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Exploring hypotheses for reduced growth and truncated size structure of Georges Bank yellowtail flounder

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ABSTRACT

The biological status of the Georges Bank yellowtail flounder population remains uncertain. Relative fishing mortality (catch/survey biomass) has been low in recent years, yet biomass is not showing signs of strong recovery. Population structure should have recovered following decreases in fishing mortality, yet age and length composition in the catch and survey data are skewed toward younger and smaller fish in recent years. Several factors could potentially explain these observations. The truncated age structure undoubtedly is contributing to the truncated size structure, which suggests an increase in total mortality. However, the few fish reaching older ages are also relatively smaller than in years past, so sub-lethal processes directly affecting length are likely important as well.

Fish condition (weight/length) has decreased markedly since the mid-1990s, with perhaps an upturn in the last few years, and might be linked to poor growth. Ocean productivity regime changes can influence fish productivity and thus landings, size structure, and condition. High levels of fishing mortality can potentially drive the evolution of smaller body size. Migrations can explain changes in population size structure if larger fish move to areas where they are less available to the fishery and survey. Because there is some evidence that trawling can result in changes in prey availability, changes in trawling intensity might affect fish productivity. Changes in overall abundance and density can result in density-dependent effects, such as increased competition for food, which could influence productivity and condition. Disease can also have strong impacts on fish population dynamics if rates of infection and mortality are high.

We examined evidence for these hypotheses and did not find strong support for any. However, there is some correlational evidence that the ocean regime in this region may change on a sub-decadal time scale consistent with fluctuations in the North Atlantic Oscillation Index, which are in turn associated with observed landing patterns. There is also some evidence that changes in yellowtail flounder abundance, perhaps driven by changes in ocean regime, are associated with changes in fish condition. Available information suggests that fishing has not induced evolution of smaller sized fish in recent years, that reductions in trawling have not reduced flounder productivity (by reducing availability of polychaetes that may be favored by the disturbance caused by trawling), and that larger fish have not moved differentially into adjacent areas. Moreover, while disease is present in the population, information on infection rates and mortality is lacking; hence the potential impacts of disease on yellowtail flounder demographics or condition are unknown. Additional mechanisms affecting growth and size structure need to be explored, in addition to changes in total mortality that affect age structure.

Introduction

The biological status of the Georges Bank yellowtail flounder population remains uncertain due to seemingly inconsistent signals in various sources of data. Catch history suggests that fishing ramped up in the 1940s and 1950s and the stock was fished down from the mid-1960s through the mid-1980s, reaching a nadir in the mid-1990s. Recent surveys suggest that the population increased rapidly from the mid-1990s through the early 2000s, and then declined again more slowly. Relative fishing mortality (catch/survey biomass) has been low in recent years. Population structure should have recovered following reduction of fishing mortality, yet age and length composition in the catch and survey data are skewed toward younger and smaller fish. Fish condition (weight/length) has decreased markedly since the mid-1990s, with perhaps an upturn in the last few years, and might be related to reduced growth.

The truncated age structure undoubtedly is contributing to the truncated size structure, which suggests an increase in total mortality. However, the few fish reaching older ages are also relatively smaller than in years past, so sub-lethal processes directly affecting length are likely important as well. Questions and hypotheses relevant to reduced growth and truncated size structure include:

1. Why is the size structure of this population failing to rebuild despite reduction in fishing mortality? Few large fish are observed in catch or in surveys.
H1.1: ocean productivity regime change starting in mid-1990s resulted in lack of food and slow flounder growth, so that projected length structure did not materialize
H1.2: larger fish are moving out of the area in response to climate change or other extrinsic factors, skewing the observed length composition toward smaller fish that are perhaps less mobile
H1.3: intensive fishing in the 1960s, 70s, and 80s resulted in the evolution of smaller size

2. Why did the condition (Fulton's K, weight/length) of the fish decrease starting in the mid 1990's?
H2.1: temperature or other changes in ocean conditions have altered growth dynamics (Von Bertalanffy growth parameter k?) so that fish do not put on as much weight at each age as they did prior to the regime change
H2.2: reduction in dredging and trawling has reduced polychaete abundance, reducing growth rate or other aspects of growth dynamics (k?)
H2.3: the very high densities detected in the DFO surveys indicate patches of very high flounder density, causing density-dependent reductions in fish condition due to enhanced competition for food

3. Why does condition appear to be increasing in 2012-2013?
H3.1: change in ocean conditions are favoring flounder growth
H3.2: more dredging and trawling, favoring polychaetes that flounder like to eat

4. Why do tagging studies suggest high total mortality rate in 2003-2006?

H4.1: natural mortality was increased, especially on larger adults, despite the reduction in fishing mortality
H4.2: larger fish are moving out of the survey area and fishing grounds

Methods

The hypotheses collapse into the following:

Hypothesis 1: a shift in ocean productivity regime occurred in the mid 1990's, reducing flounder growth rates or changing growth dynamics such that large fish are absent and condition is poor

Hypothesis 2: intensive fishing earlier in the fishery has resulted in the evolution of smaller size

Hypothesis 3: reduction in trawling has reduced favored foods of flounder, reducing growth rates or altering growth dynamics

Hypothesis 4: larger fish moved out of Georges Bank starting in the mid 1990's.

Hypothesis 5: flounder density has increased recently, resulting in a reduction in fish condition due to competition for food and perhaps increasing the incidence of disease leading to increased mortality of certain age classes

We reviewed available data to determine whether evidence exists in support of any of these hypotheses.

Results

Hypothesis 1: a shift in ocean productivity regime occurred in the mid 1990's, reducing flounder growth rates or changing growth dynamics such that large fish are absent and condition is poor.

The North Atlantic Ocean undergoes large scale oscillations driven by atmospheric pressure changes (Hurrell, 1995), with most of the variation at the sub-decadal scale (Ottersen et al. 2001). These oscillations are reflected in values of the North Atlantic Oscillation (NAO) index. High positive values of the NAO winter (January-March) index values are associated with strong wind circulation in North Atlantic, high sea surface temperatures off western Europe, and low sea surface temperatures off eastern Canada. Circulation patterns also tend to shift: for example, the NAO appears to drive rates of inflow of Atlantic water into the North Sea (Ottersen et al. 2001).

Naturally, these changes in sea temperature and circulation can have dramatic ecological effects. Circulation changes in the North Sea related to the NAO appears to result in shifts in species composition in many groups of organisms ranging from phytoplankton to cod. NAO mediated temperature fluctuations appear to affect copepod species composition: warmer temperature and altered winter circulation patterns appear to favor *Calanus helgolandicus* over *C. finmarchicus* (Ottersen et al. 2001).

Temperature affects almost every aspect of fish recruitment: spawning timing, egg viability, larval growth and mortality, food availability, and adult growth. This being the case, it is reasonable to hypothesize that fish abundance, catch, and fish condition could be affected by the NAO – perhaps primarily through changes in metabolic rate, prey availability, and predator abundance. Phytoplankton and primary production are significantly correlated with the NAO index. In the North Sea, the abundance of a marine polychaete (*Nepthtys hombergii*) appears to be related to winter temperature; through cascading effects, the abundance of this species seems to affect the abundance of two smaller polychaete species (*Scoloplos arminger* and *Hetermastus filiformis*). In the Barents Sea, increased sea temperature is related to increased basic metabolic rates of cod, associated with increased consumption of capelin (about 100,000 tonnes per degree C). Catch records from northern Europe for herring and sardines suggest cyclical fluctuations in abundance (Ottersen et al. 2001).

The highest positive NAO values since the start of the record in 1864 was observed in 1989 (Hurrell, 1995). The NAO then dropped to an extreme low value in 1995 (Figure 1). On Georges Bank, sea temperatures were moderate during the early 1960’s (when NAO values ranged from strongly negative to weakly positive) before dropping during the 1970’s and 1980’s (when NAO values appear to increase). Starting in about 1990, temperatures started to climb (Figure 2) as NAO values peak.

[Figure 1]

[Figure 2]

The average winter NAO index shows a generally negative correlation with catch during the 1960’s (high catch, low NAO, moderate sea temperatures) with a transition in the mid-1970’s and lower catches with higher NAO values and higher sea temperatures in the 1990’s with a possible transition to a different NAO phase starting in 1990 (Figure 2: temperature; Figure 3: NAO index and catch time series; Figure 4: NAO index and catch correlation). After 1996 catch drops while NAO remains weakly positive (except for 2010 and 2013). This timing coincides with a transition from negative to positive NAO index values and from higher to lower catch levels. NAO values were relatively high throughout the 1990’s (compared to values in the 1960’s), while catch remained relatively low (Figure 3). This suggests that there may be a generally negative correlation between NAO average winter index values and GB yellowtail flounder catch (Figure 4). Outlier values of NAO index (low NAO index, low catch) occurred in 1960 and 2010 (Figure 3).

[Figure 3]

[Figure 4]

Because this analysis is purely correlational, no strong inferences can be reached regarding ocean regime shifts that could affect GB yellowtail flounder abundance, length composition, and condition. However, the association of high landings from the early 1960’s to the early 1970’s with strongly negative NAO winter index values and moderate sea temperatures is at least consistent with the hypothesis that this period reflected an oceanic regime conducive to yellowtail flounder growth and recruitment. From the early 1980’s until around 1990, an alternative regime may have occurred (higher NAO winter index values, lower catches). Around 1990, temperatures start to increase (as they appeared to also have done during the 1940’s, when cod landings dropped precipitously; Figure 2)). A recent analysis indicates that variations in productivity regimes explained variations in fish abundance and fishery yield in nearly 40% of the stocks examined (Vert-pre et al., 2012).

Increased temperature is associated with larger yolks and accelerated yellowtail flounder larval growth (Johnson et al. 1999) which would be expected to result in higher recruitment levels and higher abundance, which comports with the observed rapid increase in abundance throughout the 1990’s. However, higher temperatures may also have facilitated parasite infestations, to which yellowtail flounder are known to be subject (Anonymous). This hypothesis is explored in a later section of this paper.

