Ecosystem Considerations for the 2017 Groundfish Operational Assessment

Executive Summary

This report provides ecosystem considerations for the 2017 Groundfish Operational Assessment stocks. These stocks are affected by environmental forcing factors and trophic interactions in addition to fishing. The data presented here are provided as qualitative information to help provide context on stock status for management consideration, specifically as information that can be incorporated into Term of Reference 8: "…include qualitative written statements about the condition of the stock that will help to inform NOAA Fisheries about stock status." Indicator variables are presented in a risk analysis framework and summarized with respect to the vulnerability of each species and probable response (favorable, unfavorable, neutral or unknown) to the current status of that indicator.

Our main findings are:

- Only 8 of the Operational Assessment stocks have a low overall climate vulnerability. 7 of the stocks have at least a high overall climate vulnerability (Gulf of Maine, Georges Bank, and Southern New England/Mid-Atlantic winter flounder stocks, witch flounder, Atlantic halibut, ocean pout, and Atlantic wolfish, (Figure 13).
- Mean fall bottom temperatures have increased in the Gulf of Maine and on Georges Bank. This temperature increase is expected to have highly negative impacts on Georges Bank cod and Georges Bank haddock. Negative impacts are also expected for Gulf of Maine cod, Gulf of Maine haddock, Georges Bank yellowtail, Southern New England/Mid-Atlantic yellowtail, and Atlantic halibut (Figure 14).
- Sea surface temperature (SST) has increased over the Northeast US Shelf. This increase is expected to have highly negative impacts on the 7 stocks which have a high overall climate vulnerability and negative impacts on 5 other stocks (Figure 14).
- In recent years, warm thermal habitats have increased and cool thermal habitats have decreased. These changes are expected to have highly negative impacts on 8 stocks (GB & GM cod, GB & GM haddock, American plaice, Atlantic halibut, pollock and Acadian redfish) and negative impacts on a further 9 stocks (Figure 14).
- Recent distribution changes show a general movement of species to the northeast and into deeper waters. This may have slightly negative effects on ocean pout and Atlantic wolffish, and negative effects on the rest of the Operational Assessment stocks (Figure 14).
- Experimental habitat modeling work indicates positive population trends for GB & GM haddock, American plaice, and Acadian redfish, and highly negative trends for ocean pout (Figure 14). This analysis is largely driven by recent distributions and abundance estimates from the NEFSC survey data, and implies that the biomass of some species (e.g. haddock) may not be influenced by the current unfavorable temperatures.
- One indication of health is a fish condition index, which is currently highly positive for 4 stocks (GM haddock, American plaice, Northern windowpane, and ocean pout) with another 4 stocks being positive. 6 stocks are currently below average, but none are highly negative in the most recent year (Figure 14).
- Three-year productivity, expressed as a ratio of small fish abundance to large fish biomass, is highly positive for 2 stocks (GB haddock and GM winter flounder) and highly negative for 8 stocks (GB & GM cod, all three yellowtail stocks, GB winter flounder, pollock and Acadian redfish, Figure 14).

- We also summarize the current status of indices that we recommend to be explored further in research track assessments. These include predation, habitat, and the effect of the fall bloom on Operational Assessment stocks.

For more information on the historical spatial distributions of these and other species, visit: https://www.nefsc.noaa.gov/ecosys/spatial-analyses/
And for projected future species spatial distributions, visit: https://www.nefsc.noaa.gov/ecosys/climate-change/projected-thermal-habitat/
For a more comprehensive overview of current conditions, refer to the Ecosystem Status Report for the Northeast Large Marine Ecosystem: https://www.nefsc.noaa.gov/ecosys/ecosystem-status-report/ and the State of the Ecosystem – Gulf of Maine and Georges Bank: http://s3.amazonaws.com/nefmc.org/2_2016-State-of-the-Ecosystem-Report.pdf.

Climate Vulnerability

Although fishing remains the dominant driver of population abundance for most stocks, there is increasing evidence that climate change and decadal variability affect fish (Bell at al. 2014, Fogarty et al. 2008, Hare and Able 2007, Perry et al. 2005, Pinsky and Fogarty 2012). Hare et al. (2016) assessed both the environmental variables that are expected to change which could impact species (climate exposure) and the species intrinsic sensitivity to change (biological sensitivity) in the Northeast fish and shellfish climate vulnerability assessment (Figure 1). Winter flounder stood out as having very high climate exposure as well as high biological sensitivity, indicating that this species could be most negatively impacted by climate change (Figure 1). Atlantic halibut, ocean pout, Atlantic wolffish and witch flounder also had high biological sensitivity, and all species in the Operational Assessment had at least high climate exposure (Figure 1).

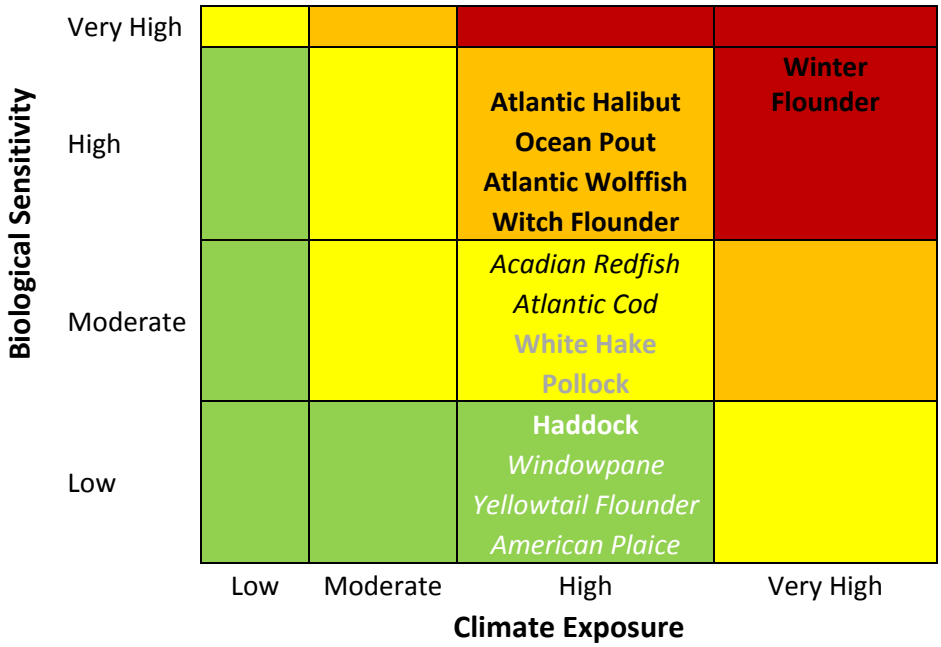

Figure 1. Overall climate vulnerability score denoted by color: low (green), moderate (yellow), high (orange), and very high (red). Certainty in score is denoted by text font and color: very high certainty

(>95%, black, bold font), high certainty (90-95%, black, italic font), moderate certainty (66-90%, white or gray, bold font), low certainty (<66%, white or gray, italic font) (Hare et al. 2016).

Many groundfish stocks on the Northeast U.S. shelf have shown distribution changes in response to climate and population changes (Nye et al. 2009). Most stocks in the Operational Assessment have life history attributes that suggest a high potential for distribution changes (Figure 2, Hare et al. 2016). Only ocean pout and Atlantic wolffish were determined to have a moderate potential for distribution changes (Figure 2).

