hence, scombrids are recognized as a species guild likely to alter population distribution in response to water temperature changes associated with climate change, as well as inter-annual variability (Overholtz et al. 1991). Overholtz et al. (2011) described how winter and early spring distributions of Atlantic mackerel have shifted about 250 km north and east over the past 40 years (see Figs. 5 & 6). This distribution shift was most significantly associated with the Atlantic Multi-decadal Oscillation (AMO), rather than with sea surface temperature. Alternatively, inter-annual variability of this trend, where warm winters alternate with colder winters associated with the North Atlantic Oscillation (NAO, per Figure 2.), caused significant changes in positioning over the shelf environment (see Fig. 6). In this case, during the cold winter of 2005, the Atlantic mackerel population positioned at a temperature optima over the offshore shelf break, and at lower latitude. Alternatively, during the "warmer" (+) NAO winter climate condition of 2007, with warmer shelf temperatures associated with warmer air temperatures, Atlantic mackerel were found at a significantly higher (poleward) latitude, and also distributed more evenly over the shelf environment. These results have drastically affected the "catchability" of Atlantic mackerel within the Mid and Northeast Atlantic fishery management boundaries, and has obviously affected stock structure and status and of this economically important species over the northwestern Atlantic coast.

IMPACTS OF ENVIRONMENTAL FORCING ON ATLANTIC MACKEREL

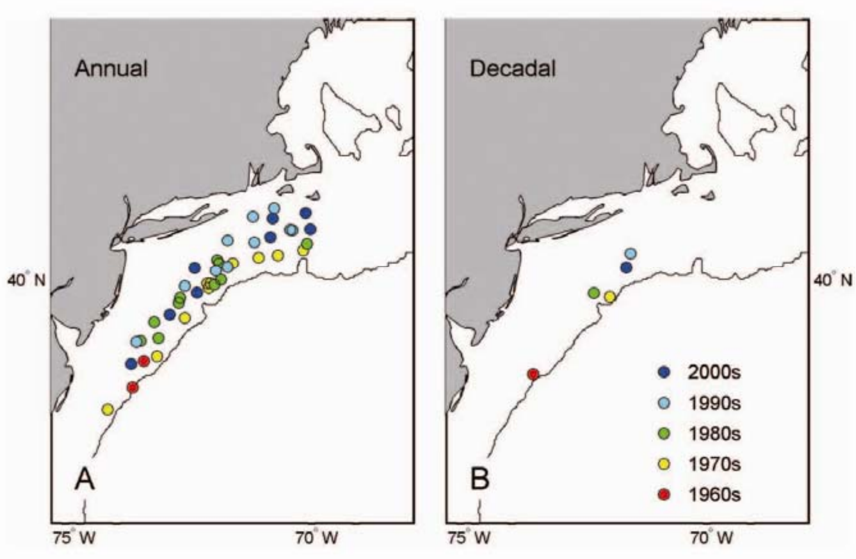

FIGURE 7. **(A)** Annual and **(B)** decadal along- and across-shelf centers of distribution of Atlantic mackerel during 1968–2007.

Figure 4. Annual and decadal distributions of Atl. Mackerel from 1968-2007. From Overholholtz et al. (2011).