Increased temperature starting in the mid-1990’s may also have triggered poleward migration of yellowtail flounder. If larger fish migrated to a greater extent than younger, smaller fish, this shift in range could explain surveys showing greater biomass but fewer large fish since the mid-1990’s. An analysis of the NEFSC spring trawl survey from 1968 to 2007 revealed that the center of biomass of many species, including yellowtail flounder, moved poleward. The center of northern yellowtail biomass appears to have migrated about 4.3 km/yr over this time period (NOAA, 2013). Yellowtail flounder are known to be able to migrate considerable distances, for example from Block Island to Georges Bank (Anonymous). However, they are found throughout a wide range of temperatures; hence, the temperature difference before (8^{o} C) and after 1990 (up to 10.5^{o} C) may not have been sufficient to drive a migration of larger adults out of Georges Bank.

Hypothesis 2: intensive fishing earlier in the fishery has resulted in the evolution of smaller size

Fishing has the potential shape the demography of fish populations by selective removal of individuals according to age, size, sex, reproductive stage, behavior, morphology or other attributes. This can result in altered patterns of growth, maturity and population structure (i.e., sex ratio, age/size frequency, life history diversity). If the affected attributes have a strong genetic basis, and if the selective pressure is sufficiently high and persistent, the population might undergo fishery-induced evolution, wherein certain traits cannot be recovered because the necessary genes become too rare or lost entirely. The potential for fishery-induced evolution has been demonstrated in a series of theoretical, experimental and field studies (reviewed by Kuparinen and Merila 2007).

Selective removal of certain age classes, size classes, reproductive stages, behaviors, etc., can change patterns of growth, maturity and population structure. However, if fishing pressure is not high enough to remove the underlying genetic traits, those outcomes should be reversible with alleviation of fishing pressure. It is also possible that the traits selected by fishing have a strong environmental basis that accounts for the variability observed in a population. If so, selective removal of certain individuals will not affect genetic structure and therefore not induce an evolutionary response, although it still might have implications for stock productivity and ecosystem function. Finally, outcomes consistent with fishery-induced selection can result via complete different mechanisms, such as environmental changes (e.g., temperature, predator/prey communities, etc.) that select for certain attributes over others.

The GBYTF stock has long exhibited a truncated age structure, with relatively few fish in the 6+ age class over most of the assessment time series (Fig. 5), despite a longevity of up to 17 years (Colette and Klein-McPhee 2002). Pulses of recruitment have episodically filled out the plus-group, but this has not been observed over a multi-year period in more than a decade since the late 1990s and early 2000s (Fig. 5). Fishing does not select for age directly, but rather via a linked trait such as size or behavior. Therefore, truncation of the age structure is not necessarily evidence of fishery-induced selection in its own right; changes in a trait that is directly selected would be stronger evidence for induced evolutionary change.

[Figure 5]

Mean weight-at-age for GBYTF shows a general declining trend for ages 4 and older over a decade beginning in the mid-2000s (Fig. 6). This followed an increase in fishing mortality from a recent low in the mid-1990s to a recent high in the mid-2000s (Fig. 7). However, fishing mortality has since declined considerably (Fig. 7), yet mean weights-at-age in these older age classes remain low (Fig. 6). It is possible that the mid-2000s spike in fishing mortality caused sufficient selection to prevent recovery of size structure despite decreasing fishing mortality.

[Figure 6]

Prior to the mid-1990s, fishing mortality was persistently high (Fig. 7), yet mean weight-at-age generally fluctuated without direction (Fig. 6). Fishing during this period used smaller mesh size that likely affected many more fish at younger ages when genotypic difference in growth were not yet fully expressed, thereby not allowing size-selective evolution to unfold. Changing selectivity away from those smaller and younger life stages toward older and larger fish in recent years might now be allowing fishery-induced evolution to occur whereas it was not possible previous. However, the brevity of the spike in fishing mortality means it is unlikely that sufficient genetic information was lost to induce an evolutionary response (see Law 2007). Moreover, Closed Area II has provided a refuge for many of the remaining yellowtail flounder on Georges Bank, including those of reproductive age (Fig. 8), which should have preserved enough genetic diversity to allow recovery of selected traits following alleviation of fishing pressure if there is sufficient mixing across the boundary of the closed area.

[Figure 7]

Although certainly not definitive, these long-term patterns in age structure (Fig. 5), weight-at-age (Fig. 6) and fishing mortality (Fig. 7), combined with the buffer provided by Closed Area II (Fig. 8) make it unlikely that fishing has induced an irrecoverable change in the demography of yellowtail flounder during the time period for which data are available. Instead, recent decreases in weight-at-age are more likely driven by strong biotic and abiotic changes in the surrounding environment. Note that this does not mean overfishing is not playing a role in recovery of the stock amidst these environmental changes by compromising reproductive output in a lower productivity context, but rather that fishery-induced evolution is not likely to be part of the problem at this stage.

[Figure 8]

Hypothesis 3: reduction in trawling has reduced favored foods of flounder, reducing growth rates or altering growth dynamics

Food availability is the most important factor affecting growth, condition, and survival of juvenile flatfish, and foraging ecology differs with location, indicating the importance of environmental variability on food selection (Amara et al. 2001). The diet of yellowtail flounder consists primarily of benthic macrofauna, including amphipods (*Unicola inermis, Ericthonius fasciatus, Ampelisca agassizi*), polychaetes (*Chone infondibuliformis, Nephtys incisa*), and sand dollars (*Echinarachius parma*). Adults may be more likely to consume crustaceans, while juveniles eat mostly polychaetes. Another study found that yellowtail flounder generally do not exhibit ontogenetic shifts in diet, eating polychaetes and amphipods throughout their lives. For all species, including yellowtail flounder, the amount of food being eaten peaked in the early 1980s and subsequently declined through the end of the time series in 1998 (Link et al. 2002).The prey ratio per body weight decreases as the fish grow from young-of-the-year to age 4+ from 6.2% to 1.1% of body weight per day (Johnson et al. 1999). Yellowtail flounder exhibit a similar feeding intensity at all sizes, and feeding intensity decreases with depth (Gonzalez et al. 2006). Yellowtail flounder on the Grand Banks were found to have a slightly different diet composition, with northern sand lance making up more than 40% of stomach contents. Consumption of sand lance and polychaetes was found to be higher in fish greater than 30cm in length (Gonzalez et al. 2006). Studies of other flatfish (*Limanda limanda and Pleuronectes platessa*) found they can alter their diet to increase feeding opportunities and to avoid interspecific conflicts (Amara et al. 2001).

While many studies exist in the literature on the effects of trawling on habitat and benthic fauna, many are inconsistent in their methods and findings. Many of the studies measuring the impacts of trawling have been conducted in the North Sea (Kenchington et al. 2007), where significant, long-term changes in benthic fauna have been observed

(Jennings et al. 2001). Significant changes were found in the epibenthic community in the Bay of Fundy over a period of three decades, which were attributed primarily to the impact of fishing gears, and largely to scallop dredging, a significant fishery in the area (Kenchington et al. 2007). In contrast, short-term fishing effort may have little or no impact on benthic fauna (Kenchington et al. 2007).

The specific impacts of trawling will depend of course on habitat type and quality. Yellowtail flounder prefer sand or sand-mud substrates, where their favored prey items are plentiful (Johnson et al. 1999). The U.S. side of Georges Bank is largely sand with the exception of the Northern Edge and Georges Shoal areas, which consist of gravel pavement or gravelly sand with some cobble and boulder. Recent survey data show the majority of yellowtail flounder on the U.S. side of the Hague Line to be concentrated in the southern part of Closed Area II, which is primarily sandy bottom. A study comparing habitat inside and outside of the closed area found 47.18% of Closed Area II to be dominated by sand with emergent fauna, mostly tubes created by amphipods and polychaete worms, with a larger percentage of area with this habitat type inside of the closed area than outside of it (Linholm et al. 2004).

When trawling was conducted on soft, shallow sediment, a negative effect of trawling on the biomass, species richness, and production of epifauna was found in the North Sea (Hiddink et al. 2006). The reduction in species richness is largely correlated to a loss of larger animals, which disappear faster and are less resilient. However, these results did not hold true for infauna, which may be a more likely food source for yellowtail flounder. Similarly, Kaiser et al. (2002) found that heavily trawled areas were likely to be dominated by polychaetes and other small-bodied organisms. Trawling activity may shift the benthic prey community in a way that increases the abundance of polychaetes and other small infauna by reducing the abundance of larger benthic species (Jennings et al. 2002). The act of trawling may also expose polychaetes that were previously buried, and fish have been observed to feed in trawl tracks on newly exposed fauna (Kaiser and Spencer 2004). Low or moderate levels of trawling on sand could potentially have neutral or positive effects for plaice living in sandy habitats, because this may cause polychaetes to proliferate (Jennings et al. 2002). Because yellowtail flounder primarily inhabit sandy bottom on Georges Bank, it might be expected that trawling could also have neutral or positive effects on yellowtail flounder prey availability, especially for juveniles (if trawling shifts infaunal communities toward polychaetes and smaller organisms).

Sullivan et al. (2003) found abundance of yellowtail flounder to increase at one experimental site within two days of scallop dredging, to have then decreased after three months, and returned to previous levels of abundance the following year. They also found an increase in smaller yellowtail after the dredging took place. Yellowtail flounder prey items were unchanged after dredging. However, another site did not exhibit the same results, and they attributed these findings to spatial and seasonal variance. Another study (Shephard et al. 2010) found a positive link between growth and trawling on another flatfish, plaice, on sand habitats in the Celtic Sea, which was attributed to increased polychaete abundance from trawling activity. The study found that biomass did not change appreciably, but polychaetes were found to replace other organisms after trawling.

