Appendix 1 to the SAW52 Assessment Report.
The following is an excerpt from:

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SARC 52 SUMMARY REPORT

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Review Committee
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Appendix 1.

The Review Committee and NEFSC scientists developed a method at the meeting for combining information on winter flounder across regions to help inform the spawner-recruit relationships used in developing projections and Biological Reference Points. The method is described below and uses likelihood-based AIC methods to find a reasonable compromise between a spawner-recruit relationship based on combined data sources and the individual spawner-recruit estimates associated with the individual stocks of winter flounder. This method maximizes the fit to both the SNE/MA and GBK datasets while minimizing the differences between relationships in the adjoining regions.

FMSY, SSBMSY, and MSY were estimated using a spawner-recruit model applied over a range of values for steepness (defined as the slope of the stock recruitment curve near the origin). It was assumed, based on the biology of the species, that steepness should be similar between the different stocks. These stocks are neighbouring populations of the same species that share common reproductive strategies. Fecundities at size are similar, although larval survivorship and recruitment to the fishery may vary between areas. Because the data available for any one stock may not be sufficient to fully parameterize a spawner-recruit relationship, some method of bringing additional information to bear on the estimates would be useful. Initially estimates of steepness from the work of Myers et al. (1999) were used as a prior for estimating the spawner-recruit relationship, but because the Myers et al. data include only more distantly related Pleuronectids than those present in these assessments it was felt that some way of using information available in the adjacent stocks would be more appropriate.

The objective was to find values of steepness chosen to be as similar as possible between stocks within the constraints of the information content available within each stock. A strategy was outlined that allowed the steepness parameters to be chosen among a range of values that provided reasonable fits to the spawner-recruit data for each individual stock, but were also reasonably close in the parameter space to each other. A profile of ΔAICs for each spawner-recruit model was developed from each of the two available stocks. The profiles are provided in Figure 1 below. It was considered that values of steepness associated with the AIC values that are within 2 units of the minimum AIC for each stock would be within a range of realistic values (Burnham and Anderson, 2002).

Once the profiles were generated, the fit for a given stock that resulted in the AIC that was closest to the minimum AIC value from the opposite stock was chosen within the constraint that the choice was not outside the ΔAIC = 2 bound for the given (original) stock's minimum fit. For the SNE stock this means steepness was set at the largest value possible within ΔAIC = 2 of its minimum fit (steepness = 0.61). For the GBK stock this means steepness was set at the smallest value such that ΔAIC = 2 of its minimum fit (steepness=0.78). Thus, the model estimates were shrunk towards each other, making steepness as similar as possible without losing the stock specific characteristics of the recruitment process.

The BRP estimates derived for the winter flounder stocks based on the spawner-recruit relationship specified in this way are direct MSY-based estimates and we believe are the most appropriate for use in informing management decisions at this time.

Burnham, K. P., and Anderson, D.R. 2002. Model Selection and Multimodel Inference: A Practical Information-Theoretic Approach, 2nd ed. Springer-Verlag.

Myers, R. A., Bowen, K. G., Barrowman, N. J. 1999. Maximum reproductive rate of fish at low population sizes. Can. J. Fish. Aquat. Sci. 56: 2404-2419.

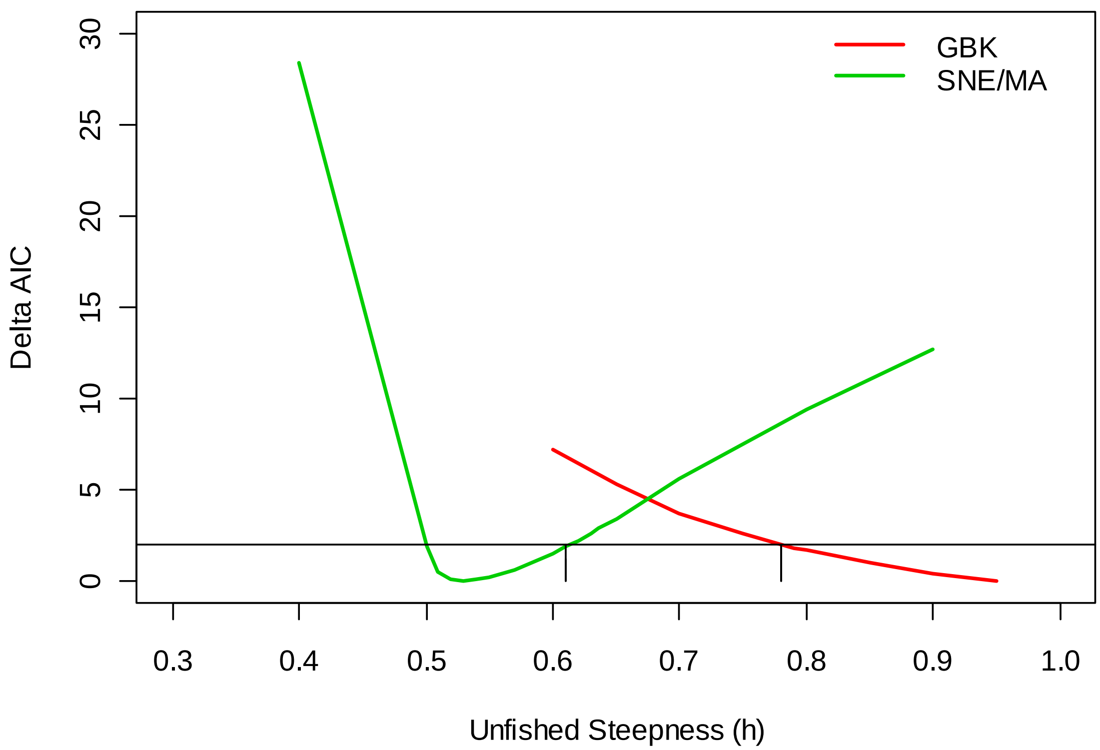

Figure 1. Delta AIC (AIC – min(AIC)) for each region's fitted spawner-recruit relationship over a range of fixed steepness parameter values. The curves correspond to the AIC values from the fits for the two regions (Georges Bank and Southern New England / Mid-Atlantic). The black horizontal line corresponds to the Delta AIC threshold of 2. Steepness values corresponding to an AIC below 2 are not considered statistically different from one another with a region. The vertical black lines show the locations of the most similar steepness parameters that are still within the range of best estimates for each model. The steepness values corresponding to this criteria are 0.61 for SNE/MA and 0.78 for GBK.

Appendix 2 to the SAW/SARC-52 Assessment Report.

[SAW52 Editor's Note: This Appendix 2 contains many, but not all, of the Working Papers that were developed and/or considered by the SAW Working Group during its meetings before the SARC peer review. As such, these WPs do not necessarily contain final results. They are included to serve as background materials to the final Assessment Report.]

Quick List of WP's in Appendix 2:

1. Stock structure
2. Survey strata sampling
3. Fish maturity schedule
4. Stock structure
5. Catch allocation
6. Management regulations
7. Length-based survey calibration
8. Fish maturity methods

9a. and 9b. VMS stock apportionment

10. Industry-based survey
11. Discard rate estimates
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16. Biological Reference Points and stock vulnerability (also called WP_D_16)
17. SCAA Model - SNEMA (Rademeyer and Butterworth)
18. SCAA Model Update - SNEMA (Rademeyer and Butterworth)
19. SCAA Model - GOM (Rademeyer and Butterworth)

An Interdisciplinary Assessment of Winter Flounder (*Pseudopleuronectes americanus*) Stock Structure

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Abstract

An interdisciplinary review was undertaken to evaluate the stock structure and management of winter flounder (*Pseudopleuronectes americanus*) throughout its geographic range in the northwest Atlantic. Information on morphology, tagging studies, genetics, larval dispersal, life history traits, environmental signals and meristics was considered. In the coastal waters of the United States, winter flounder are managed as three separate units; Georges Bank, Gulf of Maine and Southern New England/Mid-Atlantic. In Canadian waters, winter flounder are managed as three units: western Scotian Shelf (NAFO Div. 4X), eastern Scotian Shelf (NAFO Div. 4VW), and the southern Gulf of St. Lawrence (NAFO Div. 4T). Estuarine spawning, which likely plays an important role in reproductive isolation and population structure, is non-existent on Georges Bank and Browns Bank, variable in more northern habitats and may be obligate in southern New England. Contingent groups are likely present in several regions, and merit further research. Despite evidence for local population structure, information from tagging, meristic analysis, and life history studies suggest extensive mixing within stock units, thereby supporting the current U.S. management regimen. Genetic analysis and parasite markers indicate that Canadian management units are distinct. However, examination of inshore and offshore winter flounder within division 4X suggests little interchange occurs between these groups. Based on their distribution and life history traits, several flounder stocks likely exist within the 4T management area. A stock composition analysis of mixed-stock fisheries would be useful to facilitate the management and assessment of winter flounder in both U.S. and Canadian waters.

Introduction

Accurate stock assessment and effective fishery management requires identification of self-sustaining groups within species. Stock identification involves interdisciplinary analysis of life history information, genetics, geographic variation of phenotypic traits, movement and environmental signals (Cadrin, et al., 2005). Advances in several of these disciplines warrant reanalysis and re-evaluation of stock structure as new information arises (Begg and Waldman, 1999).

Although stock identification techniques have been used in fisheries science for over a century, no consensus has been reached on how to best define a unit stock (Waldman, 2005a). Early definitions of the term stock were based on utilization by fisheries. More recent definitions of fish stocks have focused on demographics, and imply that a degree of spatial and temporal discreteness is needed for a stock to evolve (Waldman, 2005a). Hilborn and Walters (1992) defined a stock as an arbitrary group of fish large enough to be essentially self-reproducing, with members of each group having similar life history characteristics. Booke (1981) stated that socks can have either a genetic basis or a phenotypic basis, in which the expression of life history characteristics are dependent upon the environment.

Stock assessment models assume that individuals within a stock exhibit homogenous vital rates and life cycle closure (Cadrin et al., 2005). Therefore, well informed stock boundaries are necessary to manage and assess fish stocks accurately. For example, if two distinct biological stocks are managed as a single unit, a common catch limit (or Total Allowable Catch) may lead to the overexploitation of the less productive component, and the under utilization of the more productive component (Ricker, 1958). Problems with assessment models can also arise (i.e., retrospective patterns), when landings from a fishery are classified to the wrong stock area.

Stock identification studies that utilize multidisciplinary methods typically produce the most accurate results (Coyle, 1998). Certain approaches (i.e., meristics and microsatellite markers) can be used to detect for differences in fish stocks that may have arisen in the recent past, while other techniques (i.e., allozymes, coding DNA) are more conservative, and require longer periods of isolation to become recognizable between different stocks. An interdisciplinary approach also creates a more robust baseline, making more techniques available for use in subsequent stock composition analyses.

Winter flounder are found in coastal waters (0-125m) of the Northwest Atlantic from North Carolina, northward to Newfoundland (Figure 1; Bigelow and Schroeder, 1953; McCracken, 1963; Pereira et al., MS 1999; Collette and Klein-MacPhee, 2002), and the distribution of this species is centered between New Jersey and Nova Scotia (Perlmutter, 1947). Winter flounder are managed as three stocks in U.S. coastal waters; Gulf of Maine, Georges Bank, and Southern New England/Mid-Atlantic (SNE/MA; Figure 2; NEFSC 2003). The winter flounder resource is managed as three units in Canadian waters (Figure 3): (1) Browns Bank, St. Marys Bay and Bay of Fundy winter flounder are managed concurrently in NAFO Div. 4X; (2) winter flounder from the Scotian Shelf and points eastward are managed together in NAFO Div. 4VW; and (3) winter flounder are managed as one unit in the Southern Gulf of St. Lawrence in NAFO Div 4T. Winter flounder are present in coastal waters around Newfoundland (NAFO Div. 3), but due to sparse data and a limited directed fishery, this species is not managed under a catch limit in this area (DFO, MS 1996).

The stock structure of winter flounder has been investigated since the early 1900's (e.g., Kendall, 1912; Lobell, MS 1939). Early research on winter flounder was focused primarily on migration, life history rates and analysis of meristic characters. Over time, more disciplines such as genetics, parasitic characters and hydrodynamic modeling were used to investigate winter flounder stock structure. Currently, newer methods such as otolith chemical analysis (Jackman et al., MS 2010) and telemetry tagging are being used to better understand the stock structure of winter flounder.

The objective of this review is to synthesize information on the stock structure of winter flounder (*Pseudopleuronectes americanus)* throughout its geographic range by reviewing benchmark case studies from a variety of disciplines. The synthesis is used to assess the appropriateness of current management protocols in both the United States and Canada, based on the available scientific information. In regions where stock boundaries are uncertain, opportunities for future research are discussed.

Review of Stock Identification Information

Life History Traits

Dispersal of early life stages- Winter flounder exhibit relatively isolated metapopulation structure in the bays and estuaries along the east coast of North America (Perlmutter, 1947; Saila, 1961). This species spawns adhesive and demersal eggs (Klein-MacPhee, 1978), which limits dispersion. Larvae are pelagic, and undergo metamorphosis after an average of two months in the water column (Chambers and Leggett, 1987). Larvae which are bottom-oriented and negatively buoyant, have been observed to be more abundant near the benthos (Pearcy, 1962; Klein-MacPhee, 1978).

Pearcy (1962) studied the Mystic River estuary in Connecticut, and found that while net transport in the estuary was seaward, transport in the bottom layers of the estuary was landward. Pearcy (1962) found that larvae can control their vertical position in the water column in relation to the tide, which will promote retention within estuaries and allow juveniles to settle in close proximity to their hatching site. Hydrodynamic modeling studies have estimated that rates of larval retention in estuaries is likely high (Crawford and Carey, 1985; Chant et al., 2000). Thus, estuarine spawning and nursery grounds appear to be closely linked (Pearcy, 1962; Pereira et al., MS 1999). However, the fate of larvae spawned in coastal and offshore areas is poorly studied, and warrants further attention (i.e., DeCelles et al., MS 2010).

Life History Traits- Population parameters such as growth and age at maturity can be used to distinguish among discrete stocks of fish because these parameters are phenotypic expressions of the interaction between genotypic and environmental influences (Begg, 2005). Life history parameters for winter flounder have been derived using both fishery dependent and fishery independent sources of data. Winter flounder exhibit faster growth rates in southerly latitudes, and females typically grow faster and attain larger sizes than males (Table 1).

Analysis of scale annuli patterns (Lux, 1973) and tagging data (Howe and Coates, 1975) found that winter flounder on Georges Bank exhibit faster growth rates than the SNE/MA and Gulf of Maine stocks. Results from a common garden experiment suggest that the rapid growth exhibit by Georges Bank winter flounder has a genetic basis (Butts and Litvak, 2007). Based on tag return data (Howe and Coates, 1975) and aged scale samples (Witherell and Burnett, 1993), flounder in the SNE/MA stock area have been shown to grow slightly faster than in the Gulf of Maine (Figures 4 and 5). However, Berry et al. (1965) calculated slower growth rates for winter flounder in Narragansett Bay, RI.

Growth rates of winter flounder in Canadian waters have a similar latitudinal gradient. Winter flounder have been observed to grow faster in the 4X stock area than in the 4T stock area (Figure 6). Growth rates within the 4T area are dynamic, as winter flounder in the northern Gulf of St. Lawrence (St. Lawrence Estuary) were shown to exhibit slower growth than flounder in the Southern Gulf of St. Lawrence (Figure 6; McCracken, 1954; Vaillancourt et al., 1985). Fraboulet et al. (2009) captured spawning flounder from three regions in Canada: Passamaquoddy Bay, Chaleur Bay, and the St. Lawrence estuary. Common garden experiments showed that larval growth rates had a paternal component, and that larvae sired by males from the St. Lawrence estuary exhibited the slowest growth rates.

Winter flounder exhibit a clinal gradient in maturity at age throughout their geographic range, with individuals maturing faster in more southerly latitudes (Collette and Klein-MacPhee, 2002). Estimates of age and size at 50% maturity of winter flounder are depicted in Table 2. Differences in the timing and location of spawning events are useful stock identification criterion because they can lead to reproductive isolation among stocks by reducing gene flow (Bailey et al., 1999). Winter flounder exhibit a latitudinal gradient in time of spawning. While peak spawning times vary interanually, spawning typically occurs earlier in southern latitudes (Table 3).

Morphology

*Meristics- F*in ray counts have been used to investigate stock structure in winter flounder. Geographic variation in meristic characters, such as fin ray counts, between different stocks of fish suggest that there is little interchange between these stocks, and that reproductive isolation is possible. Meristic characters are the products of interactions between the genetics of an individual and its environment (Waldman, 2005b).

Kendall (1912) found that winter flounder from Georges Bank possessed significantly more fin rays than those from inshore regions, and initially described these offshore specimens as a new species (*P. dignabilis*). He also noted other morphometric differences, and described Georges Bank winter flounder as possessing shorter heads, different coloration and larger sizes than flounder taken inshore. Perlmutter (1947) calculated that winter flounder from the Georges Bank stock had significantly more anal, dorsal and pectoral fin rays than flounder from the SNE/MA and Gulf of Maine stocks areas. Lux et al. (1970) obtained similar findings for Georges Bank flounder using anal and dorsal ray counts. Lux et al. (1970) reported that adult winter flounder from the SNE/MA stock area had significantly more fin rays than those sampled from the Gulf of Maine. Pierce and Howe (1977) sampled young over the year winter flounder at 23 estuarine locations throughout Massachusetts waters. They also concluded that winter flounder in the SNE/MA stock possessed more fin rays than flounder in the Gulf of Maine. However, Pierce and Howe (1977) did not detect any significant differences in fin ray counts between estuaries, suggesting that individual estuaries do not contain unique stocks.

Environmental signals

Patterns of parasitic infestation- Parasites can be useful tools in stock identification studies. If a fish becomes infected with a parasite that has a known endemic range, it can be inferred that the fish was within that range within the life span of the parasite (MacKenzie and Abaunza, 2005). When groups of fish have unique parasitic characters, it can be inferred that there is limited movement of individuals between those groups.

Scott (1982) examined parasitological differences between winter flounder in the southern Gulf of St. Lawrence (NAFO area 4T) and the western Scotian Shelf (NAFO area 4X). Significant geographic variation was found between the two areas for three parasite species; *Derogenes varicus, Fellodistomum furcigerum* and *Lecithaster gibbosus*. Scott (1982) concluded that based on these parasitological characteristics, winter flounder in the Gulf of St. Lawrence and those on the western Scotian Shelf constitute separate stocks.

McClelland et al. (2005) examined 189 adult winter flounder from four geographic regions: St. Marys Bay, Georges Bank, Browns Bank, and Sable Island Bank. Seven parasite species were examined, including five species of digeneans and two species of larval nematodes. Individual fish could be identified to their sampling site with an 84% overall classification accuracy using a discriminant function analysis. Parasite characteristics provided evidence that the Georges Bank stock was distinct from groups of winter flounder in adjacent Canadian coastal waters.

Biochemical analysis- Similar to parasitic infestation, chemical contaminants can serve as acquired marks and be used to infer isolation or mixing among groups. Carr et al. (1991) sampled winter flounder at a polluted site (Boston Harbor, MA) and a relatively pristine control site (Plymouth Bay, MA). Carr et al. (1991) measured several biochemical parameters for each group of fish and found that about 50% of the fish collected in Boston Harbor had apparent apoptotic hepatic lesions (AAHPC), while lesions were not detected in any of the fish collected from Plymouth Bay. Other biochemical parameters (i.e., amino acid concentrations, glycogen levels) were also differed significantly between the two sites. Given the significant differences in chemical contamination between the two groups of sampled fish, it can be inferred that little or no interchange occurs between the two areas, despite their geographic proximity.

Gardner et al. (1989) examined the prevalence of liver disease in winter flounder collected at eight locations in the SNE/MA and Gulf of Maine stock areas. Flounder sampled offshore in the SNE/MA area (Martha's Vineyard) had low rates of liver disease (9%) while flounder from inshore locations such as New Bedford Harbor (57%) and Narragansett Bay (31-63%) had greater incidence of liver disease. In the Gulf of Maine stock, liver disease was prevalent in flounder sampled form Boston Harbor (83%), and less frequent in flounder captured in Cape Cod Bay (22%). While these studies were not conducted for stock identification purposes, chemical biomarkers have potential application to be used in examining stock boundaries for winter flounder.

<u>Genetic analysis</u>

Microsatellite Analysis- Microsatellite characters are currently the most suitable genetic tools used for stock identification research. Microsatellites have high genetic variation that can be detected at individual loci, can be analyzed relatively easily and there are a large number of loci that can be screened (Wirgin and Waldman, 2005).

Microsatellite studies of winter flounder in Canadian waters revealed the existence of at least four distinct stocks (McClelland et al., 2005). Mature winter flounder were sampled from four geographic locations; Georges Bank, Browns Bank, Sable Island Bank and St. Marys Bay, and analyzed using four microsatellite loci. The Georges Bank sample was found to be the most genetically distinct, while the Browns Bank and Saint Marys Bank samples had the least genetic dissimilarity. Fish were classified to their capture site with 86-96% accuracy using a discriminant function analysis.

Crivello et al. (2004) sampled winter flounder larvae from three spawning areas (Niantic, Thames and Westbrook rivers) in Long Island Sound, NY. Of the 18 tests conducted (six microsatellite loci at three sampling locations), 13 were found to deviate from the expected Hardy-Weinberg equilibrium. In addition, these differences were geographically based, with the greatest amount of genetic differences observed between the two most distant groups, and the least amount of difference between the two closest groups. These results suggest that local populations of winter flounder along the coats may be at least partially isolated from one another.

Gene expression- Fletcher and Smith (1980) and Fletcher et al. (1985) examined the timing of antifreeze protein formation and termination exhibited by winter flounder in four locations: Long Island, NY; Nova Scotia; Passamaquoddy Bay; and Newfoundland. Their research found that the timing of gene expression differed in populations between the four regions, and suggested that these differences may be genetically based, implying that the populations are distcinct. Hayes et al. (1991) analyzed the copy number and arrangement of antifreeze protein genes in winter flounder from nine locations. A large copy number for the antifreeze protein gene was found in flounder sampled from locations where ice or low temperatures commonly occur (Shinnecock Bay, Bay of Fundy and Newfoundland). In areas where winter temperatures are warmer (Passamaquoddy Bay, Georges Bank, and Browns Bank), the copy number for this gene was reduced. In addition, Browns Bank and Georges Bank flounder had dissimilar copy numbers and tandem components, suggesting that these groups were genetically distinct, despite their close geographic proximity. However, the results of Hayes et al. (1991) should be considered with caution, because only one fish was sampled from each location.

Seasonal Movements and Applied Marks

Tagging studies can provide important insight into the stock structure of marine fish. Movement data obtained from tagging can be used to estimate the geographic ranges of different stocks, the physical and environmental boundaries that restrict movement between groups, and the rates of interchange between individuals in different stock areas. Groups of fish that are discrete in time or space are managed more appropriately as a single unit. However, if multiple groups of fish exhibit overlapping distributions, they are typically managed more appropriately as a single stock.

Mark-recapture studies have provided evidence that winter flounder exhibit spawning site fidelity (Perlmutter, 1947; Saila, 1961; Danila and Kennish, MS 1982; Scarlett and Schneider, MS 1986; Phelan, 1992). For example, Perlmutter (1947) tagged winter flounder from New Jersey to Maine, and divided the tagging area into ten strata for analysis. Ninety four percent of tagged individuals were recaptured within the stratum in which they were tagged, and limited movement was observed during the spawning season. Phelan (1992) also found evidence for fidelity of individuals tagged within the Inner New York Bight, as many individuals were recaptured in close proximity to their release location (i.e., spawning site) after over 100 days at liberty.

The seasonal movement patterns of winter flounder vary between the three U. S. stocks. Seasonal movements in the Gulf of Maine are typically localized and confined to inshore waters (Perlmutter, 1947; McCracken, 1963; Howe and Coates, 1975). Coates et al. (MS 1970) reported that the mean displacement of tagged individuals in the Gulf of Maine was only 5.1km. In the Gulf of Maine, adults are typically found in deeper coastal waters during the winter months, and move inshore to shallow coastal waters in the spring as temperatures increase (Bigelow and Schroeder, 1953; Howe and Coates, 1975; DeCelles and Cadrin, 2010).

Winter flounder in the SNE/MA area undergo more extensive migrations, typically leaving shallow bays and estuaries in the spring and summer months as water temperatures increase above 15^{o}C. Several tagging studies documented a general trend for SNE/MA flounder to disperse to the south and east during the summer months (Perlmutter, 1947; Saila, 1961; Howe and Coates, 1975; Powell, 1989; Phelan, 1992). During these migrations, some flounder in the SNE/MA stock will move short distances to cooler coastal waters, while others have been observed making longer migrations. For example, Powell (1989) observed that some adult flounder tagged in Narragansett Bay dispersed eastward to Nantucket Shoals and the waters south of Marthas Vineyard. During the summer and fall migration, members of the localized inshore groups of winter flounder in the SNE/MA stock intermix in coastal waters, a phenomenon described by Phelan as a "dynamic assemblage". Based on tag-recapture data the mean displacement of winter flounder tagged in the SNE/MA stock area was 26.5km (Coates et al., MS 1970). Flounder on Georges Bank remain offshore year round (Howe and Coates, 1975), and seasonal movement patterns on Georges Bank are difficult to distinguish (Coates et al., MS 1970). Individuals in the Georges Bank stock are not dependent upon estuaries to complete their life cycle.

Tagging studies have shown that the rate of interchange between the three U. S. stocks is low. Howe and Coates (1975) found that only 1.7% of tagged flounder moved between the Gulf of Maine and the SNE/MA area, and that little interchange (0.49%) exists between the SNE/MA and Georges Bank stocks. These findings suggest that the three management units of winter flounder in U.S. coastal waters are relatively discrete, and that reproductive isolation is likely between these stocks.

Tagging studies provide evidence of contingent structure in the SNE/MA and Gulf of Maine winter flounder stocks. Contingents are cohesive groups of fish within a population that exhibit a common migration pattern (Cadrin and Secor, 2009). Contingent migrations may make a stock more resilient to overfishing, increase genetic diversity and cause variable susceptibility to anthropogenic impacts (Secor, 1999; Hilborn et al. 2003). Contingent structure within winter flounder stocks warrants further research, and contingent structure should be considered in management and designations of Essential Fish Habitat.

In the SNE/MA stock, evidence of contingent structure has been observed using mark-recapture experiments. Historically, two groups of winter flounder were thought to be present off Long Island; a migratory group and a resident ("bay") group (Lobell, MS 1939; Perlmutter, 1947). Lobell (MS 1939) and Olla (1969) documented the presence of a resident group of flounder that remained in Great South Bay, NY throughout the summer, where temperatures were as high as 24^{o}C. A recent acoustic telemetry experiment (Sagarese, MS 2009) found evidence of a resident group of adult flounder, which remained in Shinnecock Bay during the summer, where temperatures reached 24^{o}C. Scarlett and Schneider (MS 1986) also found evidence for partial migration in winter flounder that were tagged in the Shark and Manasquan Rivers, NJ. In most years, tagged flounder in this region dispersed to deeper coastal waters during the summer months. However, in 1984, few offshore movements were observed, and nearly all flounder were recaptured in close proximity to the tagging sites.

There is some evidence to suggest that contingent groups of flounder may be spawning in coastal waters in the SNE/MA stock area. Phelan (1992) reported that some flounder tagged in the New York Bight were recaptured in coastal waters, rather than estuaries, during the spawning season. Phelan postulated that these individuals likely did not spawn offshore and were either late inshore spawners or possibly did not spawn at all to conserve body mass. More recently, Wuenschel et al. (2009) collected ripe fish off the coast of New Jersey, and suggested that in this region, some flounder may be spawning in coastal waters, rather than estuaries.

Contingent structure has also been recognized in some regions of the Gulf of Maine stock area. Based on tag return data, Howe and Coates (1975) suggested that groups of flounder may be spawning in coastal waters, rather than estuaries. Recently, acoustic telemetry has been used to study the movements and distribution of adult winter flounder. Acoustic telemetry allows the behavior of individual fish to be tracked with high spatial and temporal resolution, and allows for the recognition of contingent behavior (Secor, 1999). Using acoustic telemetry, DeCelles and Cadrin (2010) observed two contingents of winter flounder, which exhibited divergent spawning behavior. One contingent spawned in coastal waters, while another contingent was observed migrating to estuaries during the spawning period.

Fairchild et al. (MS 2010) tagged forty adult winter flounder with acoustic transmitters on the southern portion of Jeffreys Ledge. Acoustic receivers were deployed as gates across the mouths of six estuaries from Portsmouth, NH southward to the Annisquam River, MA. She found that the majority of tagged winter flounder remained in coastal waters during the spawning season, while a small number migrated to estuaries to spawn.

McCracken (1963) observed seasonal distributions of winter flounder in several regions of Canada. In St. Marys Bay and Passamaquoddy Bay, New Brunswick (NAFO Div. 4X) winter flounder dispersed to deeper water during the winter months, and gradually moved inshore to shallow water to spawn during the spring. During the summer months, some large fish dispersed to deeper waters in the bays, while other remained in the shallows. In Pubnico Harbor, Nova Scotia, McCracken (1963) found that flounders began to return to the shallow waters of the bay in April. During the summer months, adult flounder left the bay, and moved to coastal waters where water temperatures were cooler.

In the Gulf of St. Lawrence, winter flounder exhibit a patchy distribution. Trawl surveys have found this species to be abundant east and west of the Magdalen Islands, east of Prince Edward Island, in Northumberland Strait, in the Miramichi estuary, and Chaleur Bay (Morin et al., MS 2002). Based on tag return data, the seasonal movements of adult flounder in the Gulf of St. Lawrence appear to be limited (DFO, MS 2005). McCracken (1963) observed that in Northumberland Strait, mature flounder will overwinter in cool deep waters, move to shallow inshore areas in the spring, and return to deeper waters (15-24m) during the summer months. Trawl survey data shows that flounder appear to overwinter in deeper waters 10-20 km offshore of the Magdalen Islands (Hanson and Courtenay, 1996). In contrast, winter flounder appear to overwinter in the shallow waters of the Miramichi estuary in the southern Gulf of St. Lawrence (Hanson and Courtenay, 1996). Hanson and Courtenay (1996) reported that flounder began to enter the Miramichi estuary in late autumn, and overwintered in this habitat, where water temperatures were warmer than the Southern Gulf, and where a refuge existed from flowing ice packs. In spring as the salinity of the estuary was reduced by snow melt, adult fish left the estuary and migrated to spawning grounds in coastal waters.

Winter flounder appear to be common in near shore waters (<60 m) along the coast of Newfoundland and Labrador (Kulka and DeBlois, MS 1996), although its distribution in shallow water is not well sampled by commercial catches and trawl surveys. Kennedy and Steele (1971) observed that winter flounder in Long Pond, Conception Bay, Newfoundland exhibited seasonal distribution patterns that were similar those undertaken by winter flounder in the SNE/MA stock. Individuals remained inshore in shallow waters from September until June. After spawning in May and June adults migrated offshore to deeper waters to feed. Similar movement patterns were also observed by Van Guelpen and Davis (1979) in Conception Bay, where storm-induced turbulence or the formation of ice in shallow waters caused winter flounder to temporarily emigrate to deeper inshore waters. Results from a small-scale tagging study conducted by Van Guelpen and Davis (1979) indicated that flounder display a high degree of residence in Conception Bay.

In summary, tagging information suggests that limited mixing occurs between the current management areas. Seasonal movement patterns also vary by geographic region. South of Cape Cod, it appears that winter flounder mix in coastal waters in summer, but exhibit fidelity to estuarine spawning grounds in winter and spring. In more northern habitats, residence in estuarine habitats is variable, with some groups spawning on offshore banks, others wintering in estuaries, and others occupying estuaries briefly. Contingent structure appears to exist, because this species has been shown to exhibit divergent spawning behaviors and partial migration. These differences in spawning behaviors may have important implications for reproductive mixing or isolation among spawning groups.

Synthesis and Conclusion

Basis for Assignment of Management Stock Units in the United States and Canada

Prior to 1996, winter flounder were managed as four stock units in the U.S. waters of the northwest Atlantic: Mid-Atlantic, Southern New England, Georges Bank and Gulf of Maine. In 1996 (at the 21st Stock Assessment Workshop, SAW), the Southern New England and Mid- Atlantic groups were combined to form a single unit for assessment purposes (Shepherd et al., MS 1996). The decision to combine these stocks was primarily based on tagging data (Perlmutter, 1947; Howe and Coates, 1975; Phelan, 1992), which indicated that mixing of individuals occurred between these two stock areas. Life history traits (growth rate and length structure) were also observed to be similar between the two units.

The stock structure of Gulf of Maine winter flounder was also reviewed at the 21st SAW. The review concluded that sufficient interchange exists between populations of winter flounder in the Gulf of Maine to manage them as a single stock unit (Cadrin et al., MS 1996). The 28th SAW examined the stock structure of Georges Bank winter flounder and determined that based on (a) tagging data (Howe and Coates, 1975), (b) meristic analysis (Lux, 1973) and (c) differences in life history characteristics (Lux et al., 1970) that the winter flounder on Georges Bank should be managed as a separate stock.

The geographic distribution of winter flounder observed during Canadian summer research vessel surveys on the Scotian Shelf (Stobo et al., MS 1997; DFO, MS 1997) and in the Southern Gulf of St Lawrence (Morin et al., MS 2002; MS DFO 2005) provides the basis for the management units of flounder in Canadian waters. Winter flounder came under TAC management on the eastern (NAFO Div. 4VW) and western (NAFO Div. 4X) Scotian Shelf in 1994. Due to the lack of reliable landings statistics, yellowtail flounder, witch flounder, winter flounder and American plaice are managed concurrently under a single TAC on the Scotian Shelf (DFO, MS 2002b).

Winter flounder have been managed under a TAC in the southern Gulf of St. Lawrence (NAFO Div. 4T) since 1996, although the first assessment of this stock was conducted in 1994 (DFO, MS 2005). Several localized stock units (or partially isolated breeding populations) are thought to exist in the region based on geographic differences in resource survey abundance trends, but information to assess local stock units is limited (Morin et al., MS 2002). A sentinel trawl survey was initiated in 2003 to monitor the distribution and abundance of winter flounder in nearshore areas of the Gulf of St. Lawrence (DFO, MS 2005). Winter flounder are distributed in the coastal waters of Newfoundland (NAFO Div. 3), but are not managed under a TAC system due to continued data limitations (DFO, MS 1996).

Critique of Assigned Stock Units

The management of winter flounder fisheries in U.S. waters is generally consistent with the multidisciplinary information that is available on stock structure. In Canadian waters, stock structure may exist at finer spatial scales than are currently considered in management. Questions regarding the stock structure of this species in both U.S. and Canadian waters persist, despite past research. As stock identification techniques continue to develop and mature, new information may become available to manage and assess this species at finer spatial scales. The most useful information for managers will incorporate a holistic approach, with the goal of achieving congruent results from multiple disciplines (Begg and Waldman, 1999).

Several lines of evidence imply that winter flounder are appropriately managed as separate stock complexes in the SNE/MA and Gulf of Maine. Tagging studies (i.e., Perlmutter, 1947, and Howe and Coates, 1975) showed that patterns of seasonal migration vary dramatically between the two stocks. SNE/MA winter flounder exhibit faster growth than the Gulf of Maine stock (Figures 4 and 5), and spawn earlier in the year (Table 3). Additionally, meristic characters indicate that the flounder resources in these areas comprise disparate stocks (Perlmutter, 1947; Lux et al., 1970; Pierce and Howe, 1977).