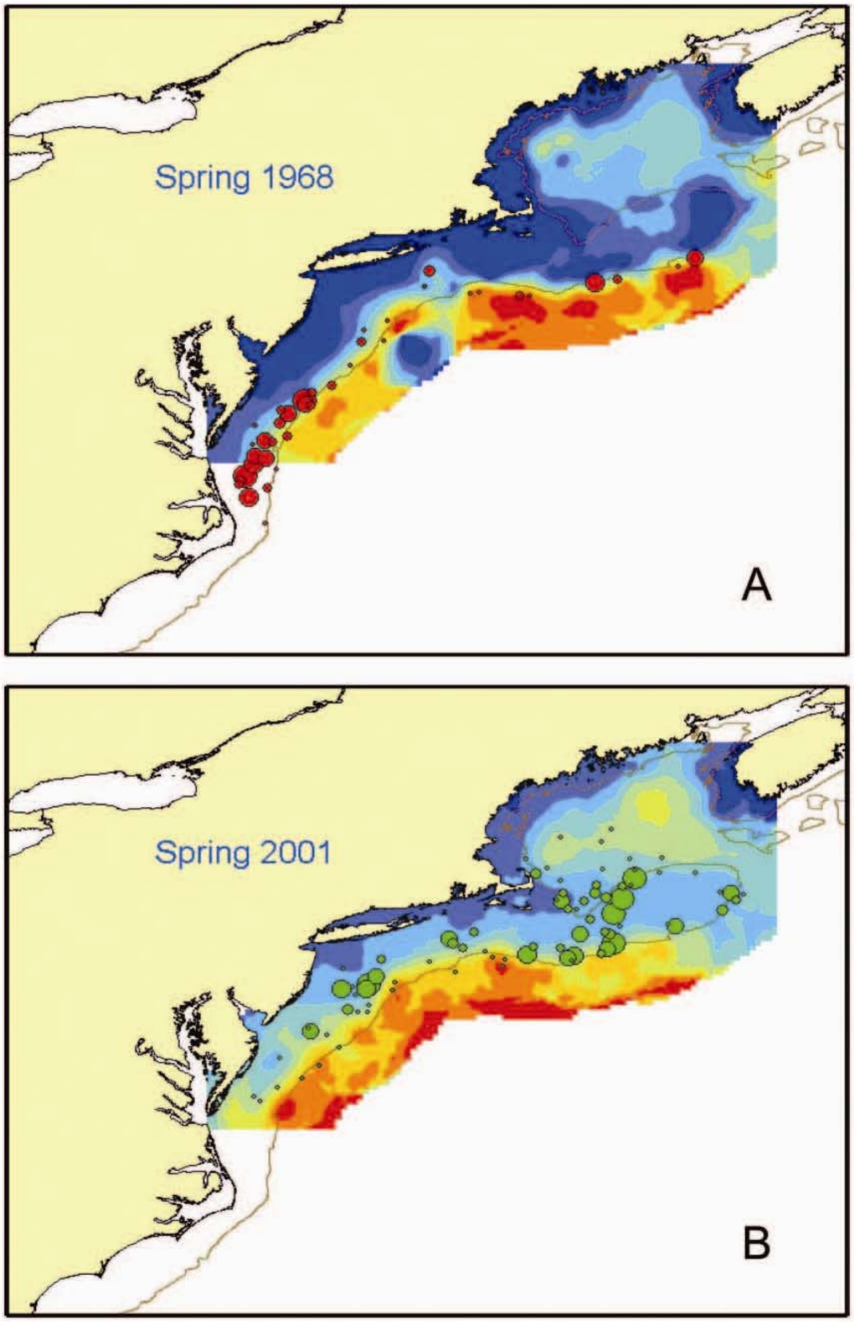

FIGURE 3. Distributions of Atlantic mackerel and bottom temperatures from Northeast Fisheries Science Center spring bottom trawl surveys during **(A)** cold (1968) and **(B)** warm (2001) periods. Fish catches are represented by dots, with the dot size being proportional to that of the catch. Isotherms range from 4°C (dark blue) to 12°C (red).

Figure 5. Annual distributions of Atl. Mackerel from A) 1968 and B) 2001. From Overholtz et al. (2011).

IMPACTS OF ENVIRONMENTAL FORCING ON ATLANTIC MACKEREL 225

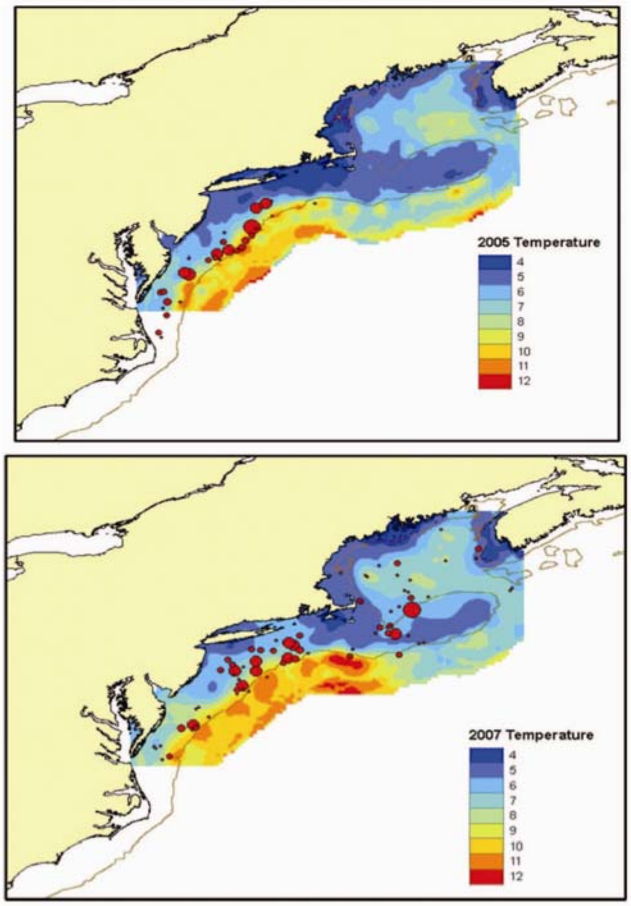

FIGURE 5. Distributions of Atlantic mackerel and bottom temperature from Northeast Fisheries Science Center spring bottom trawl survey in 2005 (top panel) and 2007 (bottom panel). See Figure 3 for additional details.

Figure 6. Annual distributions of Atlantic Mackerel from A) cold 2005 and B) warm 2007 winter seasons. From Overholtz et al. (2011).