A study of stomach contents from 25 years of trawl survey data found yellowtail flounder to eat primarily polychaetes and gammarid amphipods (Link et al. 2002). The authors found no significant shift in diet across the time series (1973-1998) other than a slight shift from gammarids to other amphipods in the 1980s, and back again in the 1990s. This suggests that trawling does not affect trophic dynamics of yellowtail flounder or many other flatfish. These benthic fauna are likely to recover very quickly from trawling, and while trawling may reduce the size of these benthic species, flatfish may prefer smaller polychaetes and crustaceans.

All of this suggests that bottom trawling is not likely to have negative impacts on prey availability for yellowtail flounder, and could have positive impacts, at least for juvenile yellowtail flounder. Collie (1987) noted that a large decline in the abundance of polychaetes or gammarids could strongly influence yellowtail flounder or winter flounder dynamics. Winter flounder on Georges Bank in contrast to yellowtail flounder have rebounded to some extent after suffering from low abundance for several years. As noted earlier, many of the yellowtail flounder on the U.S. side of Georges Bank are found within Closed Area II. This area is currently closed to most trawling activity, although this area does allow for limited access scallop dredging through a rotational access area program, and some groundfish trawling takes place here as well through a Special Access Permit. Because the footprint of scallop dredging is smaller than that of the otter trawl, and because effort of both gear types is reduced within the closed area, it is possible that a reduction in trawling and dredging activity has reduced the availability of polychaetes and thus reduced prey availability for yellowtail flounder, particularly for juveniles, which are more likely to rely on polychaetes as a primary food source (Johnson et al. 1999). However, yellowtail flounder diet is not limited to polychaetes, and as such a reduction in fishing activity may result in increased abundance of other prey species. There is likely a relationship between the increased density of yellowtail flounder within the closed area and the reduced fishing effort within this area. At the same time, these findings suggest that reduced fishing effort could possibly have a negative effect on prey availability for yellowtail flounder within the closed area.

Hypothesis 4: larger fish moved out of Georges Bank starting in the mid 1990’s

Most assessment models assume closed stock conditions, where fish remain within a specified stock area. Immigration and emigration can be sources of error in assessment models, therefore it is important to explore the potential of fish to move beyond the boundaries of the assessment. In fact, if larger fish moved out of Georges Bank in the mid 1990’s, this could explain in part survey data showing a lack of age structure rebuilding in response to low fishing pressure. For the purposes of this hypothesis, age is used as a proxy for larger fish.

Catch at age data are available from the Georges Bank yellowtail flounder assessment as well as stock assessment (TRAC 2013) on two other stocks, Gulf of Maine/Cape Cod

(NEFSC 2012a) and Southern New England/Mid Atlantic (NEFSC 2012b). The relative catch-at-age for ages five and six-plus do not indicate any long-term declines in these age classes on Georges Bank since the mid-1990's (Figure 9). The relative catch at age for ages five and six-plus across the three stocks all have experienced increases since the 2000's, but none of the stocks experience increases that were notably greater than the others (Figures 10 and 11). The relative increasing trends in the non-Georges Bank stocks for ages four, five, and six-plus indicate that those increases were likely to be the result of improving age structure within those stocks (Figures 12 and 13).

[Figure 9]

[Figure 10]

[Figure 11]

[Figure 12]

[Figure 13]

Survey data at age indicate similar trends, slight increases in older ages for all stocks (Figures 14 and 15). It does not appear that older fish specifically have been leaving Georges Bank for adjacent areas. The increases in catch or survey at age for stocks in these adjacent areas appear to be more closely linked to their improving stock condition.

[Figure 14]

[Figure 15]

A study by Wood and Cadrin (2013) used cooperative tagging data from 2003-2006 to examine the movement and mortality of yellowtail flounder among the three stock areas. They found that movement was greater than previously thought between Southern New England/Mid Atlantic and Georges Bank stocks, but attributed at least some of that movement to the study design and release locations (Wood and Cadrin 2013). They concluded that the current assessment uncertainties were unlikely to be the result of large scale movement between areas and a mark-recapture model indicated similarly high levels of fishing mortality as the conventional stock assessment.

Hypothesis 5: Increased flounder density reduced fish condition due to competition for food and higher incidence of disease.

The question of concern for this hypothesis is whether increased local density of yellowtail flounder has resulted in a reduction in fish condition and/or an increase in disease. Classic density-dependent condition theory suggests that as density increases, there is increased intraspecific competition for food or other resources, and as a result, average condition of the population declines. Also, higher densities can increase the transmission rate of disease, spreading a potentially harmful infection to a larger proportion of the population more quickly.

Pereira et al. (2012) investigated the density-dependent condition hypothesis. The study found that during periods of low abundance, the range of yellowtail across Georges Bank contracted towards more favorable habitats on the Northeast Peak. Since 1994, much of the preferred habitat (Stratum 1160 in Fig. 16) has been closed to targeted groundfishing, both in Closed Area 2 on the U.S. side, and seasonally in parts of Canada's Area 5Z (Figure 16, white outline and bold black outline, respectively). From 1994 to around 1999, density in Stratum 1160 increased, while yellowtail density in other Georges Bank strata remained constant or decreased.

The authors used a proxy for condition as the deviation from a mass/weight relationship derived for GBYTF. The authors found that during the period of high abundance (and higher density) in the early 2000s, condition did in fact decrease in females compared to the low-abundance period, but there was no significant change in condition for males (Figure 2). The difference between sexes could potentially be explained by the fact that male yellowtail have lower energy requirements than females, especially during the spawning season, such that even in a higher-abundance, higher-density area, male flounder could still find adequate food (Pereira et al., 2012),

[Figure 16]

Pereira et al. used values for abundance, condition, and density that were averaged over multiple years (low abundance years: 1992-1995; high abundance years: 1999-2004). In more recent years, abundance and density measures have decreased to values closer to the 90s lows. Therefore, following logically from the conclusions in Pereira et al., female condition is likely at an intermediate to improved state compared to the early 200s, high-abundance years. There is no evidence that local density in preferred yellowtail habitats has continued to increase since the mid-2000s. Therefore, although there is evidence that density-dependent effects are present in Georges Bank yellowtail, density has decreased since the early 2000s, likely reducing the possibility of compromised stock condition due to lowered condition.

[Figure 17]

There has also been some very preliminary evidence of icthyophonus in yellowtail flounder on Georges Bank. Ichthyophonus is a disease-causing protist that, in some species of fish, can have a high mortality rate (Carlton Huntsberger, personal communication). Preliminary data suggest an infection rate of around 2.5% in yellowtail. It is possible that with higher density, such as that seen in the early 2000s on Georges Bank, the parasite can spread more quickly through the population. Depending on the true transmission rate and mortality associated with icthyophonus (factors which are not yet known for yellowtail flounder), even this low infection rate could be affecting the species. However, very little information and data have been gathered concerning icthyophonus in yellowtail flounder, and until further research is done, it is impossible to draw firm conclusions on the effect of the disease on overall yellowtail population dynamics.

Discussion/Conclusions/Summary/Recommendations

We reviewed available data to evaluate the potential for changes in ocean productivity regime, effects of trawling on food availability, fish migration, evolution of smaller size driven by fishing, and density dependent effects to explain observed changes in growth and size structure of Georges Bank yellowtail founder. Our conclusions related to each hypothesis are as follows:

Hypothesis 1: a shift in ocean productivity regime occurred in the mid 1990's, reducing flounder growth rates or changing growth dynamics such that large fish are absent and condition is poor

High landings from the early 1960's to the early 1970's are associated with strongly negative NAO winter index values and moderate sea temperatures, consistent with the hypothesis that this period reflected an oceanic regime conducive to yellowtail flounder growth and recruitment. From the early 1980's until around 1990, an alternative regime may have occurred (higher NAO winter index values, higher sea temperatures on Georges Bank, lower catches). Around 1990, temperatures start to increase (as they appeared to also have done during the 1940's, when cod landings dropped precipitously). A recent analysis indicates that variations in productivity regimes explained variations in fish abundance and fishery yield in nearly 40% of the stocks examined (Vert-pre et al., 2012). While no strong inferences can be drawn from the correlation between NAO winter index, sea temperature, and yellowtail landings, there are plausible mechanisms that could relate these changes to changes in yellowtail flounder productivity, e.g., if moderate sea temperatures are conducive to yellowtail flounder growth and reproduction.

Hypothesis 2: intensive fishing earlier in the fishery has resulted in the evolution of smaller size

There is no strong evidence of fishery induced selection of smaller size. Higher levels of fishing mortality have occurred in the past, yet mean size and age fluctuated without apparent trend. There is some indication of a decrease in mean size in recent years, but similar decreases have reversed in past. The recent increase in fishing mortality was smaller than spikes in past, also suggesting that fishing mortality may not be the main driver of this recent decrease in mean size. More targeting of larger sizes recently may create conditions for fishing induced evolution of smaller sized flounder in the future, and we might be observing the early stages of fishery-induced evolution that will become stronger through time.

Hypothesis 3: reduction in trawling has reduced favored foods of flounder, reducing growth rates or altering growth dynamics

Trawling may have increased polychaete availability (increasing food for juvenile flounder). However trawling has been reduced in closed areas, while flounder abundance is higher in these areas, a finding inconsistent with this hypothesis. Amphipods are abundant in the closed area, which may support higher flounder productivity if flounder are able to shift prey preferences.

Hypothesis 4: larger fish moved out of Georges Bank starting in the mid 1990's

Available evidence does not indicate movement of larger, older Georges Bank yellowtail into adjacent areas. Moreover, tagging studies indicate fairly high site fidelity.

Hypothesis 5: flounder density has increased recently, resulting in a reduction in fish condition due to competition for food and perhaps increasing the incidence of disease leading to increased mortality of certain age classes.

Increased abundance is associated with decreased fish condition for adult females up until 2004, but density has been decreasing while fish condition is also low. Fish condition appears to have increased slightly in recent years, perhaps suggesting a density-dependent increase in growth. Pathogenic organisms have been found in the yellowtail flounder population, but there is as yet no information on infection rates, transmissibility, and mortality. As a result, no inferences about the effects of disease on observed patterns of abundance, size structure, or fish condition are possible at this time.

