Additional TOR 1: Butterfish Condition

Additional TOR 1: Describe life history characteristics and the stock's spatial distribution, including any changes over time. Describe ecosystem and other factors that may influence the stock's productivity and recruitment. Consider any strong influences and, if possible, integrate the results into the stock assessment.

Butterfish Condition:

Condition is an index of fish health, where fatter fish are generally healthier, and changes in condition can have direct implications for stock assessments, catch quotas and management, and may indirectly impact fish recruitment and mortality. Le Cren (1951) described relative condition (*Kn*), which reduces the bias of very small and large fish:

*Kn = W/W'*100*

Where *W* is the weight of an individual fish and *W'* is the relative length-specific mean weight for the population in a given region. For this work, length-weight coefficients from Wigley et al. (2003) were used to calculate *W'*. Individual fish weights were total body weights from Northeast Fisheries Science Center (NEFSC) fall bottom trawl surveys. Butterfish are generally summer spawners, and the fall survey was chosen to reduce variability of gonad weights in the spring survey as butterfish ramp up for spawning. *Kn* was averaged on a NEFSC bottom trawl strata resolution.

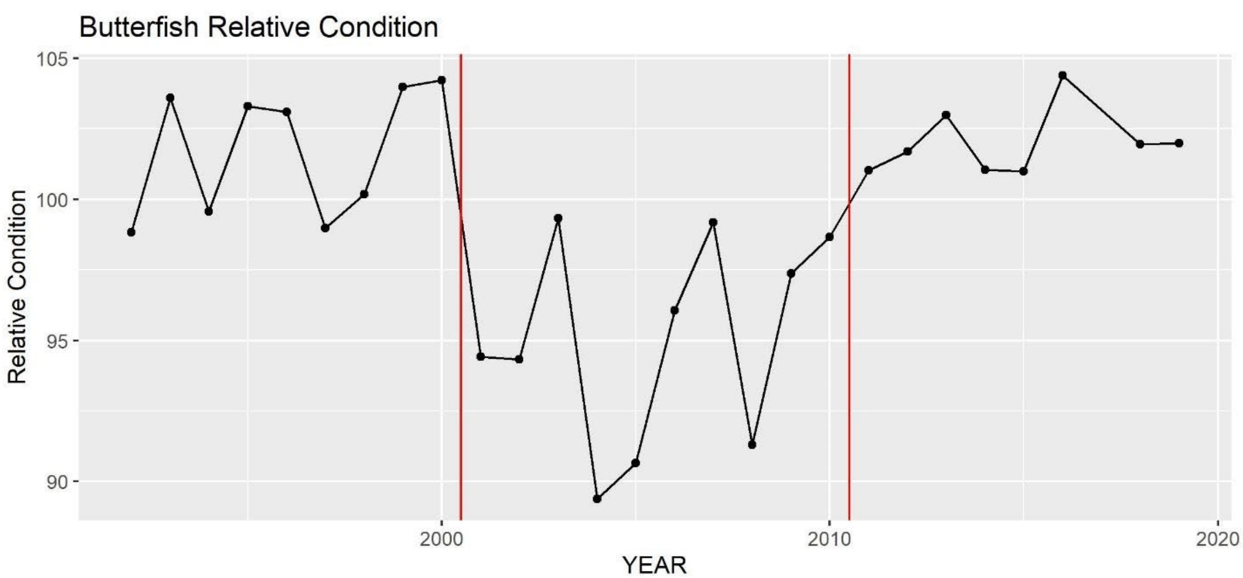

Figure 1. Butterfish relative condition over time, with significant change points (red lines).

Relative condition for butterfish was generally above average through 2000, was below average through 2010, and has since been above average (Figure 1). A similar pattern is seen for a number of other fish species in the Northeast US shelf region, although improved condition since 2009 has been inconsistent across species (Figure 2). Chronological clustering using multivariate regression trees were performed through the rpart package in R to test for change points. Significant change points for butterfish condition were found after 2000 and after 2010 (Figure 1). Similarly, Perretti et al. (2017) found a regime shift change after 2000, where the dominance of small bodied copepods during the 1990s corresponded to above average recruitment during that period, followed by low recruitment and dominance of large bodied copepods from 2000-2010. Perretti et al. (2017) included 18 commercially important species found on the Northeast US shelf, however butterfish was not included in the study. Friedland (2021) also found environmental links to recruitment, where haddock recruitment was significantly predicted by the magnitude of the fall phytoplankton bloom in the year before.