While it is likely that localized population structure exists in the SNE/MA stock, it would be practically impossible to identify and manage each of these units as a discrete entity. In this region, most commercial fishing effort occurs when adult fish from each localized stock are mixed in coastal offshore waters. In stock composition analysis, individuals harvested in a fishery are examined to estimate the relative contribution of each stock to the biomass that is available for harvest in an area (Prager and Schertzer, 2005). Multiple approaches can be used for stock composition analysis (i.e., meristics, genetics and parasite characteristics), based on the differences that exist between disparate stocks. Stock composition analysis in the SNE/MA area would help to address questions regarding the relative contribution of each local population to the fishery harvest. In particular, stock composition analysis is needed in the Great South Channel and Nantucket Shoals. This region supported a historical trawl fishery that targeted cod and winter flounder during the summer and fall. Winter flounder are known to spawn on Nantucket Shoals (Pereira et al., MS 1999), and flounder tagged in this region appeared to remain on Nantucket Shoals and the Great South Channel throughout the year (Coates et al., MS 1970). Some winter flounder have been observed migrating from inshore areas to the Great South Channel and Nantucket Shoals during the summer months (i.e., Powell, MS 1989). Therefore, it is possible that flounder harvested in this region may represent a mixture of migrants from inshore populations in the SNE/MA area, as well as a resident component of flounder that spawn on Nantucket Shoals and the Great South Channel.

The Georges Bank stock should be managed as a single transboundary resource in the U.S. and Canadian waters of Georges Bank. Winter flounder in this area exhibit the highest growth rates (Figures 3 and 4) and the largest sizes (Table 1) throughout the range of the species. Fin ray counts (i.e., Lux et al., 1970) suggest that winter flounder on Georges Bank are discrete from other areas. Additionally, Georges Bank flounder exhibit little interchange with inshore stocks. Genetic studies examining gene expression (Hayes et al., 1991) and microsatellite markers (McClelland et al., 2005) suggest that Georges Bank flounder are distinct from those found on the western Scotian Shelf. Flounder on Georges Bank and the western Scotian Shelf also exhibit disparate parasite characteristics (McClelland et al., 2005).

Gulf of Maine winter flounder are the least studied of those in U.S. waters. Historical tagging data (Perlmutter, 1947; Howe and Coates, 1975) indicate that seasonal movements are limited, and that several local stocks may be present in the Gulf of Maine. New mark-recapture experiments would be help to investigate population structure in the Gulf of Maine. Tagging pre-spawning and spawning flounder throughout the Gulf of Maine would be an effective way to examine mixing rates between individuals in local spawning populations. Genetic analysis of spawning flounder using microsatellite markers would also be useful to reveal the degree of local stock structure that exists in the Gulf of Maine. At present, there is no research that distinguishes Gulf of Maine winter flounder from those found in inshore Canadian waters of the Bay of Fundy or the Scotian Shelf. In addition to tagging studies, data from trawl surveys may also be examined to detect any persistent differences in life history traits between inshore flounder populations in the northern Gulf of Maine and southern New Brunswick. Winter flounder in these regions may also be connected through larval dispersal. Coupled biophysical individual based models would be useful for examining the possibility of larval transport between the Gulf of Maine and the Scotian Shelf (e.g., DeCelles et al., MS 2010).

Contingent structure within flounder stocks warrants further investigation. Acoustic telemetry has shown promise in identifying contingent spawning and migratory behavior for this species (Sagarese, MS 2009; DeCelles and Cadrin, 2010; Fairchild et al., MS 2010). Coast-wide receiver arrays, which were proposed by Grotheus and Able (2007), would be a useful tool for examining the prevalence of costal spawning winter flounder groups. Evidence for coastal spawning could also be gathered using benthic ichthyoplankton surveys. Since winter flounder spawn adhesive and demersal eggs (Klein-MacPhee, 1978), spawning locations can be inferred from areas where eggs are sampled. Directed trawl surveys during the spawning season would also offer insight into the relative importance of coastal spawning in winter flounder stocks.

Management units of Canadian winter flounder are assigned on the basis of abundance patterns derived from resource surveys. These stock boundaries could be refined using a variety of complimentary stock identification techniques. Life history traits (such as growth and maturity), which are sampled during research surveys could be used to improve the resolution of stock boundaries. Other disciplines, such as genetics and meristics may also prove useful in the investigation of Canadian stock structure for this species.

Currently, all winter flounder in NAFO Div. 4X are managed under a single TAC encompassing four different flounder species (witch, yellowtail, plaice and winter flounder). However, evidence suggests that at least two stocks of winter flounder exist within the western Scotian Shelf (NAFO Div. 4X). McClelland et al. (2005) found that winter flounder on Browns Bank are distinct from those inhabiting St. Marys Bay based on microsatellite analysis and parasitic characteristics. In addition, Hayes et al. (1991) noted differences in the expression and copy number of antifreeze protein genes between Browns Bank winter flounder and those in the inshore areas of the Bay of Fundy. Additionally, data from the spring survey in the Scotian shelf has found evidence for a stock of winter flounder that spawn offshore on Browns Bank (Neilson and Hurley, MS 1986). A mark-recapture study could be used to look for movement between flounder on Browns Bank and inshore areas of the Scotian shelf. If limited interchange exists between these two regions, they may be managed more appropriately as separate stocks.

On the eastern Scotian Shelf (NAFO Div. 4VW), the distribution of winter flounder is restricted to Sable Island Bank. Analysis of parasitic characters and microsatellite markers suggest that flounder on the eastern Scotian Shelf are distinct from other Canadian stocks (Scott, 1982; McClelland et al., 2005). Based on the available literature, winter flounder in the 4VW region appear to be managed appropriately as a single stock.

Winter flounder in the southern Gulf of St. Lawrence stock (NAFO Div. 4T) are geographically isolated from other stock units, and analysis of microsatellite markers and parasite characteristics suggests the flounder in the Gulf of St. Lawrence are distinct from other stocks (McClelland et al., 2005). While multiple stocks of winter flounder are likely present in the southern Gulf of St. Lawrence, the resource is managed as a single stock due to data limitations (Morin et al., MS 2002). Winter flounder exhibit a patchy distribution throughout the region, indicating that several stocks may be present (Morin et al., MS 2002). Seasonal movements appear to differ between winter flounder in different regions in the Southern Gulf of St. Lawrence. For example, flounder in some regions (Miramichi estuary) overwinter in estuaries, while in other areas (Magdalen Islands) they occur in offshore waters during the winter (Hanson and Courtenay, 1996). Growth rates (Figure 6) vary substantially between flounder in the southern (Northumberland Strait) and northern (St. Lawrence estuary) Gulf of St. Lawrence, and common garden experiments suggest the slow growth exhibited by flounder in the St. Lawrence estuary may have a genetic basis (Fraboulet et al., 2009).

There are several methods available to investigate the fine-scale stock structure of winter flounder in the Gulf of St. Lawrence. Conventional tagging experiments could be used to determine whether interchange occurs between the local populations that are present in the Gulf of St. Lawrence. Information gathered from the sentinel trawl survey could also be used to look for persistent differences in life history traits between flounder from different regions of the 4T stock. Finally, microsatellite markets could be used to investigate fine-scale stock structure in the Gulf of St. Lawrence.

Interdisciplinary stock identification analyses provide researchers, managers, and assessment scientists with a more holistic perspective on the spatial structure of marine fish populations. Incorporating results from multiple disciplines increases the probability that stock boundaries will be assigned accurately (Hohn, MS 1997). Further, in many instances, disparate approaches (i.e., genetic and phenotypic) will yield complimentary information (Coyle, 1998).

More recent studies using advanced technology, such as acoustic telemetry, have revealed the presence of complex spatial structure in populations of winter flounder. Accounting for this spatial structure in fisheries management and stock assessment is challenging, and will require new analytical approaches (i.e., Cadrin and Secor, 2009). To manage winter flounder stocks with greater spatial resolution, concurrent advances in stock identification and stock assessment methodologies will be needed.

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List of Tables and Figures

Table 1.

Stock Area	Region	Sex	K	$L_{inf\ (cm)}$	t_0	Source
SNE/MA	Narragansett Bay, RI	Male	0.27	39.0	-0.23	Berry et al. (1965)
	Narragansett Bay, RI	Female	0.29	45.1	0.07	Berry et al. (1965)
	South of Cape Cod	Male	0.25	47.7	-	Howe and Coates (1975)
	South of Cape Cod	Female	0.34	48.8	-	Howe and Coates (1975)
	South of Cape Cod	Male	0.31	45.9	0.16	Witherell and Burnett (1993)
	South of Cape Cod	Female	0.31	49.0	0.25	Witherell and Burnett (1993)
Georges Bank	Eastern Georges Bank	Male	0.37	55.0	-0.05	Lux (1973)
	Eastern Georges Bank	Female	0.31	63.0	0.05	Lux (1973)
	Georges Bank	Male	0.37	53.4	-	Howe and Coates (1975)
	Georges Bank	Female	0.45	62.2	-	Howe and Coates (1975)
Gulf of Maine	North of Cape Cod	Female	0.37	45.5	-	Howe and Coates (1975)
	North of Cape Cod	Male	0.41	39.8	0.38	Witherell and Burnett (1993)
	North of Cape Cod	Female	0.27	49.0	0.07	Witherell and Burnett (1993)
4X	St. Marys Bay	Combined	0.34	43.9	0.35	McCracken (MS 1954)
	Scotian Shelf	Male	0.45	39.7	0.41	Neilson and Hurley (MS 1986)
	Scotian Shelf	Female	0.30	46.3	0.92	Neilson and Hurley (MS 1986)
4T	Northumberland Strait	Combined	0.25	40.2	0.38	McCracken (MS 1954)
	St. Lawrence Estuary	Combined	0.22	37.6	0.73	Vaillancourt et al. (1985)

Table 2.

Stock	A50 Males (y)	A50 Females (y)	L50 Males (cm)	L50 Females (cm)	Citation
SNE/MA	2.0	3.0	20-25	20-25	Perlmutter, 1947
	3.3	3.0	29.0	27.6	O'Brien et al., MS 1993
	3.1	3.0	28.0	28.3	Witherell and Burnett, 1993
Georges Bank	1.9	1.9	25.6	24.9	O'Brien et al., MS 1993
Gulf of Maine	3.3	3.5	27.6	29.7	O'Brien et al., MS 1993
	3.3	3.3	27.2	28.7	Witherell and Burnett, 1993
Gulf of St. Lawrence	-	-	21	24	DFO, MS 2010
Newfoundland	6.0	7.0	21.0	25.0	Kennedy and Steele, 1971

Table 3.

Stock	Nov	Dec	Jan	Feb	Mar	Apr	May	Jun	Citation
SNE/MA			****	****	XXXX	****			Pearcy, 1962
	****	****	****	****	****				Fairbanks et al., MS 1971
			****	****	XXXX				Buckley et al., 1991
					****	****			Monteleone, 1992
			****	XXXX	XXXX	****	****		Collette and Klein-MacPhee, 2002
Georges Bank						****	****		Kendall, 1912
						****	****		Bigelow and Schroeder, 1953
					****	****	****		Reid et al., MS 1999
Gulf of Maine					****	XXXX	****		Bigelow and Schroeder, 1953
					****	****			Lux and Kelly, MS 1982
						****	****		Normandeau Associates, MS 2009
					****	XXXX	****		Fairchild et al., MS 2010
Passamaquoddy Bay							****		McCracken, 1963
							****		Fraboulet et al., 2009
St. Lawrence Estuary								****	Fraboulet et al., 2009
Newfoundland					****	****	XXXX	XXXX	Kennedy and Steele, 1971
								****	Van Guelpen and Davis, 1979

Figure 1.

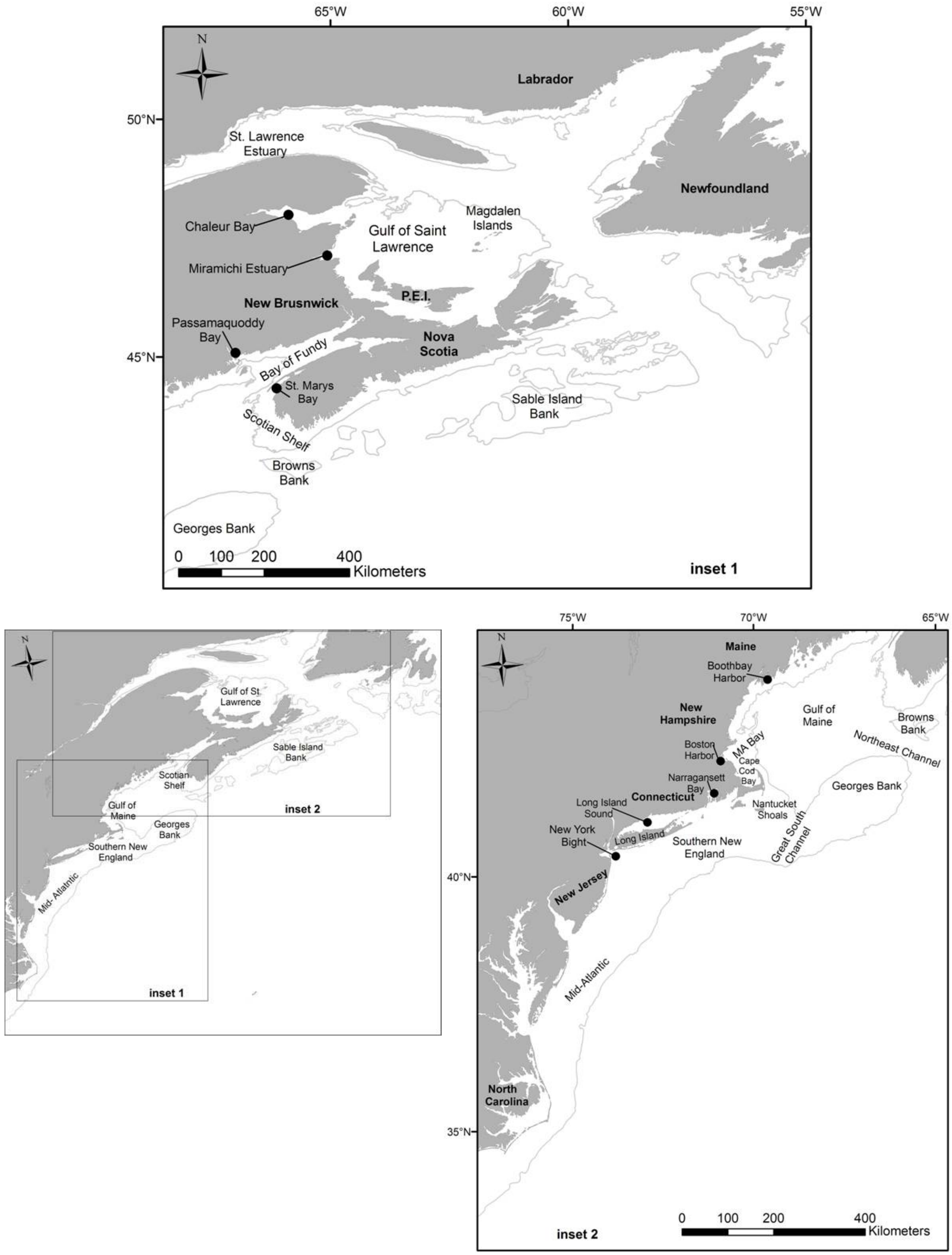
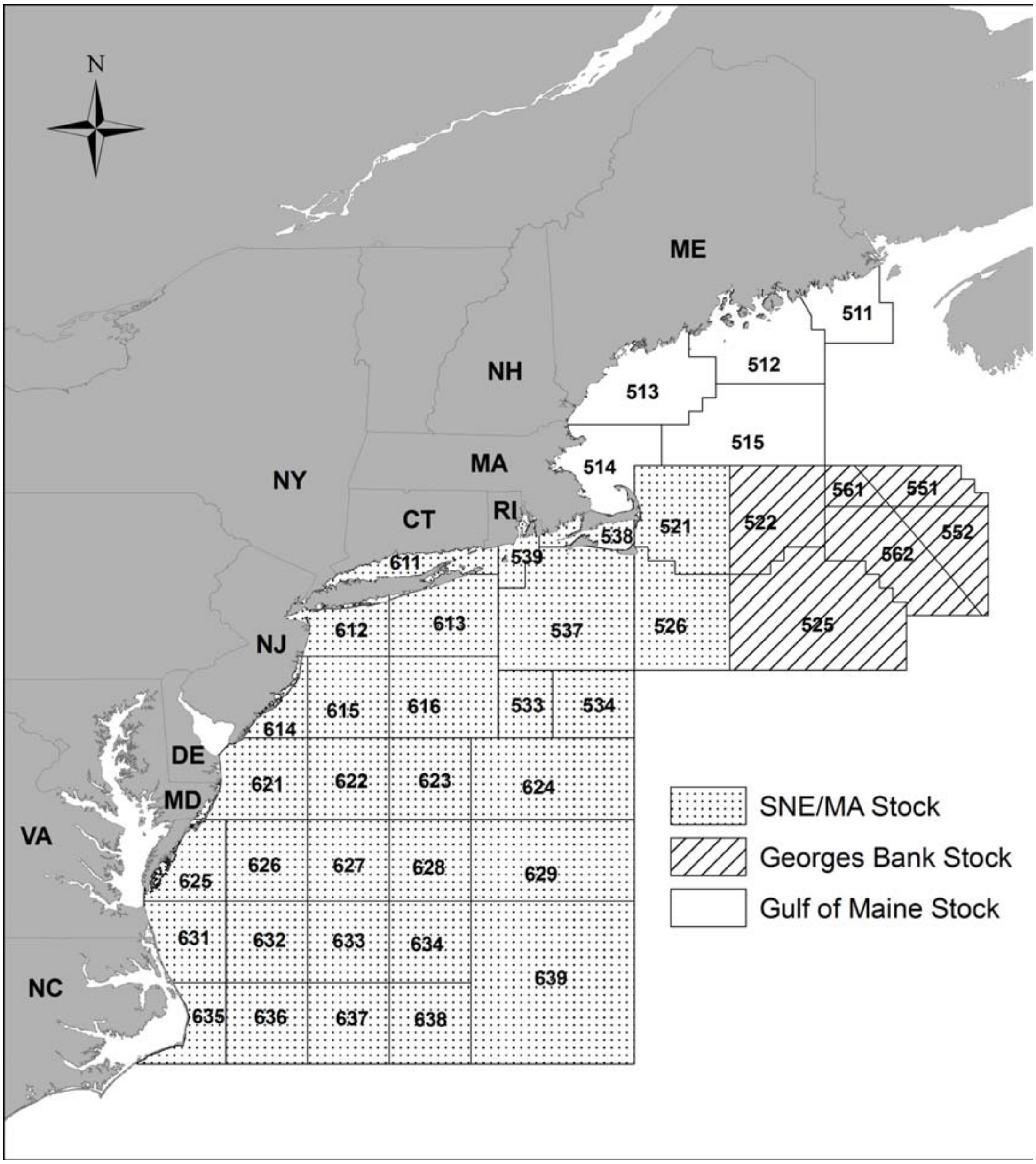

65°W
60°W
55°W
50°N
45°N
Labrador
St. Lawrence Estuary
Newfoundland
Chaleur Bay
Gulf of Saint Lawrence
Magdalen Islands
Miramichi Estuary
New Brusnwick
P.E.I.
Passamaquoddy Bay
Nova Scotia
Bay of Fundy
St. Marys Bay
Sable Island Bank
Scotian Shelf
Browns Bank
Georges Bank
0 100 200 400
Kilometers
inset 1
Gulf of St. Lawrence
Sable Island Bank
Scotian Shelf
Gulf of Maine
Georges Bank
Southern New England
Mid-Atlatnic
inset 2
inset 1
75°W
70°W
65°W
Maine
Boothbay Harbor
New Hampshire
Gulf of Maine
Browns Bank
Boston Harbor
MA Bay
Northeast Channel
Cape Cod Bay
Narragansett Bay
Connecticut
Georges Bank
Long Island Sound
Nantucket Shoals
New York Bight
Long Island
Southern New England
Great South Channel
40°N
New Jersey
Mid-Atlantic
North Carolina
35°N
inset 2
0 100 200 400
Kilometers

Figure 2.


N
ME
NH
NY
MA
CT
RI
NJ
DE
MD
VA
NC
511
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515
514
521
522
561
551
552
562
538
539
611
612
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537
526
525
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533
534
614
621
622
623
624
625
626
627
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632
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635
636
637
638
SNE/MA Stock
Georges Bank Stock
Gulf of Maine Stock

Figure 3.

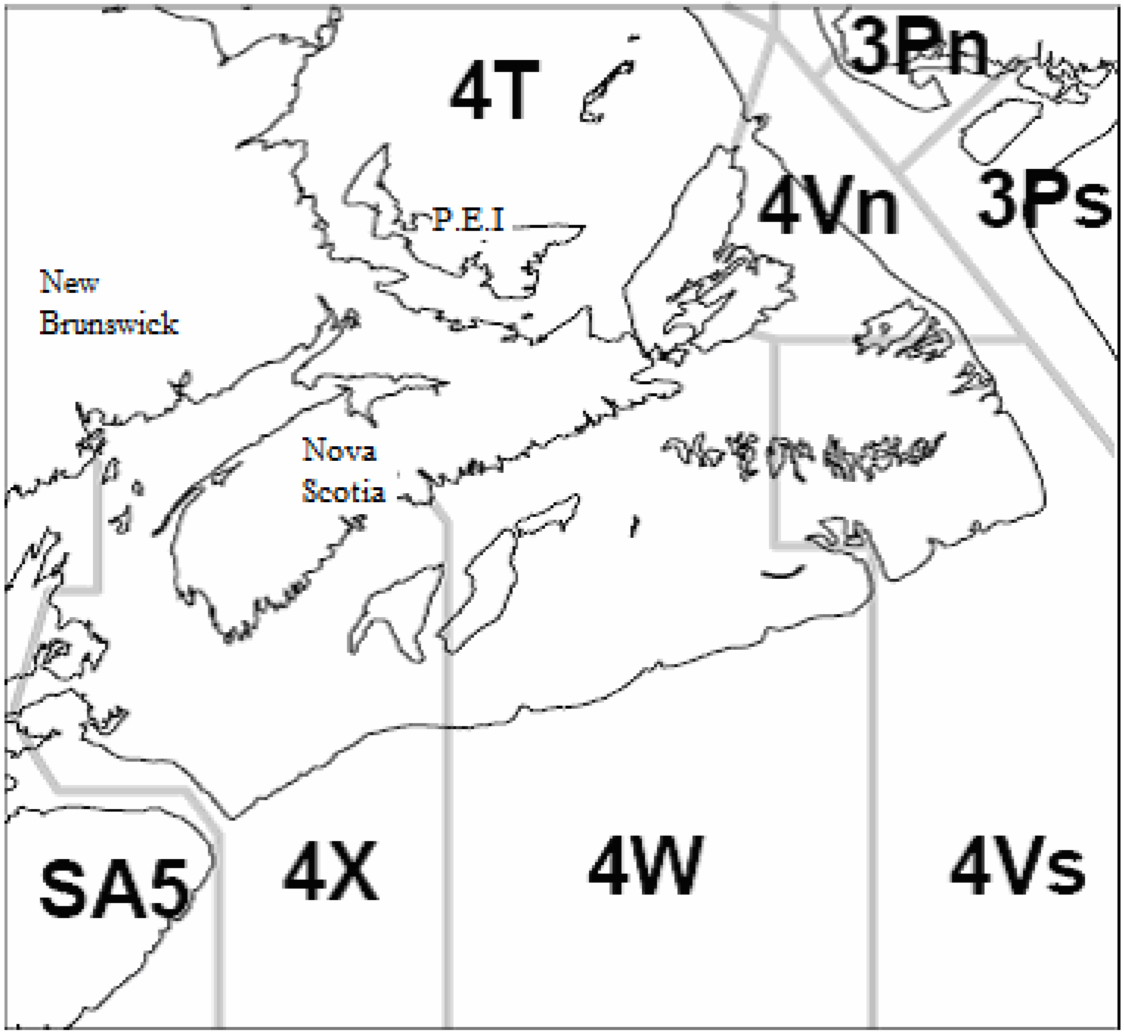
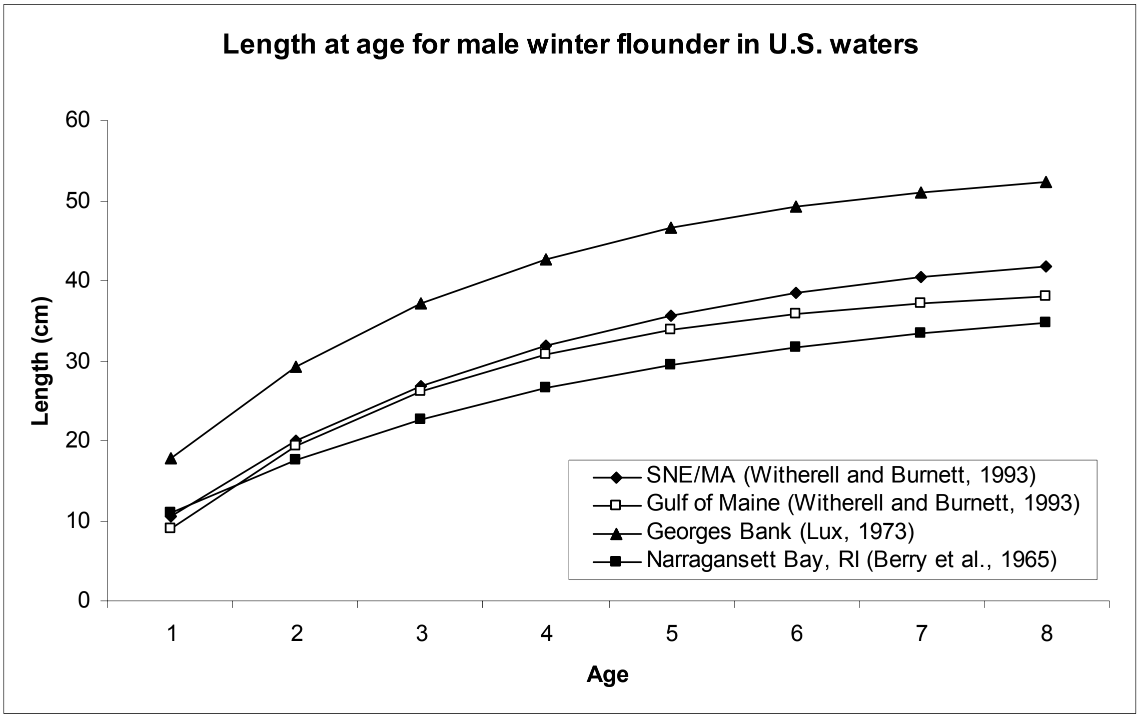


Figure 4.



Length at age for male winter flounder in U.S. waters
60
50
40
30
20
10
0
Length (cm)
1
2
3
4
5
6
7
8
Age
SNE/MA (Witherell and Burnett, 1993)
Gulf of Maine (Witherell and Burnett, 1993)
Georges Bank (Lux, 1973)
Narragansett Bay, RI (Berry et al., 1965)

Figure 5.

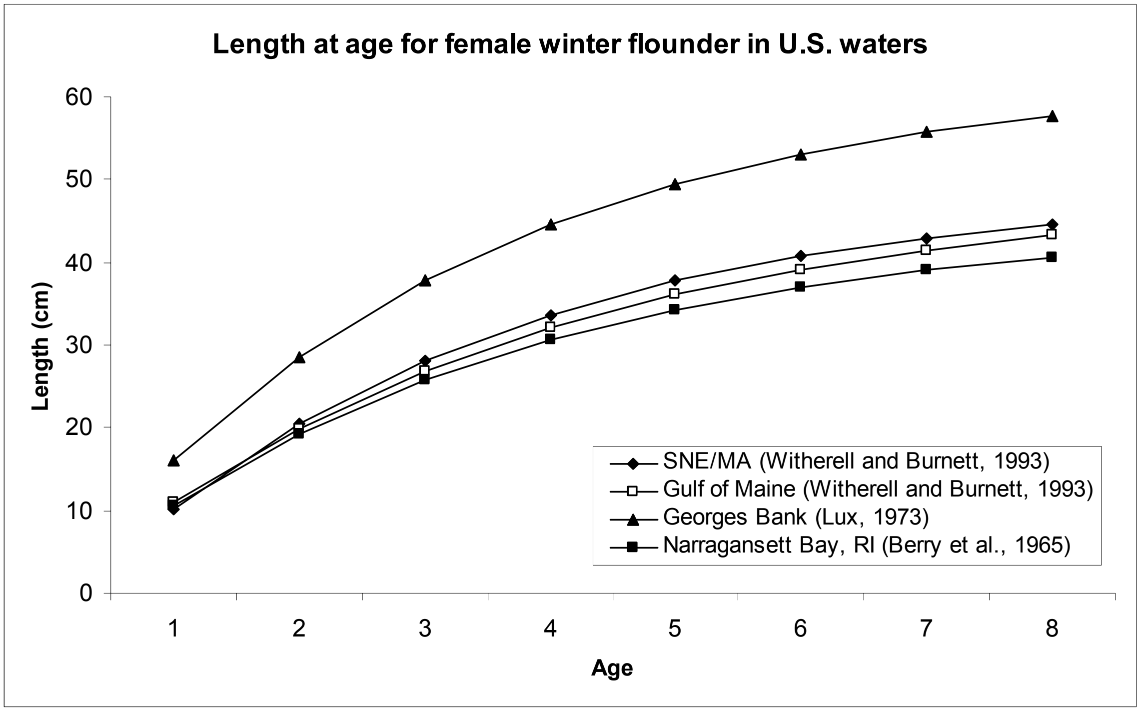
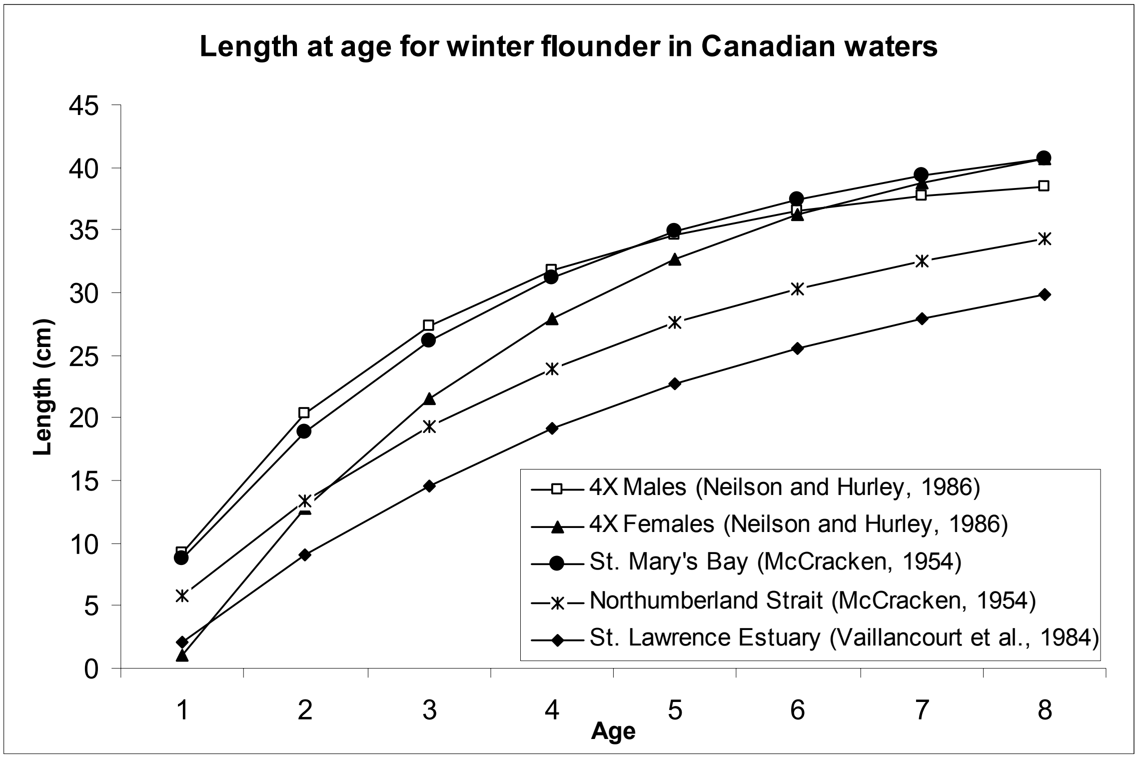

Length at age for female winter flounder in U.S. waters
Length (cm)
Age
0
10
20
30
40
50
60
1
2
3
4
5
6
7
8
SNE/MA (Witherell and Burnett, 1993)
Gulf of Maine (Witherell and Burnett, 1993)
Georges Bank (Lux, 1973)
Narragansett Bay, RI (Berry et al., 1965)

Figure 6.


Length at age for winter flounder in Canadian waters
Length (cm)
Age
4X Males (Neilson and Hurley, 1986)
4X Females (Neilson and Hurley, 1986)
St. Mary's Bay (McCracken, 1954)
Northumberland Strait (McCracken, 1954)
St. Lawrence Estuary (Vaillancourt et al., 1984)

Impacts of reduced inshore strata sampling on NEFSC trawl survey indices for SNE/MA winter flounder

Introduction

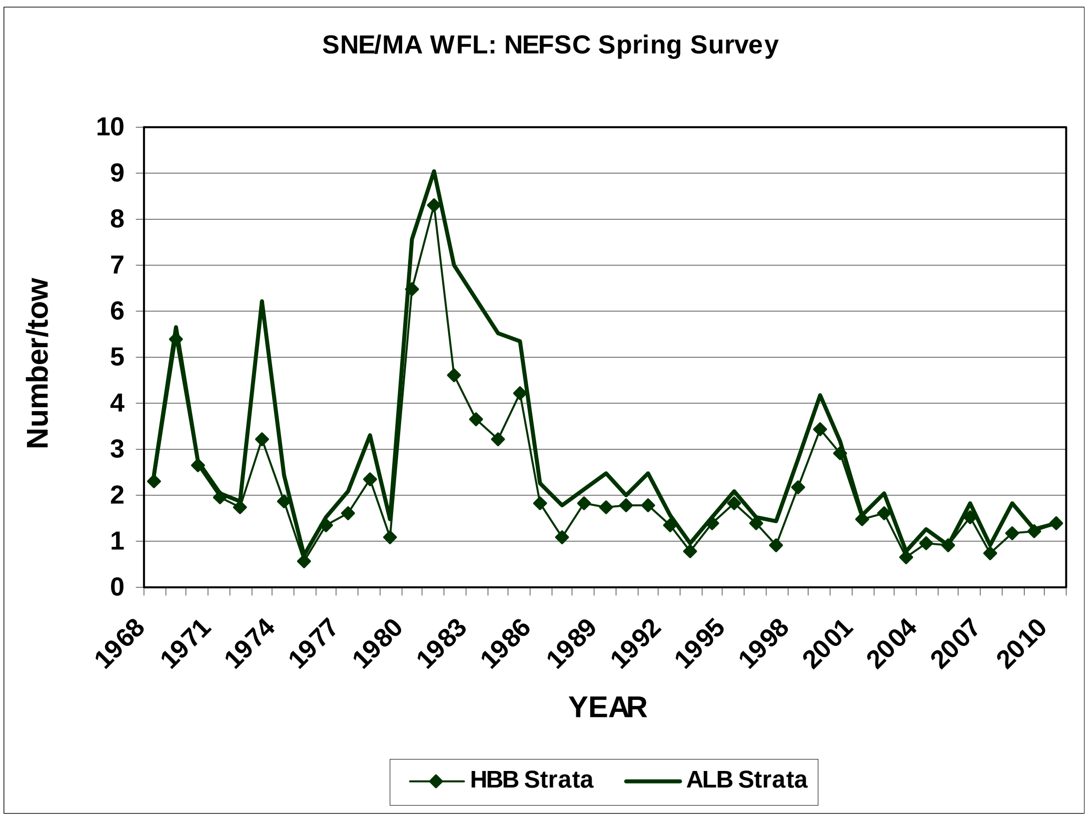
Important changes in the NEFSC bottom trawl survey that were implemented beginning with the 2009 spring survey have significant implications for the use of these data in stock assessments. Prior to 2009, multispecies bottom trawl surveys were conducted primarily on the NOAA FSV *Albatross IV* and infrequently on the NOAA FSV *Delaware II*. The 2009 and 2010 surveys were conducted using the NOAA FSV *Henry B. Bigelow.* The bottom trawl fishing gear used for sampling has also been changed. Prior to 2009, the survey was conducted with a Yankee 36 bottom trawl and 450-kg polyvalent trawl doors. Beginning in 2009, the survey now uses a 400 x 12, 4-seam bottom trawl with 550-kg PolyIce oval trawl doors. The survey towing speed was also changed, decreasing from 3.8 knots prior to 2009 to 3.0 knots beginning in 2009. The new towing speed was selected after extensive scope and tow speed trials conducted on both the FSV *Delaware II* and the FSV *Henry B. Bigelow* and consideration of the range of species to be sampled. The tow duration has also changed from 30 minutes (timed from when the winches were locked until they were reengaged) to 20 minutes of actual bottom time (as determined by net monitoring systems). The adjustments to both tow speed and tow duration have resulted in a decrease of average tow distance from 1.9 nautical miles prior to 2009 to an average tow distance of 1.0 nautical miles beginning in 2009 (Brown 2009).