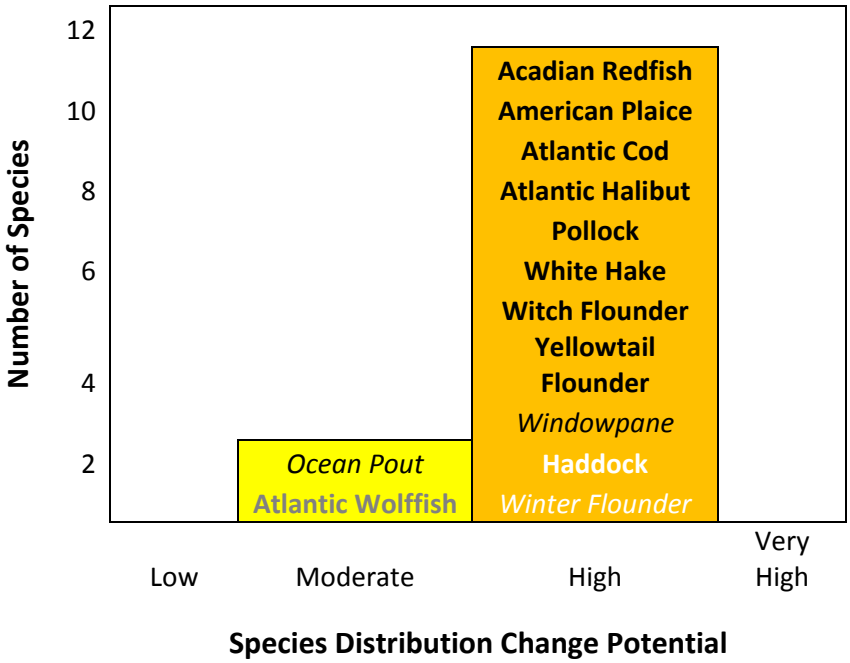

Figure 2. Potential for a change in species distribution denoted by color: low (green), moderate (yellow), high (orange), and very high (red). Certainty in score is denoted by text font and color: very high certainty (>95%, black, bold font), high certainty (90-95%, black, italic font), moderate certainty (66-90%, white or gray, bold font), low certainty (<66%, white or gray, italic font) (Hare et al. 2016).

Hare et al. (2016) determined that most Operational Assessment groundfish species would experience a negative effect from climate change due to decreased productivity or shifts out of the region (Figure 3). Windowpane flounder is the only species that was determined to have a neutral effect from climate change.

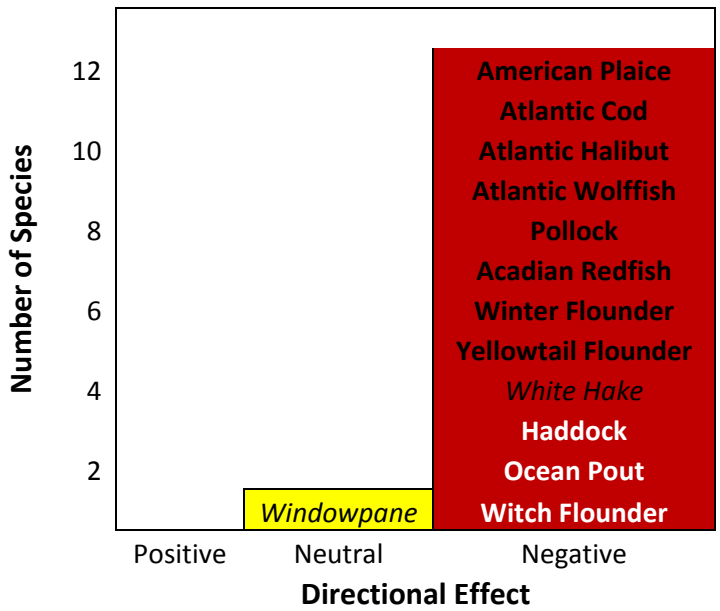

Figure 3. Directional effect of climate change denoted by color: positive (green), neutral (yellow), negative (red). Certainty in score is denoted by text font and color: very high certainty (>95%, black, bold font), high certainty (90-95%, black, italic font), moderate certainty (66-90%, white or gray, bold font), low certainty (<66%, white or gray, italic font) (Hare et al. 2016).

Temperature

The thermal conditions at the bottom of the water column are extremely important in defining the habitats for the majority of resource species. Unlike sea surface temperatures that can be measured synoptically with satellite telemetry, bottom temperatures must be measured directly from ship surveys and other means. Thus, we often have incomplete spatial and temporal sample coverage to describe bottom temperature conditions. Recently, scientists at the NEFSC developed an interpolation approach that provides a more accurate depiction of spring and fall bottom temperatures. Bottom temperatures from the survey are corrected for date of collection to a standard date in April for the spring survey time frame and in October for fall. From these standardized data, a mean temperature anomaly field is developed, which represents the long term average of bottom temperature. The data for an individual survey is then used as the basis of the annual bottom temperature field after it is mathematically combined with the mean field. The time series of April (Figure 4a&b, panel A) bottom temperature in the Gulf of Maine and Georges Bank suggest no trend over time, whereas the October (Figures 4b, Panel B) temperatures steadily increased over the past half century to historic highs in both regions for 2016 (Figure 4). Species that are at the southern end of their range such as Atlantic cod can be particularly vulnerable to increases in bottom temperature (Drinkwater 2005).

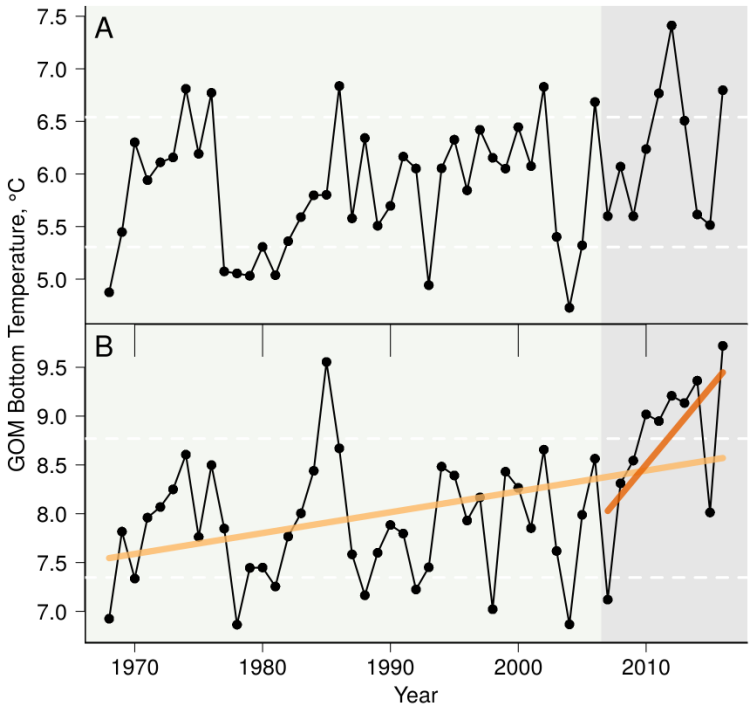

Figure 4a. Bottom temperatures from NEFSC bottom trawl surveys in the Gulf of Maine standardized to a date in April (A) and October (B).

