FATE proposal: Incorporating an environmental index into the Southern New England Mid Atlantic yellowtail flounder stock assessment with potential predictability

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Background

Yellowtail flounder comprises one of the important groundfish fisheries in the Northeast United States and is currently assessed and managed as three separate stocks; Georges Bank, Gulf of Maine and Southern New England. As revealed by the analysis of the NEFSC trawl survey data, changes in distribution have occurred over the last 45 years at the coastwide scale that can only be explained by the combined influence of overfishing and different population productivity as the Northeast US shelf has warmed (Nye et al. 2009). Therefore, the role of overfishing in reducing spawning stock biomass (SSB) and the role of warm water temperatures in changing population productivity must be understood to effectively manage this species. Knowing that environment-recruitment relationships hold up best at the edges of a species range (Myers 1998), this species presents an opportunity to understand the relative importance of climate and fishing for different stocks that span a latitudinal gradient with the Southern New England- Mid Atlantic Stock (SNEMA) being at the southern range of the yellowtail flounder population.

Previous studies have identified a link between climate and recruitment success of yellowtail flounder especially in Southern New England. In the 1940s, a fishery for yellowtail flounder developed, but when it rapidly declined in the early 1950s, warm temperatures were thought to have played a role (Taylor et al, 1957, Royce et al. 1959). In the 1960s and 1970s the abundance of SNEMA yellowtail flounder was very high, during which time the shelf was very cool (Nye et al. 2009, Friedland and Hare 2007). High fishing pressure particularly from the foreign fleet during the 1960s through the 1970s reduced the abundance of SNEMA yellowtail flounder significantly. Since 1992, strict regulations have been put in place along with closed areas, but the stock has not recovered in twenty years. The North Atlantic Oscillation (NAO) and its effect on stratification of the water column and temperature was identified as one potential reason that the stock had not recovered (Sullivan 2005). Sullivan et al. (2000) documented with a 3-year benthic monitoring survey that YOY yellowtail flounder settle in the Southern New England area primarily in the Mid-Atlantic cold pool, the remnant cold winter water beneath the warm surface layer after stratification in the spring (Houghton et al. 1992, Benway and Jossi 1998).

The low recruitment trend over the last twenty years is a major source of uncertainty in the most recent stock assessment of SNEMA yellowtail flounder (Fig 1). The assessment explored the mid-Atlantic cold pool as a possible mechanism for reduced recruitment; however, it did not fully explain the recent low productivity of this stock. We propose to build upon this experience to incorporate a revised environmental index directly into the SNEMA yellowtail stock assessment model. However, the environmental indices that we will examine could provide an additional benefit of predictability

Approach

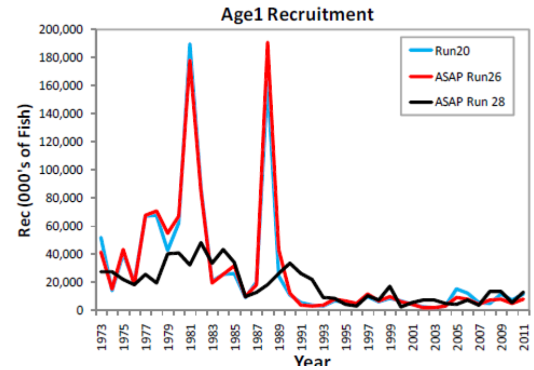

Figure 1: Comparison of Age-1 recruitment estimated from three Runs that were considered in the 2012 SNEMA yellowtail flounder stock assessment. ASAP Run 28 included the Mid-Atlantic cold pool index.

Understanding the reasons for poor recruitment of SNEMA yellowtail flounder in the recent time period, is crucial to determine whether SNEMA yellowtail flounder is overfished (NEFSC 2012). In the 2012 stock assessment, two strategies were used to compensate for changes in recruitment regime, one using age-1 recruitment from a "recent" time period, 1990-2010, essentially assuming that stock productivity has fundamentally changed since the 1990's. The second scenario uses the entire age-1 recruitment time series (1973-2010) but separates recruitment into "two stanzas" of recruitment determined by whether SSB is either above or below an estimated threshold of 4,319 mt. Biomass reference points and conclusions about whether the stock is overfished were dependent on which recruitment scenario was adopted. Under the "recent" low recruitment scenario, the stock is not overfished and the stock would also be considered rebuilt despite being at abundances lower than recorded in the past. However, under the "two stanza" recruitment scenario, the stock is still considered overfished. By incorporating an environmental variable into the stock assessment, the divergent management advice provided by different assumptions can potentially be avoided.

As such, we propose to:

(a) Investigate the physical linkage between changes in atmospheric indices, temperature regime and yellowtail flounder recruitment and productivity for several years after a fluctuation in the Azores High pressure.
(b) Develop predictive relationships between environmental indices and recruitment and SSB and assess the skill of such a prediction scheme
(c) Incorporate the environmental indicator into the stock assessment in one of three ways.

