Silver hake tracks changes in Northwest Atlantic circulation

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Summary
Recent studies documenting shifts in spatial distribution of many organisms in response to a warming climate highlight the need to understand the mechanisms underlying species distribution at large spatial scales. Previous work documented the remote oceanographic processes governing the spatial distribution of adult silver hake, Merluccius bilinearis, a commercially important fish in the Northeast US shelf region. Changes in spatial distribution of silver hake over the last 40 years are highly correlated with the position of the Gulf Stream (GS). Silver hake shifted their spatial distribution in direct response to local changes in bottom temperature on the continental shelf that are responding to the same large scale circulation change affecting the GS path, namely changes in the Atlantic Meridional Overturning Circulation (AMOC). Further analysis illustrates that other species also respond to this remote forcing, suggesting that the GS position is the best leading indicator of thermal conditions resulting in ecosystem change on the shelf. If AMOC weakens as is suggested by global climate models, silver hake and other species will remain in a poleward position, the extent to which could be forecast at both decadal and multidecadal scales.

Introduction
Shifts in spatial distribution of many Northeast US fish populations over the last forty years were concurrent with the recent warm phase of the Atlantic Multi-decadal Oscillation (AMO), an index based on sea surface temperature (SST) thought to be linked to Atlantic Meridional Overturning Circulation (AMOC). AMOC variability is suggested to be transmitted to the Northeast US shelf region through temperature and flow variations arising from the Labrador Sea and Subpolar gyre to the north. Variability in the vicinity of the GS is dominated by the changes in the north-south position of the GS on interannual to decadal time scales, while the changes in velocity, volume transport, and width of the GS are relatively small. The north-south GS position change is strongly correlated with changes in SST and circulation in the Slope Water region between the GS and the shelf, but the influence of the GS on the continental shelf ecosystem is not well understood. We examined the correlation of the GS position with silver hake and other species on the Northeast US shelf.

Materials and Methods
The data to quantify fish spatial distribution, population size and bottom temperature were obtained from the NOAA Northeast Fisheries Science Center (NEFSC) trawl surveys. Center of mass (COM) of each population was calculated using the methods of Nye et al. (2009, 2011). Details regarding the construction of the index of the position of the north wall of the Gulf Stream (GS) are given in Joyce et al. (2009). Quarterly or seasonal values are available for the GS index, but the spring value was used for majority of the analysis.

Results and Discussion
The COM changed very little over time for the northern silver hake, but there has been a gradual increase in the COM for southern silver hake indicative of its poleward shift in distribution. Cross correlation analysis on the 41-year time series revealed that the GS index is significantly correlated with southern silver hake COM ($r_{max} = 0.72$, $P < 0.001$) and the biomass of northern silver hake ($r_{max} = 0.43$, $P = 0.005$). When the time series were linearly detrended the GS position was still significantly
correlated with the COM for southern silver hake ($r_{\text{max}}=0.60$, $P<0.001$) and biomass of the northern silver hake population ($r_{\text{max}} =0.44$, $P=0.0062$).

We hypothesized that the mechanisms by which the GS path shifts are reflected in silver hake spatial distribution are through its relationship with bottom water temperature to which adult fish directly respond. Indeed, the position of the GS was highly correlated with mean-stratified bottom temperature averaged over the entire shelf ($r_{\text{max}} =0.51$, lag=0, $P<0.001$). Upon closer examination, bottom temperature averaged within the southern population boundary, the area from which silver hake moved, increased from about 10°C when the GS was in a more southerly position, to more than 12°C when the GS was more northerly, well above the preferred temperature range of silver hake, (Fig. 1a). Average temperatures within the northern population area also increased with the GS index, but approached the preferred temperature range of silver hake (Fig. 1a). The average temperature at which the southern silver hake population was found remained within the 6-10°C temperature range that silver hake prefer and there appears to be no relationship of catch temperature with the GS (Fig 1a), indicating that silver hake remain within their preferred temperature range by shifting their distribution (Fig 1b).

Similar correlations between the GS index and COM for red hake, spotted hake, Atlantic mackerel and alewife have been observed. The established relationship between the GS path and AMOC (Joyce & Zhang 2010) potentially provides a way to predict the likely changes in GS path and fish distribution at longer time scales using sophisticated global climate models. That the spatial distribution of commercially important fish species might be forecast by a remote oceanographic feature represents a promising advance in the way that environmental indices can be used to forecast fish distribution and abundance.

References

Figure 1: The relationship between the Gulf Stream index and the (a) bottom temperature (only stations >100m) in the southern region (gray triangles) and northern region (gray squares) is shown along with the catch temperature of southern silver hake (black points). Temperature in both the northern and southern regions increase with GS index with temperatures in the southern region elevated above silver hake temperature preferences. In contrast, the average temperature at which silver hake were found remains the same indicating that as temperatures increase in the south, silver hake shift their distribution poleward as indicated by (b) COM of southern silver hake.