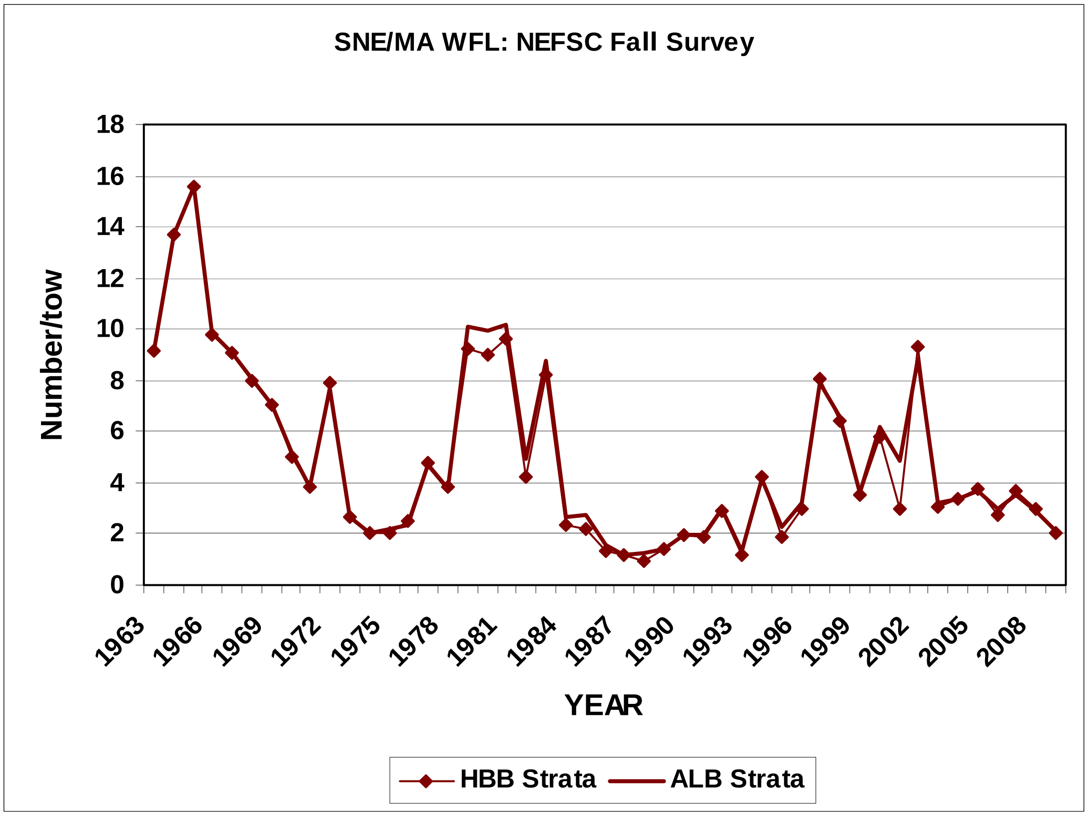
Station allocation also changed significantly due to an increase in total available vessel time from 48 to 60 sea days and a reduction in inshore sampling by the FSV *Henry B. Bigelow*. At the time that inshore strata in the mid-Atlantic were historically sampled (March), survey results indicate low densities of commercially and recreationally important species. These areas will continue to be sampled by the Northeast Area Monitoring and Assessment Program (NEAMAP) bottom trawl survey, although later in the year (late April – early May). As a result of station reallocation, station density was increased significantly in offshore strata that have historically demonstrated higher densities of fish particularly in the mid-Atlantic and southern New England regions (Brown 2009).

The change in station allocation impacts the strata set used in the SNE/MA winter flounder assessment, which has included inshore strata 1-29 and 45-56, in depths from about 10 to 27 meters (5 to 15 fathoms) from Outer Cape Cod to coastal Maryland, as well as offshore strata 1-12, 25, and 61-76. In 2009-2010 (and in the future), the FSV *Henry B. Bigelow* sampled only the deepest inshore strata, from 18 to 27 meters (10 to 15 fathoms). Inshore strata were first included in the SNE/MA winter flounder NEFSC spring indices beginning in 1973, when strata 1-29 and 45 were sampled. Throughout the time series, several inshore strata occasionally have not been not sampled, most often the shallowest strata on Nantucket Shoals (52), in Nantucket Sound (53, 54), east of Cape Cod (56), in Buzzards Bay (45, 51), in Rhode Island Sound (47), along Long Island, NY (3, 12), along coastal New Jersey (18, 21) and coastal Delaware (24, 27).

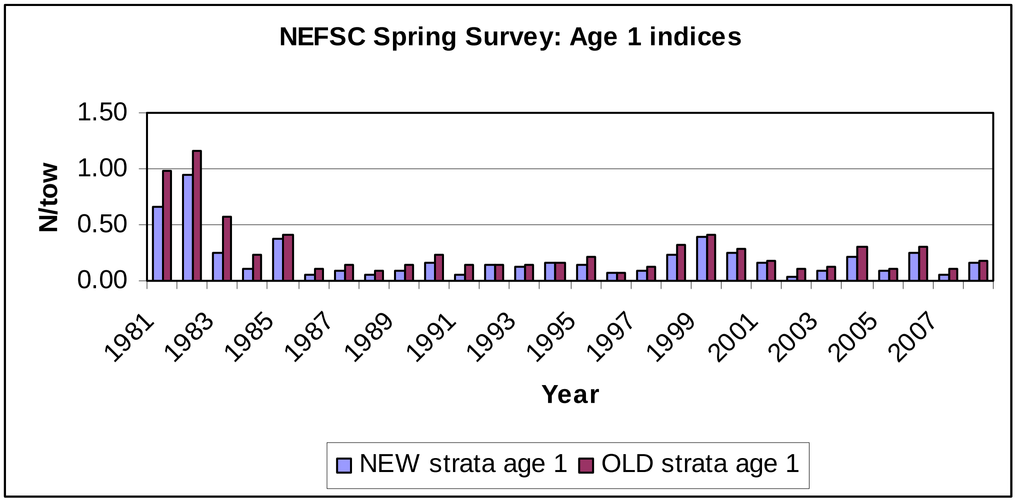
HBB vs. ALB strata set indices

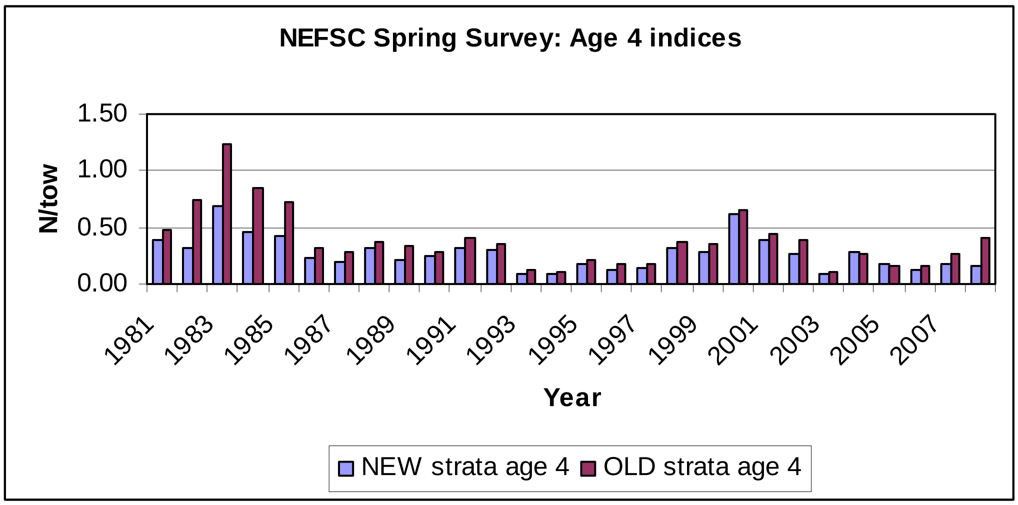
To examine the impact of the revised station allocation on the NEFSC spring and fall survey indices used for model calibration in the assessment (i.e., the 2008 GARM 3 1981-2007/2008 assessment ADAPT VPA model), indices from a new survey strata set including only the deepest inshore strata (HBB strata) were compared with those currently used (ALB strata) for 1981-2008. The following figures indicate that the differences in general are largest for the spring series and the absolute differences area largest during 1982-1985, when the HBB strata set indices average 35% lower than the ALB strata set indices (3.90 fish/tow compared to 6.03 fish/tow). Patterns in biomass indices (kg/tow) are very similar to those in the numeric indices. The strata that consistently account for the differences are inshore strata 1, 4, 7, 9 and 10 along Long Island; inshore strata 12 and 13 off Raritan Bay, NY; inshore strata 18, 19, 21, and 24 off southern New Jersey; inshore stratum 45 off Rhode Island; and inshore stratum 55 on Nantucket Shoals.

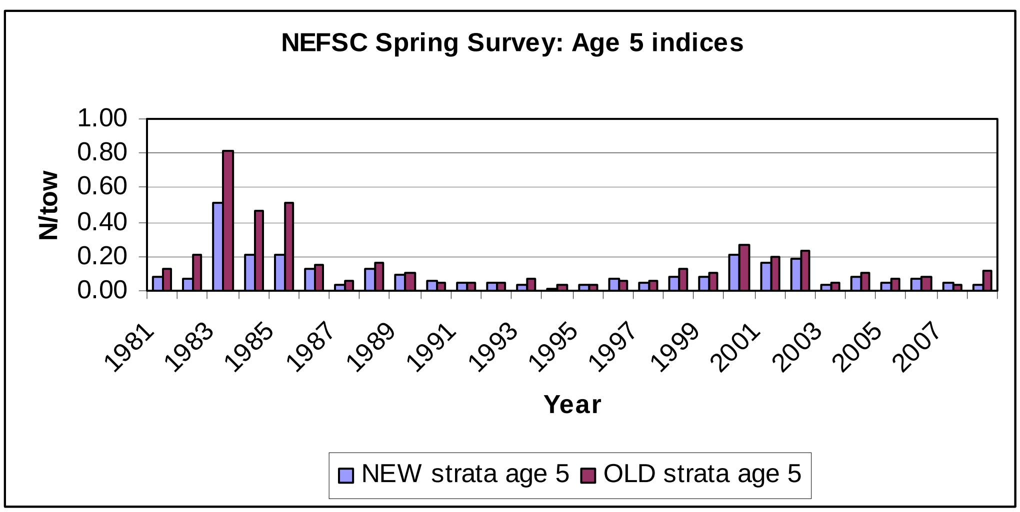



SNE/MA WFL: NEFSC Fall Survey
Number/tow
18
16
14
12
10
8
6
4
2
0
1963
1966
1969
1972
1975
1978
1981
1984
1987
1990
1993
1996
1999
2002
2005
2008
YEAR
HBB Strata
ALB Strata

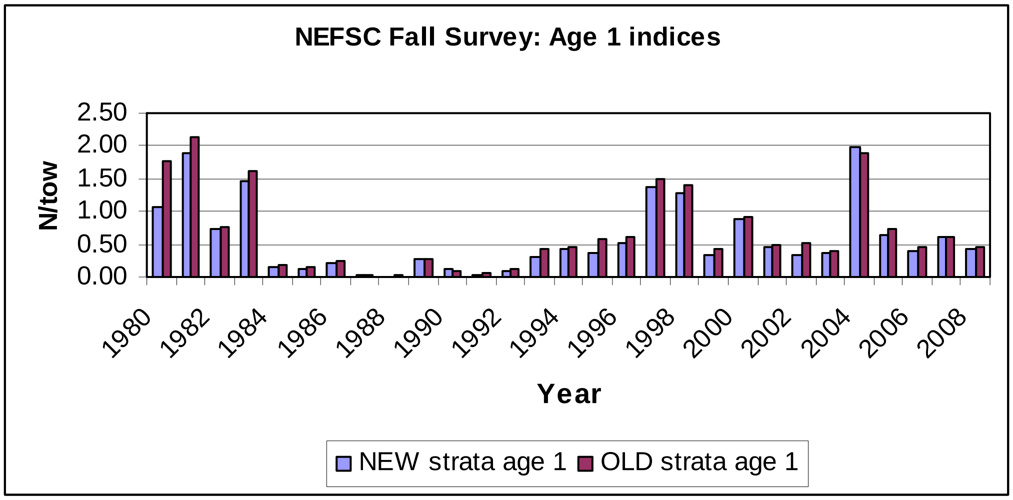
For the indices at age, the differences are largest for the Spring indices at ages 1, 4, and 5, at about a 25% average decrease over the time series, with the largest absolute differences generally for the early to mid 1980s.

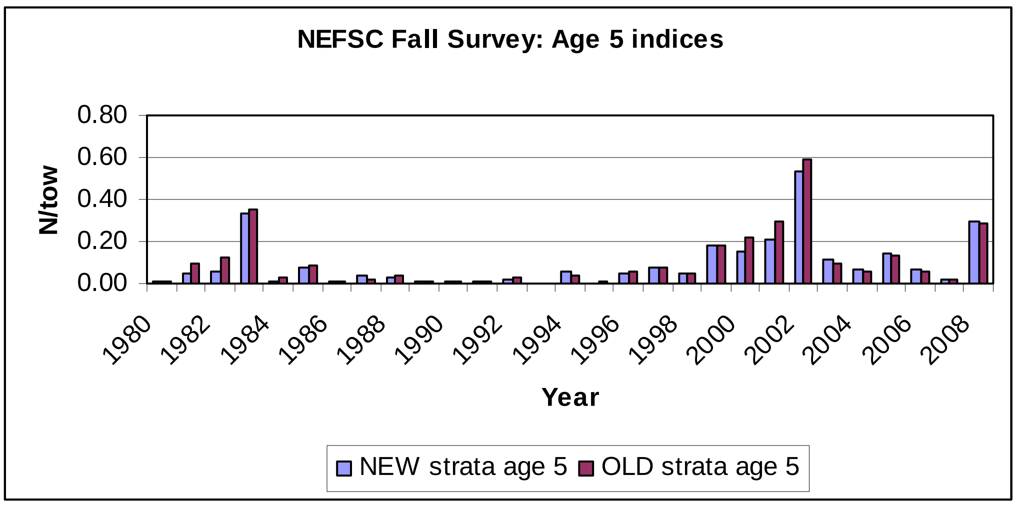






The Fall survey differences are largest for ages 1, and 5, at 14% and 11% average decrease over the time series, with the largest absolute differences generally for the early to mid 1980s and early 2000s.

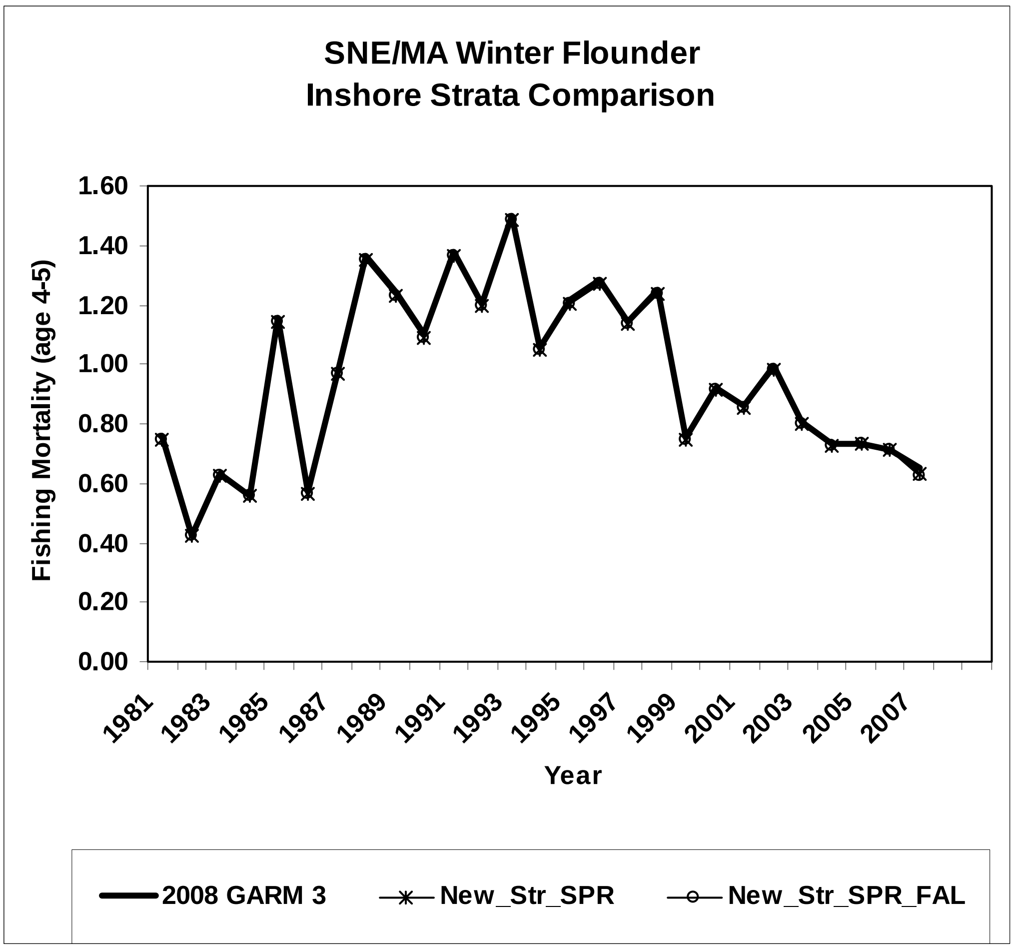




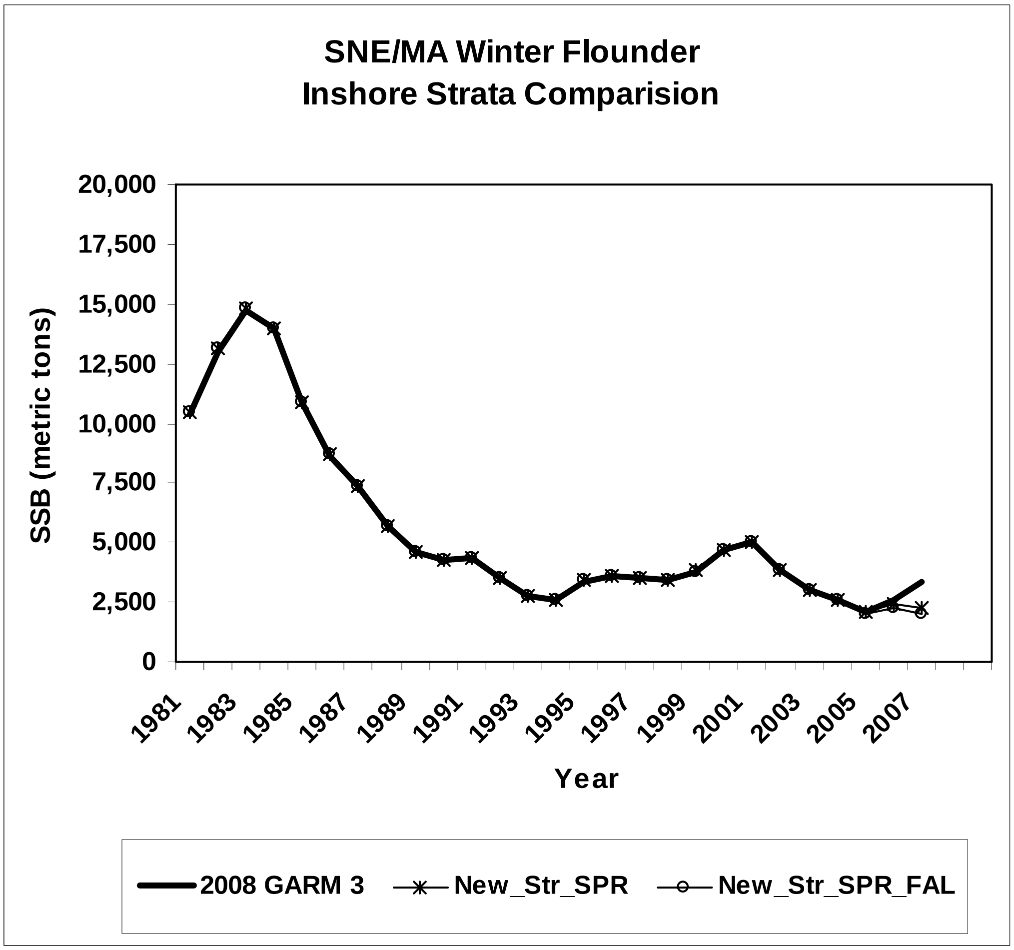
Impacts on the 2008 GARM 3 ADAPT VPA calibration

To evaluate the potential impact on the SNE/MA winter flounder assessment of the changes in the strata set and resulting NEFSC trawl survey spring and fall abundance indices, new versions of the 2008 GARM3 ADAPT VPA was constructed using the HBB strata set for the entire NEFSC time series (see previous figures). The “SPLIT” calibration configuration (breaking the NEFSC spring and fall, MADMF, RIDFW, CTDEP, DEDFW, and NYDEC survey series between 1993-1994) and the values of all the other survey data (state agency and NEFSC winter) remained the same.

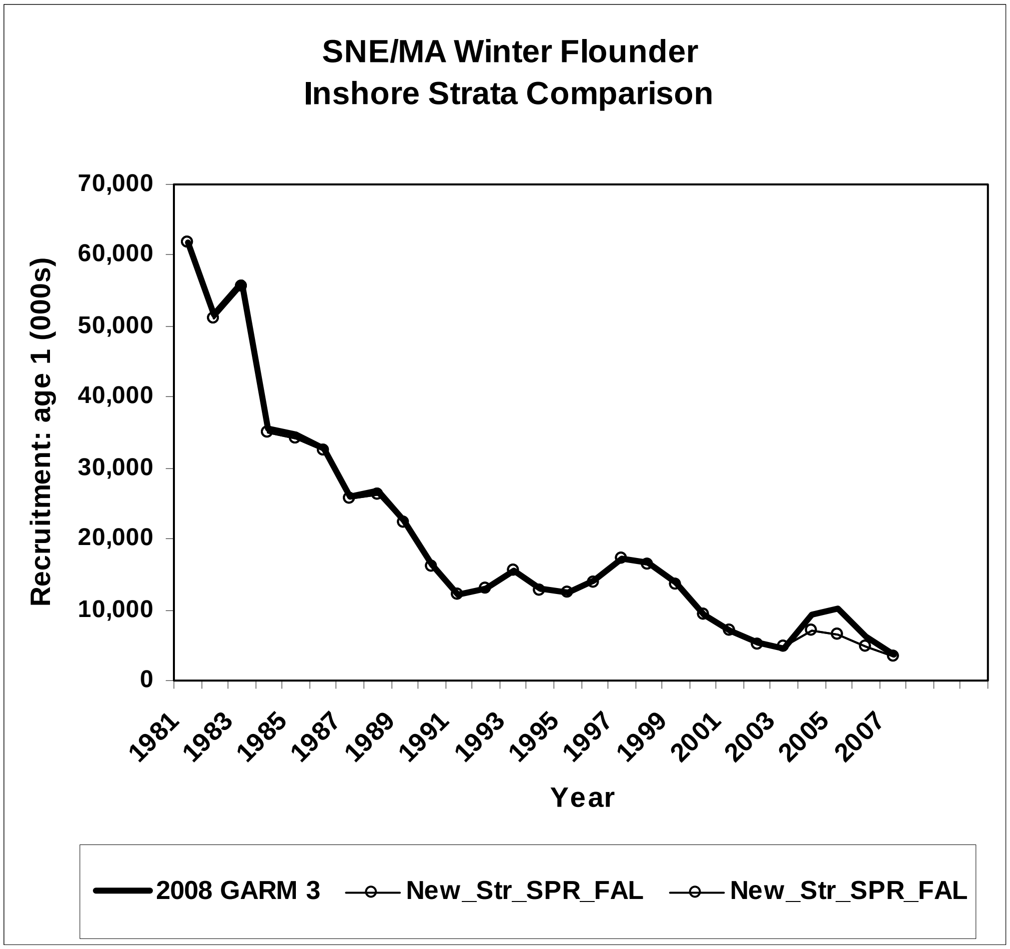
The impact of the new strata sets indices (either just Spring or both Spring and Fall) was negligible for the estimates of fully recruited Fishing Mortality (F, ages 4-5).



The impact of the new strata sets indices (either just Spring or both Spring and Fall) was more important for the estimates of SSB and R at the end of the time series. The 2007 estimate of SSB (2,006 mt)from the New_Str_SPR_FAL run including the HBB inshore strata set for both Spring and Fall series was 40% lower than the 2008 GARM 3 estimate (3,368 mt). This difference was due to differences in stock size estimates for the 2003-2005 year classes for the New-Str runs, which were 24% lower for the 2003 year class (2004 age 1), 37% lower for the 2004 year class (2005 age 1), and 21% lower for the 2005 year class (2006 age 1).



Given that the values of the early time series recruitments from SSB above 5,700 mt are virtually identical, and that mean weights and partial recruitment are virtually identical, there would be no effect on the calculated biological reference points from the strata set change for the 2008 GARM3 data. Going forward, the reference points may change as new data are added.



Conclusion

For the 2011 SARC 52 assessment, one choice is to retain the ALB strata set, and acknowledge that some fish historically sampled in the shallowest inshore strata sets will not be included in the 2009-2010 indices. Given past observations, this is likely to result in a slight negative bias in the 2009-2010 indices compared to the indices that would have been obtained had those strata been sampled. It should be noted that, however, that due to logistical issues (weather, mechanical breakdowns, fixed gear interference) the *specified* strata set (both inshore and offshore strata) has not always been completely sampled in the past (i.e., there is no absolute “consistently” *sampled* strata set).

The other choice is to adopt the indices from the HBB strata set, and acknowledge that a large number of fish historically sampled in the shallowest inshore strata sets will not be included in the time series, and also recognizing that the time series of consistently sampled strata begins in 1976. The advantage of this choice is that the entire series has a more “consistent” sample basis. The Working Group concluded that use of the consistent HBB strata set was best.

The Working Group also noted that winter flounder were rarely caught in the two deepest bands of offshore strata (e.g., 7-8, 11-12, etc.). The Working Group recommended that the NEFSC spring and fall survey series be revised to reflect a strata set consistent with that being sampled by the HBB (i.e., using only the deepest band of inshore strata) and excluding the two deepest bands of offshore strata (i.e., generally consistent with the set used for the Winter survey series). The revised strata set for SNE/MA winter flounder includes inshore strata 2, 5, 8, 11, 14, 17, 20, 23, 26, 29, 45, 46, and 56, and offshore strata 1, 2, 5, 6, 9, 10, 25, 69, 70, 73, and 74, for the years 1976 and later.

References

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SARC 52 Southern Demersal Working Group (SDWG)
Working Paper 3 – January 2011

Maturity

Background

In the 1999 SARC 28 review of the SNE/MA winter flounder stock assessment (NEFSC 1999), the SARC recommended re-examination of the maturity schedule used in the yield per recruit (YPR) and virtual population analyses (VPA) to incorporate any recent research results. The SARC 28 and previous assessments used the maturity schedule as published in O=Brien et al. (1993) for winter flounder south of Cape Cod, based on data from the MADMF spring trawl survey for strata 11-21 (state waters east of Cape Cod, Nantucket sound, Vineyard Sound, and Buzzards Bay) sampled during 1985-1989 (n = 301 males, n = 398 females). Those data provided estimates of lengths and ages of 50% maturity of 29.0 cm and 3.3 yr for males, and 27.6 cm and 3.0 yr for females, and the following estimated proportions mature at age. The female schedule (with the proportion at age 2 rounded down to 0.00) was used in the SARC 28 assessment YPR and VPA (NEFSC 1999).

Age	1	2	3	4	5	6	7+
Males	0.00	0.04	0.32	0.83	0.98	1.00	1.00
Females	0.00	0.06	0.53	0.95	1.00	1.00	1.00

In response to the SARC 28 recommendation, the 2002 SARC 36 (NEFSC 2003) examined NEFSC spring trawl survey data for the 1981-2001 period in an attempt to better characterize the maturity characteristics of the SNE/MA winter flounder stock complex. Data from the NEFSC survey included those judged in the SARC 28 assessment to comprise the SNE/MA complex from Delaware Bay to Nantucket Shoals: NEFSC offshore strata 1-12, 25 and 69-76, and inshore strata 1-29, 45-56. This was a much larger geographic area than that included in the MADMF survey data used in O=Brien et al. (1993). Data were analyzed in 5-6 year blocks (1981-1985, 1986-1990, 1991-1995, and 1996-2001) and for the entire time period (1981-2001), for each sex and combined sexes. Observed proportions mature at age were tabulated, and from those data maturity ogives at length and age were calculated to provide estimated proportions mature at age.

In general, the NEFSC maturity data indicated earlier maturity than the MADMF data, with L50% values ranging from 22-25 cm, rather than from 28-29 cm, and with ~50% maturity for age 2 fish, rather than ~50% maturity for age 3 fish. To investigate the apparent inconsistency between the MADMF and NEFSC maturity data, the two data sets were further compared over the same time periods (1985-1989, 1990-1995, 1996-2001) for common/adjacent survey strata (MADMF strata 11-12; NEFSC inshore strata 50-56 and offshore strata 10-12 and 25).

For comparable time periods and geographic areas, the NEFSC maturity data still consistently indicated a smaller size and younger age of 50% maturity than the MADMF data. NEFSC L50%

and A50% values range from 22-26 cm and about 2.0 yr, while the MADMF values range from 27-30 cm and about 3.0 yr. The difference in values from this comparison was not as large as for the full NEFSC data set extending southward to Delaware Bay, which incorporates components of the stock complex that mature at smaller sizes and younger ages. However, the difference was still nearly a full age class difference at 50% maturity.

Given that both length and age vary in the same direction, it seemed unlikely that the differences could be attributed to aging differences between the two data sets. Since the MADMF and NEFSC geographic areas in this comparison did not match exactly, the difference in maturity rates may be due to the extension of the NEFSC strata to somewhat deeper waters inhabited by fish that mature at a smaller size and younger age (inclusion of fish in offshore strata were necessary for sufficient sample size). Alternatively, for the size range of fish in question (20 to 30 cm length), it may be that immature and mature fish are segregated by area, with mature fish in that size interval tending to occupy inshore areas during the spring, with immature fish tending to remain offshore. Finally, there may be differences in the accuracy and consistency of interpretation of maturity stage between MADMF and NEFSC survey staff.

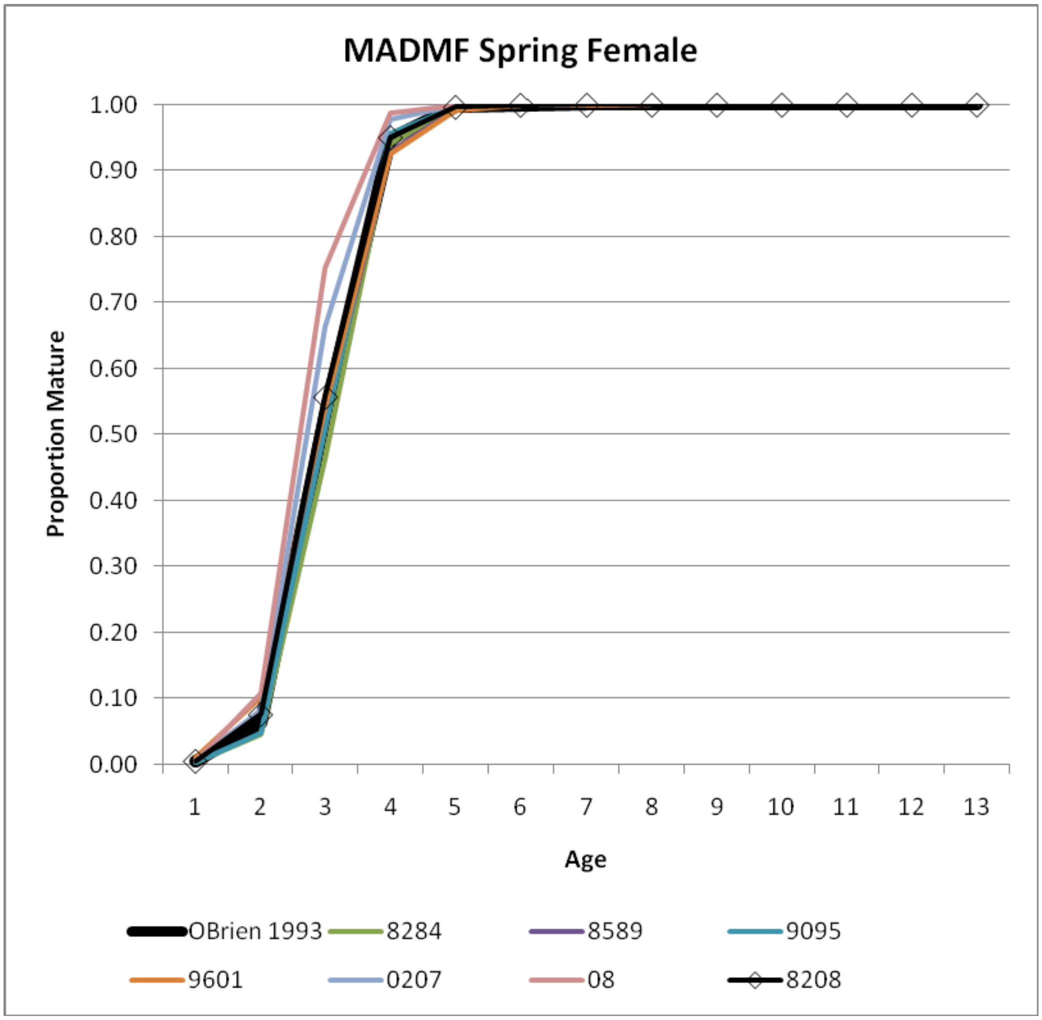
The 2002 SARC 36 considered these data and analyses and the possible causes for the noted inconsistencies, concluded that more detailed spatial and temporal analyses were needed before revisions to the maturity schedule can be adopted, and made a number of research recommendations for future winter flounder maturity work. The maturity at age schedule used in the 1999 SARC 28 assessment was retained in the 2002 SARC 36, 2005 GARM 2 (Mayo and Terceiro 2005), and 2008 GARM 3 (NEFSC 2008) assessments.