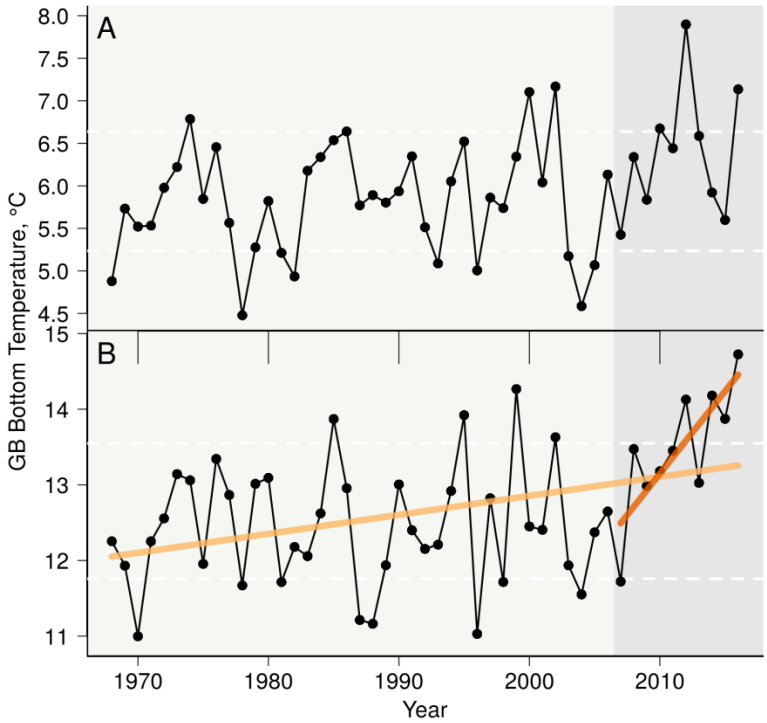

Figure 4b. Bottom temperatures from NEFSC bottom trawl surveys on Georges Bank standardized to a date in April (A) and October (B).

Table 1. Thermal ranges and preferred temperatures for Operational Assessment species from literature. The current Georges Bank mean fall temperature (14.7 degrees C) or Gulf of Maine mean fall temperature (9.7 degrees C) in 2016 exceeds preferred temperature ranges in orange cells and exceeds thermal ranges in red cells. Yellow cells are stocks that span the Georges Bank and Gulf of Maine regions, and have thermal preferences below the average of the Georges Bank and Gulf of Maine mean fall bottom temperatures.

	Thermal Range in Literature			Preferred Temperature	
Species	min	max	Ref	min	max
GM cod*	0	13	1	2	9
GB cod*	0	13	1	2	9
GM haddock	0	13	2	4	7
GB haddock	0	13	2	4	7
CCGM yellowtail	2	17	3	5	12
GB yellowtail	2	17	3	5	12
SNEMA yellowtail	2	17	3	5	12
GM winter fl	0.6	23	4	12	15
GB winter fl	0.6	23	4	12	15
SNEMA winter fl	0.6	23	4	12	15
American Plaice	-0.5	13	5	1	4
Witch flounder	-0.6	16	6	4	11
Halibut	-0.5	13.6	7	3	9
Pollock	0	14	8	6	10
Redfish	4	13	9	5	10
N windowpane	0	24	10	4	19
S windowpane	0	24	10	4	19
Ocean Pout	3	14	11	2	10
White hake*	5	14	12	5	10
Wolffish					

1 (Lough 2004), 2 (Brodziak 2005), 3 (Johnson *et al.* 1999), 4 (Pereirra *et al.* 1999), 5 (Johnson 2005), 6 (Cargnelli *et al.* 1999a), 7 (Cargnelli *et al.* 1999b), 8 (Cargnelli *et al.* 1999c), 9 (Pikanowski *et al.* 1999), 10 (Chang *et al.* 1999a), 11 (Steimle *et al.* 1999), 12 (Chang *et al.* 1999b).
*Preferred temperatures from Species Distribution Model in Selden *et al.* 2017.

Thermal ranges from the literature have been reported in Essential Fish Habitat reports (Table 1). The 2016 mean fall bottom temperatures of 14.7 degrees C on Georges Bank and 9.7 degrees C in the Gulf of Maine were compared to the thermal ranges and preferred temperatures according to stock region. The current mean bottom temperatures exceeded the preferred temperature ranges for Atlantic cod, haddock, GB and SNEMA yellowtail, and Atlantic halibut, potentially exerting a negative impact of temperature on these stocks (Table 1). Additionally, the thermal ranges reported in the literature for Georges Bank cod and Georges Bank haddock were exceeded by the 2016 Georges Bank mean fall bottom temperature (Table 1), potentially exerting a highly negative impact on these stocks. For stocks

that spanned the Georges Bank and Gulf of Maine regions, the average of the Georges Bank and Gulf of Maine mean bottom temperatures were compared to the thermal ranges and preferred temperatures, and although more uncertain, there may at least be a slight negative impact of preferred temperature ranges being exceeded for American plaice, witch flounder, ocean pout and white hake (Table 1). Note that there is no Essential Fish Habitat report for Atlantic wolffish.

Long-term temperature data records for the Northeast Shelf Ecosystem show a significant increase in sea surface temperature since the 1850s and a dramatic increase in temperature over the most recent decade (Figure 5). This depiction of thermal conditions is based on the Extended Reconstructed Sea Surface Temperature (ERSST) dataset that includes temperature records back to 1854. The Northeast Shelf Ecosystem was at a record high SST in 2012, the 2016 annual mean level was among the highest values in the time series.

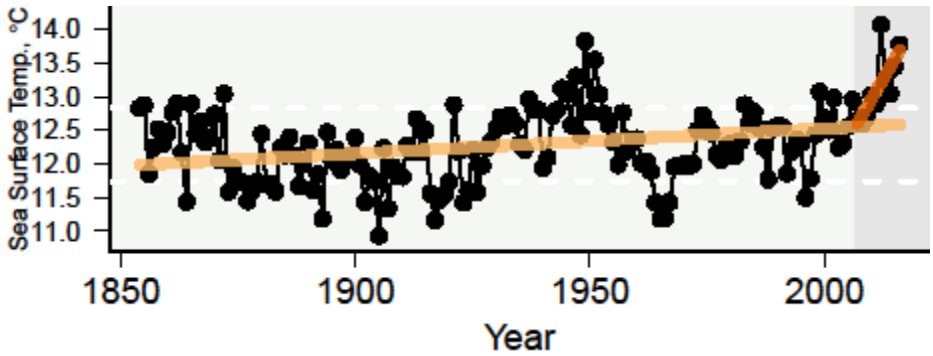

Figure 5. Extended Reconstructed Sea Surface Temperature (ERSST) for the Northeast Shelf Ecosystem.

Climate change involves not only the change in level of climate parameters, it also involves change in system variability that can be seen in more dramatic shifts in weather in terrestrial systems and in ocean parameters on the Northeast Shelf. In an examination of daily sea surface temperatures in the Gulf of Maine (A) and Georges Bank (B), system variability has increased as evidenced by the increase in the annual standard deviation of sea surface temperature, going from approximately 4.0 to 5.0 over the time period, indicating organisms have experienced greater day to day temperature excursions (Figure 6).

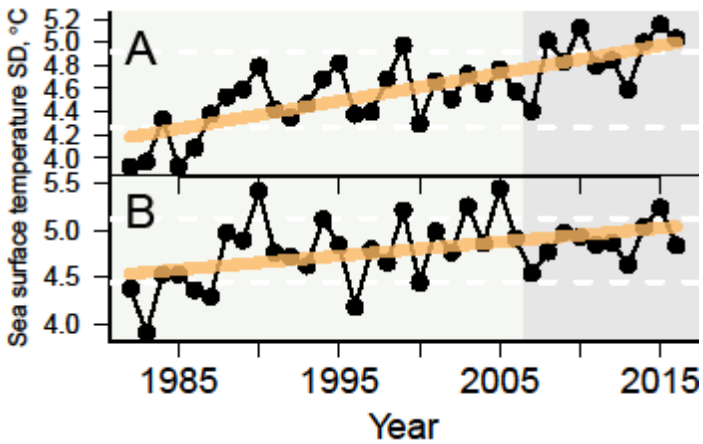

Figure 6. Standard deviation of sea surface temperature on the Northeast Shelf, Gulf of Maine (A) and Georges Bank (B).