A relationship of the survival ratio (log R/SSB) with the winter NAO in SNEMA yellowtail flounder was found by Sullivan et. al. (2005), but the two constituent atmospheric centers of action that are used to produce the NAO index, the Icelandic Low (IL) and the Azores High (AZ), are better indicators of oceanic conditions than the NAO index itself (Hameed and Piontkovski 2004). It is also thought that the "centers of action" for the NAO have shifted over time leading to many environmental relationships with the NAO to erode (Jung et al. 2003, Cassou et al. 2004, Joyce 2002, Lu and Greatbatch 2002). Thus, the NAO index itself is problematic, but the climatic process it was intended to represent is still important to ecological processes.

Atmospheric circulation over the north Atlantic is dominated by the IL pressure in the north and the AZ pressure in the subtropics. The ILP and AZP pressure represent the intensity of these pressure systems, but the location of these low and high pressure systems also change latitudinally (north-south) and longitudinally (east-west). Changes in both intensity and position can influence conditions on the shelf. In addition to examining the change in pressure in each of these systems we can use the locations of their centroids (IL Latitude, IL Longitude, AZ

Latitude, AZ Longitude) to describe environmental conditions in the SNEMA region. We have calculated these metrics using NCEP/NCAR reanalysis data by a method described by Hameed and Piontkovski (2004). Metrics of the position of atmospheric systems have not been examined for SNEMA, but are likely indicators of the thermal structure on the continental shelf in this region where atmospheric systems and water masses converge to create a large gradient in water temperature from north to south.

We investigated the predictability of recruitment of the SNEMA yellowtail flounder using data for 1963-2007 that was hindcasted using the SSB and recruitment (Age-1) from the 2008 stock assessment (1973-2007) and the NEFSC bottom trawl survey abundance indices of fish <20cm (recruits) and >20cm (SSB). Since an environmental relationship with the winter NAO has been found by Sullivan et. al. (2005), we searched for predictive relationships with the NAO and its two constituent atmospheric centers of action, the ILP, IL latitude, IL longitude and the AZP, AZ latitude and AZ longitude. Statistically significant relationships that can potentially be useful for prediction (i.e., in which the atmospheric variable leads the recruitment in time) are possible to some degree with all of these variables; however, the highest correlation is with the Azores High pressure (AHP) leading recruitment by 1 and 2 years in combination with the latitude position of the IL leading recruitment by one year (Eq 1). Moreover these two climate variables are statistically independent of each other. Hence a linear model for log-transformed recruitment was developed as given below:

$$Ln(R) = 738 - 0.70AZP_{-2} - 0.25ILLat_{-1} \qquad \text{(Eq. 1)}$$

where AZP_{-2} is the pressure of the Azores High (averaged over December-March) two years earlier and $ILLat_{-1}$ is the latitude position of the Icelandic Low one year earlier. The r^2 value for this regression is 0.41. Thus, even in this simple example we can explain some of the variation in recruitment with these two atmospheric indices and demonstrate the potential importance of lags.

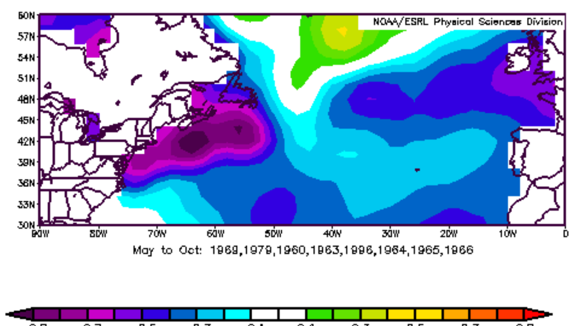

Figure 2: Sea surface temperature anomalies during SNEMA yellowtail flounder larval and juvenile stages (May-October) following winters where the Azores High Pressure was below 1 standard deviation from the mean. The NOAA extended SST were used to make this figure.

Mechanistically, we can explain how the AZP affects temperature conditions on the shelf. The AZP pressure system drives the anticyclonic surface winds that transfer momentum to the subtropical gyre in the north Atlantic. We would expect that a weaker than normal AZP corresponds to cold temperature anomalies in the Mid Atlantic Bight. Indeed, the distribution of SST anomalies during May-October following the winter in which the AZH pressure was below one standard deviation from the mean (Fig 2) shows that cold anomalies prevail over the mid-Atlantic and particularly along the east coast (-0.6°C to -0.8°C). Winters in which the IL was situated to the south of its mean position also gives cold SST anomalies in the Mid Atlantic Bight (figure not shown). We propose to examine variations of seasonal subsurface temperatures in the Mid-Atlantic Bight and the possible physical pathways from the AZ and the IL that influence the hydrography of this region.

The most recent benchmark assessment for SNEMA yellowtail flounder uses a Statistical Catch at Age model termed the Age Structured Assessment Program (ASAP; Legault and Restrepo 1999). There are three possible ways to incorporate an environmental variable into this model. We will first attempt to apply an environmentally mediated stock-recruitment functional form using AZP, ILP or related environmental variable as a covariate depending on our analysis of historical recruitment. This approach was used in the last benchmark assessment with the MidAtlantic cold pool index with some success (Figure 1; NEFSC 2012).