In conclusion, there is no strong evidence in support of any of the hypotheses we evaluated. However, there is some correlational evidence that the ocean regime in this region may change on a sub-decadal time scale consistent with fluctuations in the North Atlantic Oscillation Index, which are in turn associated with observed landing patterns. There is also some evidence that changes in yellowtail flounder abundance, perhaps driven by changes in ocean regime, are associated with changes in fish condition. Available information suggests that fishing has not induced evolution of smaller sized fish in recent years, that reductions in trawling have not reduced flounder productivity (by reducing availability of polychaetes that may be favored by the disturbance caused by trawling), and that larger fish have not moved differentially into adjacent areas.

Of course, like any fish population, multiple factors likely influence survivorship, growth, and movements, which in turn shape observed patterns of abundance, size structure, and fish condition. The absence of strong evidence for a single hypothesis does not preclude the possibility that several are operating in more moderate ways nonetheless, and that the observed patterns are due to the synergistic effects of several processes. Moreover, these factors have likely varied in intensity, and thus relative importance, over time. Finally, the processes driving truncated age structure are almost certainly linked to truncated size structure, suggesting that better estimates of total mortality are needed in addition to further exploration of sub-lethal processes that affect size and weight at age.

Literature Cited

Amara, R., Laffargue, P., Dewarumez, J. M., Maryniak, C., Lagard`ere, F., Luczac, C. 2001. Feeding ecology and growth of 0-group flatfish (sole, dab and plaice) on a nursery ground (Southern Bight of the North Sea). *Journal of Fish Biology,* 58: 788–803

Anonymous. Yellowtail flounder. http://ccesuffolk.org/assets/galleries/Marine/Fisheries-Management/yellowtail-flounder.pdf

Collette, B.B., Klein-MacPhee, G. 2002. *Fishes of the Gulf of Maine*. Smithsonian Institution Press, Washington, D.C.

Collie, J.S. 1987. Food consumption by yellowtail flounder in relation to production of its benthic prey. *Marine Ecology Progress Series*, 36: 205-213.

Gonzalez, C., Paz, X. Román, E., Hermida, M. 2006. Feeding habits of fish species distributed on the Grand Bank. Northwest Atlantic Fisheries Organization, Scientific Council Meeting – June 2006. NAFO SCR Doc. 06/31.

Hiddink, J.G., Jennings, S., Kaiser, M.J., Queirós, A.M., Duplisea, D.E., Piet, G.J. 2006. Cumulative impacts of seabed trawl disturbance on benthic biomass, production, and species richness in different habitats. *Canadian Journal of Fisheries and Aquatic Sciences*, 63: 721-736.

Hurrell, J.W. Decadal trends in the North Atlantic Oscillation: Regional temperatures and precipitation. Science 269: 676 – 679. (1995)

Jennings, S., Pinegar, J.K., Polunin, N.V.C., Warr, K.J. 2001. Impacts of trawling disturbance on the trophic structure of benthic invertebrate communities. *Marine Ecology Progress Series,* 213: 127-142

Jennings, S. Nicholson, M.D., Dinmore, T.A., Lancaster, J.E. 2002. Effects of chronic trawling disturbance on the production of infaunal communities. *Marine Ecology Progress Series*, 243: 251-260.

Johnson, D.L, W.W. Morse, P.L Berrien, and J.J. Vitaliano. Yellowtail flounder, *Limanda ferruginea*, life history and habitat characteristics. NOAA Technical Memorandum NMFS-NE-140.

Kaiser, M.J., Collie, J.S., Hall, S.J., Jennings, S. Poiner, I.R. 2002. Modifications of marine habitats by trawling activities: prognosis and solutions. *Fish and Fisheries,* 3: 114-136.

Kenchington, E.L, Kenchington, T.J. Henry, L-A., Fuller, S., Gonzalez, P. 2007. Multi-decadal changes in the megabenthos of the Bay of Fundy: the effects of fishing. *Journal of Sea Research*, 58: 220-240.

Kuparinen, A., Merilä. J. 2007. Detecting and managing fisheries-induced evolution. *Trends in Ecology and Evolution*, 22: 652-659.

Law, R. 2007. Fisheries-induced evolution: present status and future directions. *Marine Ecology Progress Series*, 335: 271-277.

Link, J.S., Bolles, K., Milliken, C.G. 2002. The feeding ecology of flatfish in the Northwest Atlantic. *Journal of Northwest Atlantic Fisheries Science*, 30: 1-17.

New England Fishery Management Council (NEFMC). 2013. Framework Adjustment 48 to the Northeast Multispecies FMP. Submitted to NOAA February 26, 2013.

Northeast Fisheries Science Center. 2012a. Assessment or Data Updates of 13 Northeast Groundfish Stocks through 2010. US Dept Commer, Northeast Fish Sci Cent Ref Doc. 12-06; 789 p.

Northeast Fisheries Science Center. 2012b. 54th Northeast Regional Stock Assessment Workshop (54th SAW) Assessment Report. US Dept Commer, Northeast Fish Sci Cent Ref Doc. 12-18; 600 p.

NOAA, 2013. Northeast Fisheries Science Center, NOAA. http://www.nefsc.noaa.gov/ecosys/climate_change/historical.html

Ottersen, G., B. Planque, A. Belgrano, E. Post, P.C. Reid, and N.C. Stenseth. Ecological effects of the North Atlantic Oscillation. Oecologia 123:1-14 (2001).

Shephard, S., Brophy, D., Reid, D.G. 2010. Can bottom trawling indirectly reduce carrying capacity in a marine ecosystem? *Marine Biology*, 157: 2375-2381.

Transboundary Resources Assessment Committee (TRAC). 2013. Stock Assessment of Georges Bank Yellowtail Flounder for 2013.

Vert-pre, K., R.O. Amoroso, O.P. Jensen, and R. Hilborn. Frequency and intensity of productivity regime shifts in marine fish stocks. PNAS doi: 10.1073/pnas.1214879110 (2012)

Wood, A.D. and S.X. Cadrin. 2013. Mortality and movement of Yellowtail Flounder (*Limanda ferruginea*) tagged off New England. *Fishery Bulletin*, 111: 279-287.

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Figures

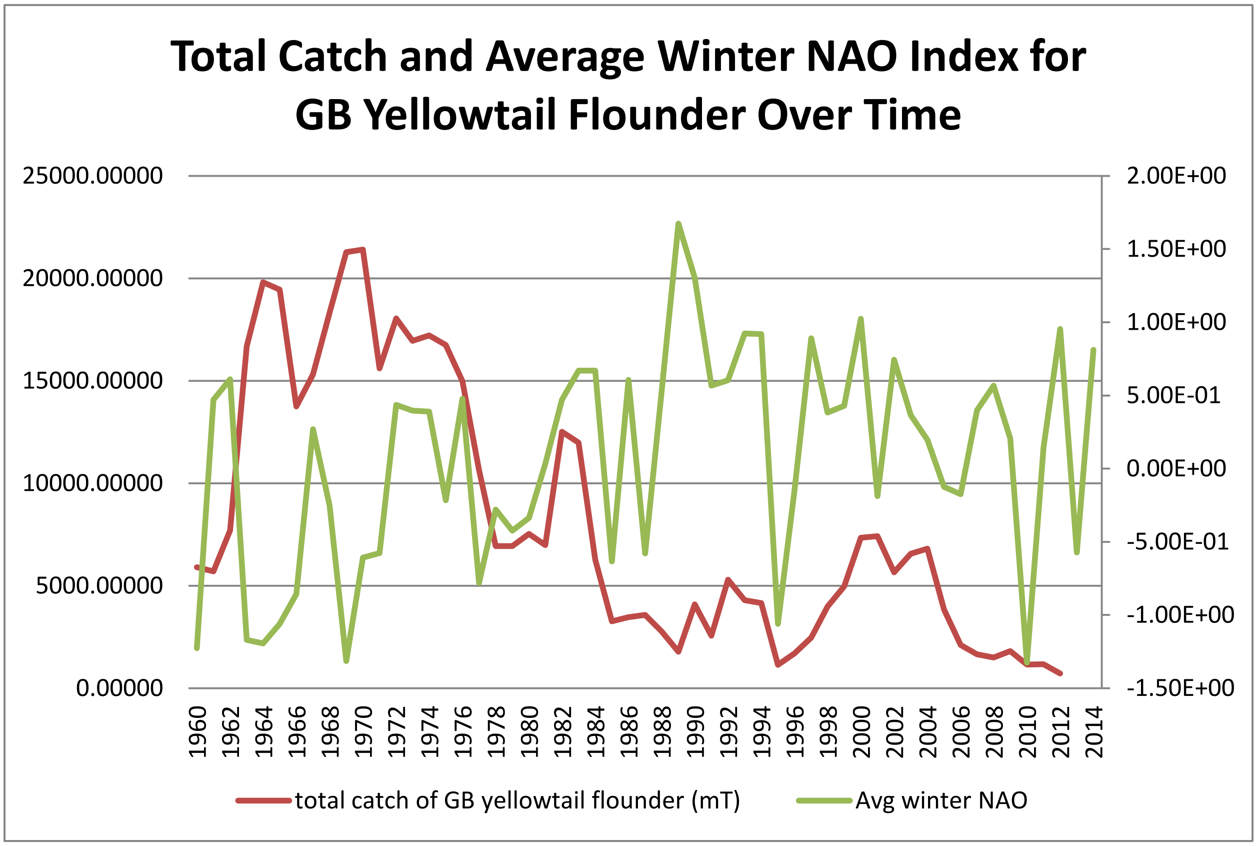

Figure 1. Total GB yellowtail flounder catch and average winter NAO index time series.