The combination of warming thermal conditions with increased variability of sea surface temperature (Figure 6) may be particularly difficult for certain species to adapt to. The vulnerability assessment indicates that all of the groundfish species are likely to be negatively impacted by this kind of environmental perturbation, except windowpane flounder which may have a more neutral response (Figure 3). In an effort to categorize these impacts on the stocks, we suggest scaling up the overall climate vulnerability score (Figure 1) by one level for each stock except for windowpane flounder to reflect the likely neutral (for windowpane) and slightly negative to highly negative impacts of this environmental shift on the groundfish species.

Temperature Habitats

Thermal conditions have the potential to affect the behavior and physiology of marine organisms through growth, reproduction, and survival (Neuheimer et al. 2011). Additionally, Selden et al. (2017) found that both historical and projected future warming reduced the spatial overlap of Atlantic cod with its prey and reduced cod's ability to exert top-down control on prey. Hence, it is one of the more important factors defining the extent of fish and shellfish habitat on the Northeast Shelf. One way of characterizing the thermal habitat for fishes is through the summation of the area of the shelf within specific thermal ranges. The reasoning applied is that as these areas expand and contract they would be variously limiting for a range of species with differing thermal requirements. The shelf ecosystem can be divided into three thermal ranges. The area of cold water habitats (1-4°C) show no time series trend despite extremely low values in recent years (Figure 7). Cold water habitats in 2016 were approximately 5,000 km^2 (2016 value marked over the time series with dashed red line, linear trend shown with blue line, regression model significance shown in upper left). Cool water habitats (5-15°C) show a negative trend over time declining on the order of 531 km^2 yr^{-1}, which is matched by a corresponding increase in warm water habitats (16-27°C) at a rate of 545 km^2 yr^{-1} (Figure 7).

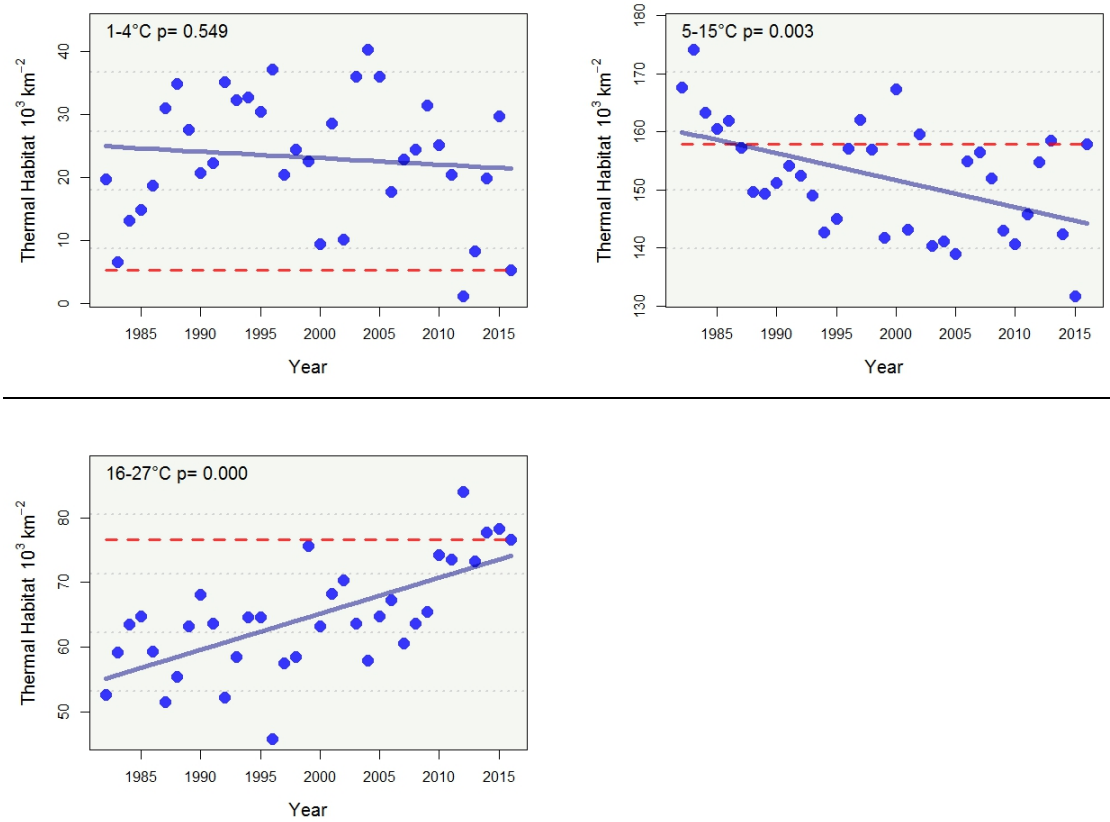

Figure 7. Thermal habitats as the summation of area on the shelf with specified temperature ranges.

All Operational Assessment species had preferred temperature ranges that were lower than the currently increasing warm water habitat of 16-27 degrees C, except for windowpane flounder (Table 1). Whereas all Operational Assessment species had preferred temperature ranges that included the currently decreasing cool water habitat of 5-15 degrees C (Table 1). Additionally, reported thermal ranges from the literature for Atlantic cod, haddock, American plaice, Atlantic halibut, pollock, Acadian redfish, ocean pout and white hake did not include the warm water habitat (Table 1). These reductions of habitat could be causing spatial contraction of ranges as well as negative impacts to the health of these species. We therefore suggest that windowpane flounder may have a neutral response to shifts in temperature habitats, whereas stocks whose thermal ranges were lower than the warm habitat may have highly negative impacts and stocks with preferred temperature ranges below the warm habitat may have negative impacts.

Habitat Models

Random forest habitat models using both static and dynamics variables have been developed for many of the resource species on the Northeast Shelf. These models estimate spring and fall habitat for the time series 1992 to 2016 reflecting the use of the ecosystem based on the biomass and distribution of each species from the NEFSC bottom trawl survey. The variables evaluated for use in these models included station salinity, station temperature, benthic complexity, satellite derived chlorophyll concentration and sea surface temperature, the gradient magnitude (front structure) of the satellite

data, and zooplankton bio-volume and taxa abundance with station depth included in all models. The random forest approach differentiates variables with strong predictive power and was used to reduce the variable set to 11 variables for each species. The models were used to estimate spring and fall habitat scores over the entire shelf over the time series. From these estimates, a swept area estimate (SAE) of species abundance was developed for species based on 10 habitat intervals where SAE is the sum of the products of habitat in each interval (km^2) times the biomass CPUE in that interval (Figure 8). This initial analysis has been done on a species basis, which makes interpretation difficult for multi-stock species. Additionally, some stocks exclude certain survey seasons in the assessment due to availability issues. Further collaborative work needs to be completed to address these considerations and decide whether the habitat scores and corresponding SAE would be relevant on a stock basis.

