Climate induced habitat changes in commercial fish stocks

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Climate change is altering the distribution and abundance of fish species in ways not anticipated by current management policy. We developed products to inform sustainable fisheries management by creating spatially-explicit, dynamic models of marine habitats that can inform stock assessments for twenty-five commercially important species on the Northeast Shelf. Improving upon methods used in the 2014 Butterfish stock assessment, we expanded the dimensions of habitat included in the models by integrating substrate, and seabed features along with the dynamic properties of the water column that change on daily to decadal time scales.

Changes in climate mediated habitat can affect the index of abundance from trawl surveys by altering catchability (q), the proportion of total biomass of a species caught in a trawl survey. Fisheries independent trawl survey data are the backbone of many stock assessments for species on the northeast shelf. Catchability is a function of availability, the proportion of total biomass within the space-time foot print of the trawl survey and detectability, the proportion of biomass within the path of a survey gear that is caught in the survey gear. The sample design for most surveys are stratified randomly over space, although they actually sample over time and space. Trawl surveys in the northeast often sample in the spring and fall when water temperatures are changing dramatically and species are migrating offshore and onshore. A single seasonal survey for the NEFSC trawl survey can span two months, during which time there can be dramatic changes in the oceanographic conditions and the location of migrating organisms.

While studies examining species temperature envelopes and projecting them into the future have been done, they have rarely been explicitly developed to inform stock assessments or combined both the water column and seafloor to get a true picture of climate induced habitat changes. The goal of this work was to provide direct benefit to management by identifying changes in the availability of populations to fishery independent surveys. In an attempt to provide a broader ecological perspective we used a mechanistic thermal response model as well as developed ecological benthic features to better consider the relationship between fish and the sea floor.

We combined data from the Northeast Fishery Science Center (NEFSC) trawl survey, the NorthEast Area Monitoring and Assessment Program survey (NEAMAP), State surveys and the benthic information from the NorthWest Atlantic Marine Ecoregional Assessment, to determine the mechanistic thermal-benthic habitat response curve for each species, and map out the spatial extent of the suitable habitat for different years and seasons with regional ocean models.

The research seeks to improve the understanding of the impacts of climate variability and change on habitat which directly regulates the abundance and distribution of managed fish stocks. Our intent is to utilize these current and historic data sets to improve the synthesis, analysis, and application of climate and marine ecosystem observations and monitoring information to improve fisheries management.

Methods

The thermal benthic habitat suitability index is integrated into stock assessments by shaping the catchability (q) of the fisheries independent trawl survey. Catchability is a function of availability and detectability. The habitat suitability index produces an estimate of availability that can be integrated into the catchability component in the stock assessment. The availability index is the ratio of the amount of suitable habitat sampled by the trawl survey to the total amount of suitable habitat calculated on a daily time step. Daily bottom temperatures were taken from the debiased ROMS/COBALT hindcast ocean model out of Rutgers University.

The thermal-benthic habitat suitability index was developed in two parts from existing fishery independent survey data which includes temperature along with synthesized benthic information from the Northeast Regional Assessment. The thermal niche model defines the potential thermal habitat available for each species on the northeast shelf. The number of fish caught at a given temperature in the trawl surveys is assumed to be a proxy for the suitable thermal habitat for each species. The thermal niche model produces a temperature response, range and optima, that can be mapped on to historic temperature fields of the northeast shelf to define the dynamic available thermal habitat in a given season and year. The model is based on the Johnson and Lewin (1946) equation which is a unimodal extension of the Bolzmann-Arrhenius function. The Bolzmann-Arrhenius function is a mechanistic model explicitly relating the effect of temperature on a biological activity.

To examine the benthic habitat relationship, we divided the entire northeast shelf into habitat patches based on substrate, including hard bottom, depth and the bathymetry. Moving beyond simple calculations of BPI, the habitat patches were first formed by dividing the entire Shelf into three features: valleys, peaks and flats based on the bathymetry. These three features were then subdivided based on depth zones and then further partitioned based on substrate. The resulting habitat patches provide an approach for examining habitat relationships more similar to landscape ecology as the abundance of fish in each tow were considered within their relationship to the larger patch as opposed to simply the exact depth or BPI at the location of the tow. The habitat patch size and shape (compactness) were also considered within the model.

The different benthic habitat components were then integrated into a Generalized Additive Model (GAM). GAMs provided the flexibility to both determine if a particular parameter was an important component of the benthic habitat relationship and determine its functional form. The thermal habitat model and the benthic habitat model were then weighted equally and combined to produce an overall thermal-benthic habitat suitability index. The thermal-benthic habitat suitability index is an expression of the probability of occupancy based on the included niche dimensions.

Results

The models produced useful thermal-benthic habitat suitability indices for eighteen of twenty-five species in the spring and twenty-four of twenty-five species in the fall.