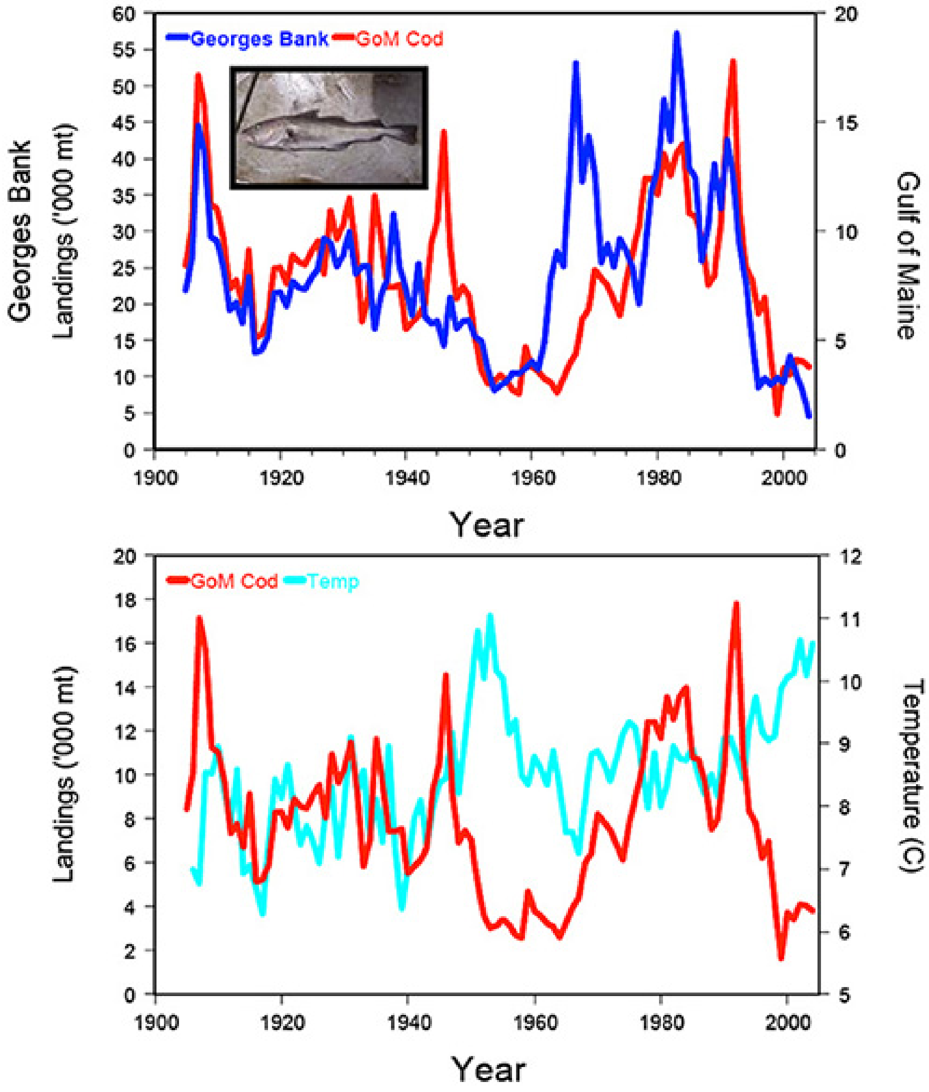

Figure 2. Georges Bank temperature and Gulf of Maine cod landings (NOAA, 2013)

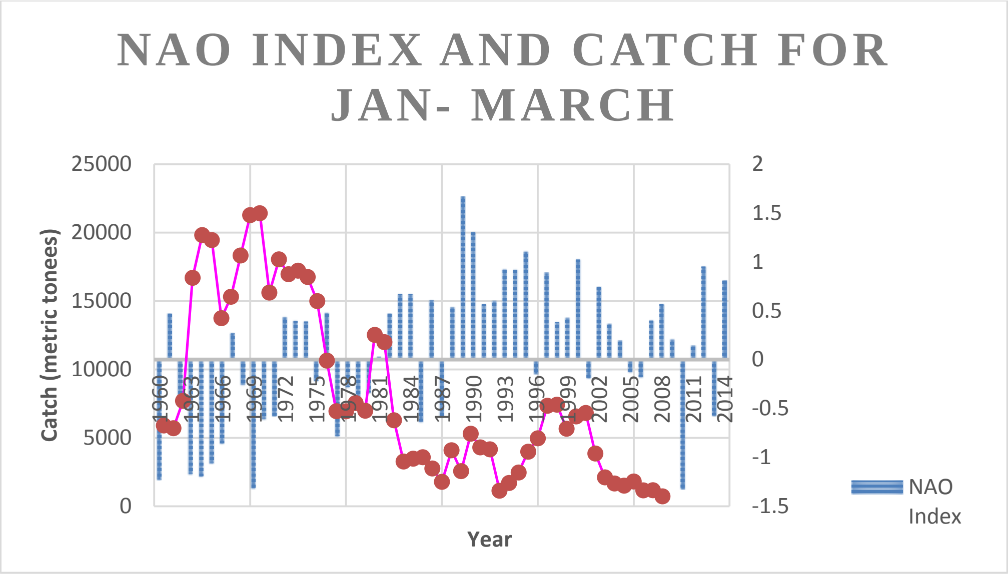

Figure 3. Time series of total GB yellowtail flounder catch (red dots) and the average winter NAO index (blue bars).

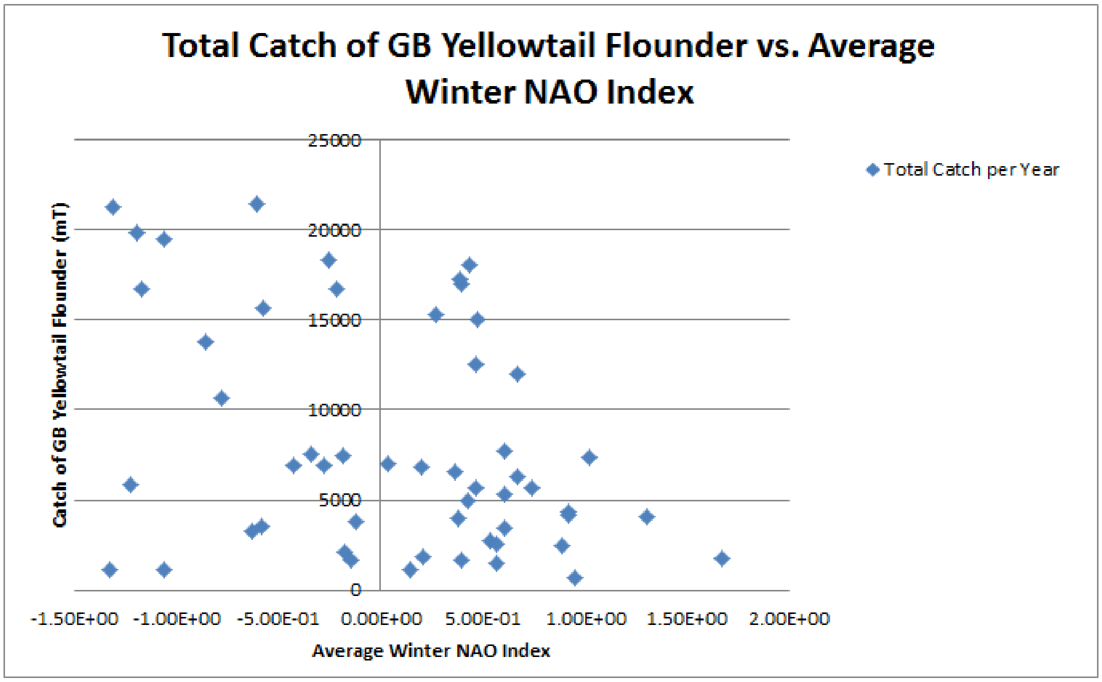

Figure 4. Average winter NAO index and total GB yellowtail flounder catch.