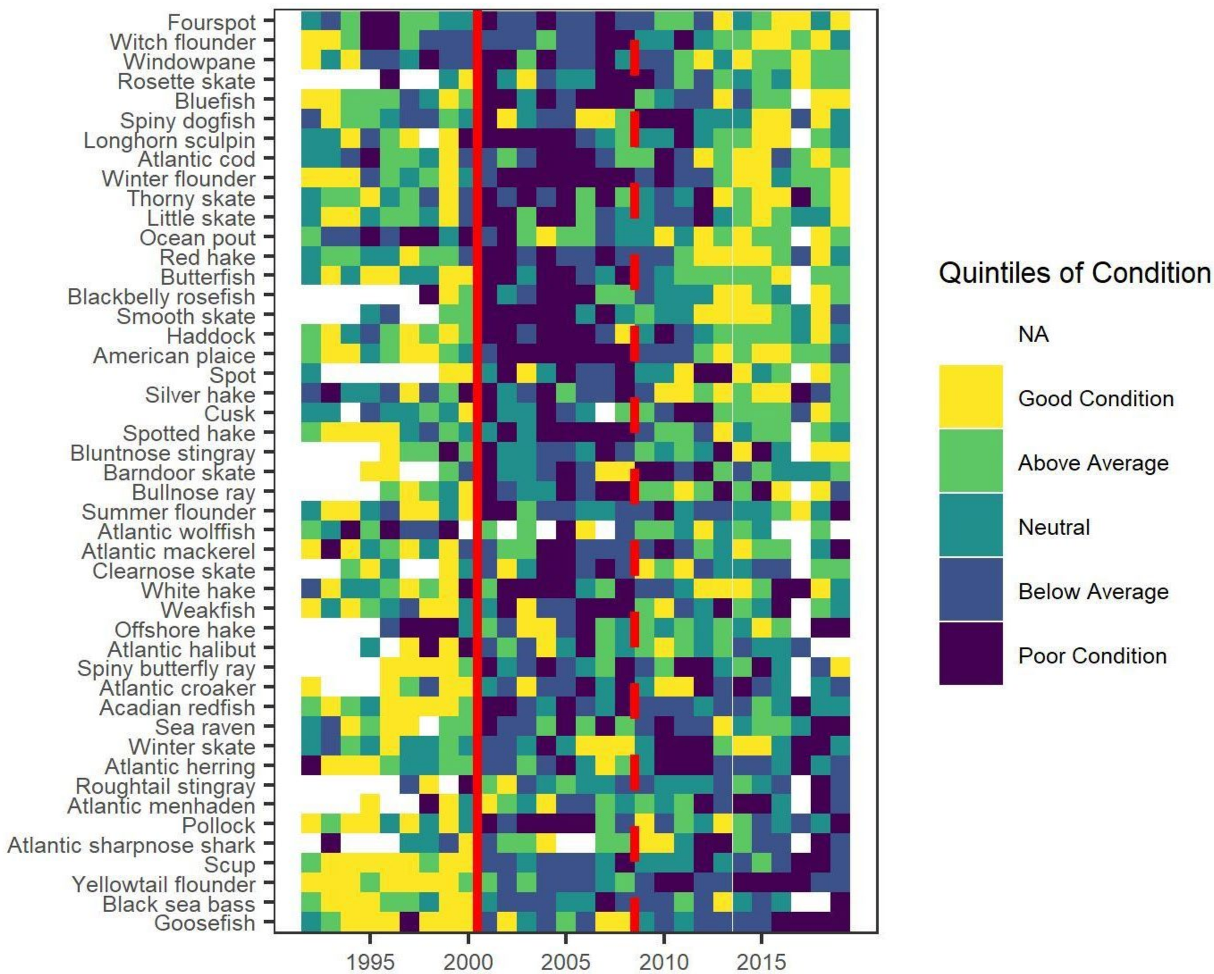

Figure 2. Relative fish condition in the Northeast US Continental Shelf region, with significant (red line) and non-significant change points (red dashed line) across all species.