The availability indices for the different species were generally variable without a trend (Fig 1). This indicates that the federal trawl survey is, on average, sampling the same amount of the potential habitat each year and season. In the spring, the availability indices for some of the species showed a decline toward the end of the time series (~2005), but a break point analysis did not show any significant changes in the slope of the trend line. The fall exhibited larger variability over time. Six species in the spring and seven species in the fall exhibited significant negative trends in their availability indices, and none of the species had significant positive trends. All linear models were tested with the Durbin-Watson statistic to evaluate autocorrelation. Linear models with autocorrelation were rerun within a generalized least squares linear model that included autocorrelation.

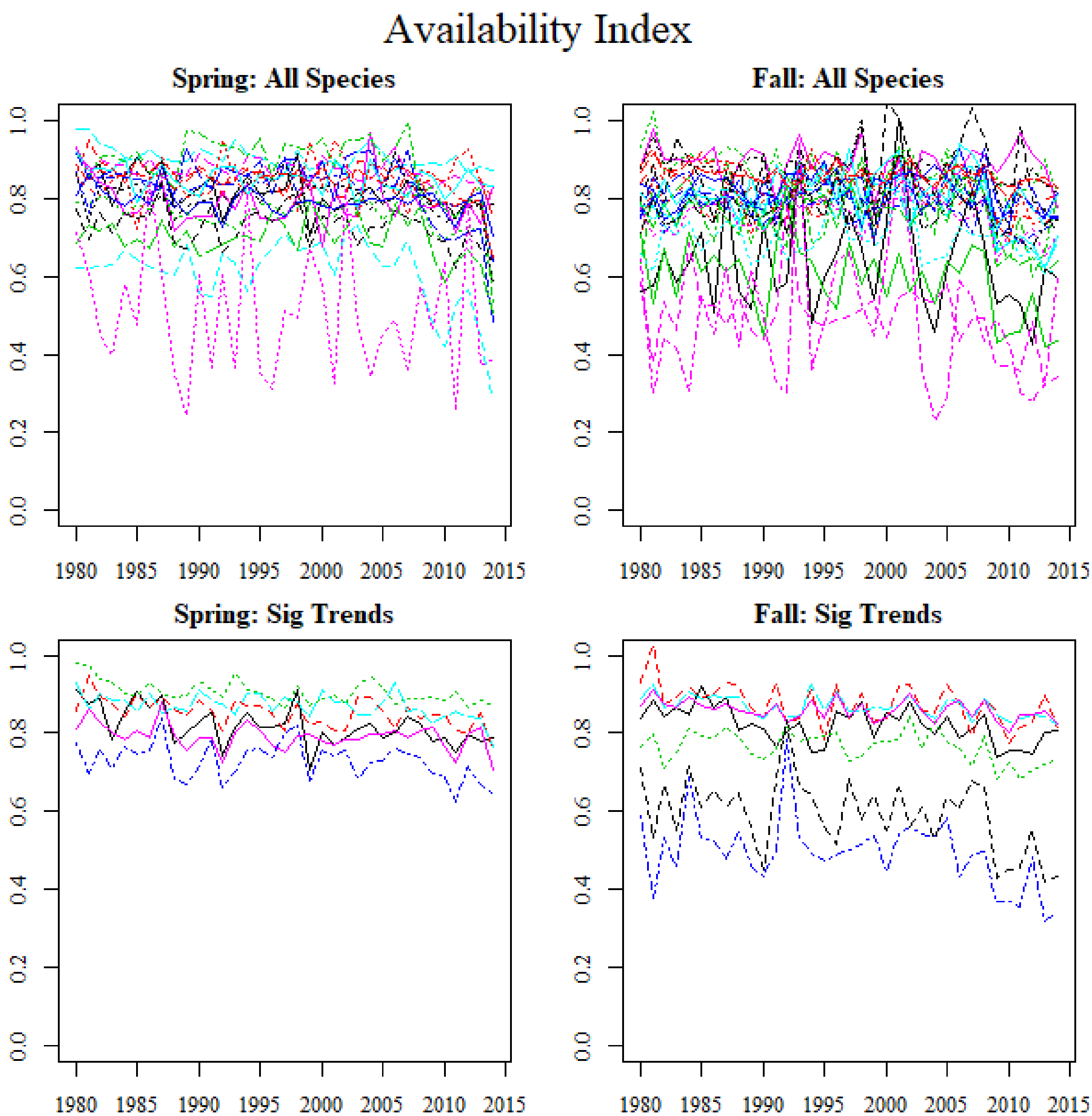

Figure 1. Availability for all species in the spring and fall. The availability index is a relative index that varies between zero and one. The values are not comparable between species, though the trends are. The two bottom plots display the indices in the spring and fall that had significant trends. All the significant trends were negative.