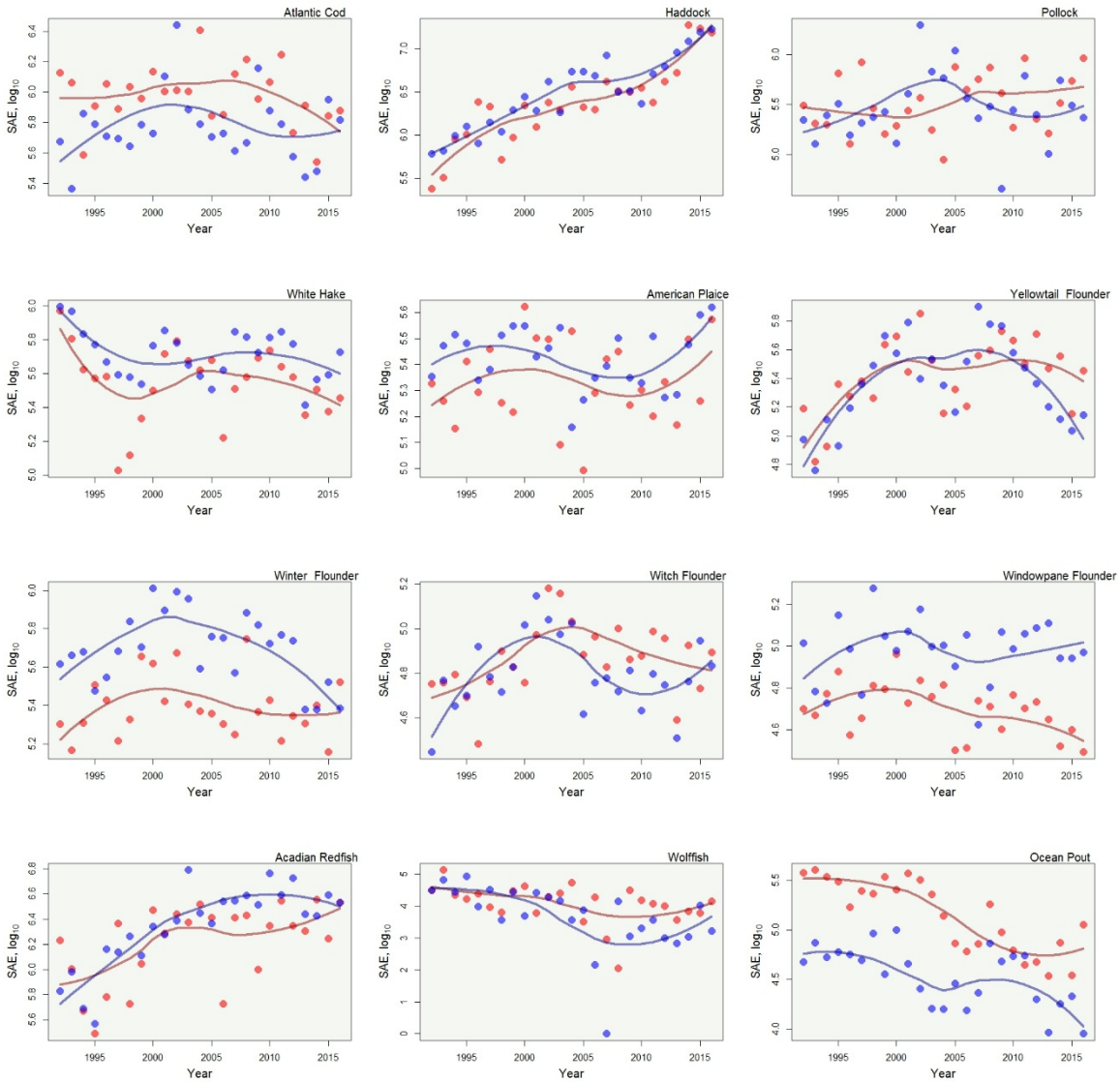

Figure 8. Swept area estimate (SAE) of species abundance based on 10 habitat intervals. SAE is the sum of the products of habitat in each interval (km^2) times the biomass CPUE in that interval. Spring time series in red and fall in blue. Line is loess smoother with span=0.8.

Most species show a concordance between spring and fall SAE estimates. The most dramatic increases in abundance appear in the time series of haddock and Acadian redfish SAE, as well as American plaice in recent years. Ocean pout has the strongest negative trend in SAE over time, whereas white hake, yellowtail flounder, winter flounder, and windowpane flounder have at least slightly negative trends in at least one season. Atlantic cod, pollock, witch flounder and Atlantic wolffish have neutral trends over time.

Distribution Shifts

The species of the Northeast Shelf ecosystem have shown changes in distribution over recent decades (Kleisner et al 2016, Nye et al 2009). Individual species have shifted distribution due to a number of reasons and these shifts can be characterized in a number of different ways. Two metrics that have been used to characterize distribution on the NE Shelf include: 1) the position in the ecosystem along an axis oriented from the southwest to the northeast referred to as the along shelf distance; and, 2) the depth of occurrence. Along shelf distances range from 0 to 1360, which relates to positions along the axis from the origin in southwest to northeast in kilometer units. Depth ranges from 0 to -260, which relates to depth of occurrence in meters. The mean along shelf distance and depth of occurrence for all species by year are shown (Figure 10). As a group, these species had an along shelf distance of approximately 870 km during the time period 1968-2016, they now have a distance of over 930 km. For most of the time series, the species averaged a depth of 100 m, they now average approximately 113 m. In general, the operational assessment species inhabit a more northern distribution and deeper depths than this larger subset of species, but show the same temporal pattern of recent shifts further to the north and into deeper waters.

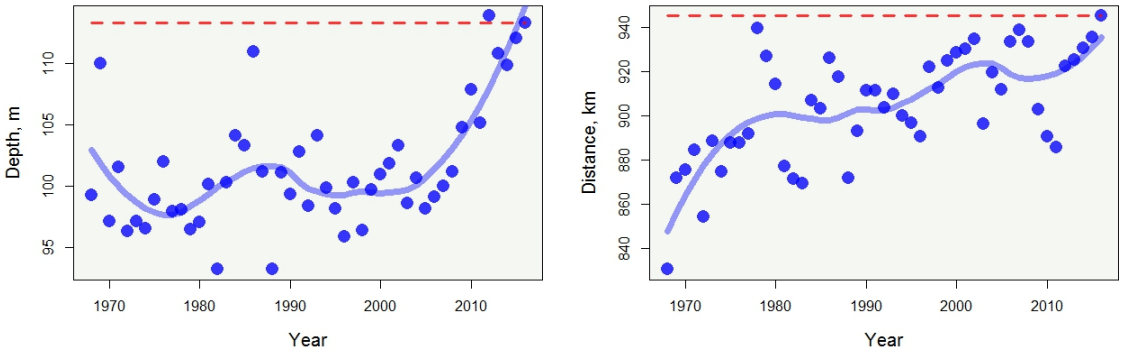

Figure 10. The mean depth and along shelf distance for all species by year. The 2016 values are marked with a dashed red line.

Based on the vulnerability to distribution changes (Figure 2), ocean pout and Atlantic wolffish may have slightly negative impacts from these changes, and all other Operational Assessment stocks may have negative impacts.

Condition

Condition is related to health and reproductive potential of fish (Peig and Green 2009). Changes in fish weight can be due to fishing pressure, prey availability, competition or other environmental changes. A

reference length-weight relationship was used to calculate anomalies of fish weight for a given length, and this relative weight was used as an index of condition. Trends in condition were analyzed for 40 finfish stocks caught on the NEFSC autumn bottom trawl survey during 1992-2016, and genders were analyzed separately for species with sexually dimorphic growth rates. 50% of the stocks declined in weight over the time series, whereas only 22% increased in weight.