A major unanswered question in the stock assessment is essentially how to model the apparent change in productivity of the system. Recruitment is considered to be the main way in which productivity is affected so it is logical to attempt to incorporate an environmental variable into the stock recruitment relationship. Indeed, this has been the most common approach in stock assessments and academic exercises. Alternatively, we could also use the AZP as a tuning index for SSB in the model similar to the way in which we use the abundance index from the NEFSC bottom trawl survey and allow recruitment to be estimated as a deviation from the mean recruitment. In this approach, we would essentially assume that the environmental index is a "survey" of the survival rate of pre-recruit fish (Methot and Wetzel 2013).

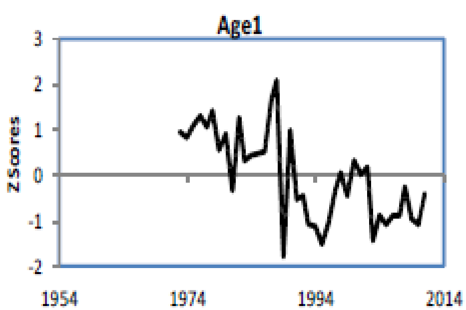

Figure 3: Standardized weight at Age-1 for SNEMA yellowtail flounder caught in the NEFSC bottom trawl survey. Taken from Figure B6 in SAW 2013

Lastly, we can use robust relationships between environmental indicators to ground truth short-term projections on adult SSB under prevailing conditions. In our preliminary analysis, we also found a high correlation between the AZP leading the SSB by 3 years. The fact that the AZP is correlated with SSB 3 years later better than R with no lags suggests that environmental influences in the early life history stage as well as processes occurring after this stage (after Age-1). This supposition is supported by the fact that weight at age over many age classes declined in the catch data (NEFSC 2012). Weight of Age-1 fish caught in the NEFSC survey declined beginning in 1990, but similar declines were not apparent in older age classes. (Figure 3, NEFSC 2012). The relationship of AZP with SSB could be used to ground truth short-term projections on adult spawning biomass under prevailing conditions. Thus, if some sort of predictive relationship between environmental variables and stock production can be made, such a tool can be useful to management in setting Annual Catch Limits (ACL's).

Benefits

The largest uncertainty in the 2012 SNEMA yellowtail flounder stock assessment is why recruitment and productivity decreased drastically in the 1990s and appears to remain at low levels despite low fishing pressure. Our investigation of atmospheric and oceanic processes that have changed the physical environment will help explain why there has been a decline in productivity. More importantly, we will attempt to incorporate these environmental conditions into the SNEMA yellowtail stock assessment using the alternative approaches described above. Feasibility for each of these modeling approaches will be evaluated in the way of model diagnostics including overall model likelihood, residual patterning in the fleet and index component and root mean square error estimates.

Incorporating an environmental variable has already been attempted for this stock with some success. Thus, our team has methodological experience in how to incorporate an environmental variable into the statistical catch at age model. Additionally, those that have been involved in managing the stock also have experience in evaluating how this information can be used in a management context. Thus, we are poised to successfully incorporate environmental indices into the SNEMA yellowtail flounder stock assessment.

Deliverables

- An analysis of environmental factors affecting not only recruitment, as represented by Age-1 fish, but also subsequent year class strength (up to Age 3 fish).
- A better understanding of oceanographic and atmospheric processes influencing environmental conditions (particularly temperature) in the SNE area.
- Incorporation of an environmental variable into a statistical catch at age model in potentially three ways that could potentially be used to inform future stock assessment of SNEMA yellowtail flounder.
- A potentially novel way of using predictability within the climate system to forecast future recruitment and SSB to help set ACLs.
- Several peer-reviewed publications and presentations at national and international meetings.

Year 1	Year 2
• Gather data from 2012 stock assessment, CTD cast data from NEFSC hydrographic database, and spring and fall bottom trawl surveys • Develop time series of AZP, IL and associated environmental variables • Explore mechanistic link between environmental variables and SNEMA YT recruitment • Develop environmental stock-recruitment relationships • Travel to Woods Hole to present results and coordinate an approach to incorporate indices into stock assessment • Present at Annual FATE meeting and one national/international meeting	• Develop predictive models of recruitment and SSB using environmental variables • Assess skill of predictions for most recent years of survey data • Travel to Woods Hole to coordinate how to incorporate environmental variable into ASAP model • Participate in stock assessment workshops for SNEMA yellowtail flounder • Publish at least 2 papers in peer-reviewed journals, one that focuses on physical aspects of the AZ and IL in the SNEMA area and the other that focuses on the relationship between SNEMA YT population and environmental relationships. • Present at Annual FATE meeting • Participate in Benchmark assessment for SNEMA yellowtail flounder in 2015-2016

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