Habitats in the ocean: Identifying biogeographic regions in the Gulf of Maine using satellite observations of sea surface temperature and chlorophyll concentration

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The purpose of this project is to evaluate how the ecology of the Gulf of Maine (GoM) is changing by using biogeographic regions as a framework to analyze satellite data in an ecological context. Unlike the terrestrial environment where biomes are relatively immobile and easily distinguishable, ocean habitats move continuously with currents and are therefore difficult to identify. The drivers of this dynamic ecological structure are the physical and chemical properties that control primary productivity and in turn impact the whole ecosystem through a bottom-up trophic cascade. Although they do not influence ecosystem structure directly, sea surface temperature (SST) and ocean color data serve as good proxies for the properties that do because they are strongly correlated with them[1,2]. With the advent of satellite remote sensing over two decades ago, we can collect daily observations of SST and ocean color at 1-km spatial resolutions around the world. This provides us with a tremendous amount of information about the properties that drive ecosystem structure. To develop biogeographic regions from this information, we can apply well-established statistical techniques to identify temporally coherent spatial patterns in the data. Once classified, these regions can be used to analyze data through an ecological context so that we can evaluate how ecosystem structure is changing in the GoM over time.

The data used for this project was collected by the Moderate Resolution Imaging Spectroradiometer (MODIS) aboard the NASA Aqua satellite, which provides daily SST and chlorophyll concentration data processed to a 1-km resolution by the University of Delaware since July 3, 2002. From this data we created 3-km resolution monthly averages and computed the anomaly, mean subtracted, and normalized values for SST and chlorophyll concentration. Empirical Orthogonal Function (EOF) analysis was then performed on these time series, and biogeographic regions were identified from spatial patterns of temporally coherent variability. The original 3-km monthly data was then spatially averaged by region to place it in an ecological context and allow for comparison.

Seven biogeographic regions were successfully identified in the GoM from EOF modes representative of ecological factors (see Fig. 1). Common among all of these regions is a warming trend, 0.08 – 0.13 °C/yr within the GoM and 0.23 °C/yr in the region closest in proximity to the Gulf Stream (light blue). The SST anomaly time series show that this Gulf Stream region leads the others from 2002 to 2008, is temporally correlated from 2008 to 2012, and lags the others from 2012 to 2017, clearly defining three intervals within the warming trend (see Fig. 2a). Despite the observed warming, there are no significant trends in the timing and magnitude of phytoplankton blooms in the regions. However, the annual average chlorophyll concentration anomaly time series exhibits low values in the first time interval, anomalously high biomass in the second interval, and highly variable values among the regions in the third time interval (see Fig. 2b). Previous studies have suggested that changing currents in the North Atlantic are responsible for altering the source of nutrients to the GoM, providing a link between changing physical dynamics and changing ecological structure[3]. The correlation in our data between the timing of lead-lag in the GS region and the timing of increased biomass lends tentative support to this link. However, in order to ensure that the mechanisms producing the observed physical and biological data are related, the bloom and physical dynamics of each region need to be further investigated.

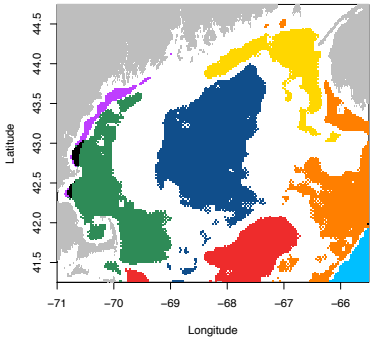

Figure 1 (left). Map of biogeographic regions derived from EOF modes.

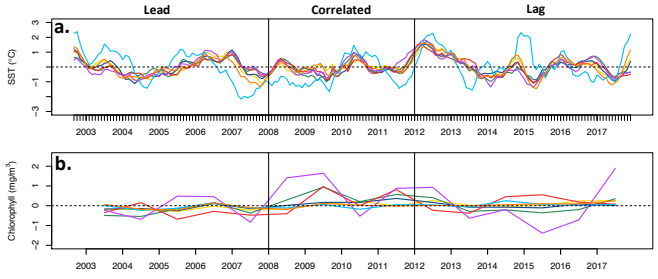

Figure 2 (bottom). Timeseries of smoothed and detrended SST anomaly data (a) and annually averaged chlorophyll concentration anomaly data (b) plotted by biogeographic region. Colors correspond to regions on the map.

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References:

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[3]Townsend, D. W., et al. (2010), A changing nutrient regime in the Gulf of Maine, *Continental Shelf Research*, *30*, 820-832.