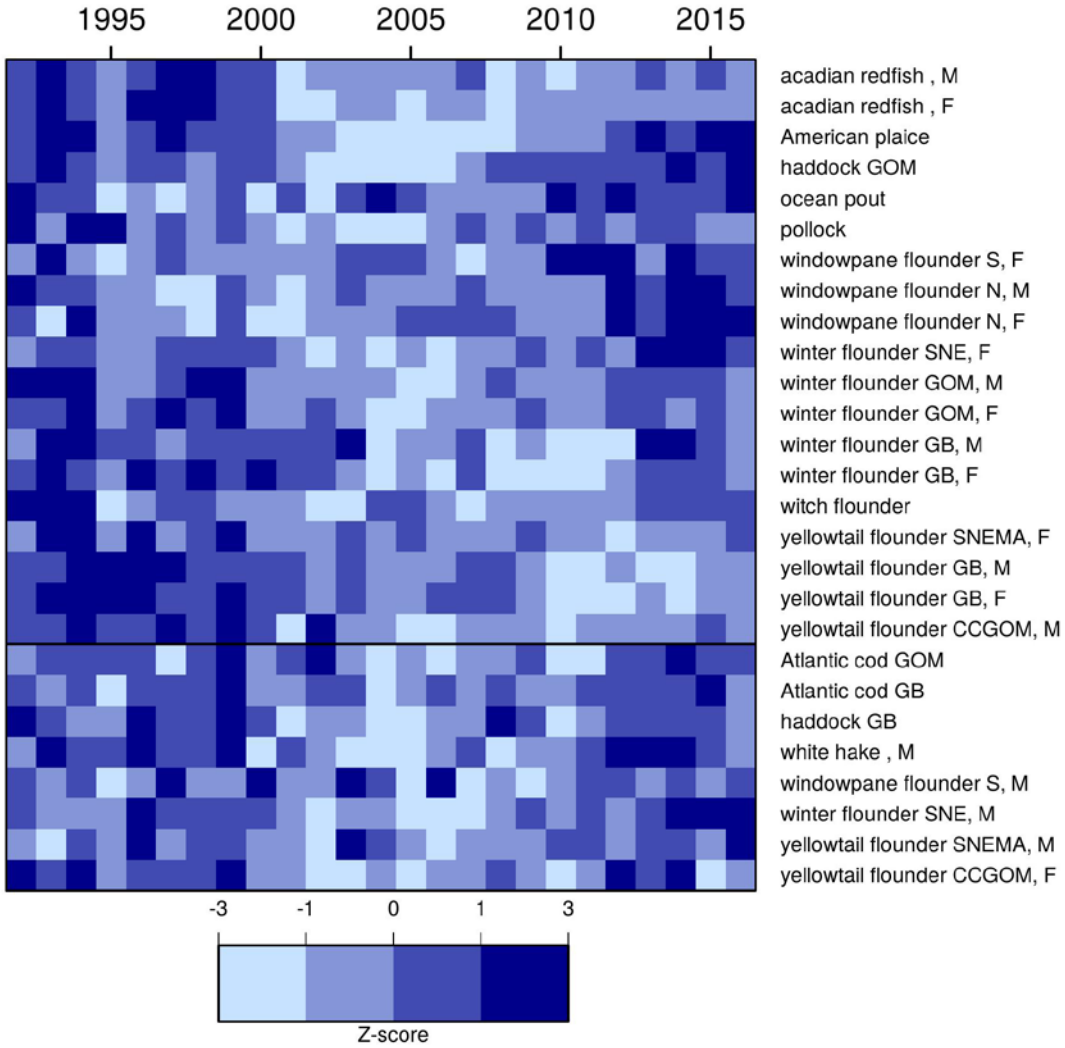

Figure 11. Condition index anomalies for Operational Assessment stocks. Stocks that have changed significantly over time are above the black line and stocks that have not changed significantly over time are below the line.

Condition declined for many Operational Assessment stocks during the 2000s, but has improved again for most species since 2012. American plaice, GOM haddock, ocean pout, Northern and Southern windowpane flounder, SNE winter flounder, witch flounder, and SNEMA yellowtail flounder all have positive condition anomalies in the current year, indicating positive or highly positive impacts on these stocks. Despite recent increases in condition, Acadian redfish, pollock, GOM and GB winter flounder, and GB and CCGOM yellowtail still have negative condition anomalies, indicating that this may have negative impacts on the stocks. No stocks currently have z-scores of condition anomalies that are more than 1

standard deviation below the mean. No significant changes were seen for the stocks and sexes below the line on Figure 11, although similar non-linear patterns of decline and recovery are apparent. Data were too sparse to perform the condition analyses for Atlantic halibut or Atlantic wolffish.

Productivity

Stock productivity was estimated using the NEFSC spring and fall bottom trawl survey data. Productivity for year t (P_t) is defined as the abundance of age-1 fish in year $t+1$ ($A1_{t+1}$) divided by the biomass of age-2+ fish in year t ($B2+_t$), i.e., $P_t = A1_{t+1} / B2+_t$. Age-1 fish were identified as those with length less than the expected length of an age-2 fish, where expected length-at-age was estimated using a generalized linear model. Individual biomass was calculated using length–weight relationships estimated from the survey data following Wigley et al. (2003). Abundance-at-length selectivity conversions from Albatross to Henry Bigelow were applied following Miller (2013). Detailed methods can be found in Perretti et al. (2017).

For species with unit stocks, productivity was calculated over the entire NEFSC survey area. For species with regional stocks, the EPU that most closely matched the area of the stock was used to calculate productivity. The z-score of the fall and spring productivity for each species was then calculated, and the two indices were averaged to create an annual index of productivity.

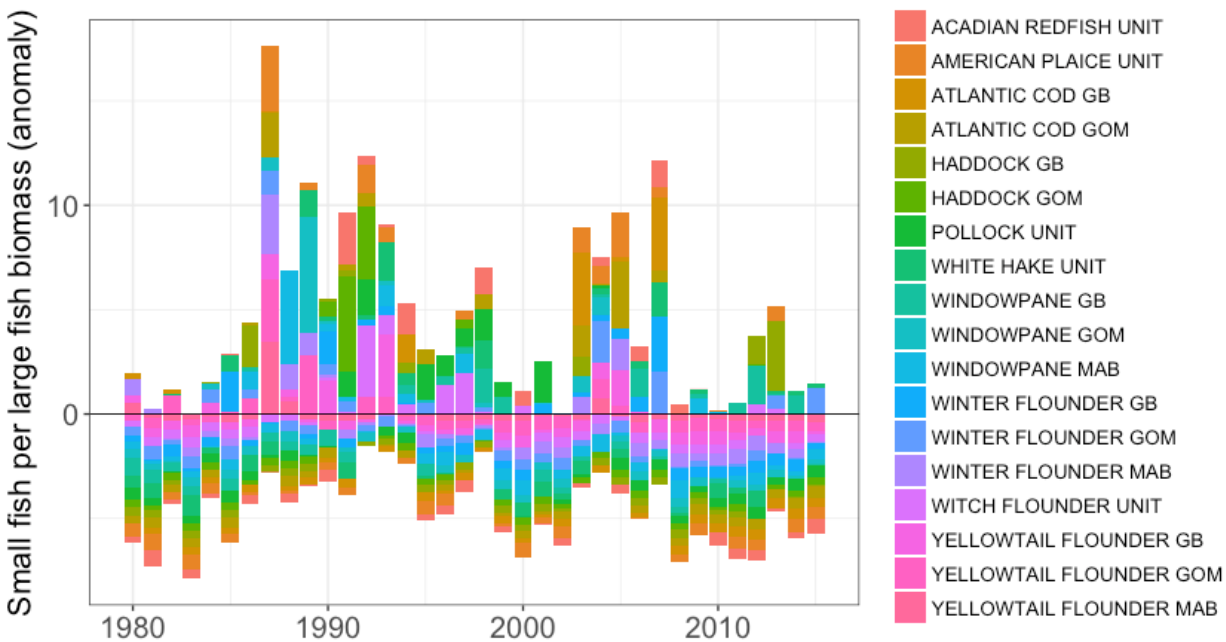

Figure 12: Fish productivity: Anomalies of age-1 fish abundance per age 2+ fish biomass, 1980-2015. Annual anomalies shown are the average of spring and fall anomalies.