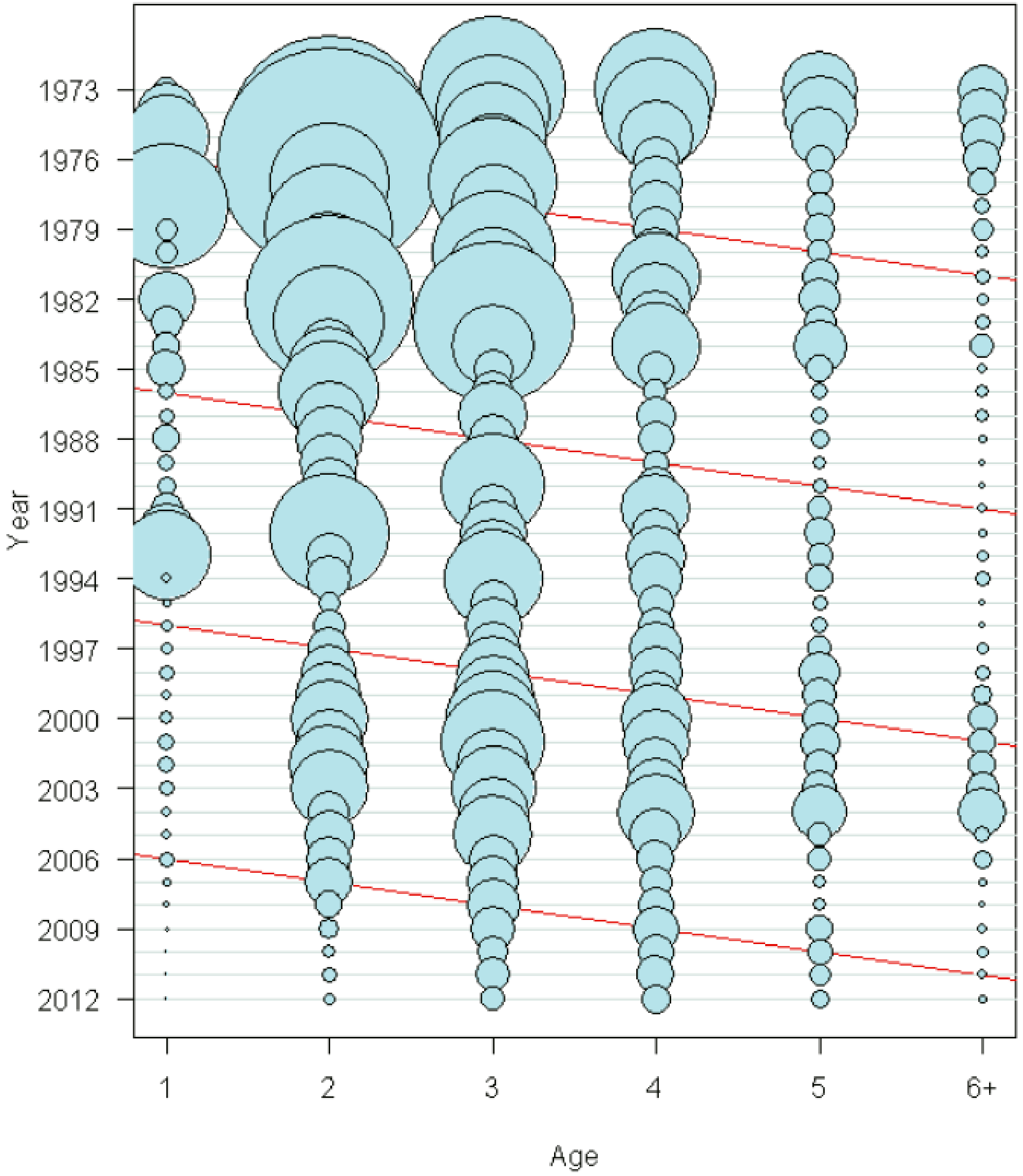

Figure 5. Catch-at-age in the Georges Bank yellowtail flounder fishery (from TRAC 2013).

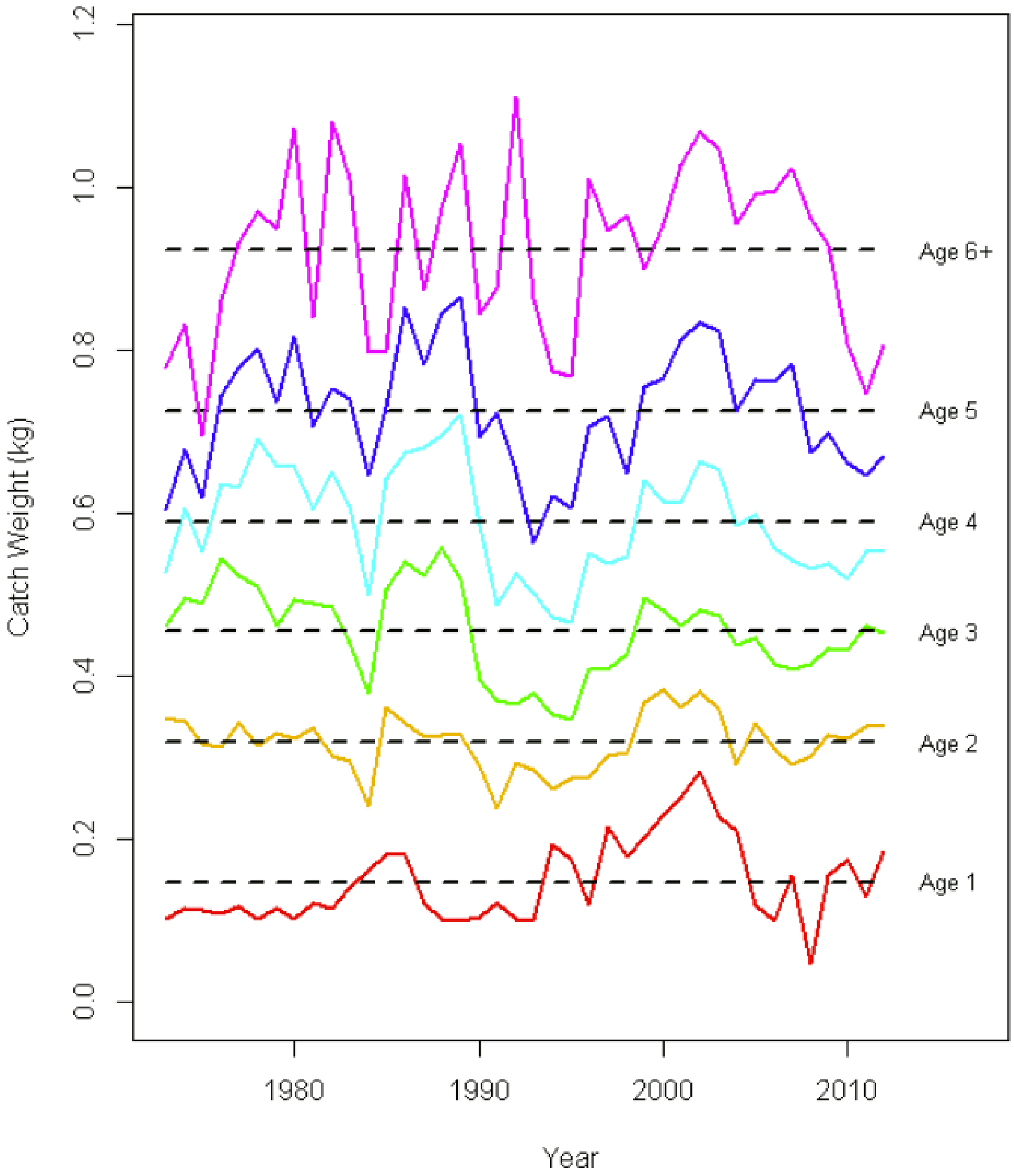

Figure 6. Mean weight-at-age of Georges Bank yellowtail flounder (from TRAC 2013).

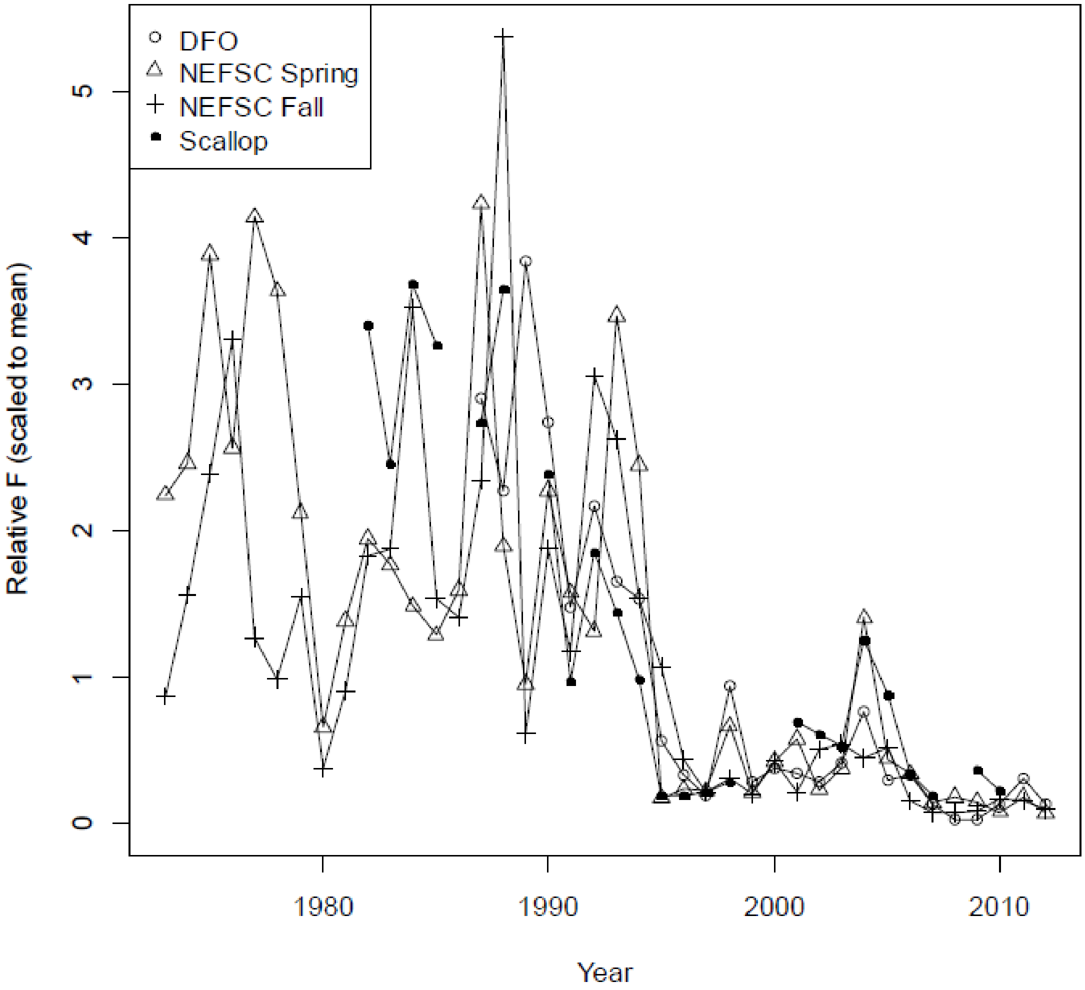

Figure 7. Relative fishing mortality (catch biomass/survey biomass) of Georges Bank yellowtail flounder (from TRAC 2013).