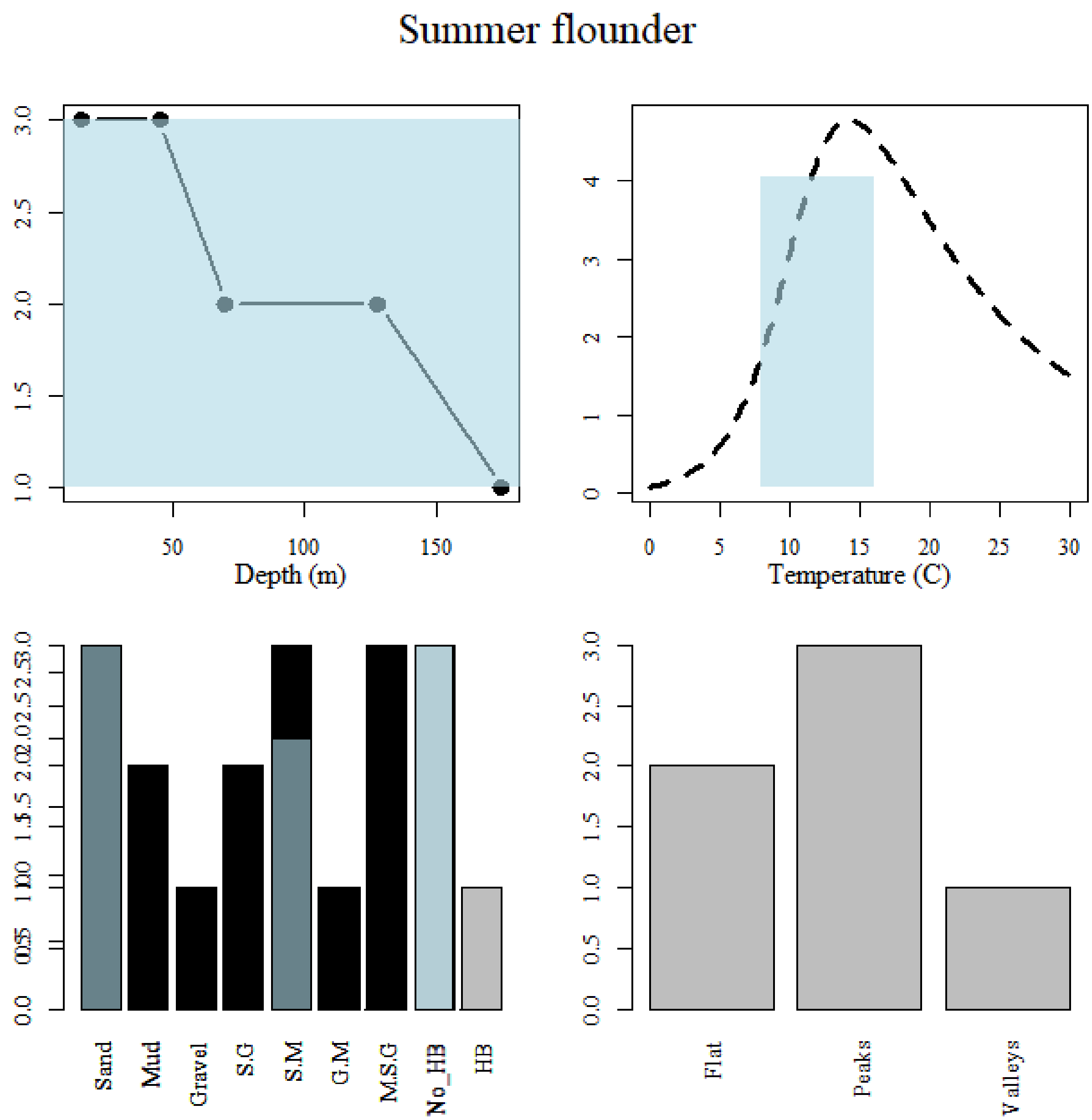

Figure 2. plots of habitat characteristics of Summer Flounder in the spring from the thermal-benthic habitat suitability index (HSI) overlaid with information from the Essential Fish Habitat documents (EFH). Summer Flounder are found over a wide depth range based on the EFH documentation (light blue), however, this study found the flatfish most prominent in shallow water with abundance decreasing with depth (black dots). EFH and the HSI both indicated similar temperature ranges and similar substrate characteristics. Summer Flounder are found predominantly on sandy substrates or sand mixed with mud or gravel or both. As expected, the species was not found on hard bottom (No HB). One of the focuses of this study was to also include the type of features where species are likely to be found. Summer Flounder are most commonly found on areas that are peaked or mounded along with flat areas. They are generally not found in valleys.

A github repository of relevant code, data samples, and links to a Jupyter notebook can be found at github.com/grievebr/COCA