**Physical geography and oceanography**

*Description*

* The oceanography of the Southeast US continental shelf is dominated by the Gulf Stream. The region is vertically stratified in the spring and summer, and the primary source of nutrients is summertime upwelling caused by the Gulf Stream (Southeast Fisheries Science Center 2017).
* From Cape Cod to Cape Hatteras, flow is primarily southward through the Mid-Atlantic Bight – faster at the shelf break, and slower at the coast and at depth (Pappalardo *et al.* 2015). There does not appear to be much seasonality in this flow regime (Lentz 2008)
* Where the Mid-Atlantic Bight current meets the water of the South-Atlantic Bight (flowing northward due to the Gulf Stream), the Hatteras Front is generated, driving offshore transport (and deflection of the Gulf Stream?) and causing an alongshore gradient in temperature, salinity, and density (Pappalardo *et al.* 2015)
* “The Gulf Stream begins upstream of Cape Hatteras, where the Florida Current ceases to follow the continental shelf. The position of the Stream as it leaves the coast changes throughout the year. In the fall, it shifts north, while in the winter and early spring it shifts south (Auer 1987; Kelly and Gille 1990; Frankignoul et al. 2001). Compared with the width of the current (about 100-200 km), the range of this variation (30-40 km) is relatively small (Hogg and Johns 1995). However, recent studies by Mariano et al. (2002) suggests that the meridional range of the annual variation in stream path may be closer to 100 km. Other characteristics of the current are more variable. Significant changes in its transport, meandering, and structure can be observed through many time scales as it travels northeast.”
  + <http://oceancurrents.rsmas.miami.edu/atlantic/gulf-stream.html>
  + Speeds up significantly downstream of Cape Hatteras; meandering intensifies
  + “According to Geosat altimetry results, the current transports a maximum amount of water in the fall and a minimum in the spring, in phase with the north-south shifts of the its position (Kelly and Gille 1990; Zlotnicki 1991; Kelly 1991; Hogg and Johns 1995). Rossby and Rago (1985) and Fu et al. (1987) obtained similar results when they looked at sea level differences across the Stream. All of these studies found that the Gulf Stream has a marked seasonal variability, with peak-to-peak amplitude in sea surface height of 10-15 cm. The fluctuation is mostly confined to the upper 200-300 m of the water column and is a result of seasonal heating and expansion of the surface waters (Hogg and Johns 1995). Height differences this small, if assumed to decay linearly to zero at 300 m, would only result in annual transport fluctuations of about 1.5 Sv (Hogg and Johns 1995).
  + “Interestingly, the variations in transport of the deep waters in the current appear to be almost opposite in phase to the surface waters, and their magnitude is more significant (Hogg and Johns 1995). As Worthington (1976) suggested, the maximum transport occurs in the spring, and the amplitude of the annual cycle is as large as 5-8.5 Sv (Manning and Watts 1989; Sato and Rossby 1992; Hogg and Johns 1995). The mechanism Worthington proposed was extensive convection south of the Gulf Stream in winter due to the atmospheric cooling of surface waters. This causes the thermocline to deepen and the baroclinic transport to increase (Fu et al. 1987). Although his idea has been controversial, alternate hypotheses have not adequately explained observations (Hogg and Johns 1995).”
* Moving south, both the width of the shelf and the band of available deeper shelf habitat shrink (shallow shelf shrinks and shelf break moves closer to shore) (Pappalardo *et al.* 2015)
* The Gulf Stream and other currents in this region are influenced by the Atlantic Meridional Overturning Circulation (AMOC) and the Atlantic Multidecadal Oscillation (AMO). The AMOC carries warm surface waters in the Atlantic to high latitudes and circulates cold, deep waters back toward the South Atlantic. The AMO measures differences in North Atlantic sea surface temperatures, and its oscillations (55-70 years apart or more) have been linked to ocean and climate effects including hurricanes and mixed layer depth (Hare *et al.* 2016a; Southeast Fisheries Science Center 2017). Positive AMO phases correlate with warmer North Atlantic sea temperatures. Long-term trends in each of these oceanographic phenomena are poorly understood.
* The North Atlantic Oscillation (NAO), an index measuring the difference in temperature between Iceland and the Azores that is linked to the westerlies across the North Atlantic, also influences oceanography in the Northeast. The NAO flips between negative (cold and dry atmospheric conditions) and positive (warm and wet atmospheric conditions) phases, and its phases have shortened in recent decades to just 1-3 years (Hare *et al.* 2016a).

*Seasonality*

**Biological description**

*Habitats*

* The Southeast US continental shelf habitat is primarily sandy and muddy bottom, with patches of rocky reefs. The Southeast has a diverse temperate assemblage as well as tropical and subtropical species found up to North Carolina (Southeast Fisheries Science Center 2017).