Since the 2002 SARC 36 assessment, the maturity data for SNE/MA winter flounder have been examined on an intermittent basis. Also, the recent work of McBride et al. (2010) examined the histological basis for maturity in winter flounder stocks, fit several maturation models to NEFSC sample data, and presented evidence for “skip” spawning in the GOM stock. This work revisits the MADMF and NEFSC maturity data for the SNE/MA, updates the 1999 SARC28 and 2008 GARM 3 examinations, and addresses some of the 2002 SARC 36 research recommendations relative to maturity.

MADMF and NEFSC data

The current work focuses on the maturity schedule for female fish, which in the past has been adopted as a proxy schedule for all the fish in the catch at age. In all cases, probit regression models assuming lognormal error were fit to the maturity data to estimate proportions mature at age. Both the MADMF and NEFSC maturity data have been recompiled and updated schedules computed.

The plot below presents the MADMF Spring survey data for the SNE/MA strata (09110-09210) updated through 2008, with year blocks for 1982-1984, 1985-1989 (corresponding to the data subset included in the O’Brien (1993) maturity schedule), 1990-1995, 1996-2001, 2002-2007, 2008, and all data combined for 1982-2008. The MADMF maturity data indicate a consistent pattern over the time series, with maturity at age 2 less than 10% across the time series, and some increase in maturity at age 3 (from about 50% to about 66%) in the 2002-2007 period.

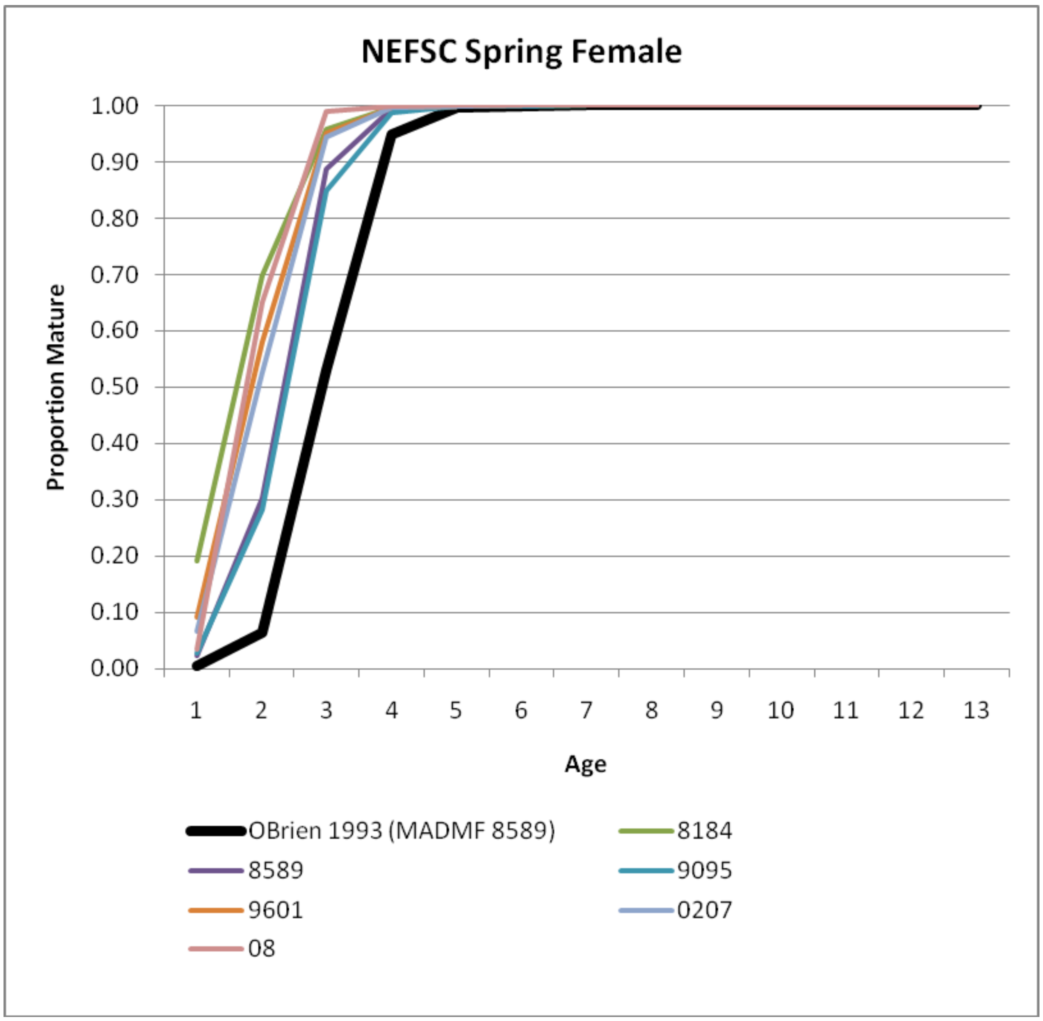


MADMF Spring Female
Proportion Mature
1.00
0.90
0.80
0.70
0.60
0.50
0.40
0.30
0.20
0.10
0.00
1
2
3
4
5
6
7
8
9
10
11
12
13
Age
OBrien 1993
8284
8589
9095
9601
0207
08
8208

The table below shows that when all the MADMF Spring female maturity data are combined (1982-2008; 8208 in the plot legend) the resulting schedule is within 2-3% at age of the O'Brien (1993) schedule used in past assessments.

Age	1	2	3	4	5	6	7+
O'Brien 1993	0.00	0.06	0.53	0.95	1.00	1.00	1.00
Current work	0.00	0.08	0.56	0.95	1.00	1.00	1.00

The plot below presents the NEFSC Spring survey data for the all SNE/MA survey strata (0101-01220, 01250, 01690-01760, 03010-03260,03450-03560) updated through 2008, with year blocks for 1982-1984, 1985-1989 (corresponding to the data subset included in the O'Brien (1993) maturity schedule), 1990-1995, 1996-2001, 2002-2007, and 2008. The NEFSC Spring maturity data indicate a more variable pattern over the time series than the MADMF Spring data, with maturity at age 2 ranging from 28% to 70% across the time series, and maturity at age 3 at greater than 90% for the entire 1981-2008 period. The NEFSC Spring data continue to indicate an age of 50% maturity (A50) of about age 2, compared to A50 = age 3 for the MADMF Spring data.

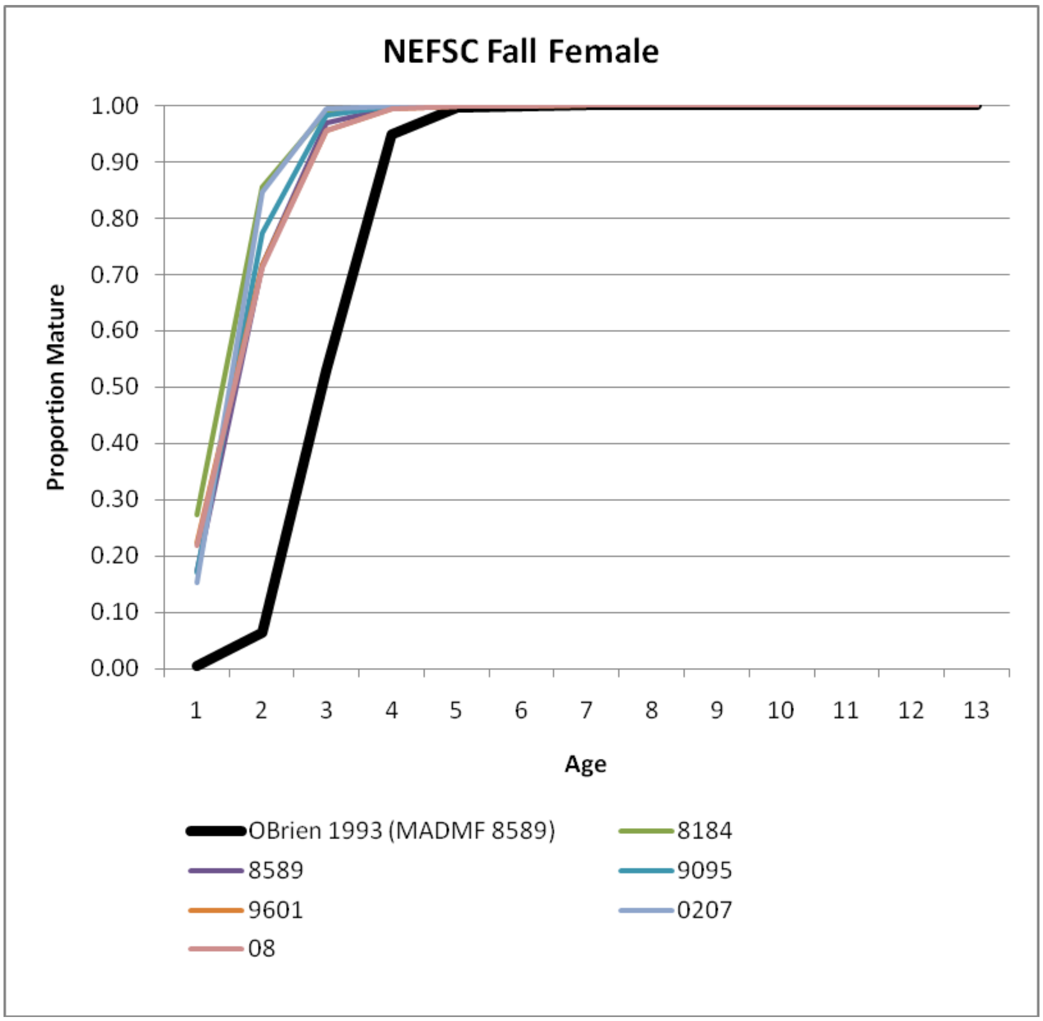


The 2002 SARC 36 assessment included Research Recommendations to "Evaluate the maturity at age of fish sampled in the NEFSC fall and winter surveys" and "Examine sources of the differences between NEFSC, MA and CT survey maturity (validity of evidence for smaller size or younger age at 50% maturity in the NEFSC data). Compare NEFSC inshore against offshore strata for differences in maturity. Compare confidence intervals for maturity ogives. Calculate annual ogives and investigate for progression of maturity changes over time. Examine maturity data from NEFSC strata on Nantucket Shoals and near George=s Bank separately from more inshore areas. Consider methods for combining maturity data from different survey programs."

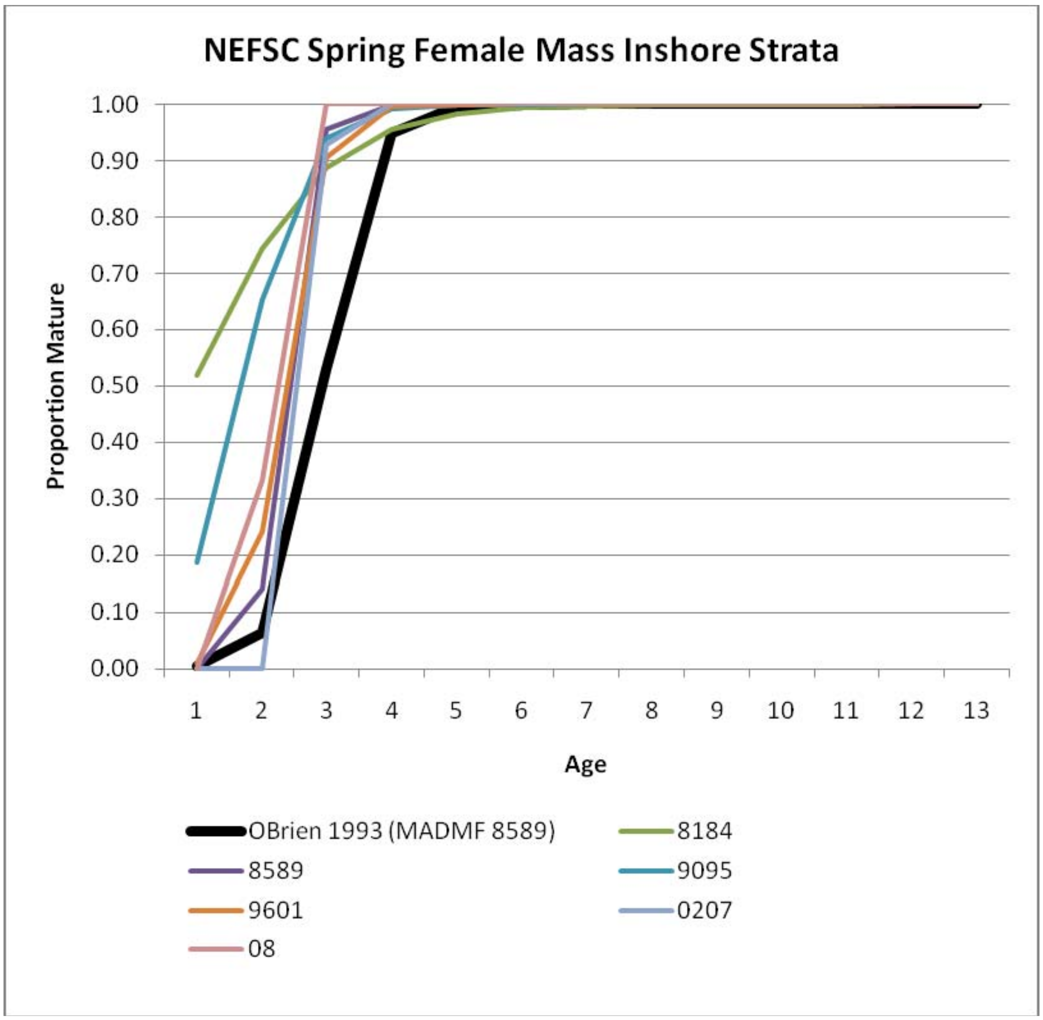
Some of these recommendations are addressed in this work. However, the NEFSC winter survey (1992-2007) age structures have not been processed, and so the associated maturity stages are not available in computerized form. Maturity data from the CTDEP trawl survey have not yet been compiled and provided in computerized form to the Working Group. As such, no analyses have been completed for those data.

Data from the NEFSC Fall survey, the NEFSC Spring survey for Massachusetts waters inshore strata (03550-03560; Nantucket Shoals), and the NEFSC Spring survey for Massachusetts water offshore strata (01090-01120 & 01250) have been compiled and analyzed in the same way as the NEFSC Spring and MADMF Spring survey full data sets, to respond to the Research Recommendations.

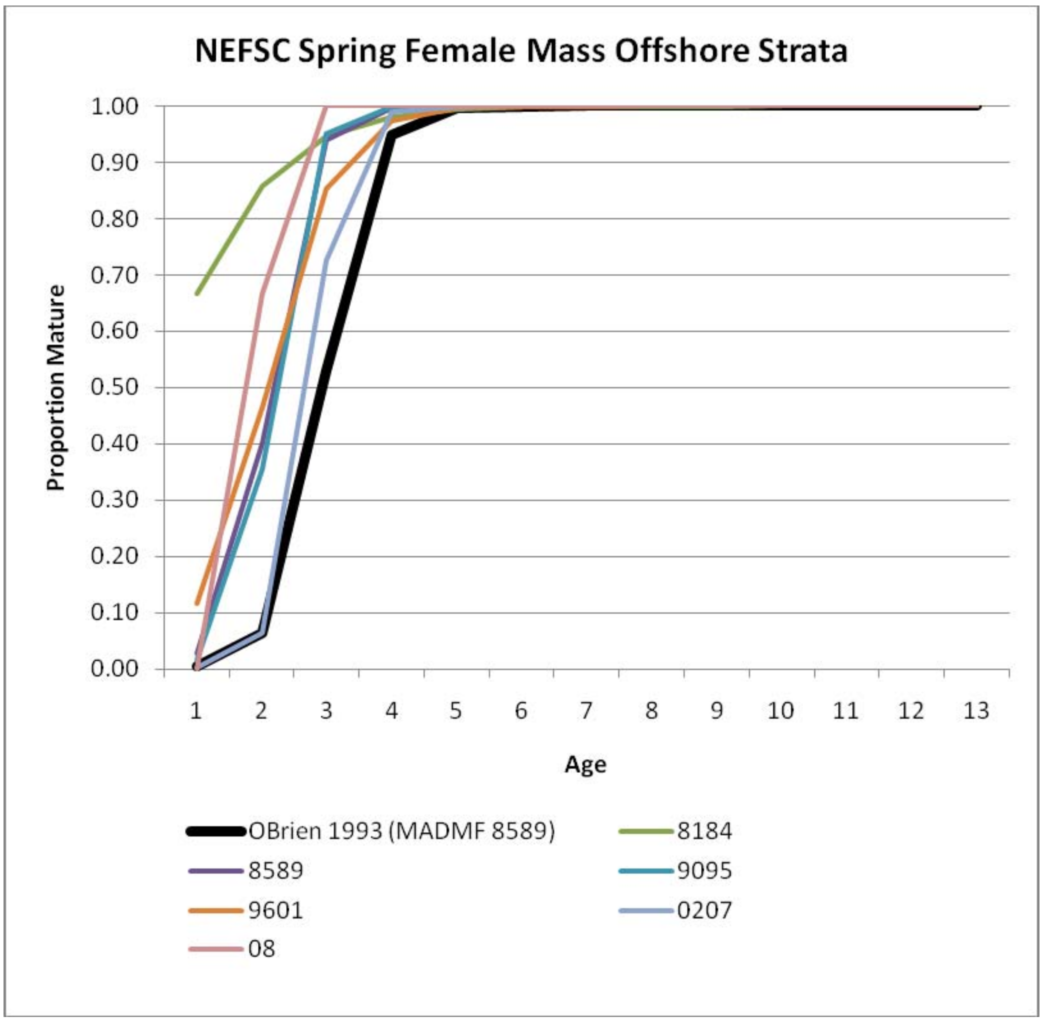
The plot below presents the NEFSC Fall survey data for the all SNE/MA survey strata (0101-01220, 01250, 01690-01760, 03010-03260,03450-03560) updated through 2008, with year blocks for 1982-1984, 1985-1989 (corresponding to the data subset included in the O'Brien (1993) maturity schedule), 1990-1995, 1996-2001, 2002-2007, and 2008. The NEFSC Fall maturity data indicate a more consistent pattern over the time series than the NEFSC Spring data, with maturity at age 2 ranging from 71% to 86% across the time series, and maturity at age 3 greater than 95% for the entire 1981-2008 period. Like the NEFSC Spring data, the NEFSC Fall data indicate an age of 50% maturity (A50) of about age 2, compared to A50 = age 3 for the MADMF Spring data.



The plot below presents the NEFSC Spring survey data for Massachusetts waters Inshore strata, which are a band of strata outside (and deeper) than the adjacent MADMF survey strata on Nantucket Shoals and Outer Cape Cod. Only NEFSC Massachusetts waters Inshore strata 03550 and 03560 were consistently sampled during the 1981-2008 period. As with the other sets, data updated through 2008, with year blocks for 1982-1984, 1985-1989 (corresponding to the data subset included in the O'Brien (1993) maturity schedule), 1990-1995, 1996-2001, 2002-2007, and 2008. The NEFSC Spring Massachusetts waters Inshore maturity data indicate a more variable pattern over the time series than the full NEFSC Spring data set, with maturity at age 2 ranging from 0% to 74% across the time series, and maturity at age 3 from 89% to 100%. Like the full NEFSC Spring data set, the NEFSC Massachusetts Inshore data indicate an age of 50% maturity (A50) of about age 2, compared to A50 = age 3 for the MADMF Spring data.



The plot below presents the NEFSC Spring survey data for Massachusetts waters Offshore strata, which includes strata 01090-01120 and 01250, in waters south of Nantucket Shoals and east of Outer Cape Cod. As with the other sets, data updated through 2008, with year blocks for 1982-1984, 1985-1989 (corresponding to the data subset included in the O'Brien (1993) maturity schedule), 1990-1995, 1996-2001, 2002-2007, and 2008. The NEFSC Spring Massachusetts waters Offshore maturity data indicate a more variable pattern over the time series than the full NEFSC Spring data set, with maturity at age 2 ranging from 6% to 86% across the time series, and maturity at age 3 from 73% to 100%. Like the full NEFSC Spring data set, the NEFSC Massachusetts Inshore data indicate an age of 50% maturity (A50) of about age 2, compared to A50 = age 3 for the MADMF Spring data.



Given the respective characteristics of the MADMF Spring and various strata set combinations of the NEFSC Spring and Fall maturity, and the indications from the McBride et al. (2010) histological work that age 2 fish are likely not mature, the Working Group concluded that the MADMF Spring survey data provide the best macroscopic evaluation of the maturity stage for SNE/MA winter flounder. The Working Group recommends that the MADMF Spring data 1981-2008 time series maturity estimates at age (age 1 - 0%; age 2 – 8%; age 3 – 56%; age 4 – 95%, age 5 and older – 100%) be used in the 2011 SARC 52 assessment.

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Response to 2008 GARM3 Research Recommendations for winter flounder

Introduction

The primary Research Recommendations from the 2008 GARM3 assessments for winter flounder were: "Assessment approaches needs [*sic*] to be explored that consider all three Winter Flounder stocks as a stock complex within which there is significant interaction amongst the individual stock components." and "The Panel also had concerns about the unit stock, not only for this stock, but for all of the Winter Flounder stocks assessed. It recommended an analysis of Winter Flounder as a stock complex, rather than as individual stocks, be undertaken" (NEFSC 2008).

The stocks are defined as they are now based on a) historical tagging studies show low rates of exchange (a few percent) between the stock areas (Howe and Coates 1975; Pereira *et al*. 1999), b) differences in the growth rates between the stocks, with GBK fish growing faster, GOM fish growing slower, and SNE fish growing at an intermediate rate (How and Coates 1975; Lux 1973; NEFSC 2008), c) differences in the rates of maturation (NEFSC 2008), d) differences in meristics, mainly fin ray counts (Lux *et al*. 1970), and e) fishery "integration" of catches from potential bay/estuarine specific-stocks in the GOM and the SNE "complexes."

Briefly, the status of the three stocks as of the 2008 GARM3 (catches through 2007) is as follows:

GOM: at 29% of BMSY, at 1.5 times FMSY - but note the assessment was not accepted as the basis for management, because of residual error trends and a severe retrospective pattern in the ADAPT VPA - therefore stock status is currently "unknown"

GBK: Overfished, at 31% of BMSY; overfishing, at 8% above FMSY; retrospective pattern acceptable

SNE: Overfished, at 9% of BMSY; overfishing, at 2.6 times FMSY; retrospective pattern acceptable using a "split" calibration configuration (most surveys broken into 2 series at 1993/1994)

Combining the assessments

This first step in responding to the Research Recommendations was to aggregate all 3 stocks together in “All Stocks” winter flounder ADAPT VPA (back-calculating model) - i.e., to assume 100% "interaction". The three catch at age matrices from the GARM3 assessments were combined into a single catch at age matrix; aggregate mean weight and maturity matrices (weighted by the respective input catch numbers at age) were also compiled. The survey calibration data were input as in the separate stock assessments.

The GOM survey data included NEFSC spring and fall, MADMF spring and fall, and Seabrook (NH) indices at age. The GBK survey data included NEFSC spring and fall and Canada DFO spring indices at age. The SNE/MA survey data included NEFSC winter, spring, and fall, MADFW spring, RIFDFW spring, CTDEP spring, NYDEC, and NJDFW indices at age.

ADAPT VPA model

The ADAPT VPA model was configured with "splits" in the survey time series as in the 2008 GARM3 GOM and SNE/MA assessments. The "split" configuration generally reduced the number and magnitude of error residual patterns for the survey calibration indices. As a result of the combined split configuration, however, newly significant residual patterns developed for some of the survey series, especially those for GBK series which were not split, generally from blocks of negative residuals early (1980s) in the time series to blocks of positive residuals after the mid-1990s. The GBK NEFSC fall survey indices developed these patterns for ages 4 and older (Figures 1-2).

The ALL_WFL_VPA exhibited a reduced retrospective pattern compared to those in the GARM3 GOM and SNE assessments (recent overestimation of SSB ranging from 8-15%; underestimation of F ranging up to 22%; Figures 3-4).

Stock size and fishing mortality rate estimates from the ALL_WFL_VPA are a "blend" of the three GARM assessment results, as might be expected. SSB declines from a peak of about 35,000 mt in 1982 to a low point in 1994 at about 6,700 mt, increases to about 15,000 mt in 2000-2001, and then declines to 9,500 mt by 2007 (Figure 5). Fishing mortality (F, ages 4-5) increases from about 0.60 in 1982-1983 to a peak of 1.28 in 1993, before generally decreasing to 0.38 by 2007 (Figure 5). Recruitment peaked at 71-72 million age 1 fish in 1982-1983, and then generally declined to less than 30 million fish since 1998 (Figure 5).

The 2007 SSB estimates from the 2008 GARM3 assessments total about 9,400 mt, while the ALL_WFL_VPA estimate is 9,538 mt, about 2% higher.

GOM:	1,000 mt
GBK:	4,964 mt
SNE:	3,368 mt
Total:	9,432 mt
ALL_WFL_VPA:	9,539 mt

The 2007 F (ages 4-5) estimates from the 2008 GARM3 assessments provide a SSB-weighted average of 0.43, while the ALL_WFL_VPA estimate is 0.38, about 12% lower.

GOM:	0.42
GBK:	0.28
SNE:	0.65
Total (SSB weighted):	0.43
ALL_WFL_VPA:	0.38

The next step was to calculate reference points and compare them to the ALL_WFL_VPA 2007 estimates. As in the GARM3 assessments, a yield and SSB per recruit analysis was used to estimate F40% as the Fthreshold proxy for FMSY. As in the GARM3 SNE/MA assessment, one hundred year projections using the recruitment for the "high-stanza" year classes (recruitment at SSB greater than 15,000 mt, an average of about 52 million age 1 fish; Figure 6) was then used to estimate MSY and SSB40% as the proxy for BMSY. Average mean weights and partial recruitment at age for 2005-2007 were used as inputs for both analyses.

F40% was estimated at 0.262; SSB40% was estimated at 70,699 mt, and MSY was estimated at 17,028 mt. The ALL_WFL_VPA results indicate that the 2007 SSB was at 14% of BMSY (overfished), and that the 2007 F was 1.5 times FMSY (overfishing).

Below is a comparison with the three GARM3 assessment reference point results.

SSB40% = BMSY

GOM:	3,792 mt
GBK:	16,000 mt
SNE:	38,761 mt
Total:	58,553 mt
ALL_WFL_VPA:	70,699 mt

MSY

GOM:	917 mt
GBK:	3,500 mt
SNE:	9,742 mt
Total:	14,159 mt
ALL_WFL_VPA:	17,028 mt

F40% = FMSY

GOM:	0.28
GBK:	0.26
SNE:	0.25
Total (SSB weighted):	0.26
ALL_WFL_VPA:	0.26

Conclusion

This exercise violates the existing assumptions of stock structure based on information about the biology, migration patterns, and fishing patterns for winter flounder. The ALL_WFL_VPA results were perhaps to be expected, as the estimates are to some degree a "blend" of the three independent stock unit inputs. Similar to the experience with the 2008 GARM3 GOM and SNE/MA assessments, the "Split" run configuration reduced trends in residuals and the retrospective pattern. Aggregation of the three stock units resulted in a larger aggregate spawning stock biomass reference point and MSY estimate, while the aggregate stock status remained overfished with overfishing occurring in 2007.

The Working Group concluded that the information available on winter flounder stock structure provides strong support for the current three stock units, and that attempts to model those units as a single complex is not worth pursuing further. The Working Group does not believe that the benefits from the single-stock analysis (a single analysis instead of three; reduced retrospective pattern; ability to model the Gulf of Maine unit within the complex) are sufficient to ignore the observed differences in biological traits (growth, maturity, fecundity) that affect the interpretation of the spawning stock reproductive potential of the three current units.

Further research could pursue use of a more complex model (e.g., Stock Synthesis) to maintain separate fishery and survey catch for the three current stock units, while allowing a small amount (a few percent) exchange between the stock units based on information from historical tagging. This approach would also respond to SARC 52 Term of Reference 8C.

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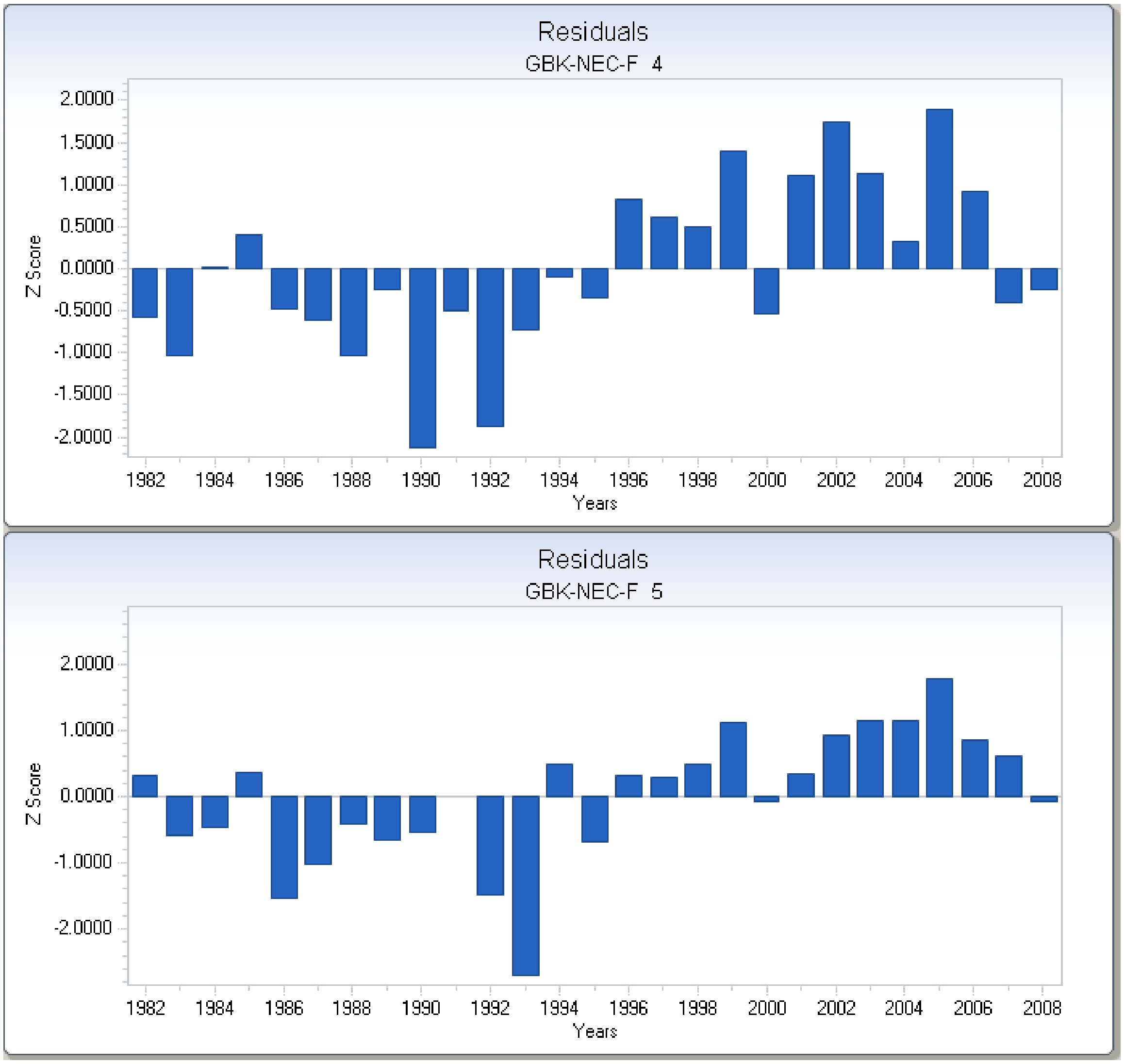

Figure 1. ALL_WFL_VPA GBK NEFSC fall survey residuals for ages 4-5.

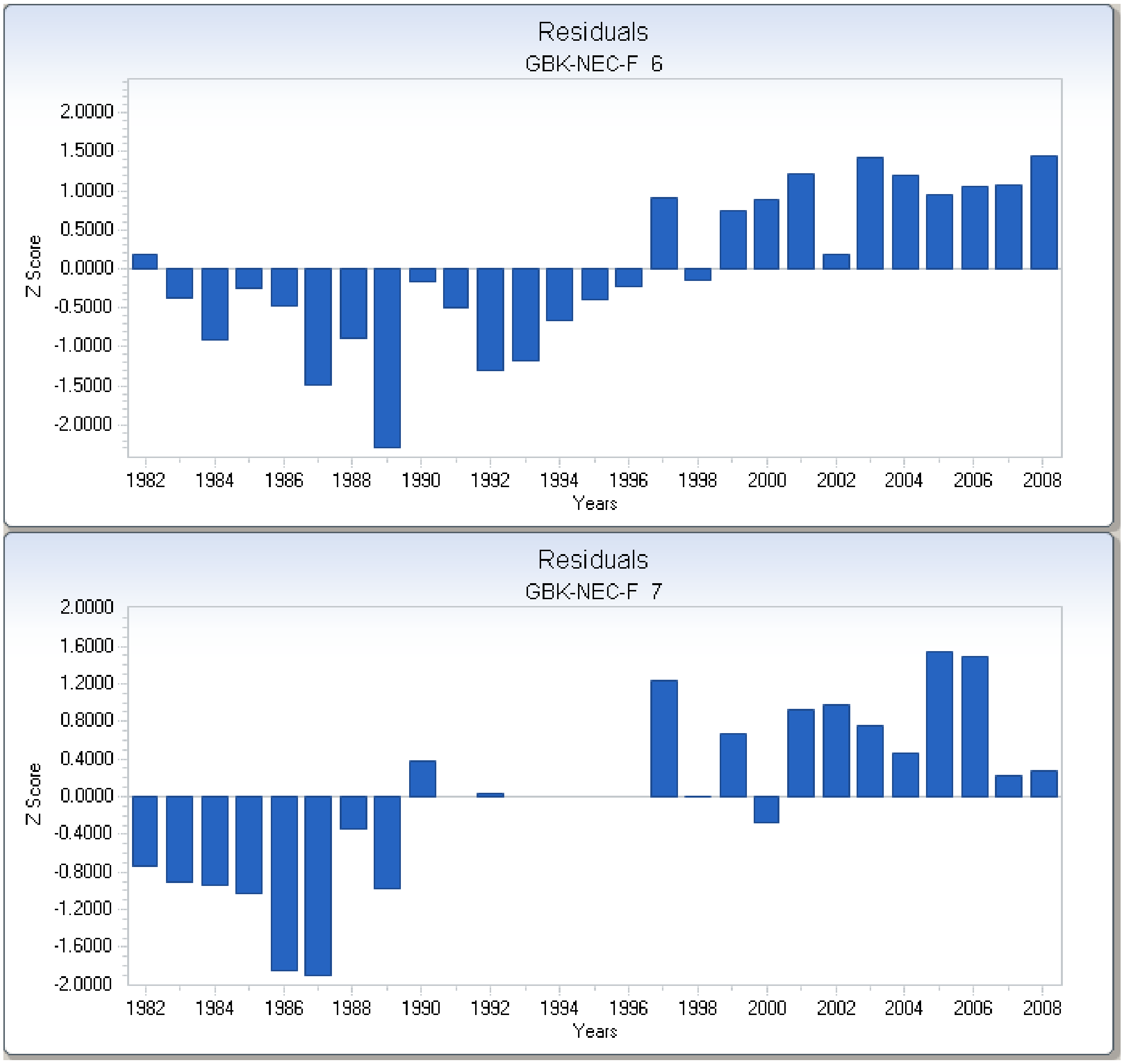

Figure 2. ALL_WFL_VPA GBK NEFSC fall survey residuals for ages 6-7.