General Additive Models of Butterfish Condition:

General Additive Models were run to predict butterfish condition based on environmental indices. The following categories of environmental indices were used for the full model, where the most informative index was selected within each category for the butterfish full model:

Kn ~ s(Local Environment) + s(Local Density) + s(Broad Environment) + s(Resource Quality) + s(Resource Availability) + s(Temporal Dependence) + s(Spatial Dependence)

The resulting butterfish full model is described below, with output shown in Figure 3:

Kn ~ s(Local bottom temp) + s(Local biomass) + s(Summer temp) + s(Copepod small/large) + s(Fall bloom magnitude) + s(Year) + s(Lat/Lon)

Where *Local bottom temp* was the average bottom temperature from the NEFSC fall bottom trawl survey, on a strata resolution. *Local biomass* was the average NEFSC fall survey butterfish weight per tow, on a strata resolution. *Summer temp* was the average bottom temperature anomaly during the summer NEFSC EcoMon survey, on an Ecological Production Unit (EPU) resolution (i.e. Gulf of Maine, Georges Bank, Southern New England/Mid-Atlantic regions). *Copepod small/large* index is the mean of the standardized small copepod anomalies minus the standardized anomaly of *Calanus* copepods, on an EPU resolution. This is a similar index of copepod size structure as used in Perretti et al. (2017). *Fall bloom magnitude* is the index of fall phytoplankton bloom magnitude, as described in Friedland (2021). *Year* and *Lat/Lon* are the year and geographic positions associated with the butterfish sample, and are included to account for temporal and spatial autocorrelation, respectively.