Classification of recent productivity (ending in 2015) for each species (Figure 14) was estimated by comparing the most recent three year mean productivity anomaly to all historical three year means. Color classifications were assigned based on the quartile in which the most recent three year mean fell (highest quartile = dark green, 50-75th quartile = green, 25-50th quartile = orange and lowest quartile =

red). Note that Atlantic halibut, ocean pout and Atlantic wolffish were excluded because they do not have Albatross to Bigelow abundance-at-length selectivity conversions.

Eight of the seventeen stocks fell in the lowest quartile of historical three-year means (GOM cod, GB cod, CCGM yellowtail, GB yellowtail, SNEMA yellowtail, SNEMA winter flounder, pollock, and Acadian redfish). While two of the seventeen stocks fell in the highest quartile (GB haddock, GOM winter flounder).

Summary

It can be difficult to quantitatively determine what level or even direction of impact some environmental drivers will have on groundfish, especially for stocks with limited research in this area. However, the Northeast fish and shellfish climate vulnerability assessment (Hare 2016) provides qualitative guidance on the vulnerability of each stock in the Operational Assessment (Figure 13).

	Vulnerability to changes in distribution	Biological sensitivity to climate change	Climate exposure	Direction of effect	Overall climate vulnerability
GB cod					
GM cod					
GM haddock					
GB haddock					
CCGM YT					
GB YT					
SNEMA YT					
GM winter fl					
GB winter fl					
SNEMA winter fl					
AmPl					
Witch fl					
Halibut					
Pollock					
Redfish					
GBGOM windowpane					
SNEMA windowpane					
OP					
White hake					
Wolffish					

Figure 13. Summary of climate vulnerability of Operational Assessment stocks denoted by color: low vulnerability (green), moderate vulnerability (yellow), high vulnerability (orange), very high vulnerability (red) from Hare et al. (2016).

The potential impacts that environmental drivers may have on stocks are categorized in Figure 14, as described in corresponding sections above.

Stock	Fall bottom temperature increasing[1]	SST increasing[2]	Cool habitats decreasing, warm habitats increasing[1]	Habitat models[3]	Fall survey distribution to Northeast and deeper waters[2]	Fish condition[4]	Productivity[5]
GM cod							
GB cod							
GM haddock							
GB haddock							
CCGM yellowtail							
GB yellowtail							
SNEMA yellowtail							
GM winter fl							
GB winter fl							
SNEMA winter fl							
American Plaice							
Witch flounder							
Halibut							
Pollock							
Redfish							
N windowpane							
S windowpane							
Ocean Pout							
White hake							
Wolffish							

Figure 14. Summary of potential impacts of ecosystem indicators on Operational Assessment stocks. Potential impacts are categorized as highly positive (dark green), positive (light green), neutral (gray), slightly negative (yellow), negative (orange), highly negative (red), or unknown (white). Potential impacts on stocks were categorized based on 1) temperature preferences, 2) vulnerability assessments, 3) trend of index, 4) current time period compared to historical quantiles, or 5) current 3-yr mean compared to quantiles of historical 3-yr means.

Other Ecosystem Considerations Needing Collaborative Development

A broad spectrum of other ecosystem drivers are available, but need further collaboration between departments and guidance from stock assessment leads. These include bottom up drivers from chlorophyll and lower trophic levels, top down drivers from predation, and multi-dimensional information relating to habitat. These are included as they may be useful to specific stocks if developed further during a research track assessment.

Fall Bloom

The fall bloom in the Gulf of Maine and on Georges Bank may play a role in haddock recruitment through a provisioning effect on spawning fish that enhances reproductive output (Friedland et al. 2015). The fall bloom on the Northeast Shelf was well developed in the Gulf of Maine, and, though chlorophyll concentrations on Georges Bank were elevated, a distinct bloom was not detected because of cloud cover issues limiting the satellite data (Current conditions summary from Ecosystem Status Report). The index is therefore not reliable for the current year in predicting impacts on recruitment for the Georges Bank haddock stock.

Predation

The groundfish species in the Operational Assessment have many predators including fish, marine mammals, sharks and sea birds. The NEFSC has an extensive fish diet database, although due to the predominant macroscopic examination of stomachs at sea and advanced digestion state, the fishes considered here are not often identified to species when prey. Therefore, with the few instances of the Operational Assessment species as prey, estimating consumption by fish predators is highly uncertain. However, considering these species, predation can be quantified with diet compositions for all prey taxa to identify feeding guilds, dietary overlap, and competition (i.e. their "ecological footprints") in addition to understanding patterns and processes of trophic interactions across numerous factors (see Smith and Link 2010).

Published diet studies for seals generally identify prey to species using otoliths, although consumption estimates were not conducted due to uncertainty or a lack of 1) recent population abundance estimates, 2) seasonal variation of residency of seals in U.S. waters, 3) temporal and seasonal changes in diet and consumption rates, 4) daily per capita consumption rates, and 5) knowledge of foraging ground usage between groundfish stock areas. Harbor and gray seals are the two most abundant seal populations in Northeast U.S. waters. Harbor seal populations in U.S. waters may be fairly stable in recent years (Waring et al. 2015) and they primarily prey on sandlance (25%), small gadids (hakes, 20%), flatfish (13%), and clupeids (13%) (Smith et al. 2015). The gray seal population is increasing at a rate of 4.5% in Canadian waters and is likely increasing in U.S. waters as well (DFO 2014, Hayes et al. 2017), although it is unknown if the rate may differ. Gray seals primarily prey on sandlance (34%), large gadids (Atlantic cod, haddock, pollock, 19%), flatfish (14%), clupeids (10%) and small gadids (hakes, 9%) (Smith et al. 2015). Without stock-specific predation estimates for seals, the impact of any potential increases in seal populations is unknown.

Trends in estimated habitat scores

Trends in spring and fall habitat scores were estimated from models developed for Northeast Shelf species over the time period 1992 to 2016. These models were fit using machine learning and based on

a suite of environmental and lower trophic level predictor variables that were fit to species biomass as an indicator of habitat score or quality. For each species, spring and fall trends in habitat estimates are represented with linear slope estimates for grid locations constrained to the segment of the shelf used by each species. These segments were based on an overall occupancy model from a kernel density function calibrated at the 99% confidence level. (Figures 15a and 15b).