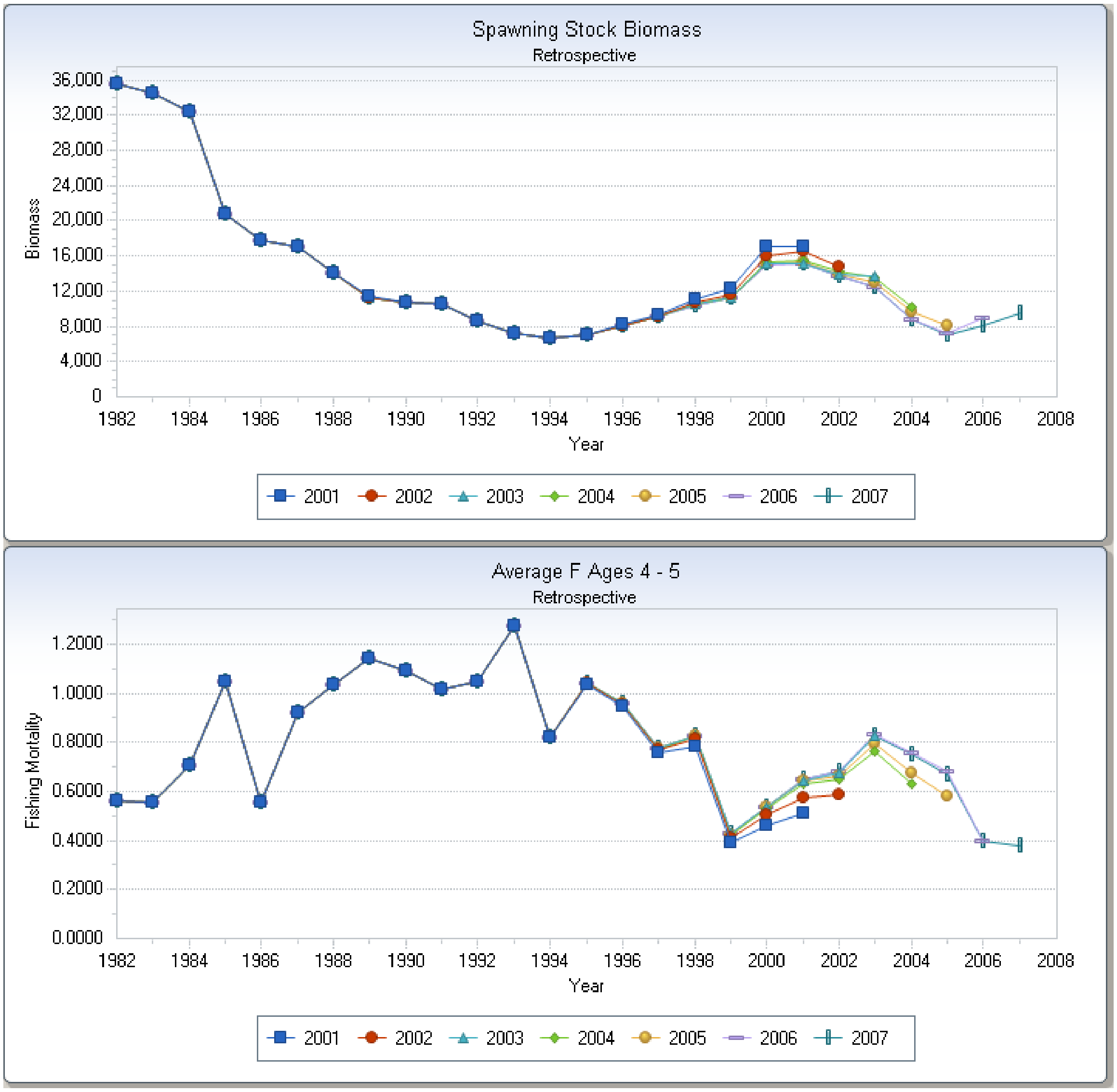

Figure 3. Retrospective patterns Absolute Differences in SSB and F from the ALL_WFL_VPA run.

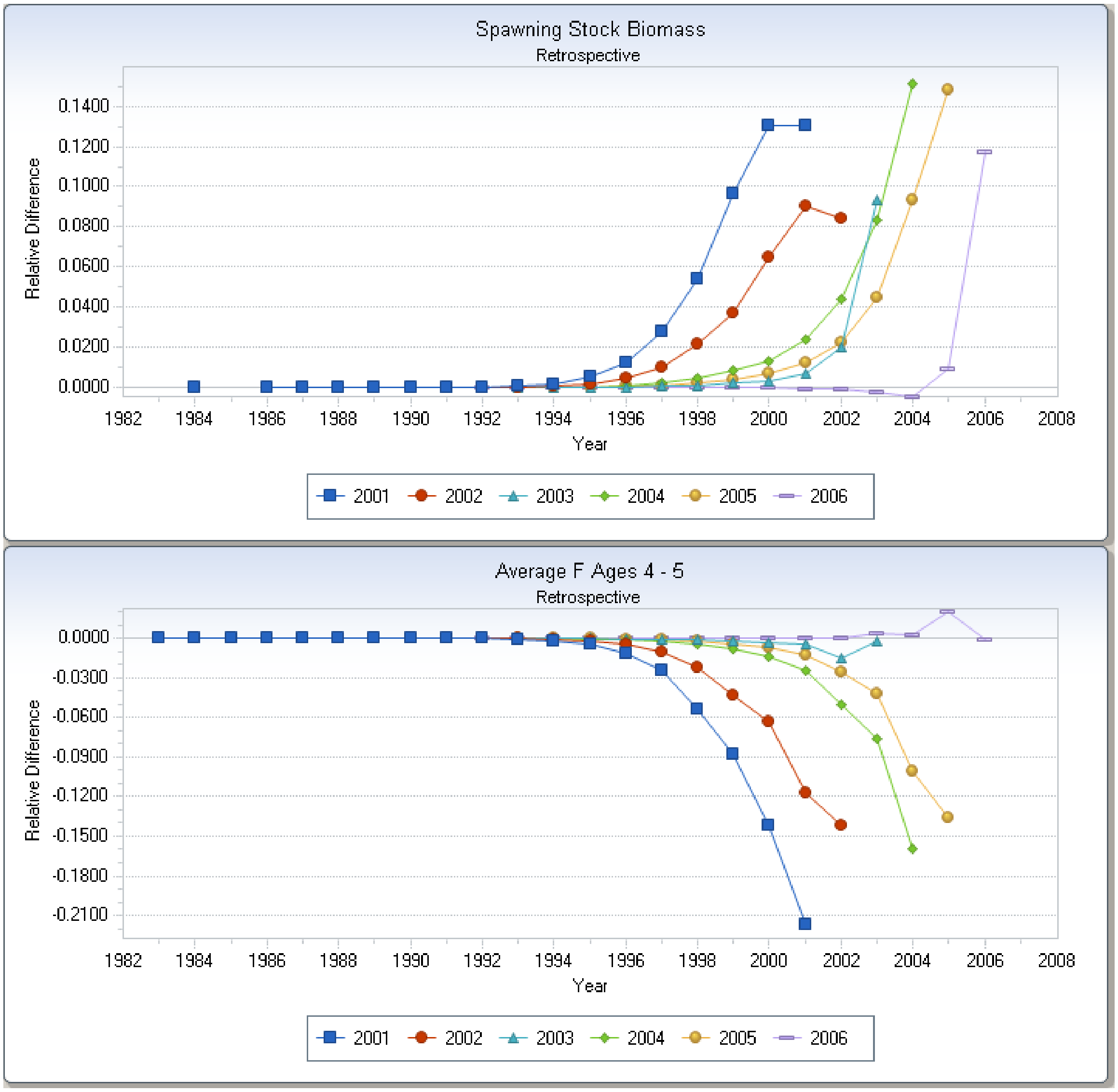

Figure 4. Retrospective pattern Relative Differences in SSB and F from the ALL_WFL_VPA run.

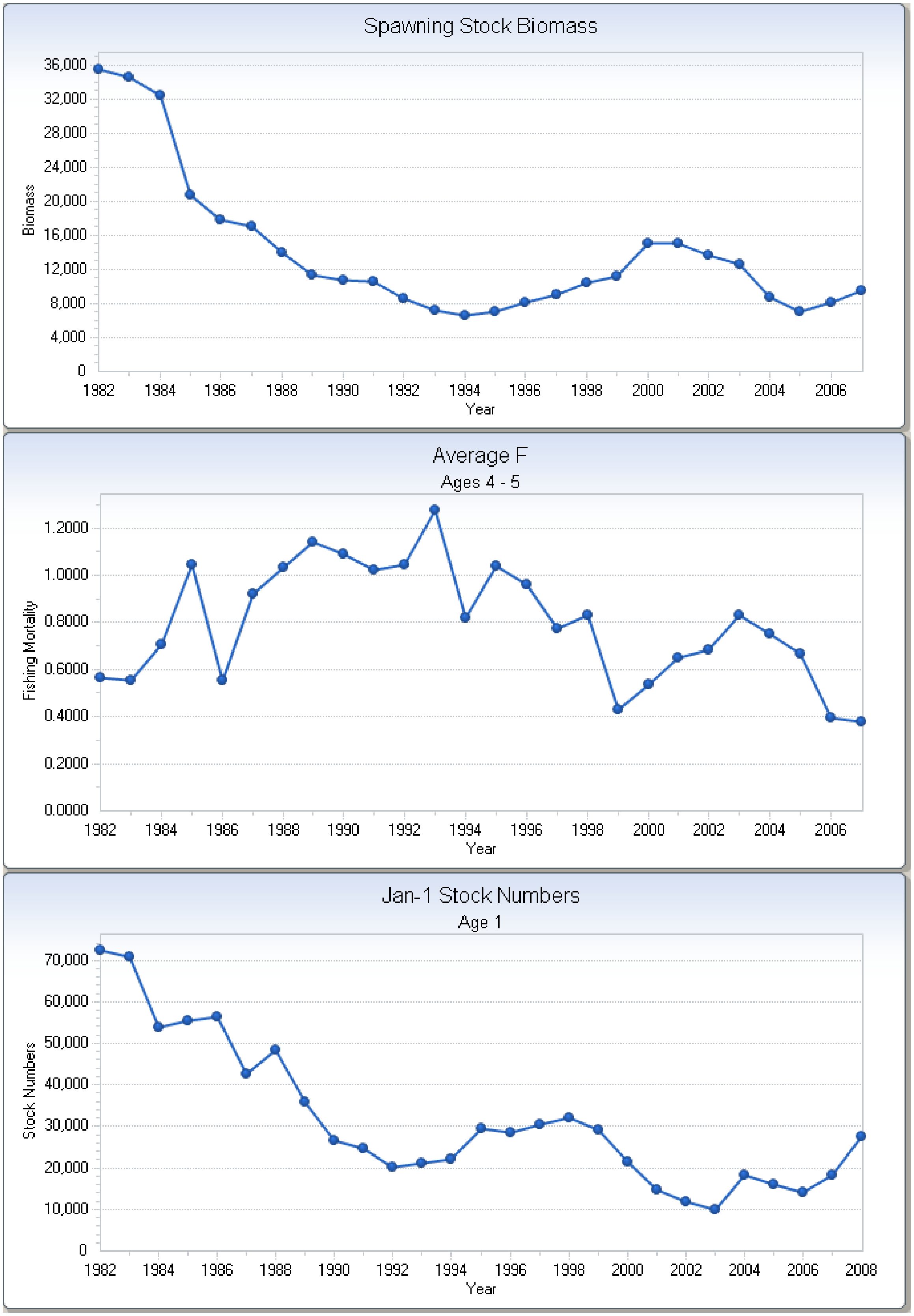

Figure 5. Trends in SSB, F, and R at age 1 from the ALL_WFL_VPA run.

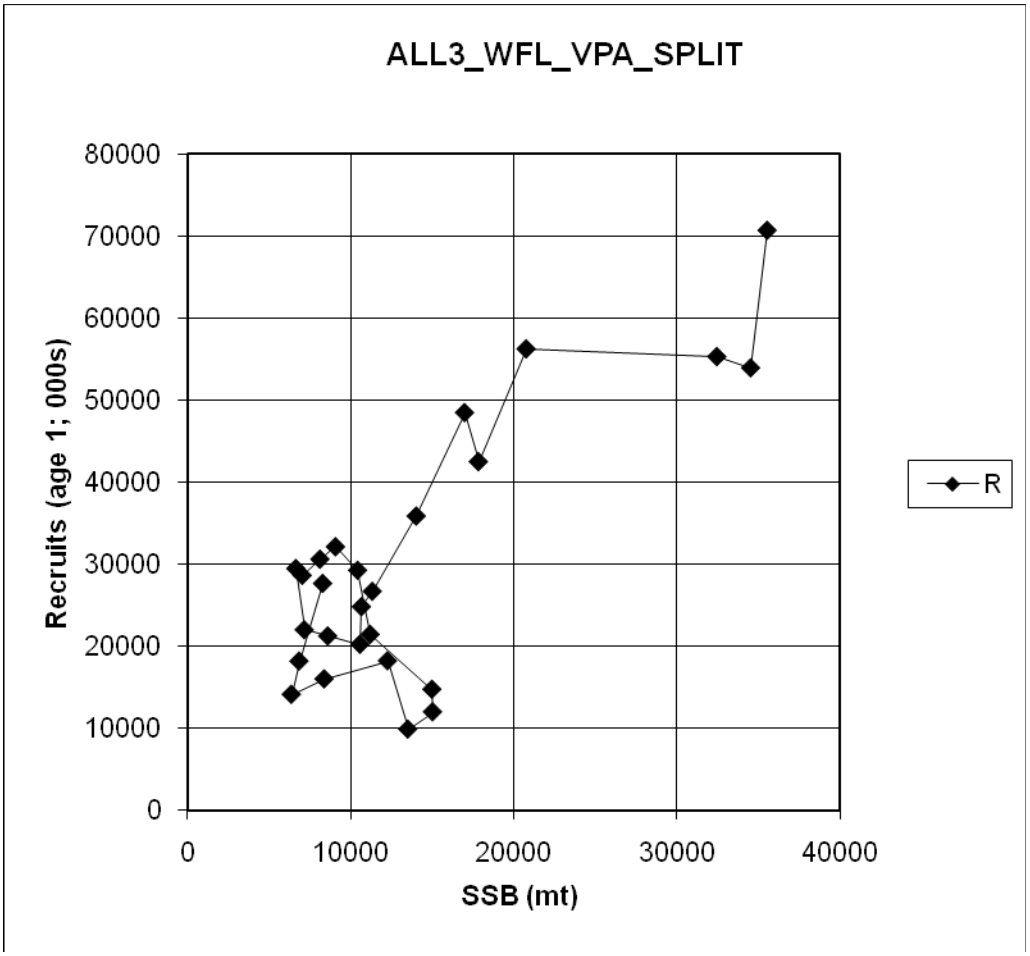

Figure 6. Stock-recruitment scatterplot for the ALL_WFL_VPA run. The six largest recruitments (averaging 52 million age 1 fish) were used in estimating the BMSY proxy = SSB40% for the FMSY proxy = F40% = 0.262.

SNE/MA Winter Flounder TOR 4

TOR 4: "Perform a sensitivity analysis which examines the impact of allocation of catch to stock areas on model performance (in TOR 5)."

The SARC Southern Demersal Working Group (SDWG) interpretation of the NRCC's intent is that we should consider the variance of the commercial landings due to the 1995 and later area-allocation scheme, use that as the basis for the magnitude of landings that might be lost or gained from the stock-specific assessments, and then run the assessment models with those changes and report the results. For all three stocks the catch consists of multiple components. For the SNE/MA stock, for example, the catch consists of 4 components. The commercial landings have a calculated Proportional Standard Error (PSE; due to the aforementioned commercial landings area-allocation procedure; available for 1995 and later years, with the mean of those years substituted for 1981-1994) ranging from <1% to about 5%; the commercial discard PSEs range from 17-35% (available for 1994-2010, mean of those years substituted for 1981-1993); the recreational landings PSEs range from 17-40%; and the recreational discard PSEs range from 18-57%. Because the PSEs for the commercial landings are low, and the commercial landings account for about two-thirds of the total catch, the total catch weighted-average annual PSEs range from 3.1-21.3%, and averages 8% (unweighted) for the 1981-2010 time series (Table 4.1).

Exercise 1

In Exercise 1, following the SDWG interpretation of how to address TOR 4, the numbers in the catch at age were increased by the non-uniform, annual average PSE values (i.e., about one Standard Error), the 2008 GARM 3 assessment model was run and Biological Reference Points (BRPs) estimated, and those results compared with the current values. For the SNE/MA stock, this step increased the numbers in the catch at age (CAA) by the annual average PSE values (ranging from a maximum of CAA*1.137 in 1985 to a minimum of CAA*1.030 in 2001), portraying the impact of an annually varying negative bias (i.e., the catch is underestimated by one PSE each year) in the current CAA. Figures 4.1-4.3 show how the F at ages 4-5 was nearly unchanged (on average, scaled down by 1%), while the SSB and R scaled up by an average of 7%.

Next, the Plus-One-PSE run BRPs were calculated and stock status evaluated. The partial recruitment pattern was unchanged (to 2 decimal places) from the 2008 GARM 3 model, so the FMSY proxy = F40% = 0.248 was unchanged (mean weights and maturity were also unchanged). The new, 7% higher recruitment values (8 highest values in the S-R pair series) were used in the 2008 GARM3 projection to calculate a new BMSY = SSB40%, estimated to be 42,096 mt, about 9% higher than 2008 GARM3 estimate of 38,761 mt. The new MSY was estimated to be 10,581 mt, about 9% higher than GARM3 estimate of 9,742 mt.

Based on the Plus-One-PSE run, stock status was still overfished (3,499 mt; 8% of BMSY) with overfishing (0.640; 2.6 times FMSY) in 2007. The overall conclusion was that the application of a relatively minor but varying "bias-correction" in one direction in this sensitivity exercise will provide biomass estimates and BRPs that scale up or down by about the same average magnitude.

Exercise 2

After review of the Exercise 1 results, the SDWG noted that the 2008 GARM 3 Data Panel commented that "…the highest percent of total landings that required matching at level B, C and D was 13% and thus inter-stock reallocations were not considered significant. While there is little impact on landings allocations amongst stocks overall, there could be issues in the case of small stocks adjacent to larger ones." The current work for the winter flounder stocks indicates that in recent years, in particular 2009 and 2010, a higher percentage is being allocated at the "no direct dealer to VTR match" area-allocation levels (B, C, and D; Table 4.2; note that 2010 data are preliminary). It was also noted that the variance calculations do not account for other errors that might occur even for dealer-to-VTR matched trips (level A). These important sources of error can include:

a) Misreporting of the true statistical area, particularly for multi-day trips
b) Errors in the dealer data related to the assignment of landings to permits (due to vessel sales or other permit transactions), which may result in landings reported in a port in a different stock area

The SDWG concluded that the calculated variance of the area-allocated commercial landings likely underestimates the true error. After taking these issues into consideration, the SDWG concluded that a tripling (3X) of the calculated average PSE would provide a useful upper bound on the degree of uncertainty in the estimated catch. For the SNE/MA stock, this step increased the numbers in the catch at age (CAA) by three times (3X) the annual average PSE values (ranging from a maximum of CAA*1.412 in 1985 to a minimum of CAA*1.091 in 2001), portraying the impact of an annually varying negative bias (i.e., the catch is underestimated by 3 PSE each year) in the current CAA. Figures 4.4-4.6 show how the F at ages 4-5 was nearly unchanged (on average, scaled down by 1%), while the SSB and R scaled up by an average of 24%.

Next, the Plus-3-PSE run BRPs were calculated and stock status evaluated. The partial recruitment pattern was unchanged (to 2 decimal places) from the 2008 GARM 3 model, so the FMSY proxy = F40% = 0.248 was unchanged (mean weights and maturity were also unchanged). The new, 24% higher recruitment values (8 highest values in the S-R pair series) were used in the 2008 GARM3 projection to calculate a new BMSY = SSB40%, estimated to be 49,828 mt, about 29% higher than 2008 GARM3 estimate of 38,761 mt. The new MSY was estimated to be 12,528 mt, about 29% higher than GARM3 estimate of 9,742 mt. Based on the Plus-3-PSE run, stock status was still overfished (3,835 mt; 8% of BMSY) with overfishing (0.640; 2.5 times FMSY) in 2007. The overall conclusion was that the application of a relatively large but varying "bias-correction" in one direction in this sensitivity exercise will provide biomass estimates and BRPs that scale up or down by about the same average magnitude.

Table 4.1 SNE/MA Winter Flounder Catch (metric tons) and Proportional Standard Error (PSE)

Year	Comm Land	COML PSE 1995-2010	Comm Disc	COMD PSE 1994-2010	Rec Land	RECL PSE 1981-2010	Rec Disc	RECD PSE 1981-2010	Total Catch	Weighted PSE
1981	11,176	0.8	1,343	27	3,154	18	91	25	15,764	6.6
1982	9,438	0.8	1,149	27	3,493	36	63	48	14,143	11.8
1983	8,659	0.8	1,311	27	3,485	17	127	25	13,582	7.7
1984	8,882	0.8	986	27	5,510	20	148	21	15,526	9.5
1985	7,052	0.8	1,534	27	5,075	27	230	30	13,891	13.7
1986	4,929	0.8	1,273	27	2,949	20	66	23	9,217	10.7
1987	5,172	0.8	950	27	3,169	18	61	23	9,352	9.4
1988	4,312	0.8	904	27	3,510	17	69	21	8,795	10.1
1989	3,670	0.8	1,404	27	1,792	24	49	57	6,915	12.5
1990	4,232	0.8	673	27	1,063	18	31	18	5,999	6.9
1991	4,823	0.8	784	27	1,184	19	51	24	6,842	7.1
1992	3,816	0.8	511	27	387	16	15	23	4,729	4.9
1993	3,010	0.8	457	27	813	30	31	27	4,311	9.3
1994	2,128	0.8	341	35	594	21	29	26	3,092	8.7
1995	2,593	0.4	159	30	650	23	32	23	3,434	6.3
1996	2,783	0.5	175	29	714	20	30	29	3,702	5.8
1997	3,548	0.7	277	19	627	25	31	29	4,483	5.4
1998	3,138	0.7	173	32	290	30	13	36	3,614	4.7
1999	3,349	0.5	62	27	320	25	14	27	3,745	3.1
2000	3,704	0.4	148	29	870	25	32	35	4,754	6.0
2001	4,556	0.4	28	29	549	23	14	25	5,147	3.0
2002	3,084	0.6	93	35	223	33	12	34	3,412	3.8
2003	2,308	0.5	185	30	323	22	11	35	2,827	5.0
2004	1,636	1.2	84	23	214	23	8	37	1,942	4.7
2005	1,320	1.2	106	27	124	37	14	30	1,564	6.0
2006	1,720	0.5	152	20	136	40	16	34	2,024	4.9
2007	1,628	0.6	115	17	116	40	5	42	1,864	4.2
2008	1,113	0.8	109	23	73	30	3	36	1,298	4.4
2009	271	2.3	165	35	86	29	9	28	531	17.2
2010	174	4.5	153	34	28	51	8	40	363	21.3
Means	3941	0.9	527	27.5	1384	25.9	44	30.4	5895	7.8

Table 4.2. Percent of landings by Area-Allocation level (ALEVEL A,B,C,D, X and unallocated) for SNE/MA winter flounder.

	1995	1996	1997	1998	1999	2000	2001	2002	2003
A	63.6%	64.5%	60.8%	63.8%	66.4%	71.1%	69.9%	64.0%	69.6%
B	21.1%	19.4%	23.6%	19.3%	21.9%	18.9%	19.8%	24.2%	15.5%
C	6.5%	8.1%	8.5%	9.4%	5.9%	3.9%	5.2%	7.4%	9.5%
D	0.2%	0.2%	0.1%	0.1%	0.1%	0.4%	0.7%	0.3%	0.6%
Unallocated	8.6%	7.8%	6.9%	7.4%	5.8%	5.7%	4.4%	4.1%	4.8%
Grand Total	100.0%	100.0%	100.0%	100.0%	100.0%	100.0%	100.0%	100.0%	100.0%

	2004	2005	2006	2007	2008	2009	2010	Total
A	59.2%	62.4%	70.8%	71.0%	69.3%	57.2%	27.8%	66.1%
B	20.6%	14.9%	16.6%	19.8%	25.7%	16.4%	43.4%	20.4%
C	4.6%	9.4%	5.2%	5.5%	3.8%	21.6%	19.0%	6.8%
D	9.6%	8.6%	3.0%	0.3%	0.7%	2.4%	9.3%	1.2%
Unallocated	6.0%	4.7%	4.3%	3.5%	0.5%	2.3%	0.5%	5.5%
Grand Total	100.0%	100.0%	100.0%	100.0%	100.0%	100.0%	100.0%	100.0%

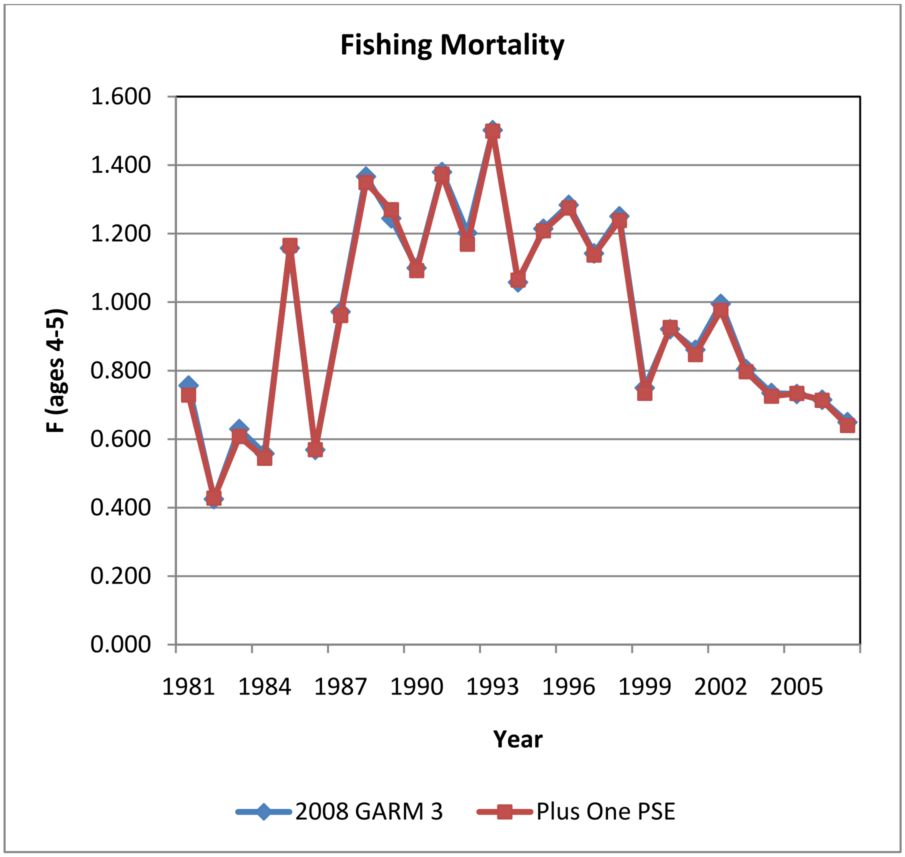

Figure 4.1. Comparison of fishing mortality rate (F ages 4-5) estimates from the 2008 GARM 3 assessment model and the Plus-One-PSE model run.

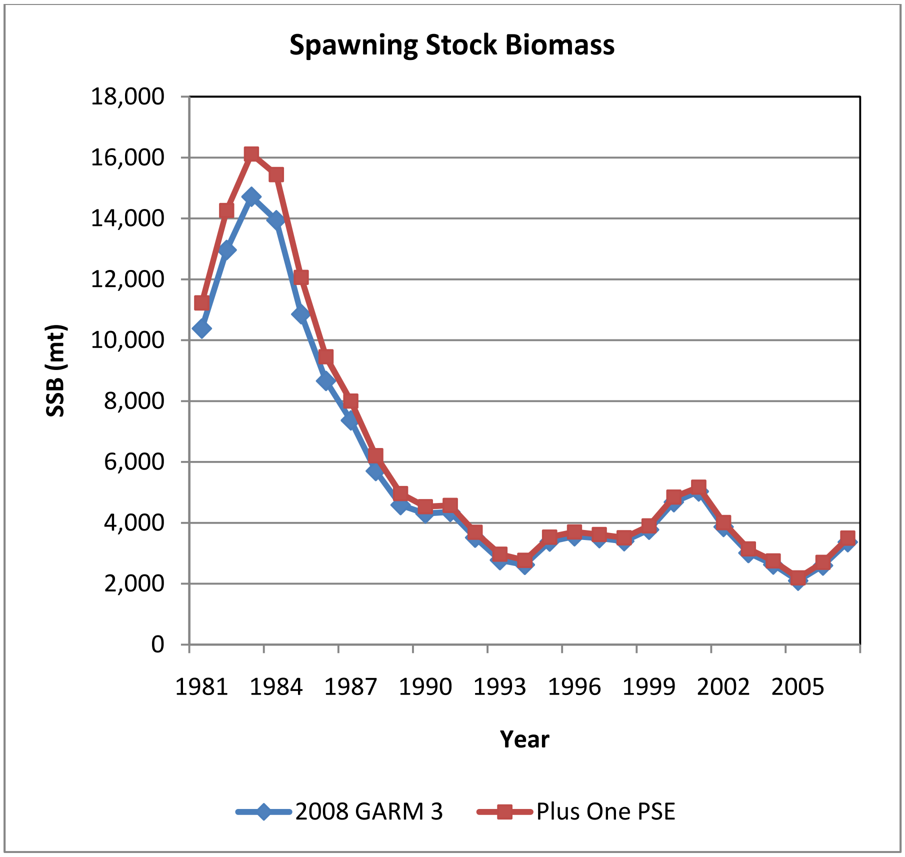

Figure 4.2. Comparison of SSB (mt) estimates from the 2008 GARM 3 assessment model and the Plus-One-PSE model run.

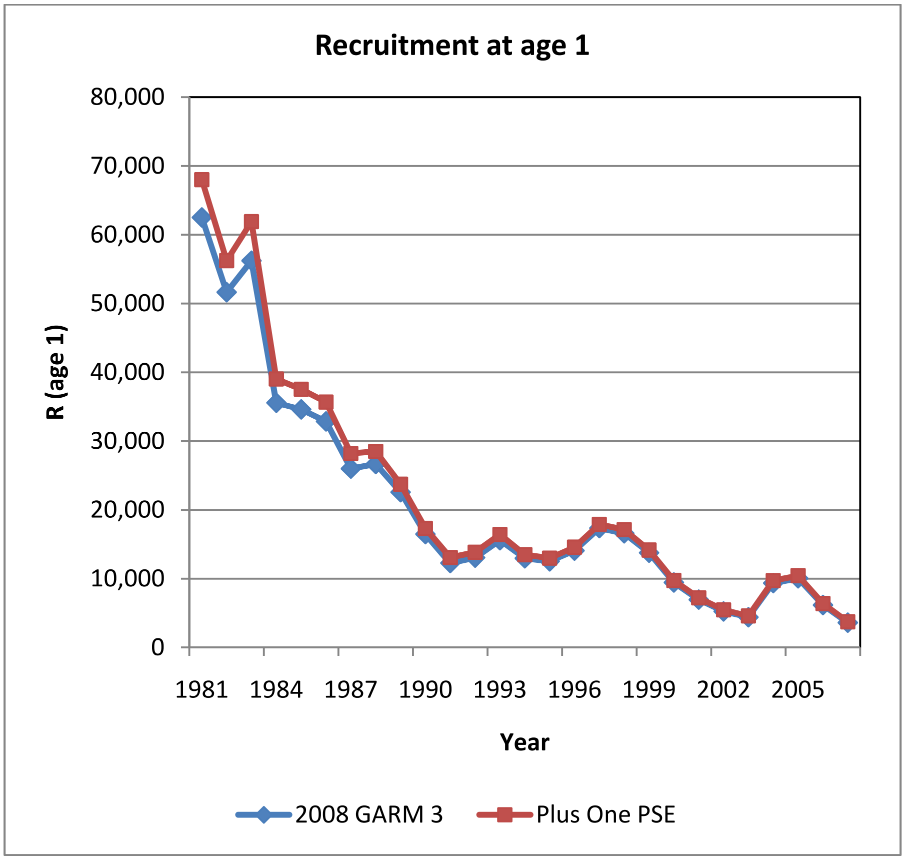

Figure 4.3. Comparison of Recruitment (R, thousands of age 1 fish) estimates from the 2008 GARM 3 assessment model and the Plus-One-PSE model run

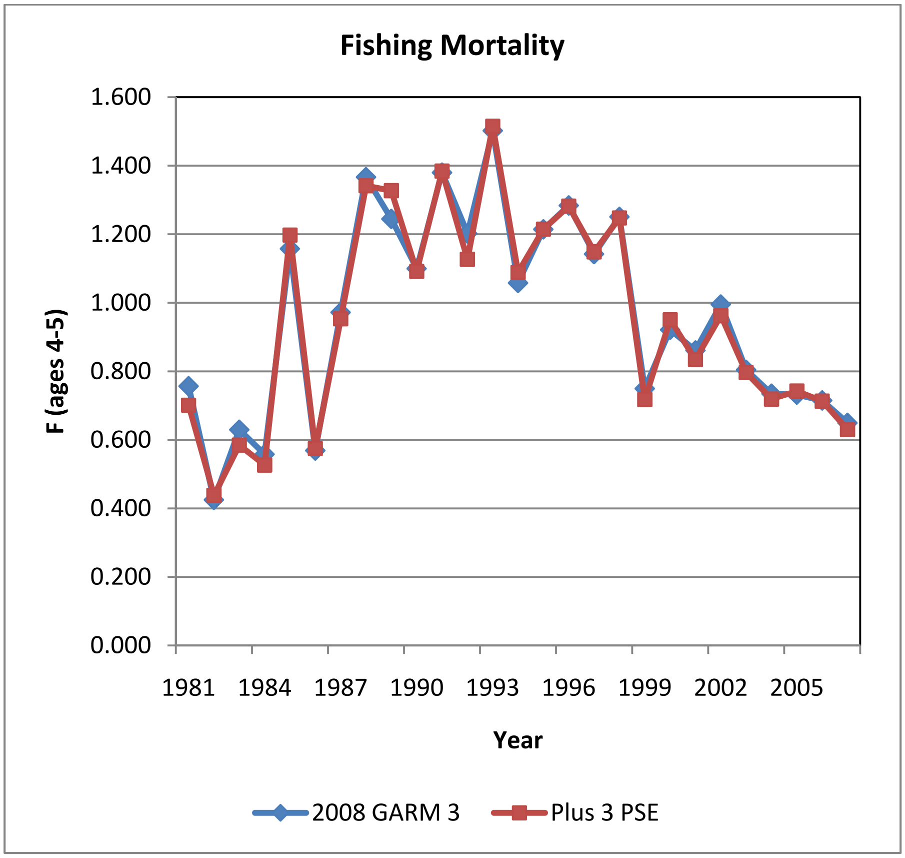

Figure 4.4. Comparison of fishing mortality rate (F ages 4-5) estimates from the 2008 GARM 3 assessment model and the Plus-3-PSE model run.