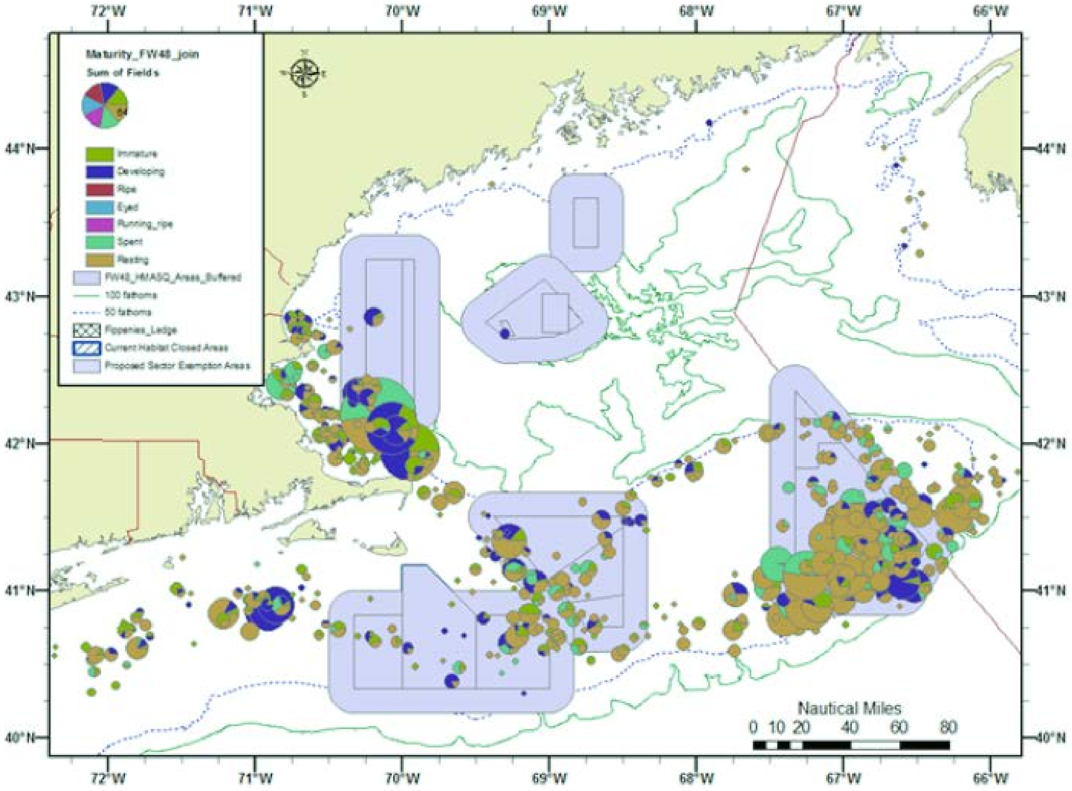

Figure 8. Distribution of female yellowtail founder reproductive stages in the Gulf of Maine and on Georges Bank relative to fishery closed areas from the NEFSC fall trawl survey, 2002-2011 (from NEFMC 2013).

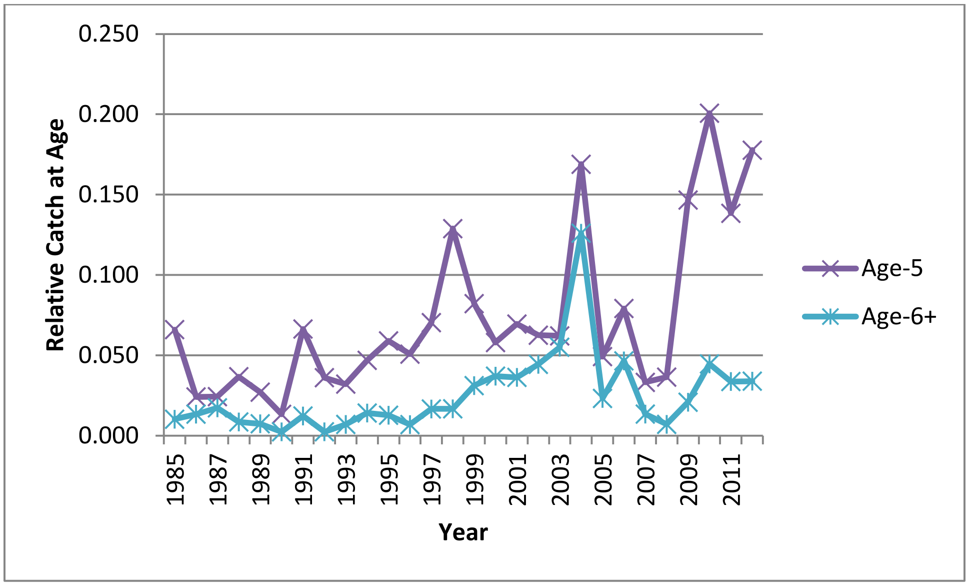

Figure 9. Relative catch at age for ages 5 and 6+ for Georges Bank yellowtail flounder, 1985-2012.

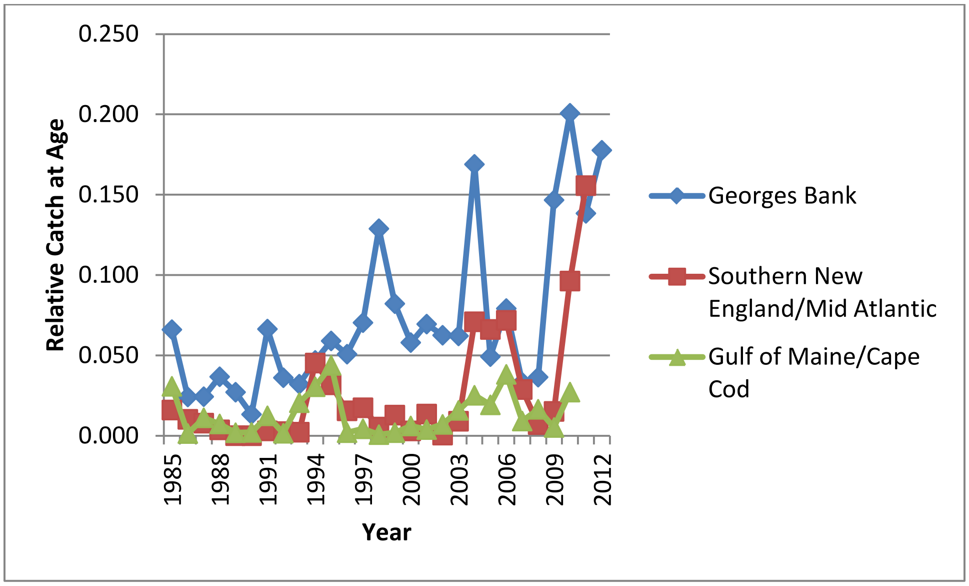

Figure 10. Relative catch at age for age-5 for Georges Bank, Southern New England/Mid Atlantic, and Gulf of Maine/Cape cod yellowtail flounder, 1985-2012.

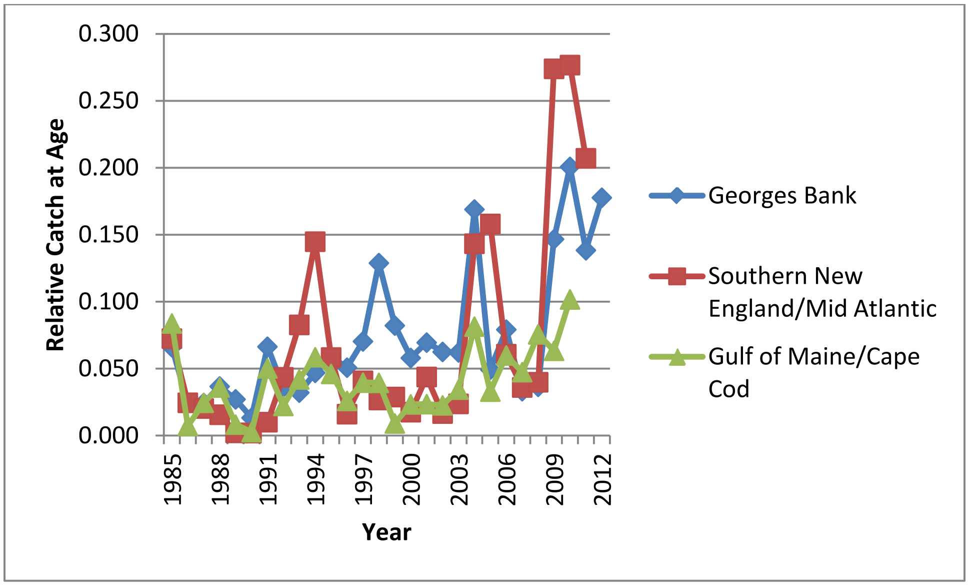

Figure 11. Relative catch at age for age-6+ for Georges Bank, Southern New England/Mid Atlantic, and Gulf of Maine/Cape cod yellowtail flounder, 1985-2012.

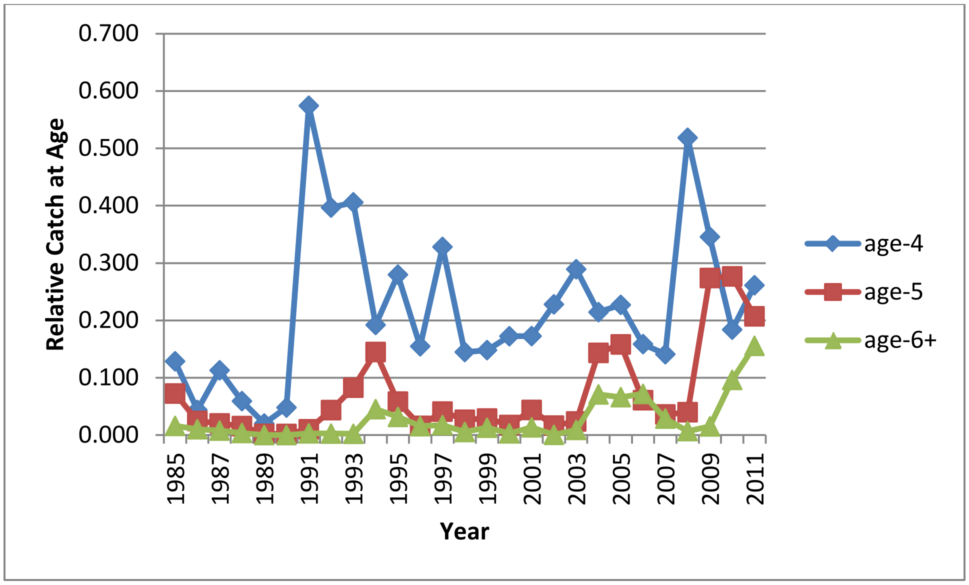

Figure 12. Relative catch at age for ages 4, 5, and 6+ for Southern New England/Mid Atlantic yellowtail flounder, 1985-2011.