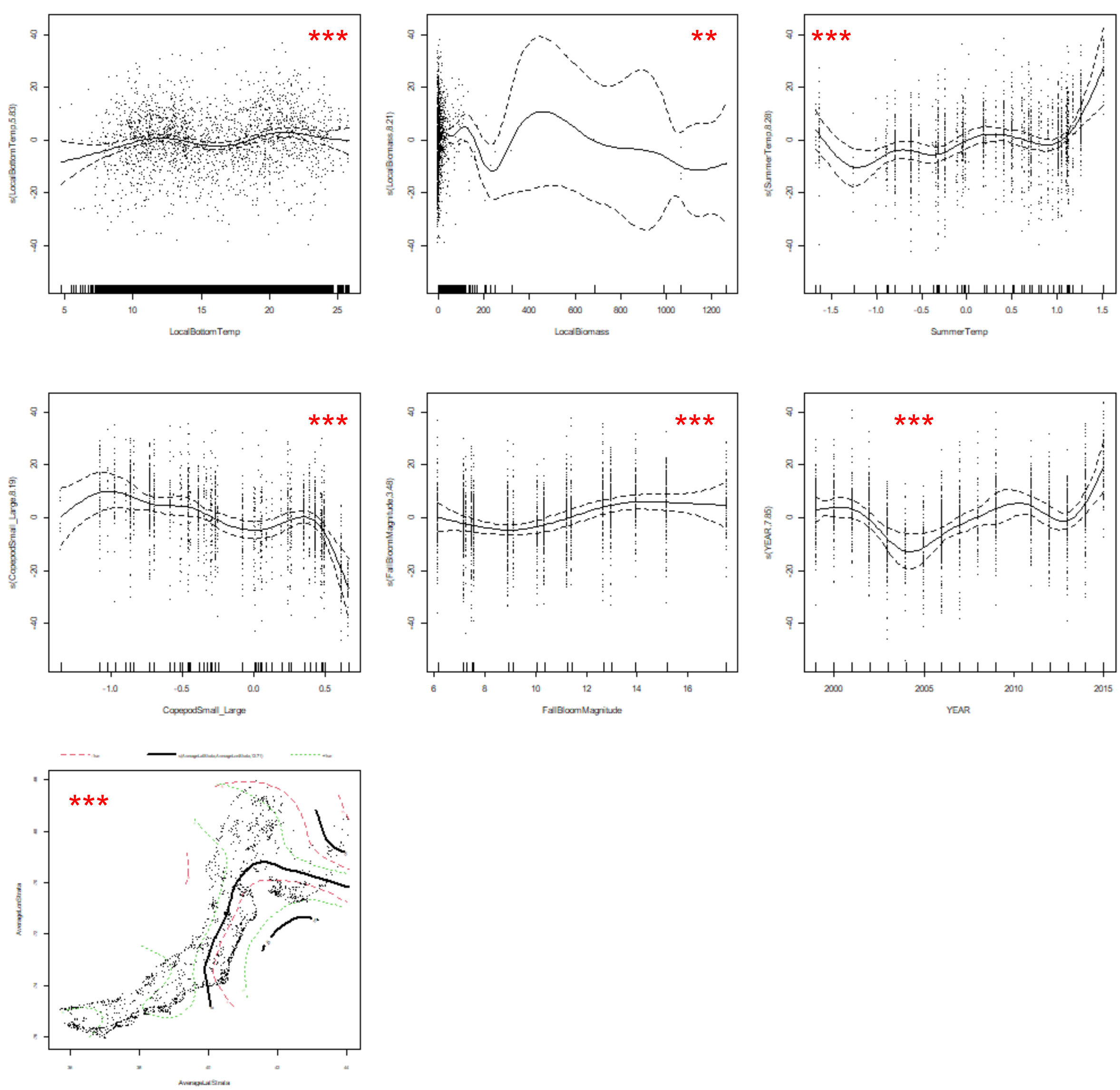

Figure 3. General Additive Model results predicting butterfish condition based on environmental indices. ** indicates $p < 0.005$, *** indicates $p < 0.001$.

Deviance explained for the full butterfish model was fairly low (24%), which is somewhat expected given that individual fish weights taken on NEFSC surveys include total fish weight. Therefore variability from stomach and gonad weights is not accounted for in the full model.

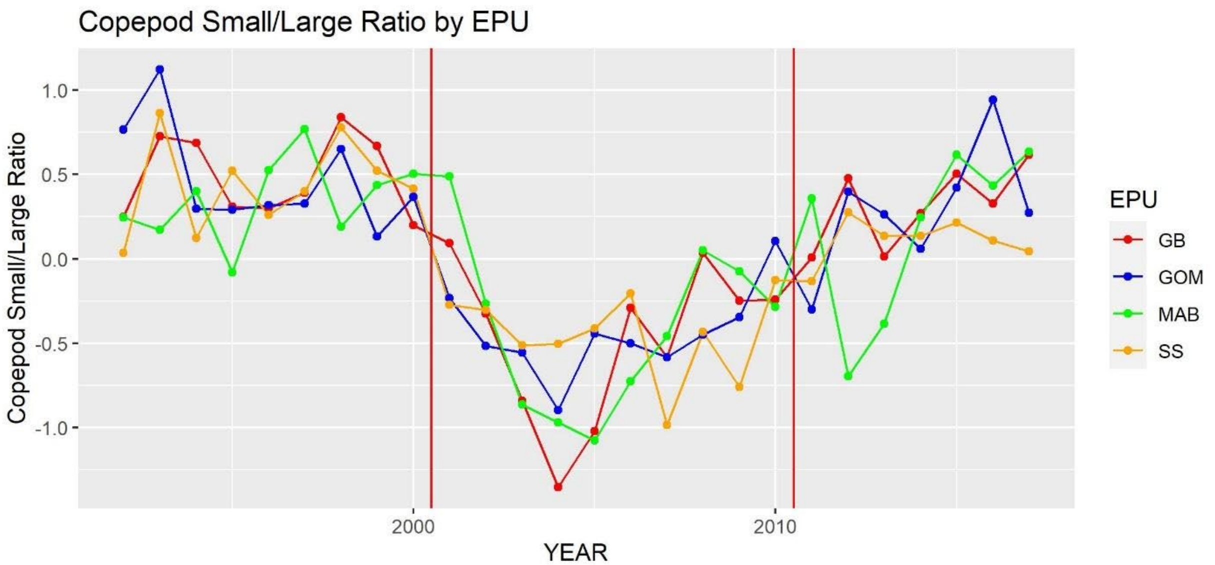

Figure 4. Copepod size structure index by EPU, with significant change points (red vertical lines).