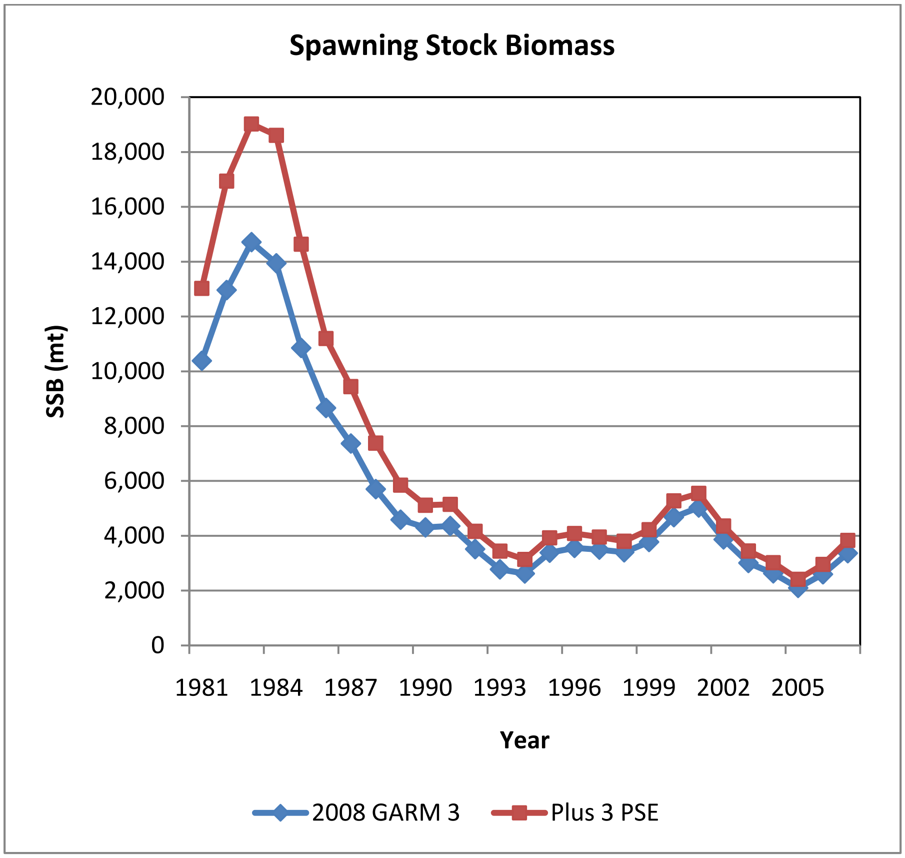

Figure 4.5. Comparison of SSB (mt) estimates from the 2008 GARM 3 assessment model and the Plus-3-PSE model run.

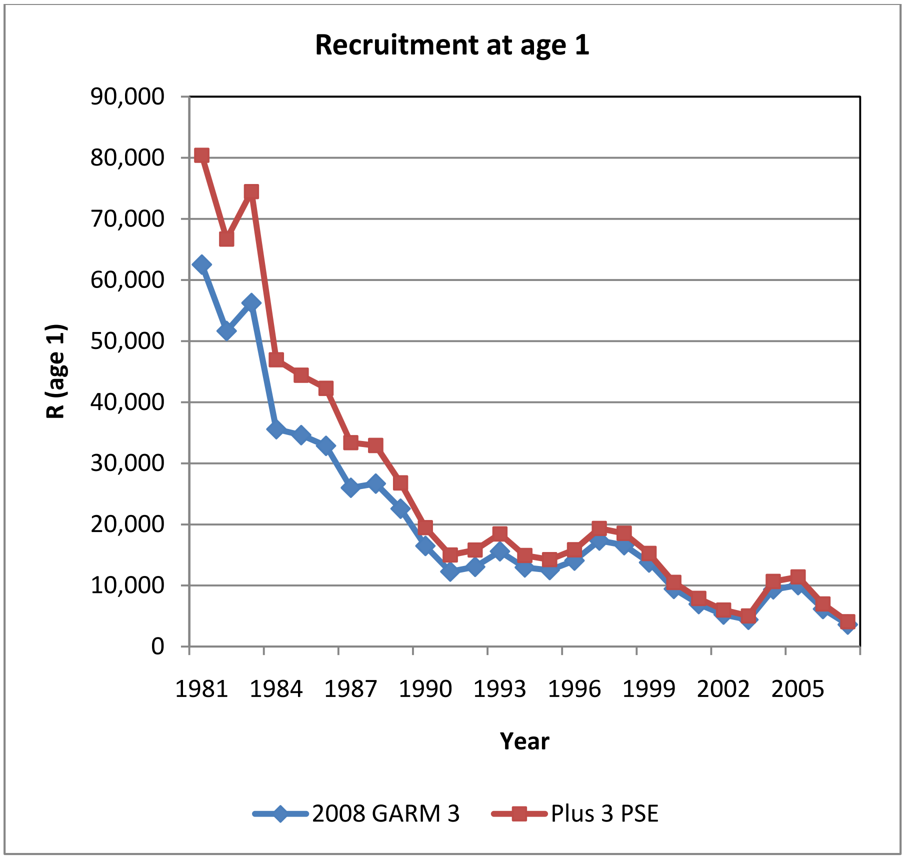

Figure 4.6. Comparison of Recruitment (R, thousands of age 1 fish) estimates from the 2008 GARM 3 assessment model and the Plus-3-PSE model run.

SDWG Background WP# 6
May 2011
Management Regulations

2001
January 9 – March 17 April 16 – April 30 Northern Shrimp season (61 days)
November 6: Daily haddock possession limit removed (maximum 50,000 lbs.-trip).
2002
February 15-March 11: Northern Shrimp season (25 days with days off)
May 1: Interim rule as a result of FW 33 lawsuit settlement agreement. Continuation of most measures from previous frameworks. DAS: 15 hour minimum charged for all trips over 3 hours Vessels limited to 25 percent of allocation May 1 through July 31, 2002 (only) Prohibition on front-loading DAS Minimum size: Cod 22 in. Gear: GOM Regulated Mesh Area (RMA): 6.5 in. diamond or square codend minimum, 6.5 inch mesh for trip gillnets, 6.5 inch mesh standup (roundfish) or 7 inch mesh tiedown (flatfish) for day gillnets. All areas: day gillnets limited to 50 standup/100 tiedown nets. *Hook gear*: de-hooking devices with spacing of less than six inches prohibited. Closures: WGOM year round closure extended (was to sunset May 1); Cashes Ledge Closed Area (year round); year round Cashes Ledge East and West closure added; add blocks 124/125 May, blocks 132/133 June, Recreational: Cod minimum size 23 in., GOM party/charter limited to 10 fish combined cod/haddock, all areas private recreational limited to 10 cod Possession limits: Remain the same. Haddock possession limit of 3,000 lbs.-DAS/30,000 lbs.-trip through September 30.
June 1: Revised interim rule Minimum size: Cod 19 in. Closures: Year-round Cashes Ledge east and west closures removed Gear: *Hook*: Requirement for six-inch spacing for de-hooking gear removed
July 4: Haddock daily limit suspended. Possession limit of 30,000 lbs.-trip until September 30, 50,000 lbs.-trip thereafter.
August 1: Emergency rule implementing FW 33 lawsuit settlement agreement. DAS: DAS allocation for each permit reduced 20 percent from maximum used FY 1996-2000 (est 71,218 allocated, including carry-over). DAS counted by the minute, except for day gillnet vessels (15 hour minimum). (This change reverted to DAS counting in effect in FY 2001). Prohibition on front-loading DAS clock. Minimum size: Cod 22 in. Gear: *Trawl:* GOM/GB RMAs: 6.5 in. diamond or square codend minimum; Southern New England RMA changed to 70W to 74W (vice 72-30W). 6.5 in. square, 7 in. diamond codend in SNE RMA. *Gillnet:* GOM: Trip gillnets – 6.5 in. mesh/150 nets; Day – 6.5 in./50 standup nets, 7 in./100 tiedown nets (prohibited March-June); GB – 6.5 in./50 nets, SNE – 6.5 in./75 nets; Mid-Atlantic: Trip – 5.5 in. diamond/6 in. square, Day – 5.5 in. diamond/6 in. square. *Hook*: no de-hookers with less than 6 in/. spacing, 12/0 circle hooks or larger; GOM: 2,000 rigged hooks, GB: 3,600 rigged hooks Closures: Add GB seasonal closure areas, May – Blocks 80, 81, 118, 119, 120 (south of 42-20N) Possession limits: *Yellowtail flounder*: SNE/MA: landing/possession of yellowtail flounder prohibited south of 40N. Mar 1 – May 31: 250 lbs./trip, June 1 – February 28: 500 lbs.-

DAS/4,000 lbs. – trip. *Cod*: GOM: 500 lbs.-DAS/4,000 lbs./trip. Open access commercial permits limited to 200 lbs. regulated groundfish. Recreational: Cod/haddock: 23 in. minimum size. Party/charter: GOM RMA: April-November, 10 cod/haddock combined per person, Dec-Mar – 10 cod/haddock combined, no more than 5 cod per person per trip. Private: GOM RMA: December-March – 10 cod/haddock combined, no more than 5 cod.
2003
January 15-February 27: Northern Shrimp season (38 days with days off)
March 13: Haddock possession limit suspended until May 1.
May 1: Haddock possession limit of 3,000 lbs-DAS/30,000 lbs.-trip
May 1: Framework Adjustment 37 Modifications to whiting management measures: extension of Cultivator Shoal whiting fishery by one month (June 15-October 31), changes to default measures, minor changes to Cape Cod Bay Raised Footrope Trawl exemption area.
May 13: Haddock possession limit revised to 30,000 lbs./trip (no daily limit).
July 9: Framework Adjustment 38 Raised footrope trawl whiting fishery in the inshore GOM, July 1 – November 30 each year.
July 28: Final emergency rule implementing FW 33 lawsuit settlement agreement Recreational: Haddock, 21 in. minimum size. Party/charter: GOM: Apr-Nov, 10 cod per person, December-March, 5 cod per person. Private: GOM: December-March, 10 cod/haddock combined, no more than 5 cod. Other areas: 10 cod/haddock combined.
October 7: Haddock possession limit suspended for the remainder of the fishing year.
2004
January 19-March 12: Northern Shrimp season (40 days with days off)
May 1: Implementation of Amendment 13. Measures based on emergency rule and measures in effect prior to interim rule. DAS: DAS for each permit re-categorized. Category 1: 60% of maximum DAS used FY 1996-2001 in years that permit landed 5,000 pounds regulated groundfish (est. 43,000 allocated). Category B: 40% of maximum DAS used FY 1996-2001 in years that permit landed 5,000 pounds regulated groundfish; can only be used in specific programs. DAS leasing and transfer programs allow DAS exchanges between vessels under limited conditions. (200 lbs. of winter flounder can be retained by vessels fishing for fluke west of 72-30 W without using a DAS). Minimum Size: No change from emergency rule (commercial); 22 inch cod, 19 inch haddock (rec) Gear**:** *Trawl*: No change from emergency rule. *Gillnet*: GOM/GB: Day-6.5 in./50 standup nets, no seasonal restriction on tie-down nets; Trip: 6.5 in. mesh/150 nets. SNE/MA: 6.5 in. in. mesh/75 nets. *Hook: GOM:* 2,000 hooks. *GB*: 3,600 hooks Closures: Same as emergency rule, with addition of habitat closed areas; all except Jeffrey Bank and NLCA habitat closed area are within existing year-round closed areas. Possession limits: *GOM cod*: 800 lbs-DAS/4,000 lbs.-trip. GB cod: 1,000 lbs.-DAS/10,000 lbs.-trip. *CC/GOM yellowtail flounder*: April, May, October, November - 250 lbs. trip, other months 750 lbs.-DAS/3,000 lbs-trip. *SNE/MA yellowtail flounder*: March –June, 250 lbs. trip, other months 750 lbs.-DAS/3,000 lbs-trip. *Haddock*: 3,000 lbs.-DAS/30,000 lbs.-trip. Special Management Programs: *US/Canada Area*: hard TAC on cod, haddock (SAs 561, 562), yellowtail flounder (SAs 522, 525, 561, 562). Cod possession limit: 500 lbs-DAS/5,000 lbs-trip, not more than 5 percent of catch. No DAS charged to/from SAs 561, 562. Exempted Fisheries: Northern Shrimp fishery area restriction removed; General Category scallop fishery exemption in SAs 537, 538, 539, and 613.
May 14: Haddock possession limit suspended for remainder of the fishing year.
June 1: CAII Yellowtail Flounder Special Access Program Access to CAII south of 41-30N by trawl vessels targeting yellowtail flounder. Limited to 320 trips (total), two trips per vessel per month, yellowtail flounder limited to 30,000 lbs./trip. Authorized use of Category B DAS.

June 23: Amendment 10 to the Atlantic Sea Scallop FMP. 10-in. square mesh twine top required for all scallop dredge vessels in all areas.
September 3: CAII Yellowtail Flounder SAP ends (no trips can begin after this date)
November 2: Framework Adjustment 39 (Scallop Framework Adjustment 16) Scallop dredge vessel access to portions of groundfish mortality CAII and NLCA in 2004, CAI and CAII in 2005, and CAI and NLCA in 2006. Season: June 15 through January 31. Possession limits: 1,000 lbs. regulated groundfish, no more than 100 lbs. cod. In NLCA, limited to 250 lbs.-trip yellowtail flounder in June. (Outside of access program, scallop vessels continue to be limited to 300 lbs. regulated groundfish per trip). Yellowtail flounder catch capped at 10 percent of target TAC for the stock.
October 1: Closure of SAs 561 and 562 to all fishing on a multispecies DAS. Prohibition on the possession of yellowtail flounder from SAs 522, 525, 561, 562.
November 19: Framework Adjustment 40A *Closed Area I Haddock SAP* Access to small area of CAI to target haddock using longlines. Limited to 1,000 mt haddock TAC. Season ends December 31. *Eastern US/CA Area Haddock SAP Pilot Program* Access to northern corner of CAII and adjacent area to target haddock using separator trawl. Season: May 1 through December 31. Authorized use of Category B DAS. *Category B (regular) DAS Pilot Program* Vessels can use Category B (regular) DAS to target healthy stocks. Catch (kept and discarded) limited to 100 lbs. of cod, American plaice, white hake, witch flounder, ocean pout, SNE/MA winter flounder and windowpane flounder, 25 lbs.-DAS/250 lbs.-trip of yellowtail flounder. Maximum of 1,000 DAS can be used in each of four quarters from November 1, 2004 through October 31, 2005.
2005
January 14: Eastern US/CA reopened, yellowtail flounder daily poundage limit lifter (maximum remains 15,000 lbs./trip). Cod trip limit of 5,000 lbs./trip in Eastern US/CA area. Vessels fishing in Eastern US/CA area must use haddock separator trawl.
February 9: GB yellowtail flounder trip limit reduced to 5,000 lbs./trip in (entire) US/CA Management Area.
April 1: Eastern US/CA area closed until April 30, 2005, possession of GB yellowtail flounder prohibited in entire US/CA Management Area.
May 1: Eastern US/CA Area reopens at beginning of fishing year. Measures revert to those implemented May 1, 2004.
May 3: Haddock trip limit removed for remainder of the fishing year.
May 26: FW 40B implemented. Changes DAS leasing and transfer program, modifies GB Hook Sector provisions, adopts reporting requirements for herring vessels, modifies trip gillnet provisions. *CAII Yellowtail Flounder SAP* Changes starting date to July 1, reduces trip limit to 10,000 lbs, number of trips per vessel per month is one, process established for adjusting the total number of trips.
June 8: Emergency action to control bycatch of haddock in the herring fishery establishes trip limit and overall TAC.
June 15: Implementation of FW 16 to the Sea Scallop FMP authorizes General Category Scallop vessel participation in scallop access areas. Scallop access areas in CAI and CAII open for all vessels on this date.
June 27: Announcement that no trips will be allowed in the CAII Yellowtail Flounder SAP in FY 2005.
July 12: NE multispecies DAS vessels are limited to one trip per month in the Eastern US/CA area.
July 18: Multispecies DAS vessels are prohibited from fishing in the Category B (regular) DAS program in the GB cod stock area through July 31.
July 27: NE multispecies trawl vessels are required to use a haddock separator trawl when fishing in the Eastern US/CA area.
August 26: Eastern US/CA area is closed to all limited access multispecies DAS vessels because 90

percent of the GB cod TAC for the area is projected to be harvested.
September 6: CAI scallop access area is closed to General Category scallop vessels.
September 13: *CAI Hook Gear Haddock SAP* FW 41 to the Northeast Multispecies FMP implemented. This action allows non-sector longline vessels to participate in the CAI Hook Gear Haddock SAP. The October 1 – December 31 season is divided in half, with sector vessels fishing in the first half and non-sector vessels in the second.
October 6: Participation in the Category B (regular) DAS Pilot Program is prohibited because the quarterly allocation of 1,000 DAS is used. The program ends for FY 2005.
October 31: Boundaries of the sea scallop access areas within CAI and the NLCA access areas are adjusted.
December 12: Northern shrimp fishery opens and will remain open through April 30, 2006.
December 21: The trip limit for NE multispecies vessels fishing for GB yellowtail flounder is changed from unlimited to 15,000 lbs per trip. The quota for the second period of the CAI Hook Gear Haddock SAP is increased to 536.6 mt.
2006
January 12: The emergency rule allowing Atlantic herring vessels to possess haddock is extended for an additional 180 days.
January 31: Areas within groundfish closed areas that are open to scallop fishing through the scallop access area program close at midnight.
February 7: The trip limit for NE multispecies vessels fishing for GB yellowtail flounder is reduced to 1,500 lbs. per DAS up to a maximum of 15,000 lbs.
February 22: The trip limit for NE multispecies vessels fishing for GB yellowtail flounder is changed to 15,000 lbs. per trip regardless of trip length.
March 24: The trip limit for NE multispecies vessels fishing for GB yellowtail flounder is increased to an unlimited amount regardless of trip length.
April 30: Northern shrimp fishery season closes at midnight.
May 1: Implementation of an emergency rule to reduce fishing mortality on groundfish stocks while FW 42 is reviewed. Revised regulations are: DAS: DAS charged at the differential rate of 1.4:1 for all areas outside the US/CA area. Minimum Size: No changes for commercial vessels. Gear**:** No changes. Closures: No changes Possession limits: *GOM cod*: 600 lbs-DAS/4,000 lbs.-trip. *GB cod*: 1,000 lbs.-DAS/10,000 lbs.-trip outside of eastern US/CA area. *CC/GOM yellowtail flounder*: May, June October, November - 250 lbs. trip, other months 500 lbs.-DAS/2,000 lbs-trip. *GB yellowtail flounder*: 10,000 lbs. per trip; *GB winter flounder*: 5,000 lbs. per trip; *SNE/MA yellowtail flounder*: March –June, 250 lbs. trip, other months 750 lbs.-DAS/3,000 lbs-trip. White hake: 1,000 lbs.-DAS/10,000 lbs.-trip. *Haddock*: Trip limit removed for duration of emergency action. Special Management Programs: ***Eastern*** *US/Canada* ***haddock SAP***: Opening delayed until August 1. Category B (regular) DAS Program: Renewed, with vessels restricted to the US/CA Area, required to use a haddock separator trawl, limited to 500 days May-June, 1,000 days in other quarters, low trip limits on stocks of concern. Recreational measures: Possession of GOM cod prohibited from November 1 – March 31. Minimum size for GOM cod increased to 24 in. Other: Vessels allowed to fish inside and outside the eastern US/CA area on the same trip.
May 19: Announcement that CAII Yellowtail SAP will not open due to low TAC.
June 19: All trawl vessels fishing in the eastern US/CA area required to use a haddock separator trawl.
July 12: General category scallop vessel access to Nantucket Lightship Close area closed due to catching yellowtail flounder incidental catch TAC.
July 20: Limited access scallop vessel access to Nantucket Lightship Close area closed due to catching yellowtail flounder incidental catch TAC.
August 11: FW 43 implemented; addresses incidental catch of regulated multispecies by herring

vessels. Haddock possession by midwater trawl vessels is allowed subject to a TAC.
September 6: Scallop vessel access to CAII closed due to yellowtail flounder bycatch.
October 1: CAI Hook Gear Haddock SAP opens.
November 22: Implementation of FW 42. Major regulatory changes: DAS: DAS charged at the differential rate of 2:1 for an area in the inshore GOM (for an entire trip if any part of the trip fished in the area) and an area in SNE (only time fishing in the area). Minimum Size: No changes for commercial vessels. Gear**:** No changes. Closures: No changes Possession limits: *GOM cod*: 800 lbs-DAS/4,000 lbs.-trip. *CC/GOM yellowtail flounder*: 250 lbs-DAS/1000 lbs. per trip. *SNE/MA yellowtail flounder*: 250 lbs-DAS/1000 lbs. per trip. Haddock trip limit unlimited. ***GB Yellowtail flounder: 10,000 lbs/trip. White Hake: 500 lbs-DAS/5,000 lbs-trip (this was an error – FW 42 says 1,000/10,000 per trip).*** Special Management Programs: *US/Canada Area*: Opening delayed until August 1. Prohibition on discarding legal sized fish. Category B (regular) DAS Program: Renewed for all areas. Trawl vessels required to use a haddock separator trawl, limited to 500 days May-June, 1,000 days in other quarters, low trip limits on stocks of concern. Prohibition on discarding legal sized fish. Recreational measures: (same as emergency rule) Possession of GOM cod prohibited from November 1 – March 31. Minimum size for GOM cod increased to 24 in. Other: (same as emergency rule) Vessels allowed to fish inside and outside the eastern US/CA area on the same trip.
December 1: Northern shrimp fishery opens: 151 days, seven days per week.
2007
March 5: Trawl vessels fishing in the eastern US/CA area allowed to use either a haddock separator trawl or a flounder net. GB yellowtail flounder trip limit reduced to 5,000 lbs.-trip for all vessels declaring into the eastern US/CA area.
April 5: Trip limit for GB yellowtail flounder increased to 25,000 lbs.-trip for the entire US/CA area for the remainder of the fishing year (through April 30).
April 25: Eastern U.S./Canada area closed to limited access multispecies vessels (through April 30, 2007).
April 30: Northern shrimp fishery closed at midnight.
May 1: Enforcement protocol for measuring nets changes. For mesh over 4.72 inches (120 mm), weight used with net spade increased to 8 kg (from 5 kg). Eastern U.S./Canada area reopens. No trips are authorized in the CAII yellowtail flounder SAP in 2007. Trip limit for GB yellowtail flounder reduced to 3,000 pounds per trip in the U.S./Canada area. Interim measures adopted for monkfish FMP restrict monkfish trip limits, reduce DAS that can be used in the SFMA, and does not allow carryover of monkfish DAS.
June 15: NLCA and CAI scallop access areas open.
June 20: Eastern US/CA area is closed to limited access multispecies DAS vessels due to cod catch.
July 8: The NLCA scallop access area is closed to General Category Scallop vessels.
July 15: The CAI scallop access area is closed to General Category Scallop vessels.
August 3: NMFS modifies permit renewal requirements for limited access multispecies vessels. Changes limit ability of vessels to fish in state waters outside of the FMP and retain eligibility for a federal limited access permit.
August 9: Minimum size for GB and GOM haddock caught by commercial vessels is reduced to 18 inches. Minimum size for all recreational vessels remains at 19 inches.
October 1: CAI Hook Gear Haddock SAP opens for GB Cod Hook Sector vessels.
October 20: The Eastern US/CA area is opened to limited access multispecies DAS vessels. The GB cod possession limit is 1,000 lb/trip for all vessels declared into the Eastern US/CA Area or the Eastern US/CA Area SAP.
November 15: CAI Hook Gear Haddock SAP opens for non-sector vessels.

November 27: GB yellowtail flounder trip limit for vessels fishing in the US/CA management area increased to 7,500 lb/trip.
November 30: Eastern US/CA area closes
December 1: Northern Shrimp fishery opens. Season scheduled for 152 days, seven days per week.
December 11: CAI Hook Gear haddock SAP second period haddock quota increased to 4,789 mt.
2008
January 10: GB yellowtail flounder tip limit in the U.S/Canada management area set at 1,500 lbs./trip
January 24: Harvesting, possessing, and landing GB yellowtail flounder from the entire U.S./Canada management area is prohibited through April 30, 2008 (applies to trips that have not begun prior to announcement).
February 6: Minimum size for both GB and GOM haddock remains at 18 inches total length; extended through August 10, 2008.
March 12: Scallop elephant trunk access area closed to General Category scallop vessels.
April 30: Northern shrimp fishery closes.
May 1: GB yellowtail flounder trip limit set at 5,000 lbs./trip Eastern U.S./Canada area opening delayed until August 1, 2008 for vessels fishing with trawl gear. Eastern U.S./Canada area opened to longline gear but with a cod cap of 33.4 mt.
May 30: CAII yellowtail SAP remains closed (no trips authorized for FY 2008).
August 1: GOM and GB haddock minimum size reverts to 19 inches. Eastern U.S./Canada management area opens to all vessels. U.S./Canada Haddock SAP opens.
August 4: Happy Birthday, U.S. Coast Guard. The Nantucket Lightship Closed Area closed to scallop vessels to prevent exceeding the yellowtail flounder incidental catch cap.
August 13: Haddock rope trawl (later called the Ruhle trawl, previously called the eliminator trawl) approved for use in the Category B (regular) DAS program and the U.S./Canada Haddock SAP.
September 15: Ruhle trawl authorized for use in the Eastern U.S./Canada management area.
October 1: CAI Hook Gear Haddock SAP opens for non-sector vessels.
October 23: GB yellowtail flounder trip limit reduced from 5,000 lbs./trip to 2,500 lbs./trip for vessels fishing in the U.S./Canada management area.
November 15: CAI Hook Gear Haddock SAP opens for GB cod hook sector vessels.
December 1: Northern shrimp fishery opens for 180 days, seven days per week. Closure scheduled for May 29, 2009.
December 23: Landing limit for Eastern GB cod increased to 1,000 lbs./DAS up to a maximum of 10,000 lbs./trip (applies to cod caught in the Eastern U.S./Canada management area).
December 30: Limited access General Category scallop fishery closed.
2009
January 26: NE Multispecies regulations adopted by FW 42 suspended as a result of a court order. No clear explanation of what measures are affected.
February 13: NMFS identifies following measures as NOT impacted by the court order to suspend measures adopted by FW 42: • Recordkeeping and reporting requirements • Gear restrictions • DAS allocations • Time and area closures • Minimum fish sizes • SAPs • Recreational measures • Cape Cod Hook Sector • Some possession limits (GOM cod 800 lbs DAS-4,000 lbs/trip,, GB cod 1,000 lbs./DAS – 10,000 lbs./trip, US/CA area trip limits Confusion continues on what regulations are not in effect.
February 17: Federal court rescinds decision to suspend FW 42 measures and limits suspension to differential DAS counting areas in the GOM and SNE/MA areas, and authorizes submission of DAS

leasing requests through March 31, 2009 (vice normal March 1 deadline for such requests).
March 9: Eastern GB cod landing limit reduced to 500 lbs./DAS – 5,000 lbs./trip. GB yellowtail flounder trip limit increased to 5,000 lbs/trip.
April 1: DELMARVA scallop access area closed to General Category scallop vessels.
April 16: Eastern US/CA area closed until May 1.
May 1: Interim rules in effect to reduce overfishing on multispecies stocks until Amendment 16 implemented. Major changes: DAS: DAS allocations reduced according to Amendment 13 schedule. Category A DAS are reduced to 45 percent of the permit's DAS baseline, an 18 percent reduction from the previous year's allocations. Differential DAS area increased in SNE/MA. Minimum Size: Haddock 18 inch minimum size. Gear**:** No changes. Closures: No changes Possession limits: *GOM cod*: 800 lbs-DAS/4,000 lbs.-trip. *GB cod*: 1,000 lbs./DAS-10,000 lbs./trip (eastern US/CA area 500 lbs./DAS-5,000 lbs./trip). *CC/GOM yellowtail flounder*: 250 lbs-DAS/1000 lbs. per trip. *SNE/MA yellowtail flounder*: 250 lbs-DAS/1000 lbs. per trip. Haddock trip limit unlimited. *GB Yellowtail flounder*: 5,000 lbs/trip. *White Hake*: 1000 lbs-DAS/10,000 per trip). GB winter flounder: 5,000 lbs./trip. Witch flounder: 1,000 lbs./DAS-5,000 lbs./trip. Possession *of ocean pout, northern windowpane flounder, and SNE/MA winter flounder* prohibited. Special Management Programs: *US/Canada Area*: Opening delayed until August 1 for trawl vessels. *SNE/MA winter flounder SAP* suspended. State waters winter flounder exemption eliminated. *CAI Hook Gear Haddock SAP* expanded to May 1 to January 31, area increased, no separation between common pool and sector participants. Recreational Measures: GB cod bag limit of n10 cod per person per day for party/charter vessels; retention of GOM cod prohibited from November through April 15; retention of SNE/MA winter flounder prohibited; haddock minimum size reduced to 18 inches. Other: Conservation tax removed from DAS transfers.
May 6: Limited access general category scallop fishery closed to IFQ vessels until June 1.
May 29: Northern shrimp fishery closes.
June 5: GB yellowtail flounder trip limit reduced to 2,500 lbs./trip
June 26: eastern US/CA Area closed to all vessels until August 1 (including fixed gear vessels) to prevent exceeding first quarter GB cod TAC.
June 29: CAII Scallop Access Area closed to prevent exceeding GB yellowtail flounder cap.
July 6: *GB winter flounder* trip limit removed. *White hake* trip limit increased to 2,000 lbs./DAS-10,000 lbs./trip.
July 19: Limited access general category scallop fishery closed to IFQ vessels until September 1.
September 15: Limited access general category scallop fishery closed to IFQ vessels until December 1.
September 17: Use of flounder trawl net prohibited when fishing in the Eastern US/CA area.
November 2: Mid-water trawl vessels fishing in CAI subject to 100 percent observer coverage, prohibition on releasing catch before sampling by observer.
November 20: In the US/CA management area, trawl vessels required to use a haddock separator trawl or Ruhle trawl south of 41-40N latitude. Any vessel fishing in this area and other areas cannot use any other gear on the same trip. Vessels fishing north of 41-40N for the entire trip can use any legal gear.
December 1: Northern shrimp fishery opens for 180 days; scheduled to close May 29, 2010.
2010
January 12: Limited access general category scallop fishery closed to IFQ scallop vessels
March 1: Limited access general category scallop IFQ program opens. Scallop fishery Elephant Trunk and DELMARVA Access Areas open.
March 11: All multispecies vessels fishing on a Category A DAS allowed to use any legal trawl gear in the Western US/CA Area (statistical areas 522, 525) (lifts restrictions adopted November 20, 2009).
April 13: All multispecies vessels fishing on a Category A DAS allowed to use a flounder trawl net in the Eastern US/CA area.

April 20: Eastern US/CA area (statistical areas 561, 562) closed to multispecies vessels and harvest, possession, and landing of GB yellowtail flounder from entire US/CA area (statistical areas 522, 525, 561, 562) prohibited.
May 1: Implementation of Amendment 16 and Framework 44. Expansion of sector management program to majority of the fishery. Major revisions to common pool measures for permitted vessels not in sectors. Adoption of additional at-sea and dockside monitoring requirements for sector vessels, and new reporting requirements for other vessels. Adoption of new US/CA area TACs. Adoption of annual catch limit (ACL) and accountability measures (AM) for most stocks. No retention of SNE/MA winter flounder, ocean pout, windowpane flounder, Atlantic wolffish. Specific allocations of GOM cod and GOM haddock made to the recreational and commercial groundfish fisheries. Key elements: *Sector Management:* Vessels in sectors subject to hard TACs for most stocks, increased at-sea monitoring (targeting 38 percent of trips), dockside monitoring; not subject to trip limits, some GOM rolling closures, groundfish DAS limits. Permits committed to sectors account for 94 percent or more of available catch except for GOM WFL (84 pct) and SNE/MA YTF (76 pct), and SNE/MA WFL (0%). Total permits committed to sectors: 762. Sector vessels required to retain all legal-sized fish (except limited to one Atlantic halibut, and the five species prohibited). Sectors required to stop fishing in a stock area when a quota (Annual Catch Entitlement, or ACE) for a stock in the area is caught. *Common pool*: Only a small portion of the ACL available to common pool vessels. Major elements of common pool regulations: DAS: Category A DAS allocations reduced to 27.5 percent of the Amendment 13 baseline allocation. All DAS charged in 24 hour increments. Minimum Size: Haddock 18 inch minimum size. Halibut size increased to 41 inches. Gear**:** No changes. Closures: No changes Possession limits: *GOM cod*: 800 lbs-DAS/4,000 lbs.-trip. *GB cod*: 2,000 lbs./DAS-20,000 lbs./trip (eastern US/CA area 500 lbs./DAS-5,000 lbs./trip). *Pollock*: 1,000 lbs./DAS – 10,000 lbs/trip; *CC/GOM yellowtail flounder*: 250 lbs-DAS/1500 lbs. per trip. *SNE/MA yellowtail flounder*: 250 lbs-DAS/1500 lbs. per trip. Haddock trip limit unlimited. *GB Yellowtail flounder*: 2,5000 lbs/trip offshore; 250 lbs./DAS-1,500 lbs./trip inshore. *White Hake*: 2,000 lbs-DAS/10,000 per trip). GB winter flounder: 5,000 lbs./trip. Witch flounder: 1,000 lbs./DAS-10,000 lbs./trip. GB winter flounder: Offshore 5,000 lb./trip. Possession *of ocean pout, windowpane flounder, Atlantic wollffish, and SNE/MA winter flounder* prohibited. Restricted Gear Areas: Areas near CAI and off SNE created to reduce flatfish catches; limited to separator/Ruhle trawls, rope trawl, certain gillnets in these areas. Limited to 500 lbs. of flatfish combined in these areas. Special Management Programs: *US/Canada Area*: Opening delayed until August 1 for trawl vessels. Prohibition on discarding legal sized fish. *SNE/MA winter flounder SAP* suspended. State waters winter flounder exemption eliminated. *CAI Hook Gear Haddock SAP* expanded to January 31, area increased, no separation between common pool and sector participants. *CAII yellowtail flounder –haddock SAP*: SAP opening authorized to target haddock (not GB yellowtail flounder_ subject to specific gear requirements. Opening date August 1. *Adjustments*: RA authorized to make in-season adjustments to trip limits and DAS counting rates. *DAS Leasing and Transfers:* Permits in CPH category allowed to participate in these programs. No conservation tax on transfers. Recreational Measures: GOM cod bag limit of 10 cod per person per day for party/charter vessels; 10 fish bag limit on all cod for private vessels; retention of GOM cod prohibited from November through April 15; retention of SNE/MA winter flounder prohibited; Atlantic wolffish retention prohibited; haddock minimum size reduced to 18 inches. Halibut size increased to 41 inches. No limit on hooks (two hook limit removed).
May 5: Northern shrimp fishery season closes
May 27: Changes to common pool trip limits: GOM haddock: 1,000 lbs./trip

GB haddock: 10,000 lbs./trip GOM winter flounder: 250 lbs./trip GB winter flounder: 1,000 lbs./trip (offshore) GB yellowtail flounder: 1,000 lbs./trip (offshore)
June 28: NLCA scallop access area opens
July 15: Pollock ACL revised; increased to 16,553 mt.
July 30: Changes to common pool measures: GB yellowtail flounder: Selective trawl gear required in Eastern US/CA area and Western US/CA area south of 41-40N. GOM cod: 200 lbs./DAS-1,000 lbs./trip
August 6: Changes to common pool measures: Pollock trip limit removed Witch flounder: 130 lbs./trip
August 31: Common pool DAS counting rate set to 2:1 for GOM and GB differential DAS areas.
September 22: Changes to common pool measures: GOM cod: 100 lbs./DAS-1,000 lbs./trip GB yellowtail flounder: 100 lbs./trip White hake: 100 lbs./DAS – 500 lbs./trip US/CA area: Selective trawl gear required to entire US/CA management area
October 18: Handgear A cod trip limit reduced to 50 lbs/trip.
December 1: Northern shrimp season opens

Winter Flounder Length-based Survey Calibration

Tim Miller, NEFSC Population Dynamics Branch

September 10, 2011

Introduction

In 2009, the *NOAA SHIP Henry B. Bigelow* replaced the *R/V Albatross IV* as the primary vessel for conducting spring and fall annual bottom trawl surveys for the Northeast Fisheries Science Center (NEFSC). There are many differences in the vessel operation, gear, and towing procedures between the new and old research platforms (NEFSC Vessel Calibration Working Group 2007). To merge survey information collected in 2009 onward with that collected previously, we need to be able to transform indices (perhaps at size and age) of abundance from the *Henry B. Bigelow* into those that would have been observed had the *Albatross IV* still been in service. The general method for merging information from these two time series is to calibrate the new information to that of the old (e.g., Pelletier 1998, Lewy et al. 2004, Cadigan and Dowden 2010). Specifically we need to predict the relative abundance that would have been observed by the *Albatross IV* ($\hat{R}_A$) using the relative abundance from the *Henry B. Bigelow* (R_B) and a "calibration factor" (ρ),

$$\hat{R}_A = \rho R_B . \quad (1)$$

To provide information from which to estimate calibration factors for a broad range of species, 636 paired tows were conducted with the two vessels during 2008. Paired tows occurred at many stations in both the spring and fall surveys. Paired tows were also conducted during the summer and fall at non-random stations to augment the number of non-zero observations for some species. Protocols for the paired tows are described in NEFSC Vessel Calibration Working Group (2007).