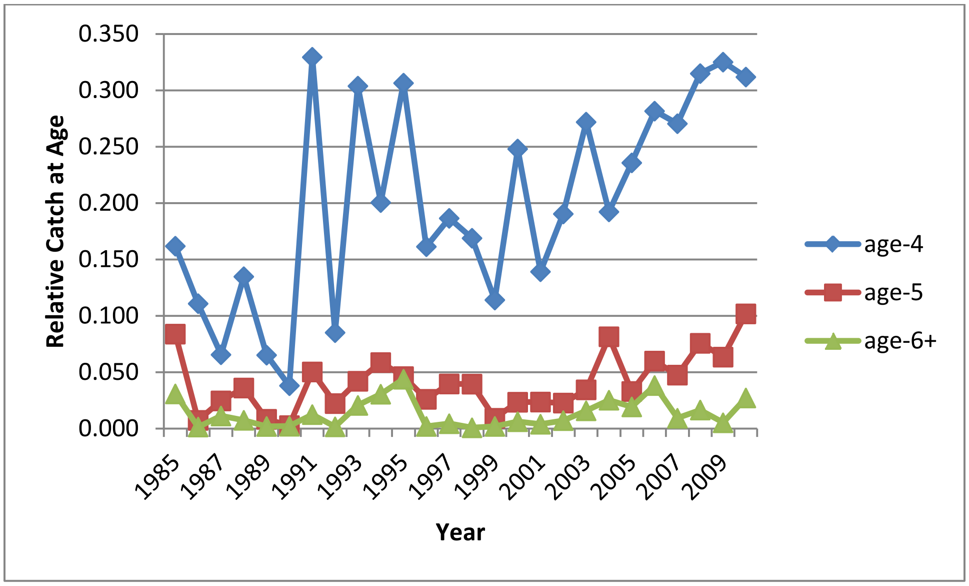

Figure 13. Relative catch at age for ages 4, 5, and 6+ for Gulf of Maine/Cape Cod yellowtail flounder, 1985-2011.

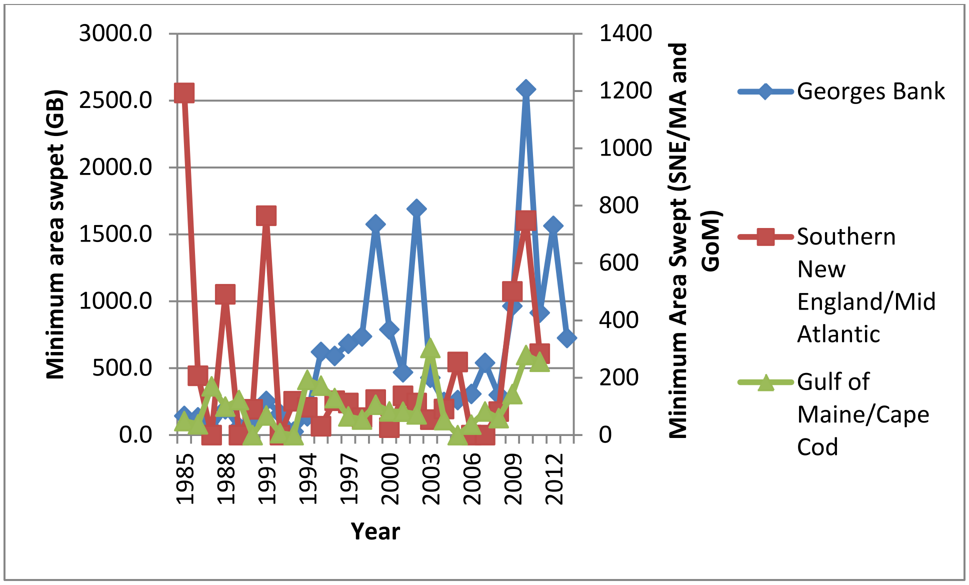

Figure 14. Minimum area swept estimates in thousands of fish for age-5 by the NEFSC spring survey for Georges Bank, Southern New England/Mid Atlantic, and Gulf of Maine/Cape Cod yellowtail flounder, 1985-2013.

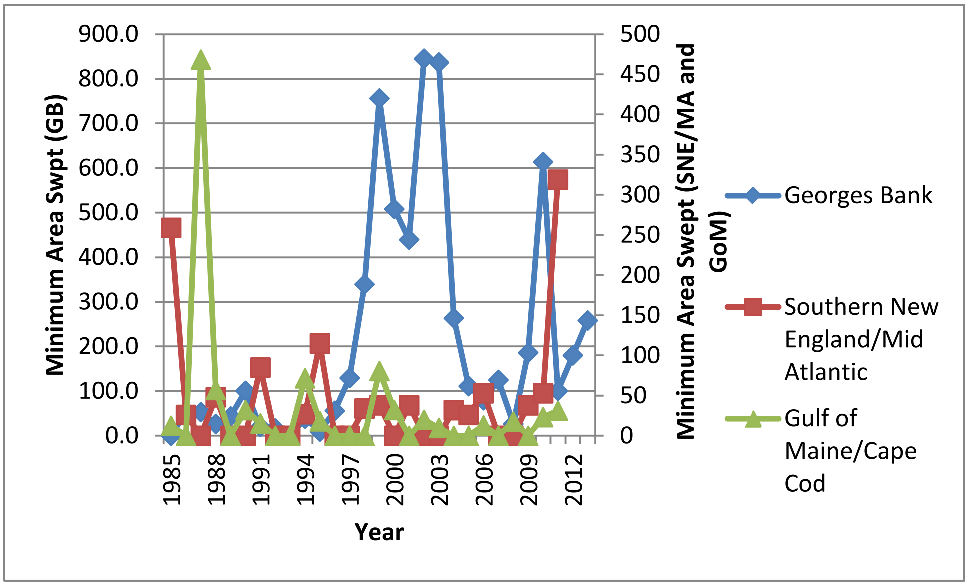

Figure 15. Minimum area swept estimates in thousands of fish for age-6+ by the NEFSC spring survey for Georges Bank, Southern New England/Mid Atlantic, and Gulf of Maine/Cape Cod yellowtail flounder, 1985-2013.

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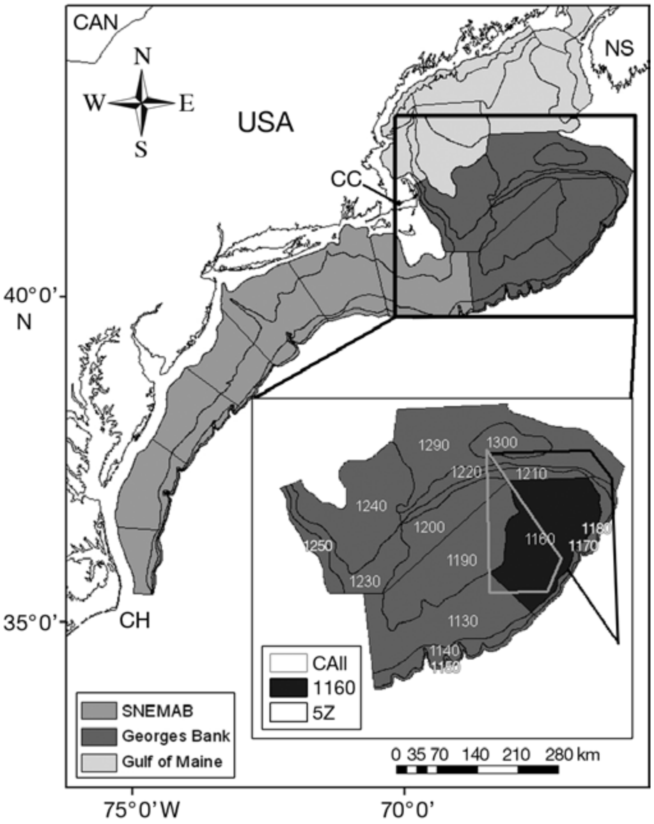

Figure 16. Distribution of habitat suitable for yellowtail flounder (Pereira et al. 2012)

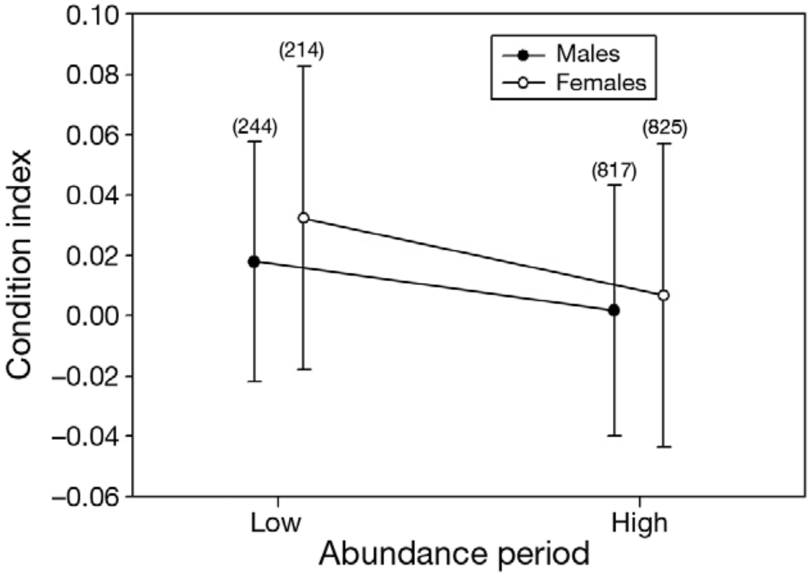

Figure 17. Mean (±SD) condition indices for yellowtail flounder during low and high abundance periods, fall and spring data combined. Sample size in parentheses. The difference is significant for females, but not for males. Reprinted from Pereira et al. (2012).