Change points over time were also seen for the environmental drivers that significantly predicted butterfish condition (Figures 4-5), using the same multivariate regression tree analyses described above. Copepod small to large anomaly differences by EPU had the same 2000 and 2010 change points as butterfish condition (Figure 4). Butterfish may be directly affected by copepods since copepods are one of their food sources. However, the link between copepods and most fish species (regardless of diet), as seen in Peretti et al.'s 2017 paper indicates that it is more likely an index of system productivity and accessibility of this productivity to higher organisms in that season and year. Just like the transfer of energy from phytoplankton blooms to copepod blooms can occur within hours or weeks, the transfer from copepods to higher inverts, benthos and fish can occur quickly. The same trend was seen with small copepod dominance corresponding to high butterfish condition in the 1990s, as well as high fish recruitment during this time period as seen in Perretti et al.'s 2017 paper. This was followed by large copepod dominance, low butterfish condition and general low fish recruitment in the 2000s, and then small copepod dominance and high butterfish condition returning in the 2010s. This implies that there is a connection between copepod size structure and butterfish condition. Perretti et al.'s paper showed some improvements in fish recruitment in 2007 and small copepod dominance after 2010, but a change point was not detected likely due to the time series ending in 2014. Although butterfish recruitment was not directly tested, fish condition and fish recruitment both are linked to environmental changes including copepod size structure, and show the same trends relating to regime shifts. These results also suggest that the ecosystem entered a new regime that is likely favorable to butterfish health starting in 2011.

Similarly, a change point was seen in 2009 for the average summer bottom temperature index by EPU (Figure 5). Summer bottom temperatures shifted warmer starting in 2010 (Figure 5), followed by improved butterfish condition starting in 2011 (Figure 1). This implies that warmer water temperatures seen to date do not appear to be negatively impacting butterfish health, and may currently be benefiting butterfish.

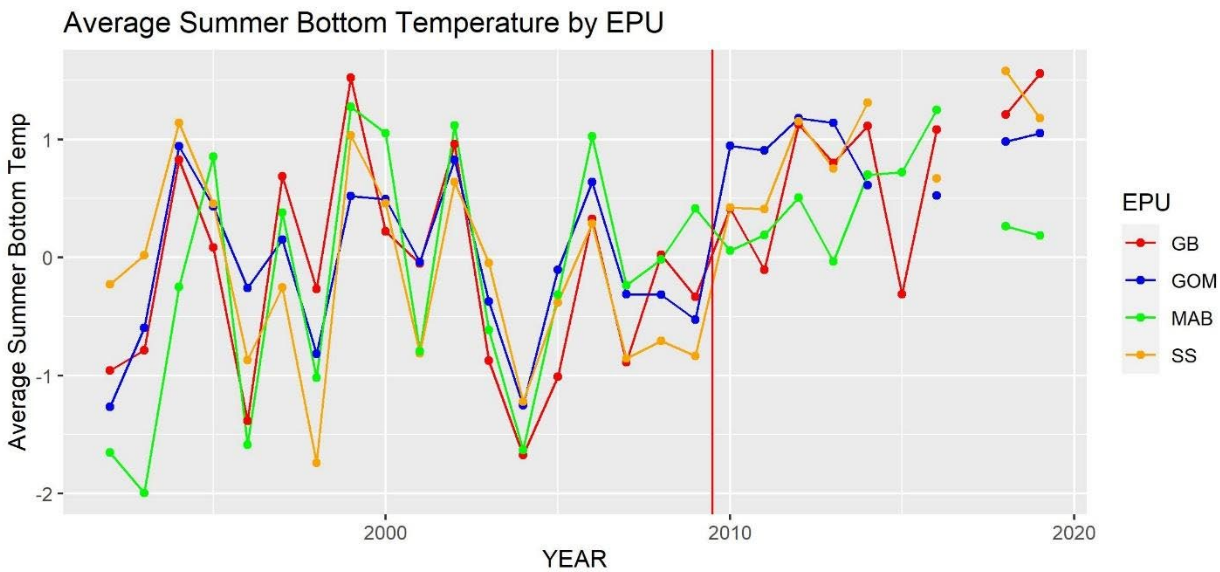

Figure 5. Average summer bottom temperature anomaly by EPU, with significant change point (red vertical line).

References:

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