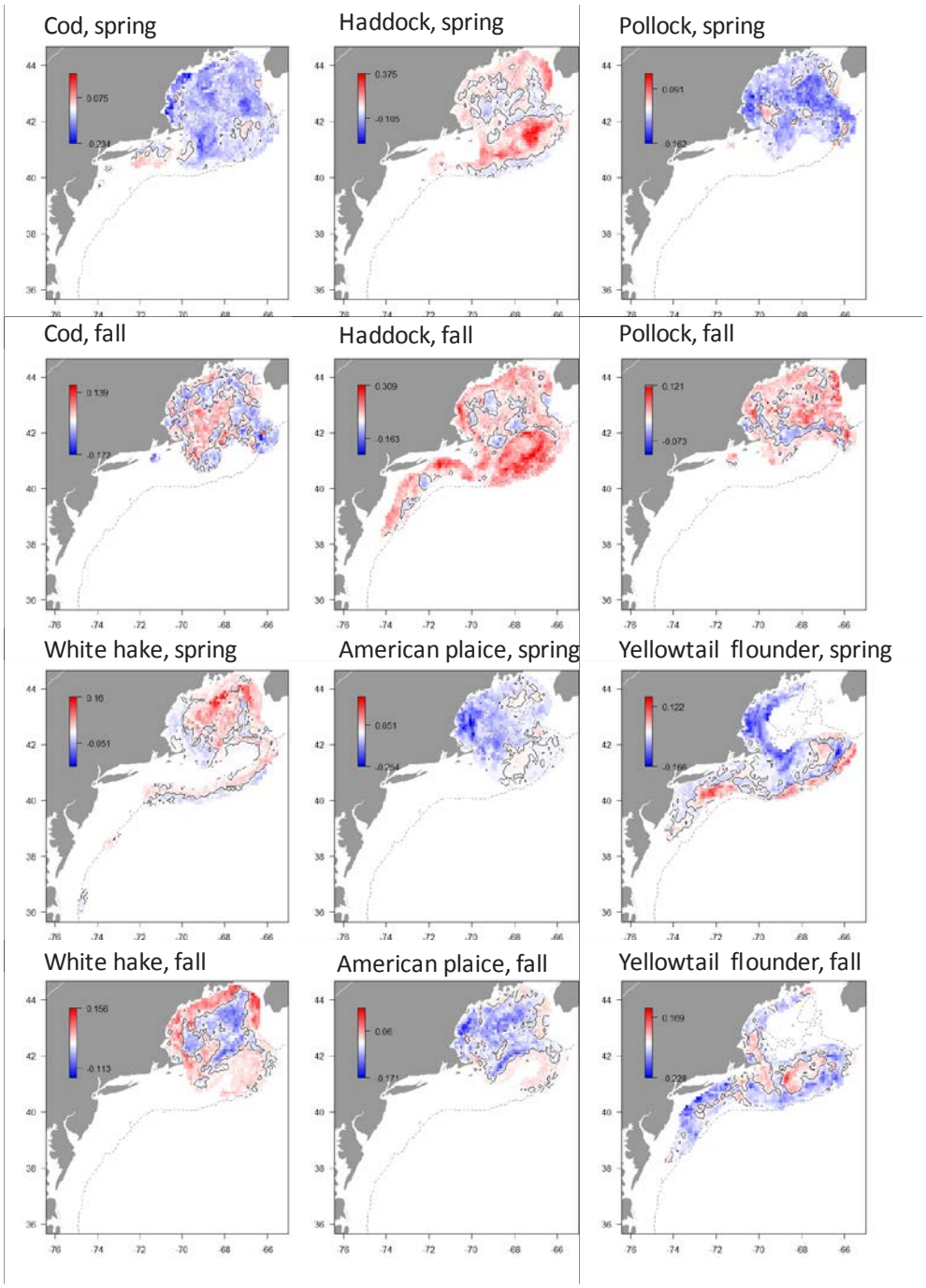

Figure 15a. Spring and fall estimated habitat score trends for Northeast Shelf species over the time period 1992 to 2016. The blue represents a negative trend in the habitat variable, the red represents a positive trend, and the black line marks zero trend.

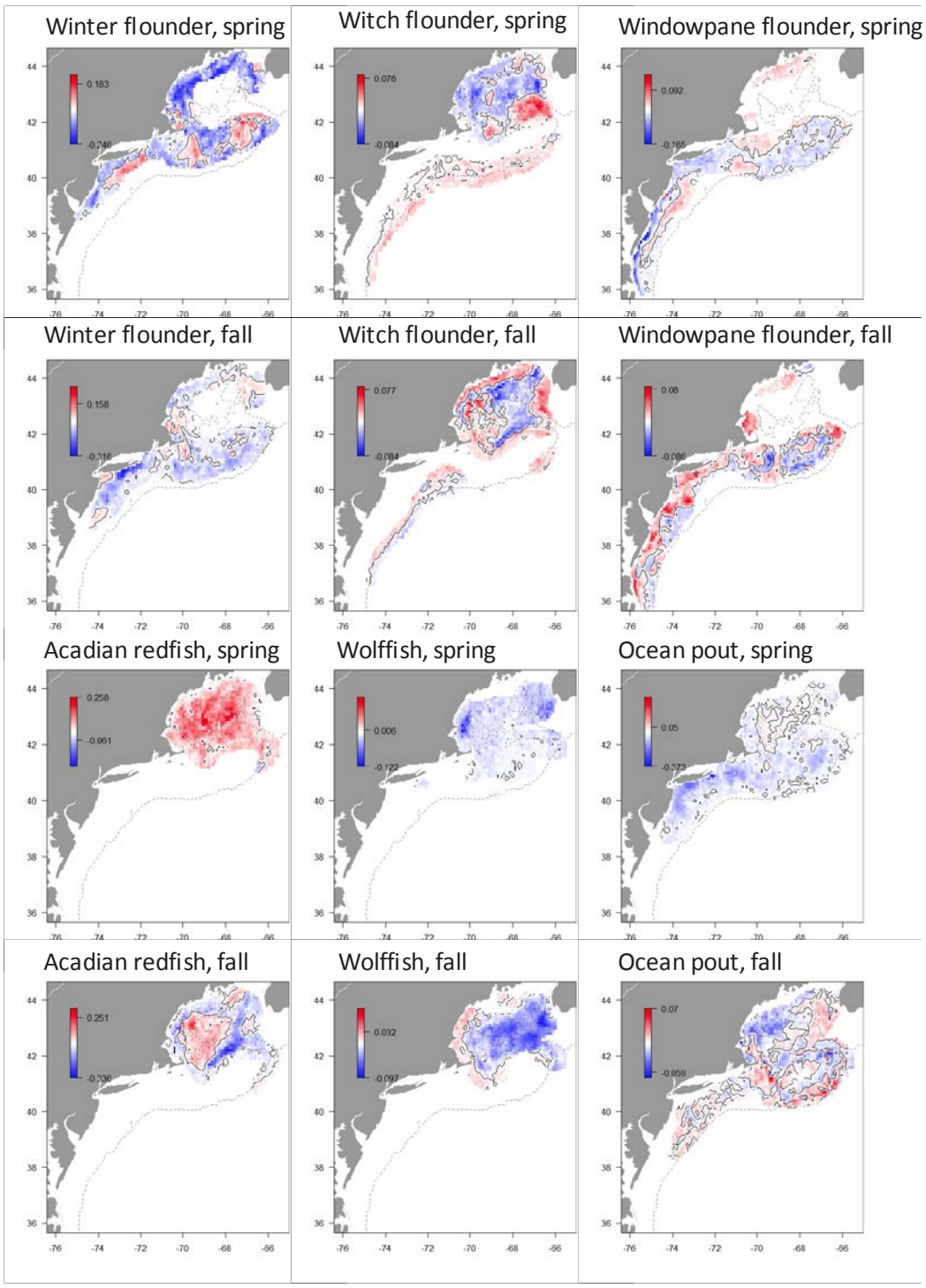

Figure 15b. Spring and fall estimated habitat score trends for Northeast Shelf species over the time period 1992 to 2016. The blue represents a negative trend in the habitat variable, the red represents a positive trend, and the black line marks zero trend.

Many species had concordant habitat changes between seasons, either indicating that habitat was increasing or decreasing in both seasons (Figures 15a and 15b). Interestingly, some species had

reciprocal changes, for example, white hake and pollock appear to have opposite habitat trends between seasons.

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