For scombrids, such as King mackerel in the south Atlantic, it is likewise clear that annual migration behavior is affected by temperature regimes in over-wintering habitats along the east coast of Florida (see Barile 2013, SEDAR38 DW-08). The NMFS- SEFSC must resolve the role of inter-annual (e.g. NAO) and long-term climate change (e.g. AMO, CO_2 driven warming) on the total landings, catchability and stock status of mackerel fisheries (both King mackerel and Spanish mackerel) in both the south Atlantic and Gulf of Mexico. Specifically, the historically significant (-) NAO event in the winter of 2009/2010 (see Fig. 2) coincided with a significant southerly and outer shelf-ward migration and positive landings year. Alternatively, in warmer years, i.e. (+) NAO climate events, fishermen have reported King mackerel population centered more northerly in their overwintering grounds, and lower catchability as the stock is more diffusely spread over the shelf. In summary, the NMFS-SEFSC must model fishing removals with now widely recognized climate change events as a co-varying factor in both "catchability" and landings history to resolve stock structure and status.

Climate change confounds NMFS- SEFSC stock assessments

The NMFS-SEFSC does not presently account for climate change in stock assessments

Based upon the recent work performed at the NMFS-Northeast Fisheries Science Center, we now know that climate change is a primary factor affecting fishery stocks in the western Atlantic, and confounds everything known about fishery exploitation, stock structure and status in traditional stock assessment models. The increasing impact of climate change and environmental variability de-couples fisheries indices of abundance based upon CPUE or landings trends. Natural mortality, fecundity, recruitment, growth and maturity rates have all been demonstrated to be affected by inter-annual environmental variability, meaning static values are not informative over time in stock assessments. Many species that have responded to “climate velocities” in the mid and northeast US Atlantic are, likewise, found in the South Atlantic region, and hence, are likely responding to climate forcing. Two species, the Gray snapper and American croaker have historically important stocks in the South Atlantic region which are now experiencing latitudinal distribution extensions northward to New Jersey.

Another sub-tropical species, Snowy grouper, has developed as a significant fishery stock between Cape Hatteras and the NC/VA border in the past 20 years; a fact that the NMFS/ SEFSC appeared oblivious and aloof to in the 2013 SEDAR 36 Snowy grouper stock assessment. The NMFS can no longer ignore these alterations in stock structure, and their implications on region-wide stock structure and status of economically important species in this advent of rapidly changing inter-annual and long-term climate change.

Modelling issues

Because environmental variability at inter-annual and long-term scales confounds traditional fisheries stock assessment models, future modeling efforts must account for these co-varying factors. Traditional models utilized in the US South Atlantic region, such as the Beaufort assessment model (BAM), may not be able to account for these co-variations, whereas more modern models, such as the Stock Synthesis III, may accurately account for environmental variability on an annual basis with adequate statistical rigor. Shirripa et al. (2009) reviewed the risks associated with the incorporation of inter-annual environmental variability on model output utilizing models that cannot accurately account for the statistical error associated with inter-annual environmental factors. As our understanding of the role of inter-annual environmental and climate change variability becomes more complex, models must be able to account for these complexities, as multiple factors at several scales are already affecting fisheries. In summary, the NMFS-SEFSC must provide resolution on the model(s) most capable of accounting for fish population dynamics and fishery removals in a changing climate; and immediately account for environmental variability and climate change as a factor in south Atlantic fishery stock assessments.

Conclusions and Recommendations for South Atlantic stock assessments

1) Inter-annual environmental variability and long-term climate change is well documented in the peer-reviewed scientific literature as a physical forcing function affecting fishery populations in the western Atlantic. These physical processes alter natural mortality, fecundity, recruitment, growth and maturity rates such that these biological processes can no longer be consider "static" rate parameters in time-dependant fishery models.

2) Several fishery stocks endemic to the South Atlantic, such as Atlantic croaker, Gray snapper, and possibly Snowy grouper, are experiencing range extensions as a result of warming of the western Atlantic Ocean; a dynamic that confounds current fishery modeling efforts by the NMFS-SEFSC. Predictive models suggest that climate change will increase spawning stock biomass (SSB) and maximum sustainable yield (MSY) of these fishery species through range extensions, thereby confounding the effects of current fishery removals on biologically-based stock management targets.

3) For "isothermic" coastal migratory pelagic (CMP) fishery species, such as Atlantic mackerel, the over-wintering population distribution, which formerly resided off of NC, has now shifted 250 km to the northeast as the result of AMO forcing, with inter-annual (+) NAO forcing causing the stock to move more northward, and on to the shelf during warmer winters. The AMO and NAO must, likewise, be considered with respect to environmentally-driven fishery stock dynamics for CMP's in the South Atlantic. This oversight by the NMFS-SEFSC must be corrected starting with the assessment modeling for King Mackerel in SEDAR 38.

4) The NMFS-SEFSC must immediately undergo an external review to evaluate the efficacy of their stock assessment models to consider environmental variability and climate change. The present increasing impact of inter-annual environmental variability and climate change de-couples the ability of traditional fisheries models to calculate accurate indices of abundance, making this review time critical.

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