*Biogeography*

* Cape Hatteras is a major biogeographic break that separates the Virginian Biogeographical Province (north) from the Carolinian (south) (Hale *et al.* 2017)
* A number of invertebrate species have northern boundaries just south of Cape Hatteras. It does not appear to account for a substantial proportion of southern range edges (possibly just an artifact of the latitudinal gradient in species richness). Most of the invertebrate species with northern range edges at Cape Hatteras seem to be deeper-dwelling species with long PLDs. In short, it is a permeable boundary, that appears to act more strongly on invertebrates with certain traits. Although Cape Hatteras coincides with a gradient in temperature, it does not show up in a simple model of where species’ thermal tolerances will be exceeded, suggesting that temperature is not the whole story. The stronger effect on species with longer PLD suggests that circulation patterns play a role, and the offshore transport at Cape Hatteras does reduce larval transport around the cape (Pappalardo *et al.* 2015)
* From Cape Cod down to just north of Cape Hatteras, a number of *southern* boundaries occur among deep-dwelling invertebrates, possibly due to the narrowing of the deep shelf and an accompanying reduction in habitat (Pappalardo *et al.* 2015)
* Among very nearshore coastal benthic marine invertebrates,

*Seasonality*

*Documented range shifts*

* From 1990-2010, observed surface and bottom temperatures in the very nearshore coastal environment on the US Atlantic coast increased significantly. This increase was accompanied by changes in the benthic marine invertebrate community: of the 30 most common species in NCA surveys, 18 showed a northward centroid shift, 20 a northern range edge extension, and 22 a southern range edge contraction. In general, species ranges contracted during the study period, because trailing edges contracted faster than leading edges expanded – possibly because of temperature-related juvenile mortality (Hale *et al.* 2017)
  + The Carolinian has warmed much more than the Virginian
  + Five species crossed from the Carolinian to the Virginian Province: the polychaetes *Magelona phyllisae, Pettiboneia duofurca, Scoletoma verrilli*, and *Thalassema hartmani* and the amphipod *Grandidierella bonnieroides.*

**Past and future changes to the ocean environment**

*Past changes*

* The Southeast experienced little warming in the 20th century, but the Northeast warmed faster than almost any other continental shelf – well over 1°C (Hare *et al.* 2016a). This warming signal has been strongly modified by the AMO; positive AMO phases correlate with warmer sea temperatures in the North Atlantic.

*Projected climate change*

* Because the AMO is currently in a positive phase, and due to its oceanographic and atmospheric conditions, the Northeast is predicted to continue warming rapidly in the 21st century, and the Southeast is expected to begin warming more quickly (Pachauri *et al.* 2015).
* The Gulf Stream and the AMOC both may slow down in this century, with potentially profound impacts for upwelling and warm water transport (Griffis & Howard 2013; Pachauri *et al.* 2015).
* “Saba et al. (2016) compared simulations and an atmospheric CO2 doubling response from four NOAA Geophysical Fluid Dynamics Laboratory (GFDL) global climate models of varying ocean and atmosphere resolution. The study found that the highest resolution climate model CM2.6 (~10-km ocean, ~50-km atmosphere) resolves Northwest Atlantic Shelf circulation and water mass distribution most accurately ([Figure 10](https://www.nefsc.noaa.gov/ecosys/climate-change/figures/fig10.png)). The CO2 doubling response from this model shows bottom ocean temperature in the Northwest Atlantic Shelf, particularly in the Gulf of Maine, warms at a rate nearly two to three times as fast as the coarser models ([Figure 11](https://www.nefsc.noaa.gov/ecosys/climate-change/figures/fig11.png)). This enhanced warming is accompanied by an increase in salinity due to a change in water mass distribution that is related to a retreat of the Labrador Current and a northerly shift of the Gulf Stream ([Figure 12](https://www.nefsc.noaa.gov/ecosys/climate-change/figures/fig12.png); [Movie 2](https://www.nefsc.noaa.gov/ecosys/climate-change/projected.html#movie2) and [Movie 3](https://www.nefsc.noaa.gov/ecosys/climate-change/projected.html#movie3)). Both observations and the climate model demonstrate a robust relationship between a weakening Atlantic Meridional Overturning Circulation (AMOC) and an increase in the proportion of Warm-Temperate Slope Water entering the Northwest Atlantic Shelf. Therefore, prior climate change projections for the Northwest Atlantic Shelf may be far too conservative.”
  + https://www.nefsc.noaa.gov/ecosys/climate-change/projected.html

*Biological consequences*

* A sophisticated climate-population model for Atlantic croaker, an important East Coast fishery species that migrates annually between the Carolinas (winter) to the mid-Atlantic (NC-NJ) in summer, predicts that in this century Atlantic croaker biomass will increase substantially (due to higher recruitment from reduced juvenile mortality during overwinter period in estuarine nursery habitat). The model also predicts a northern shift, both of the summertime leading edge, and of the population as a whole, which has already become more common in Delaware and New Jersey (Hare *et al.* 2010)
* Another equally complex model links climate models with a niche-based model (projecting future distribution based on correlation between known distribution and environment) to test the specific hypothesis that the northern range edge of grey snapper is controlled by overwinter mortality in nearshore and estuarine nursery habitats. The model used air temperature projections calibrated to the estuarine environment, which is highly correlated with air temperatures. It then projected the northern range limit of grey snapper based on cumulative degree days below 17 C, finding that the species would move northward some distance largely determined by the climate scenario. (Hare *et al.* 2012)
* A relative scoring system has been developed to assess vulnerability of species to climate change, based on climate exposure, biological sensitivity and expert opinion. When applied to the Northeast US shelf assemblage, diadromous fish and benthic marine invertebrates were the most vulnerable. A subset of biological attributes (unclear which?) were also used to score which species are most likely to shift their ranges in response to climate change. (Hare *et al.* 2016b)

Include:

* (Hare *et al.* 2010, 2012, 2016b, a)
* (Hale 2010; Hale *et al.* 2017)
* <https://www.nefsc.noaa.gov/ecosys/climate-change/projected.html>
* (Mills *et al.* 2013)
* Lentz