The methodology for estimating the calibration factors was proposed by the NEFSC and reviewed by a panel of independent scientists in 2009. The reviewers considered calibration factors that could potentially be specific to either the spring or fall survey (Miller et al. 2010). They recommended using a calibration factor estimator based on a beta-binomial model for the data collected at each station for most species, but also recommended using a ratio-type estimator under certain circumstances and not attempting to estimate calibration factors for species that were not well sampled.

Since the review, it has become apparent that accounting for size of individuals can be necessary for many species. When there are different selectivity patterns for the two vessels, the ratio of the fractions of available fish taken by the two gears varies with size. Under these circumstances, the estimated calibration factor that ignores size reflects an average ratio weighted across sizes where the weights of each size class are at least in part related to the number of individuals at that size available to the two gears and the number of stations where individuals at that size were caught. Applying calibration factors that ignore real size effects to surveys conducted in subsequent years when the size composition of the available population is unchanged should not produce biased predictions (eq. 1). However, when the size composition changes, the frequency of individuals and number of stations where individuals are observed at each size changes and the implicit weighting across size classes used to obtain the estimated calibration factor will not be applicable to the new data. Consequently, the predictions from the constant calibration factor of the numbers per tow that would have been caught by the *Albatross IV* will be biased.

Length-based calibration has been performed for groundfish (cod, haddock, and yellowtail flounder through the Trans-boundary Resource Assessment Committee process and silver, offshore, and red hakes during SARC 51 and loligo squid during SARC 51 (Brooks et al. 2010, NEFSC 2011). For those length-based calibrations, the same basic beta-binomial model from Miller et al. (2010) was assumed, but various functional forms were assumed for the relationship of length to the calibration factor. Since then, Miller (submitted) has explored two types of smoothers for the relationship of relative catch efficiency to length and the beta-binomial dispersion parameter. The smoothers (orthogonal polynomials and thin-plate regression splines) allow much more flexibility than the functional forms previously considered for other species by Brooks et al. (2010) and NEFSC (2011). Catch efficiency at length, $q(L)$, as defined here relates the expected catch to the density of available individuals on a per unit swept area basis,

$$E\left(C_{ik}\left(L\right)\right) = q_k\left(L\right) f_{ik} A_{ik} D_i\left(L\right)$$

where $D_i\left(L\right)$ is the density of available fish at station i, and f_{ik} and A_{ik} are the fraction of the catch sampled for lengths and swept area for vessel/gear k. Relative catch efficiency is the ratio of the catch efficiencies for two vessels and is related to the calibration factor,

$$\rho\left(L\right) = \frac{E\left(C_{i1}\left(L\right)\right)}{E\left(C_{i2}\left(L\right)\right)} = \frac{q_1\left(L\right)}{q_2\left(L\right)} \frac{f_{i1} A_{i1}}{f_{i2} A_{i2}}.$$

Miller (submitted) analyzed data for six species including winter flounder and the Skate Plan Development Team of the New England Fisheries Management Council has explored these methods to estimate smoother-based calibration factors for the complex of six skate species.

For SARC 52, the Working Group reviewed the work by Miller (submitted) on winter flounder in greater detail. The working group also decided to compare these results to those from another model that accounted for effects of stock area (Gulf of Maine, Georges Bank, and southern New England). The Working Group was also interested in seasonal effects, but chose not to pursue these models due to a lack of samples in the Gulf of Maine stock area during the spring survey. The lead assessment scientists for each of the winter flounder stocks also compared predicted indices in Albatross units based on the different the fitted models to check for any disparities (see their respective working documents for these comparisons).

Methods

The data used in to fit the winter flounder calibration models are numbers sampled by vessel, station, and 1 cm length class. I considered the same classes of smoothers as Miller (submitted) and the way stock areas are attributed to the calibration data are defined in Table 1. I used the model with the second best AIC_C value from Miller (submitted) rather than that with the best value as a starting point because the predicted relative catch efficiencies were virtually identical and the chosen model was substantially more parsimonious, particularly for the dispersion portion of the beta-binomial model. The chosen model assumes fourth order orthogonal polynomial smoother of the effects of length on the calibration factor and effects of area swept (A_{ik}) and sampling fraction (f_{ik}) of each vessel on the beta-binomial dispersion parameter. I accounted for stock area effects by allowing all parameters to differ by stock area (i.e., interactions of stock area with length, sampling fraction, and swept area covariates were included). I compared relative goodness-of-fit of the models using Akaike Information Criteria corrected for small sample size bias (AIC_C; Hurvich and Tsai 1989). I fit models in the R statistical programming environment (R Development Core Team 2010) and used the GAMLSSS package (Rigby and Stasinopoulos 2005, Stasinopoulos and Rigby 2007).

Results and Discussion

When fitting the fourth order polynomial models to data from each region, there were convergence issues for the Gulf of Maine likely due to over-parameterization of the length effects. When the order of the polynomial was reduced to two for this region, these issues were resolved. The resulting model performed better than the best models Miller (submitted) fit that did not account for effects of stock area (Table 2). Inspection of residuals reveals no strong trend with predicted number captured by the Henry B. Bigelow or total number captured by station and no strong departure from normality (Figure 1). The predicted relative catch efficiency was lowest at intermediate size classes for all three stock areas, but the location of the minimum was at larger size for the Georges Bank than the other stock areas. For southern New England, there were actually two minima with a slight rise in relative catch efficiency estimated between them.

When applying the relative catch efficiencies to surveys conducted in 2009 and 2010 with the *Henry B. Bigelow*, there is an important caution to note. Lengths may be observed in these surveys that are outside of the range of lengths observed during the calibration study. This problem is exacerbated when the data are broken down into stock area subsets for estimation of relative catch efficiency because the limits of the range of sizes available in the subsets can be narrower than the range of the entire data set (see Table 3). Caution must be taken in predicting catches in *Albatross IV* units at these sizes. The working group had some concern with the asymptotically increasing estimates of relative catch efficiencies at the smallest and largest sizes for the winter flounder stocks, particularly if converting historic Albatross indices to Bigelow equivalents were attempted. Sizes of fish outside of the ranges observed during the calibration study would potentially lead to extremely high Bigelow abundance indices at the extremes of the length composition for the historic data. An adaptation of the regional model was briefly explored that constrained lengths beyond a minimum and maximum length to have constant relative catch efficiencies. The minima and maxima were determined by specifying a maximum coefficient of variation (CV) of predicted relative catch efficiencies at these lengths. These CV criteria resulted in models that provided aggregate abundance indices that were very similar to the corresponding models without the CV criteria. Because no ad-hoc CV criteria were necessary in the initial models, the working group found these to be preferable.

Lastly, the swept areas for tows during the 2009 and 2010 surveys would ideally be used to predict Albatross catches at each station, but if there is little variability in the swept areas a mean can be used and the mean number per tow at length in *Henry B. Bigelow* “units” can be converted to *Albatross IV* units (Table 4).

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Table 1. NEFSC survey strata used for Gulf of Maine, Georges Bank and southern New England stock areas in length-based calibration analyses. Note that these may not be identical to those used for assessment indices.

Gulf of Maine	Georges Bank	Southern New England
01260-01270	01130-01240	01010-01120
01330-01340		01250
01351		01690-01760
01380-01400		03010-03290
03580-03610		03450-03560
03640-03660		

Table 2. Model type (thin-plate regression spline, SP, orthogonal polynomial, OP), numbers relative catch efficiency, dispersion, and total degrees of freedom, dispersion covariates, and log-likelihood for best performing models based on AIC_C.

Rank	Model Type	ρ df	ϕ df	ϕ Covariates	# Total parameters	-LL	AIC_c	Δ (AIC_c)
1	OP(Stock Area)	13	9	SF, SA	22	-1034.27	2113.38	0.00
2	OP-G	5	9		14	-1059.68	2147.70	34.32
3	OP	5	3	SF, SA	8	-1065.98	2148.04	34.66
4	OP-G	3	9		12	-1061.95	2148.16	34.78
5	PS	7.48	3	SF, SA	10.48	-1063.58	2148.30	34.92
6	OP	5	4	SF, SA	9	-1065.11	2148.32	34.94
7	OP-G	4	9		13	-1061.07	2148.44	35.06
8	OP-G	5	1		6	-1068.66	2149.39	36.01
9	OP-G	5	10		15	-1059.64	2149.67	36.29
10	OP-G	6	9		15	-1059.66	2149.71	36.33
11	OP	5	5	SF, SA	10	-1064.93	2149.99	36.61

Table 3. Predicted relative catch efficiencies for the three stock areas from the final calibration model. Values in red are outside of the range of lengths observed for the respective stock area.

Length (cm)	Gulf of Maine	Georges Bank	Southern New England
6	23469.46	13.06	2539.52
7	11462.59	13.05	827.65
8	5757.23	13.05	312.88
9	2973.68	13.04	135.45
10	1579.53	13.03	66.33
11	862.80	12.99	36.31
12	484.67	12.93	21.98
13	279.98	12.84	14.55
14	166.33	12.72	10.43
15	101.61	12.55	8.01
16	63.84	12.34	6.55
17	41.25	12.08	5.64
18	27.40	11.78	5.07
19	18.72	11.44	4.74
20	13.16	11.06	4.57
21	9.51	10.64	4.50
22	7.06	10.20	4.53
23	5.40	9.73	4.61
24	4.24	9.24	4.73
25	3.43	8.75	4.88
26	2.85	8.24	5.04
27	2.44	7.74	5.19
28	2.14	7.25	5.32
29	1.93	6.77	5.42
30	1.80	6.31	5.48
31	1.72	5.87	5.49
32	1.69	5.46	5.45
33	1.71	5.07	5.37
34	1.78	4.71	5.24
35	1.90	4.39	5.09
36	2.09	4.09	4.92
37	2.36	3.83	4.74
38	2.74	3.59	4.57
39	3.28	3.39	4.43
40	4.03	3.22	4.34
41	5.10	3.07	4.30
42	6.63	2.96	4.34
43	8.87	2.88	4.49
44	12.20	2.83	4.79
45	17.25	2.82	5.30

46	25.08	2.85	6.14
47	37.51	2.92	7.49
48	57.70	3.04	9.72
49	91.26	3.23	13.52
50	148.43	3.50	20.39
51	248.28	3.87	33.63
52	427.09	4.38	61.35
53	755.51	5.09	125.15
54	1374.39	6.08	288.90
55	2571.17	7.47	764.01
56	4946.56	9.47	2344.61
57	9786.48	12.42	8462.27
58	19911.34	16.86	36425.66
59	41660.58	23.78	189727.37
60	89639.85	34.91	1213921.55
61	198347.97	53.44	9690867.12

Table 4. Mean swept area (sq. nm) per tow for each vessel at all stations or just those where winter flounder were observed, across all areas or those occurring in the stock areas. Note that swept area is not known for every tow.

		Gulf of Maine	Georges Bank	Southern New England	Overall
Winter flounder observed	Albatross IV	0.0116713	0.0116754	0.0112200	0.0114548
	Henry B. Bigeglow	0.0070750	0.0064268	0.0065834	0.0065460
All stations	Albatross IV	0.0116610	0.0117447	0.0112734	0.0114787
	Henry B. Bigeglow	0.0072050	0.0065790	0.0066452	0.0066689

Figure 1. Randomized quantile residuals of the best performing model (as measured by AICc, see Table 1) for winter flounder in relation to the predicted number captured by the *Henry B. Bigelow* (left), the total number of fish captured at a station (middle), and their normal quantiles (right).

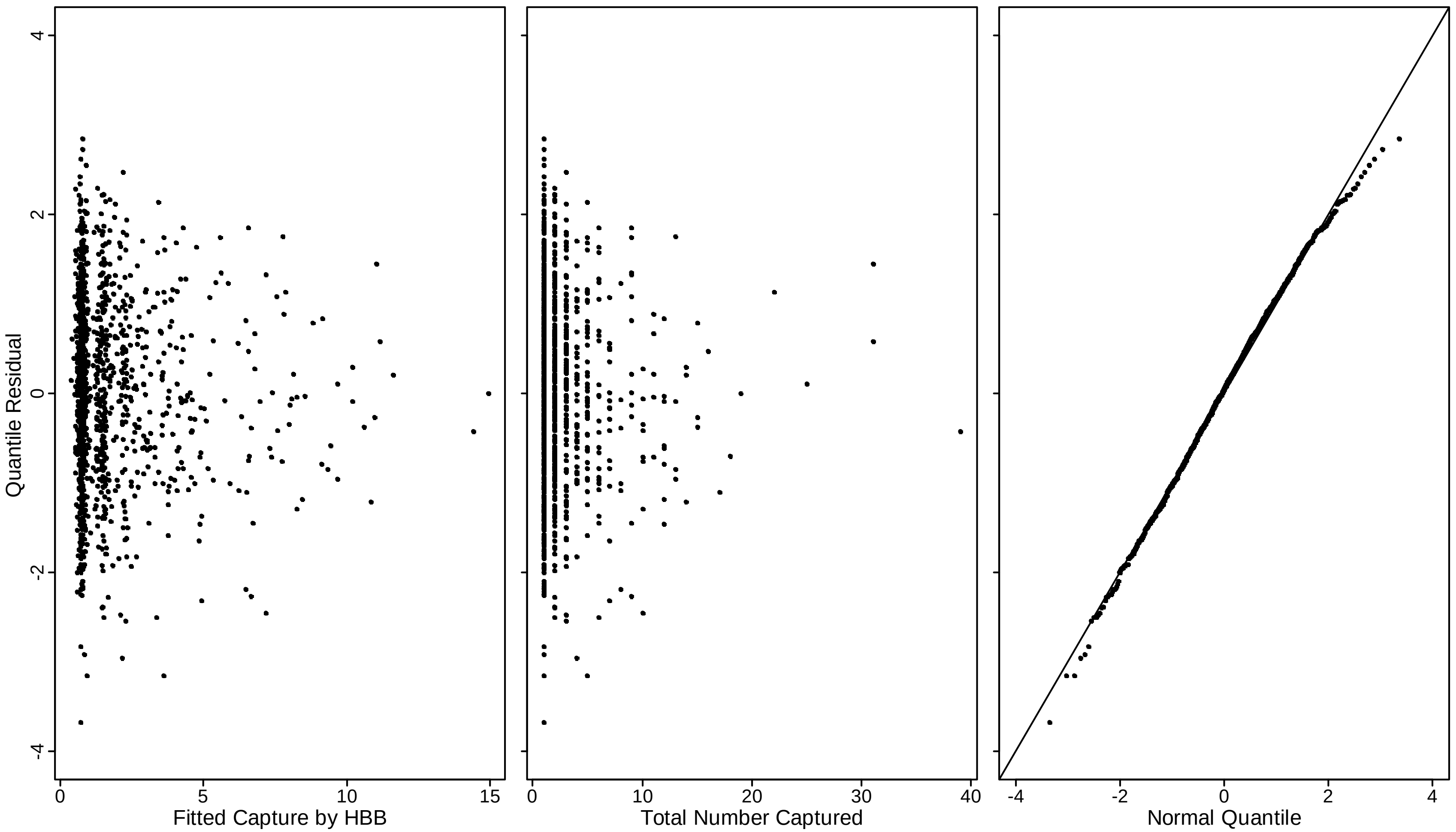
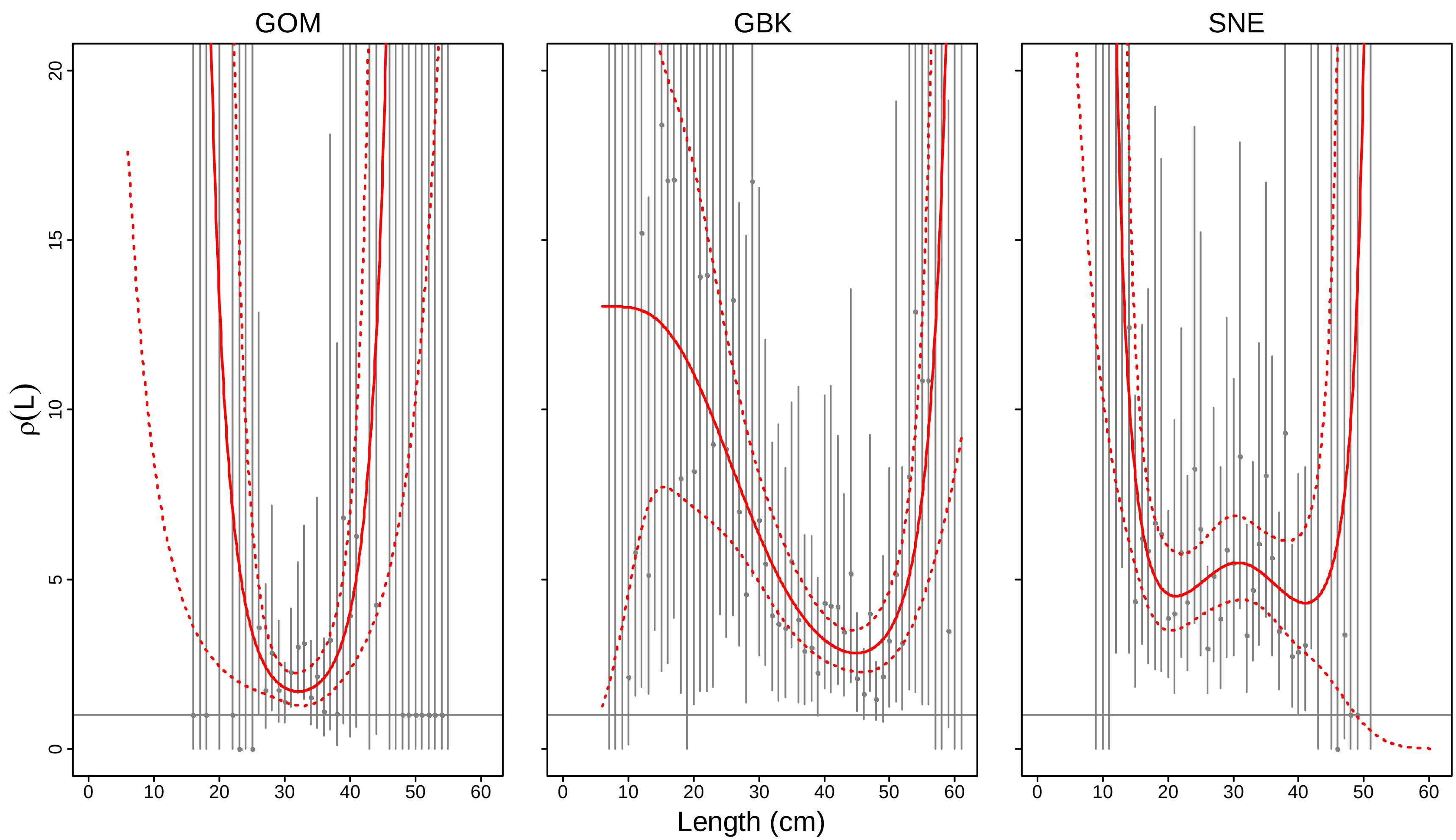


Figure 2. Estimated relative catch efficiency by stock area (columns) from the best beta-binomial model where relative catch efficiency is modeled as an orthogonal polynomial smoother of length (solid red line) and from separate models fit to data in each length class (gray points). Dotted red lines and vertical gray lines represent approximate 95% confidence intervals. Horizontal gray line represents equal efficiency of the *Henry B. Bigelow* and *Albatross IV*.



SDWG Background WP#7 (b)
May 2011
Wint. Fl Length based Calib

Winter Flounder Calibration: WP7

Beta-Binomial Model

- Binomial model at each station for number captured by Bigelow conditional on number captured by Both (Bigelow + Albatross)

$$N_{Bi}(L) \sim Bin\left(N_i(L), p_i(L)\right)$$

- Probability parameter is random across stations according to beta distribution

$$p_i(L) \sim Beta\left(\pi(L), \phi(L)\right)$$

Mean Model from CRD 10-05

$$\log\left(\frac{\pi}{1-\pi}\right) = \log(\rho)$$

- π is the (mean) probability of capture by the Bigelow
- $\rho = E(C_B)/E(C_A)$ is the calibration factor

Length Models

$$\log\left(\frac{\pi(L)}{1-\pi(L)}\right)=\log\left[\rho\left(L\right)\right]+\log\left(SA_B / SA_A\right)+\log\left(SF_B / SF_A\right)$$

- $\pi(L)$ is the (mean) probability of capture by the Bigelow
- $\rho\left(L\right)$ is the relative catch efficiency (B/A)
- SA is the swept area
- SF is the sampling fraction
- Based on $E(C)=q\times SA\times D$

Dispersion Models

- For orthogonal polynomial and penalized smoothers,

$$\log\left[\phi(L)\right] = \alpha_1 \log\left(SA_B / SA_A\right) + \alpha_2 \log\left(SF_B / SF_A\right) + \varphi(L)$$

- For the gamma-based beta-binomial model,

$$\log\left[\phi(L)\right] = \log\left[SF_A SA_A + \rho(L) SF_B SA_B\right] + \varphi(L)$$

Smoothers for Length Models

$$\log\left[\rho(L)\right] = \sum_{i=0}^{D} \beta_i g_i(L) \qquad \varphi(L) = \sum_{i=0}^{D} \beta_i g_i(L)$$

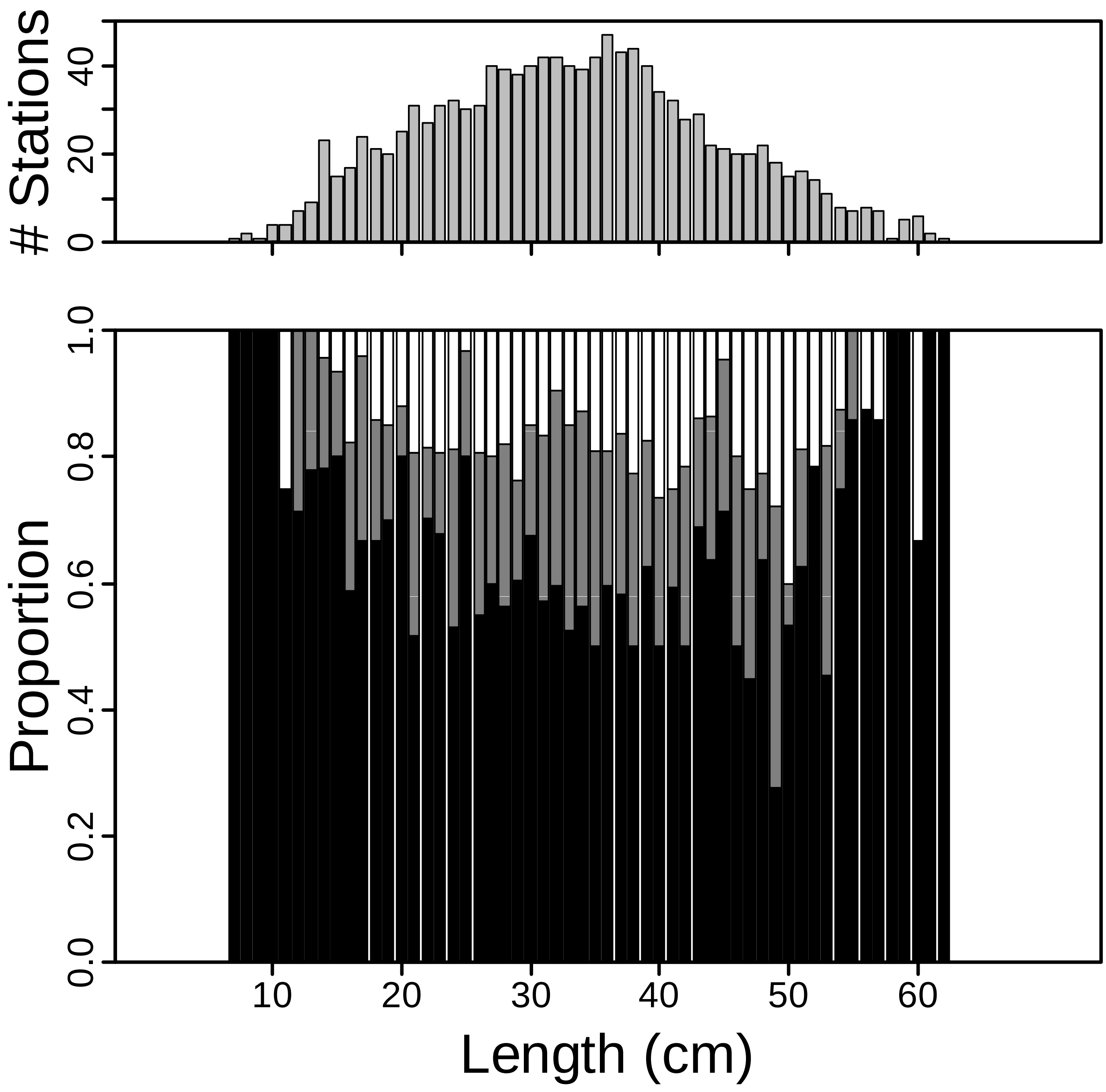
- The more terms, the less smooth the fit can be.
- For orthogonal polynomial, D is the degree of the polynomial and $g_i(L)$ are uncorrelated
  - D ranges from 0 to 12 for both relative catch efficiency and dispersion parameter
- For penalized smoothers $g_i(L)$ are basis components and D is the number of columns of the basis
  - The number parameters is estimated via a penalty term.

By Stock Region

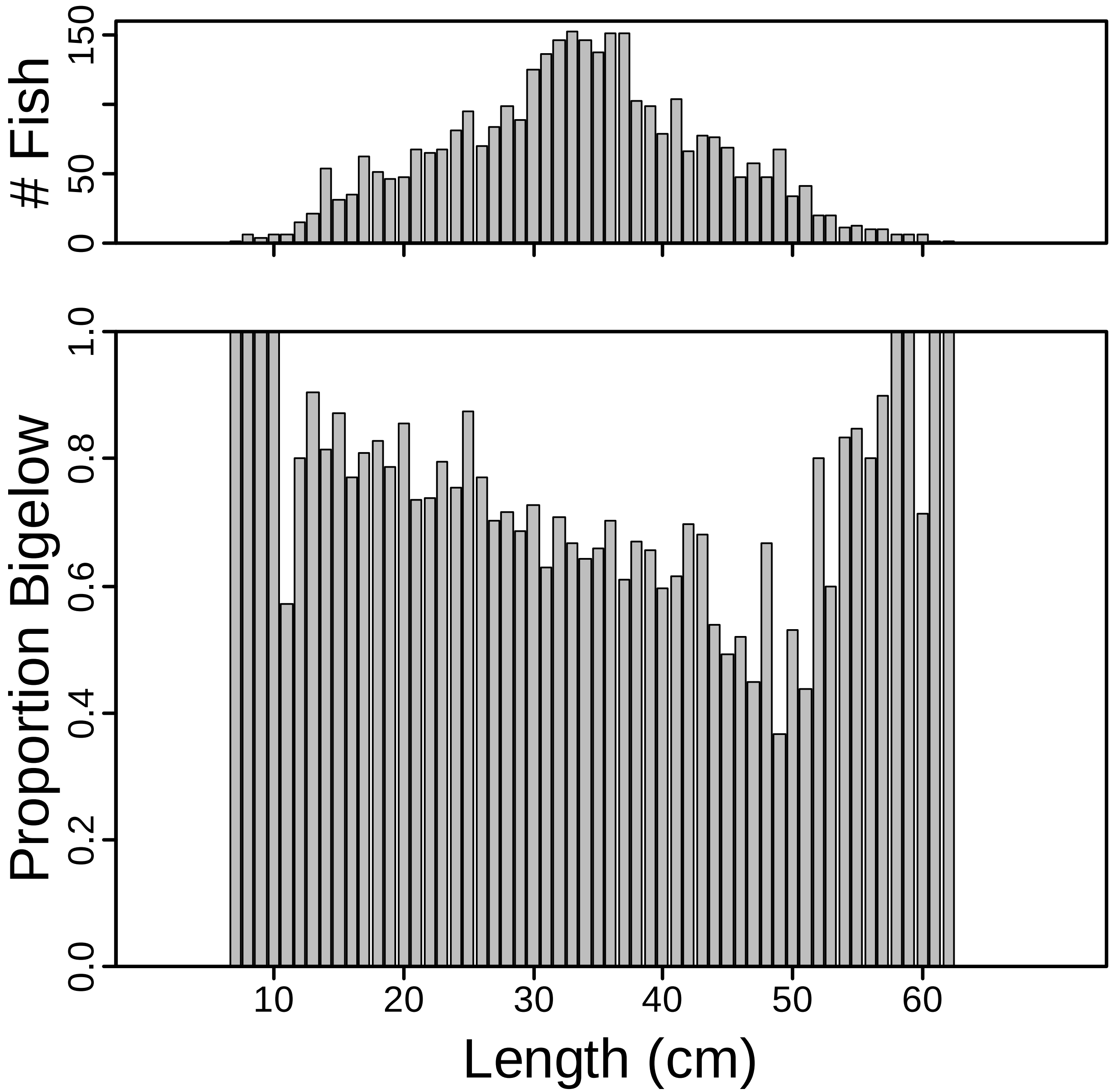
- The catchability of the survey may vary by stock region
  - ➢natural to consider differences in relative catch efficiency too
- Regional strata in Table 1 (slightly different than survey indices)
- All estimated parameters were season-specific
- Seasonal effects were of interest, but no winter flounder data for GOM in spring.

Determining a final model

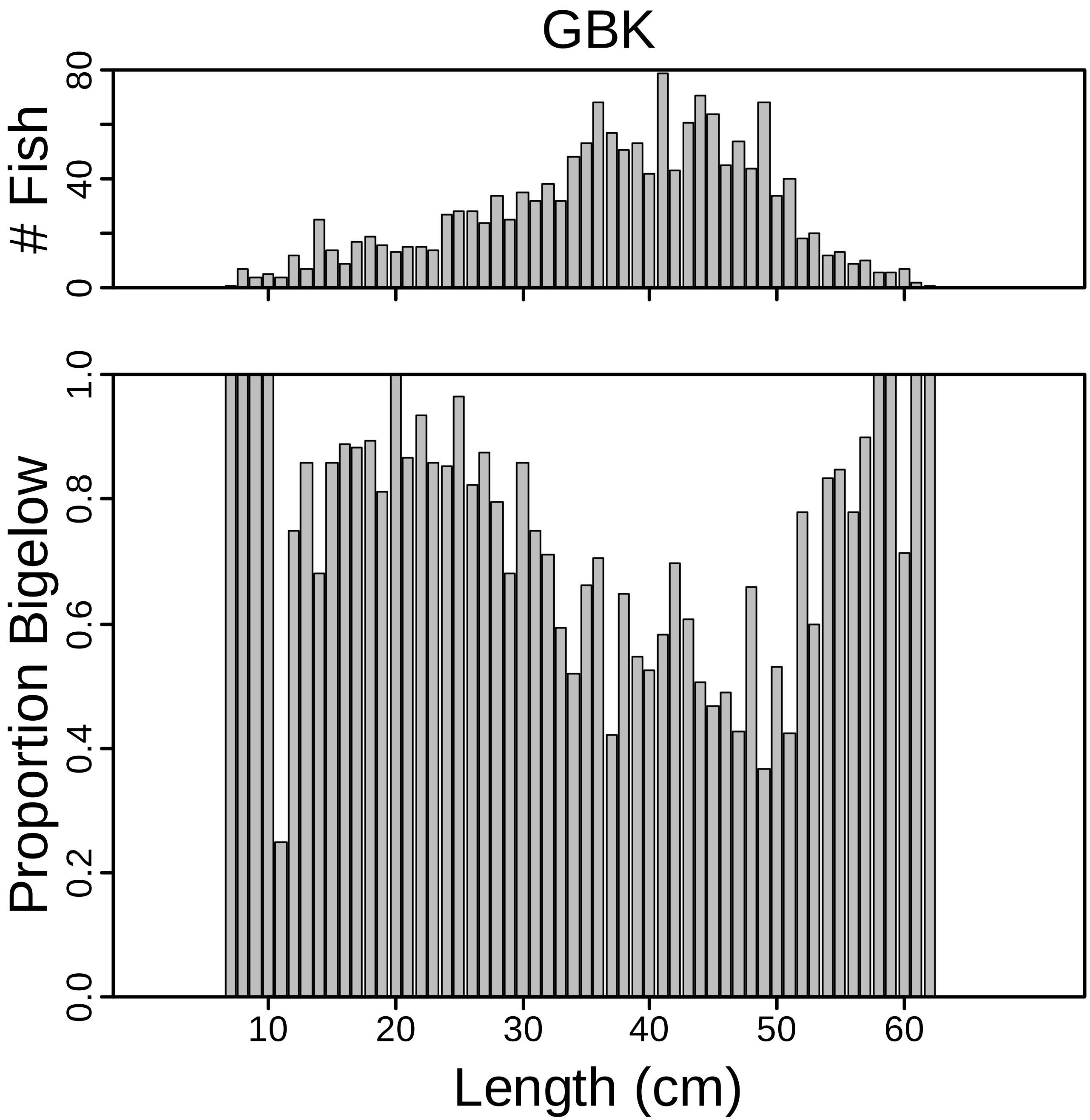
- Before considering stock area
  - The suite of fitted models with different smoothers types and numbers of parameters were compared using AIC_c.
- Then once a type of smoother was chosen,
  - the same type of smoother was used for each stock area.
- The stock area model was also compared to previously fitted models

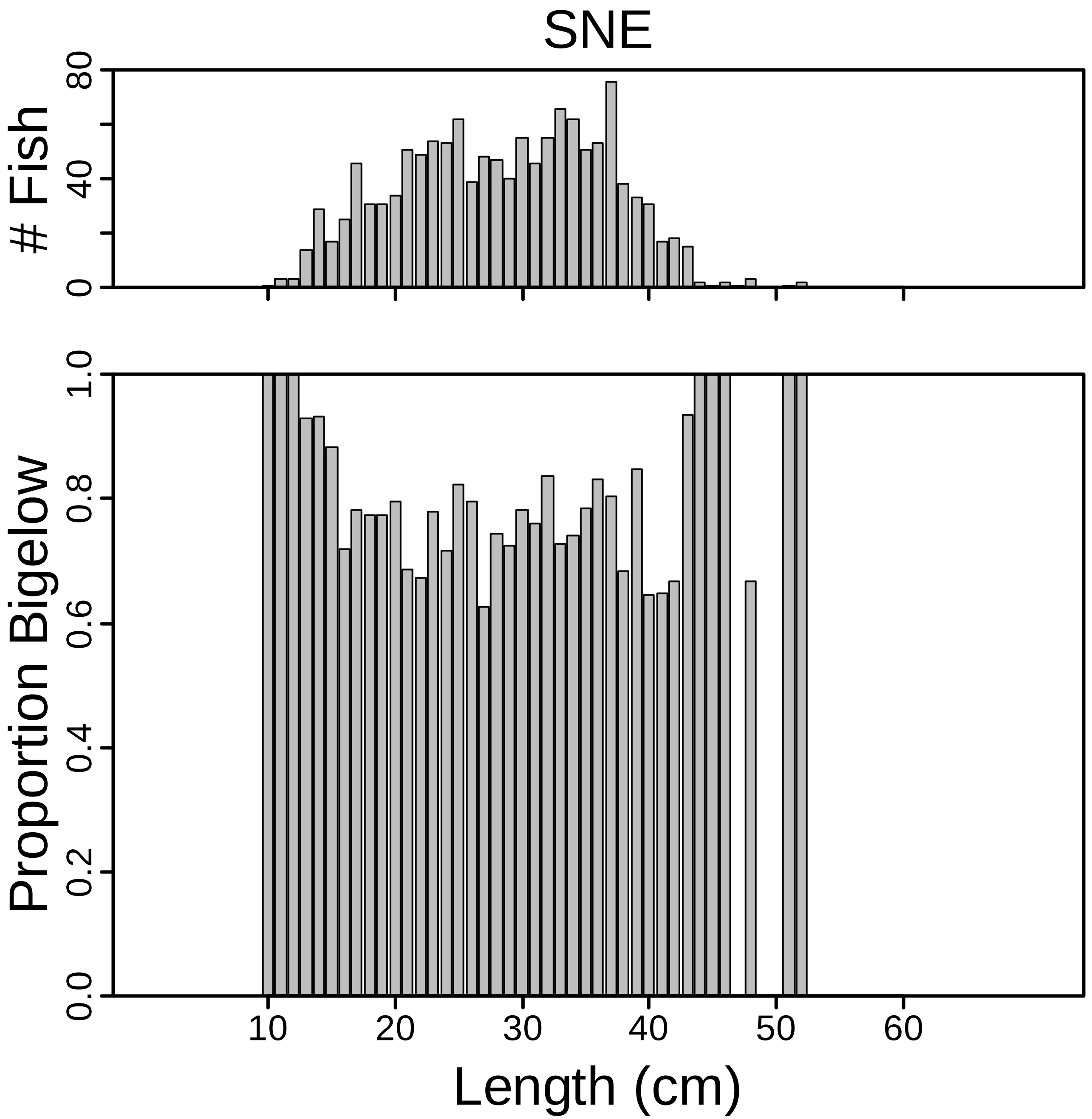


Stations
0
20
40
Proportion
0.0
0.2
0.4
0.6
0.8
1.0
10
20
30
40
50
60
Length (cm)

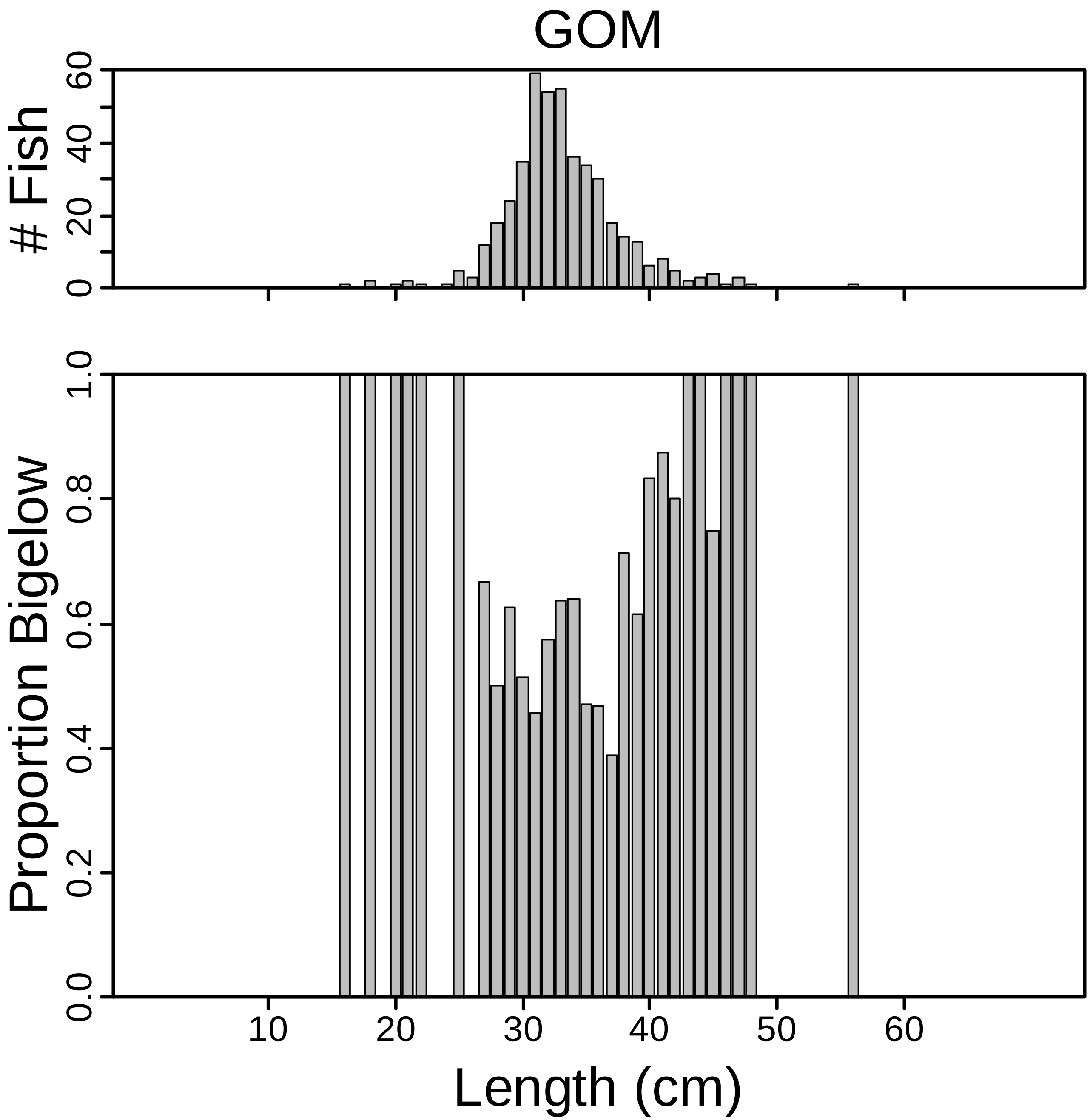


Fish
150
50
0
Proportion Bigelow
1.0
0.8
0.6
0.4
0.2
0.0
10
20
30
40
50
60
Length (cm)


GBK
Fish
0
40
80
Proportion Bigelow
0.0
0.2
0.4
0.6
0.8
1.0
10
20
30
40
50
60
Length (cm)



SNE
Fish
0
40
80
Proportion Bigelow
0.0
0.2
0.4
0.6
0.8
1.0
10
20
30
40
50
60
Length (cm)

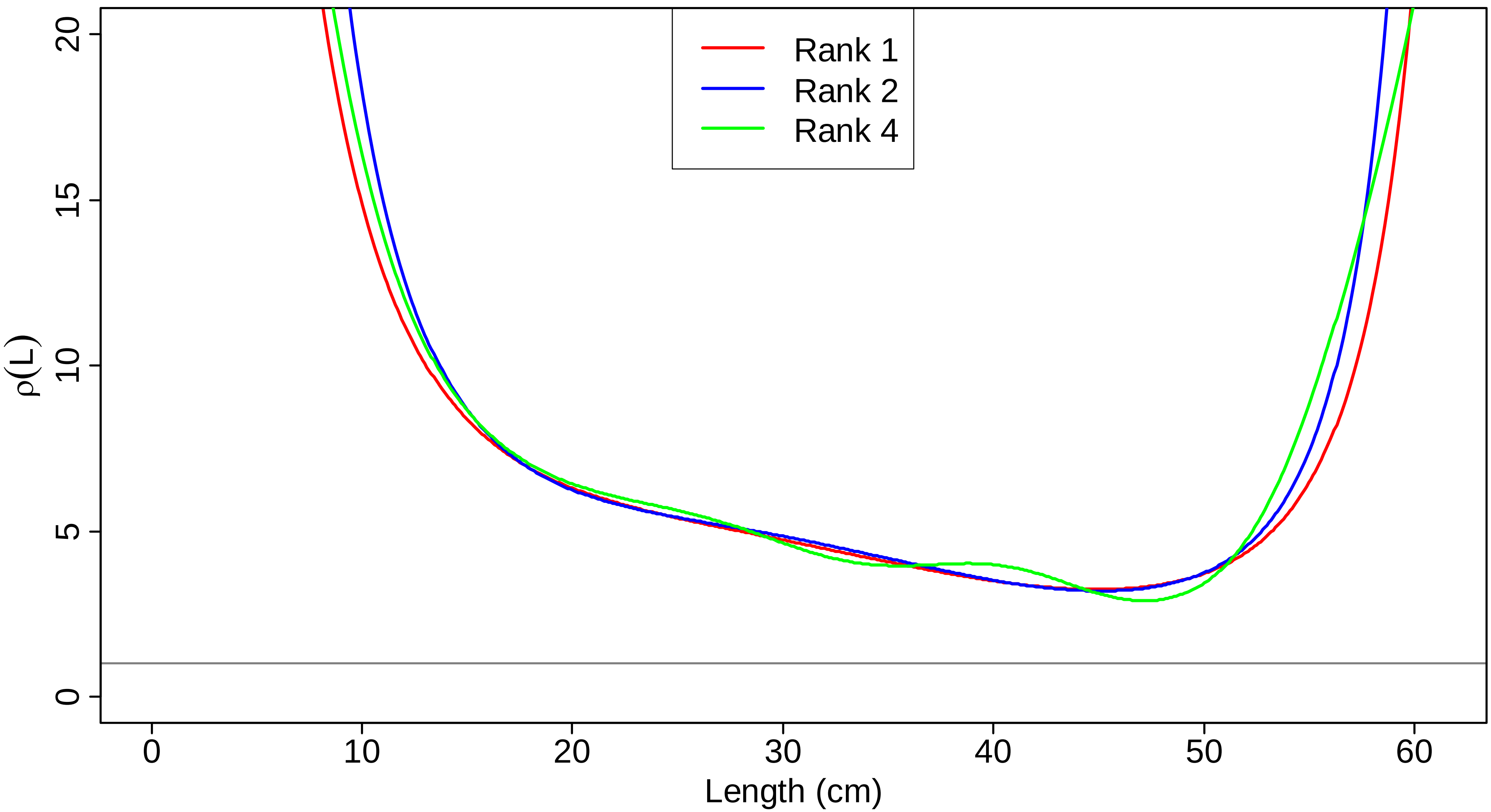

GOM
Fish
0
20
40
60
Proportion Bigelow
0.0
0.2
0.4
0.6
0.8
1.0
10
20
30
40
50
60
Length (cm)

Δ

First round of fitted models

Rank	Model Type	# ρ pars	# ϕ pars	ϕ Covariates	LL	# parameters	AIC_c	$\Delta(AIC_c)$
1	OP-G	5	9		-1059.68	14	2147.698	0
2	OP	5	3	SF,SA	-1065.98	8	2148.041	0.3425
3	OP-G	3	9		-1061.95	12	2148.16	0.462009
4	PS	7.472573	3	SF,SA	-1063.58	10.47257	2148.3	0.601108
5	OP	5	4	SF,SA	-1065.11	9	2148.324	0.62589
6	OP-G	4	9		-1061.07	13	2148.444	0.745977
7	OP-G	5	1		-1068.66	6	2149.389	1.6903
8	OP-G	5	10		-1059.64	15	2149.674	1.97597
9	OP-G	6	9		-1059.66	15	2149.706	2.007345
10	OP	5	5	SF,SA	-1064.93	10	2149.991	2.292643

Top ranked models of each class



Orthogonal Polynomials by Stock Area

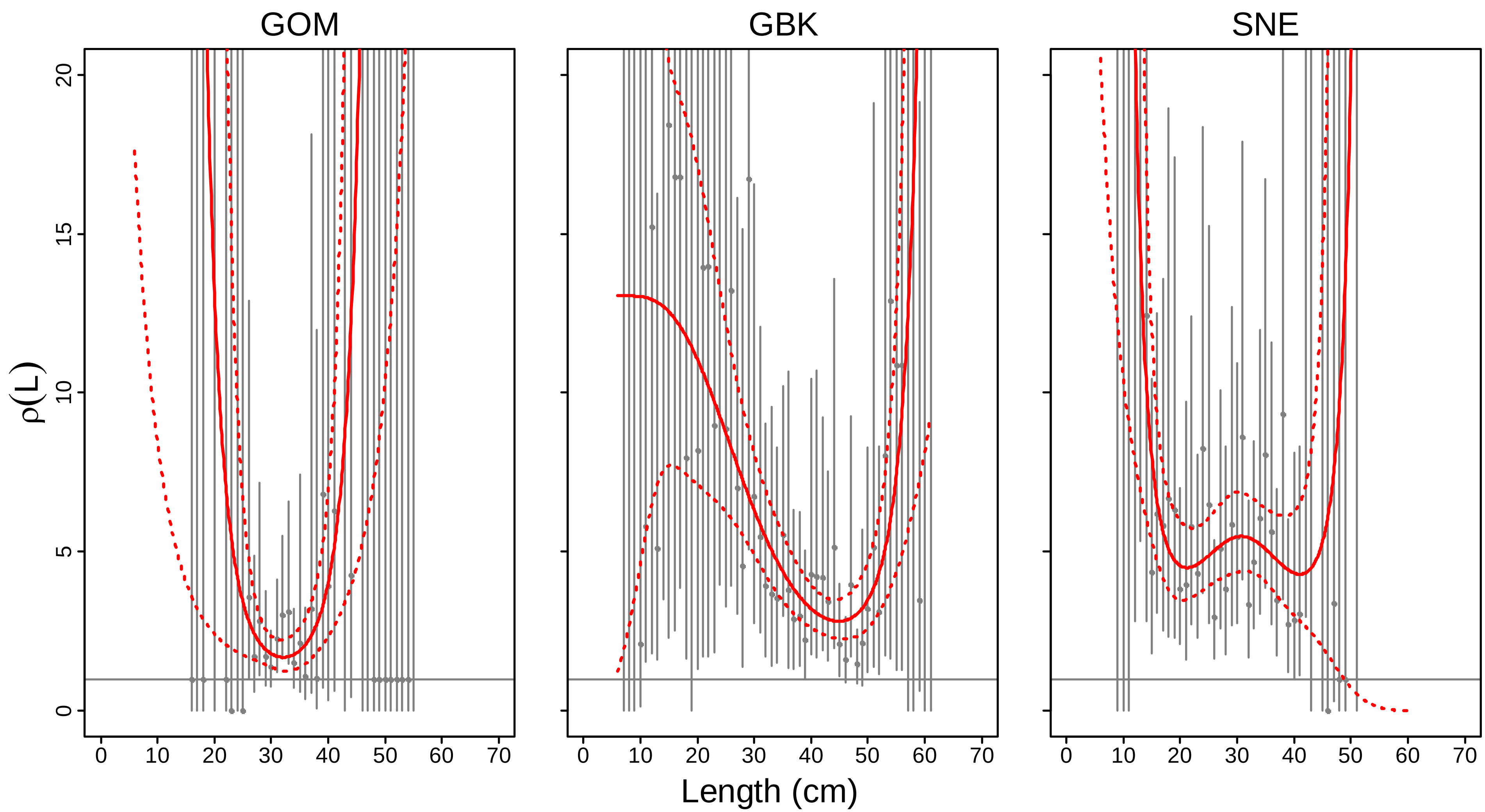
- 4 degree OP in GOM is not well behaved.
  - Over-parameterized for this region. Converges to location with inappropriate variance estimates.
  - 2 degree OP for GOM fits fine
  - Also checked constant relative catch efficiency for GOM

Δ

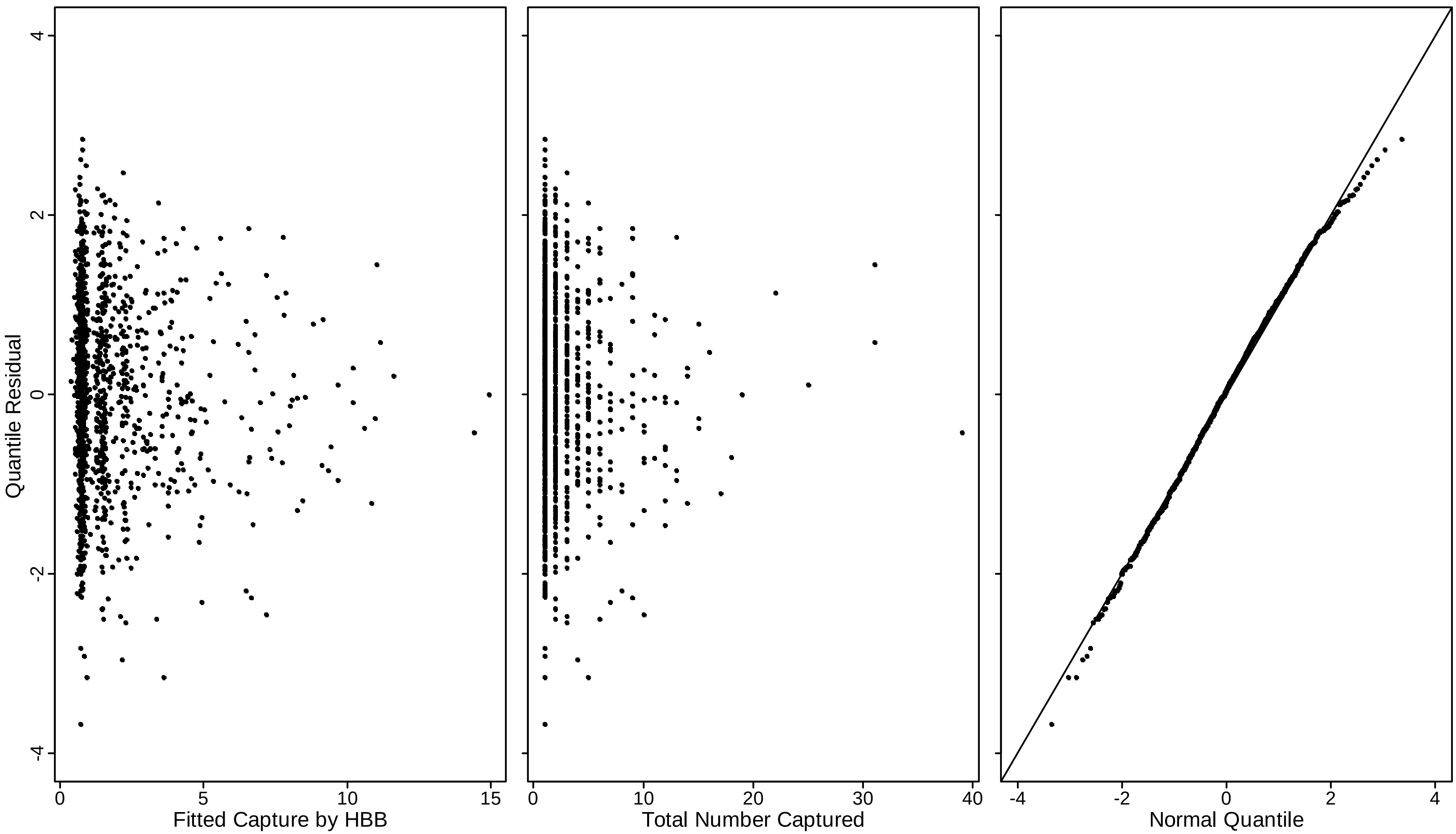
Best Fitted Models

Rank	Model Type	ρ df	ϕ df	ϕ Covariates	# Total parameters	-LL	AIC_c	(AIC_c)
1	OP(Stock Area)	13	9	SF, SA	22	-1034.27	2113.38	0.00
2	OP(Stock Area, GOM constant)	11	9	SF, SA	20	-1041.90	2124.49	11.11
3	OP-G	5	9		14	-1059.68	2147.70	34.32
4	OP	5	3	SF, SA	8	-1065.98	2148.04	34.66
5	OP-G	3	9		12	-1061.95	2148.16	34.78
6	PS	7.48	3	SF, SA	10.48	-1063.58	2148.30	34.92
7	OP	5	4	SF, SA	9	-1065.11	2148.32	34.94
8	OP-G	4	9		13	-1061.07	2148.44	35.06
9	OP-G	5	1		6	-1068.66	2149.39	36.01
10	OP-G	5	10		15	-1059.64	2149.67	36.29
11	OP-G	6	9		15	-1059.66	2149.71	36.33
12	OP	5	5	SF, SA	10	-1064.93	2149.99	36.61

WP7 Figure 2



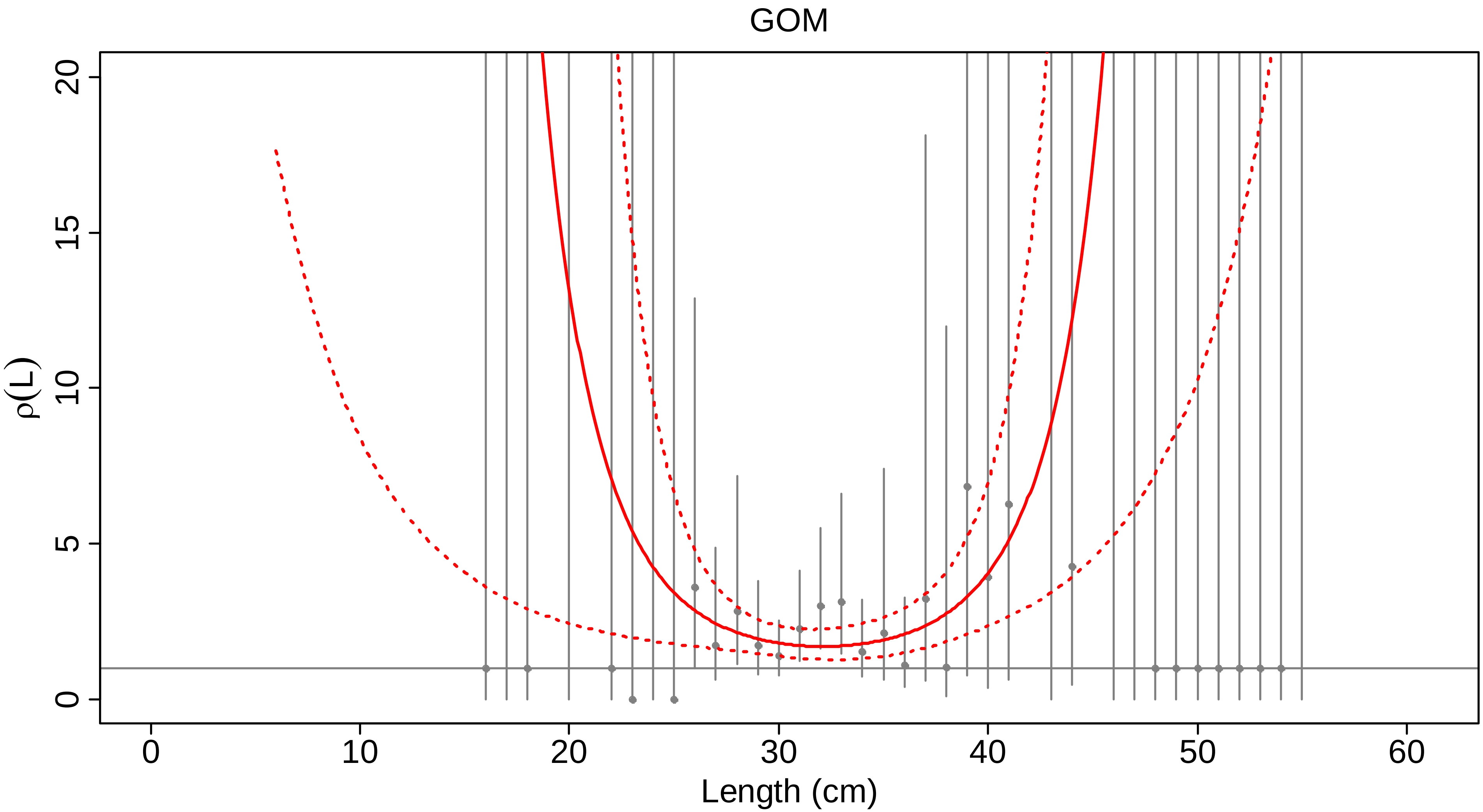
Residuals of best fitted model



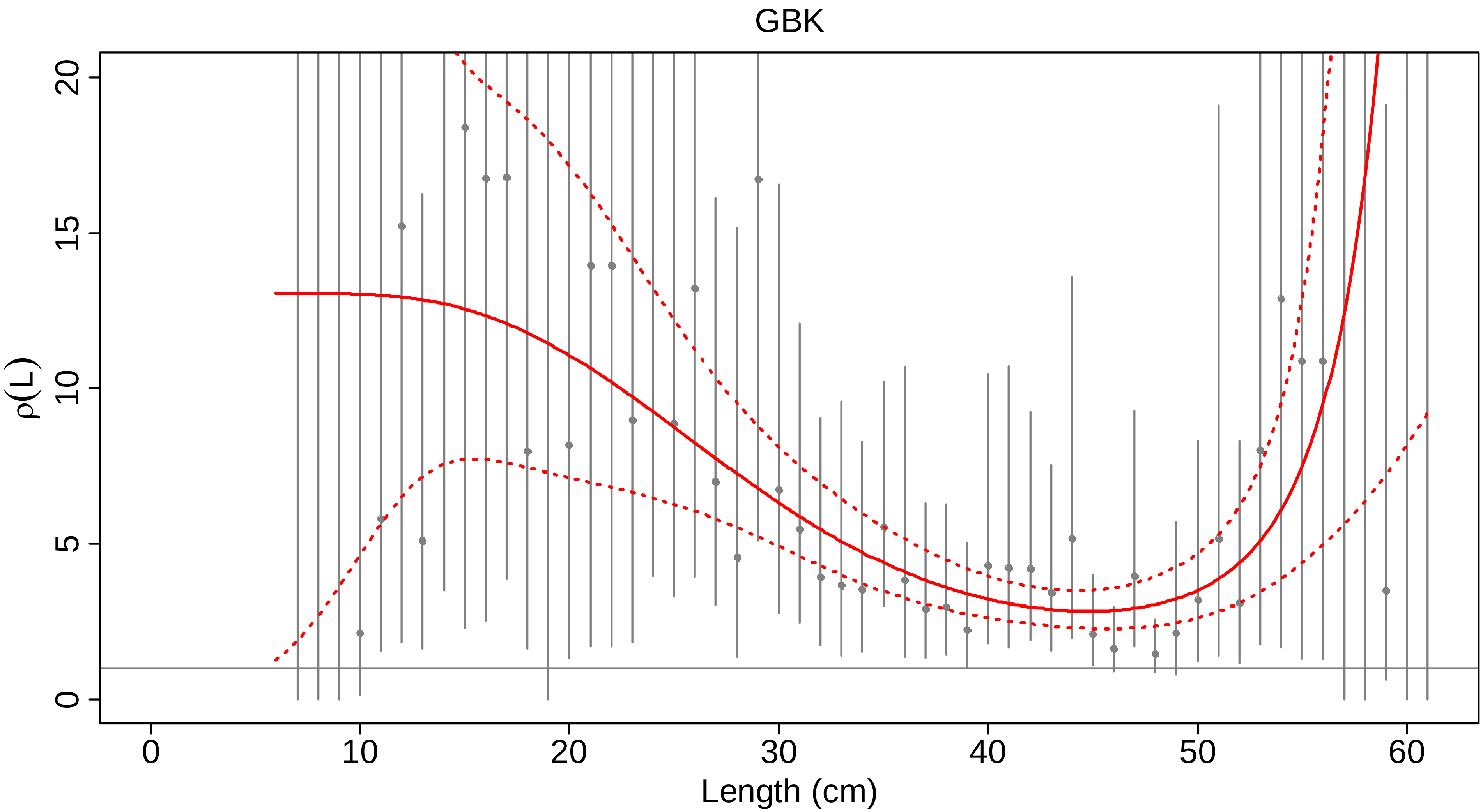
Application

- The ranges of lengths observed during the calibration study defines the limits of prediction for 2009 on (Table 3)
- The mean swept areas (Table 4) are used with the relative catch efficiencies

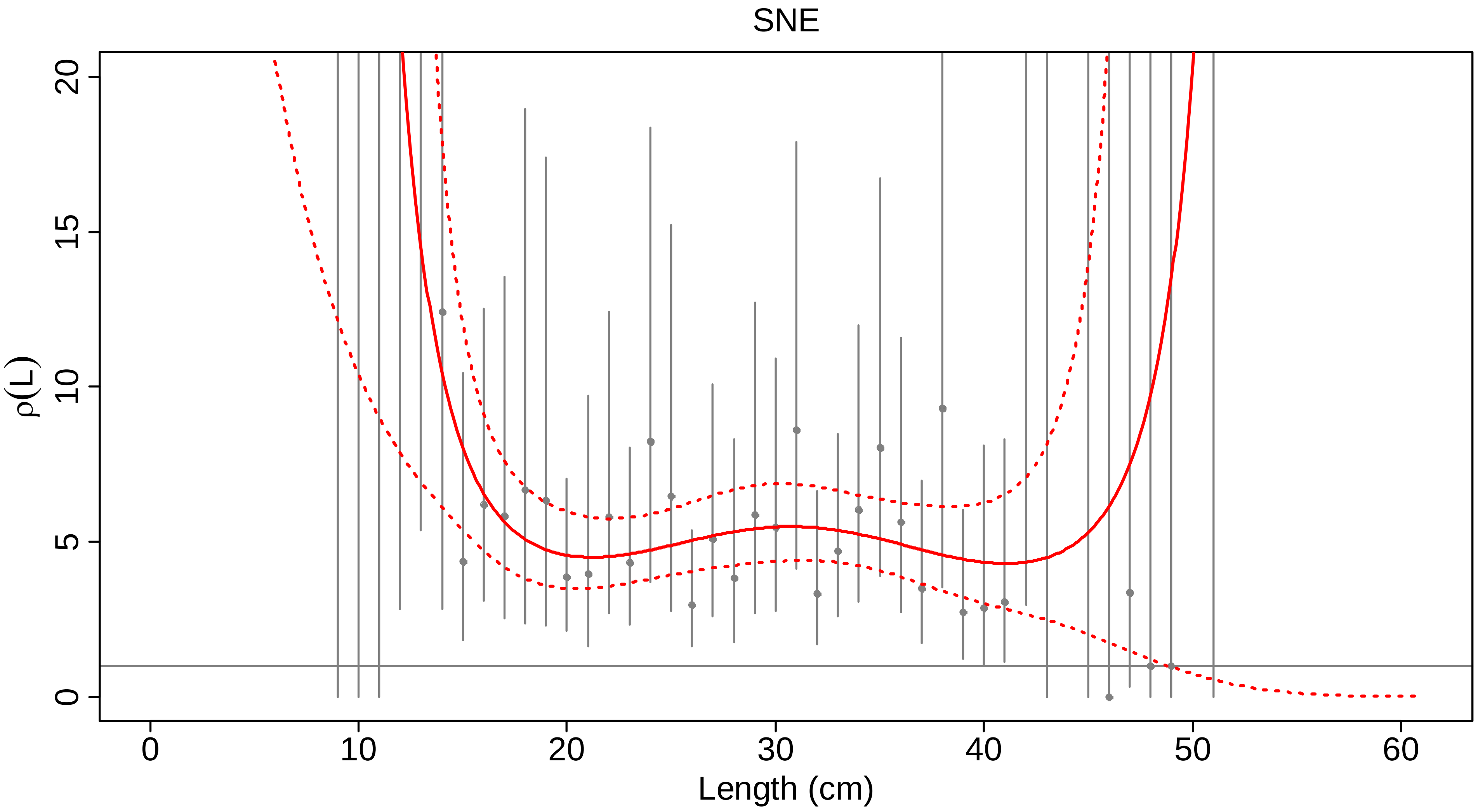
Predicted Relative Catch Efficiency (Fig 2a)



Predicted Relative Catch Efficiency (Fig 2b)



Predicted Relative Catch Efficiency (Fig 2c)



SDWG Background WP#8
May 2011
Fish Maturity Methods

Classifying female winter flounder maturity during NEFSC resource surveys: comparing at-sea, macroscopic maturity classifications with results from a gonad histology method

A working paper for SARC 52

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1.0 Background

Fish maturity needs to be assigned accurately to estimate spawning stock biomass (SSB). A common benchmark for stock assessment is to maintain a fishing rate at or lower than the rate necessary to achieve a SSB that is 20 to 40% of the estimated virgin spawning biomass (Berger, 2009). When such benchmarks are being used, accurate maturity data are necessary.

Maturity classification schemes artificially break up a continuous process into discrete classes, so all other things equal, there is a tradeoff between precision (more classes) and accuracy (fewer classes). The number of maturity classes can vary by species, sex, method, and purpose of each monitoring program or research project; as evident at dozens of fishery laboratories, the number ranges from four to ten (ICES, 2007).

For cost reasons, maturity is typically classified by a macroscopic method, examining characters such as gonad size, color, texture, or shape using fresh, dissected fish. At the Northeast Fisheries Science Center (NEFSC), there is a long history developing maturity schema, and currently, a six-class macroscopic maturity scheme is used for routine monitoring at sea (Burnett et al., 1989; Appendix Table 1). During NEFSC resource surveys, female winter flounder maturity is classified using a six-class, I-D-R-U-S-T scheme.

The I-D-R-U-S-T scheme has one immature class (I). Briefly, immature fish have a small ovary and a thin gonad wall; the immature gonad is either clear or translucent and may have color later in its development. There are five mature classes. Mature females are identified by the presence of yolked oocytes (developing eggs) preceding or during the spawning season or by evidence that a fish has spawned in the past. Briefly, females that are developing (D) have yolked oocytes (yellowish, opaque); females that are ripe (R) have hydrated (dark, clear) oocytes; females that are running ripe (U) naturally express hydrated oocytes from their vent (i.e., without pressing the abdomen); females that are spent (S) have a flaccid and often hollow, opaque gonad, which if cut open, residual eggs can often be observed; and females that are resting (T) have a small, firm ovary with a thick, opaque gonad wall.

Conceptually, a fish is only immature (I) once, and once it is mature, it cycles between developing (D), spawning (R-U), and mature but inactive (S, T) classes each year (Figure 1a). Recent evidence that fish can mature but then not spawn in every subsequent year (i.e., skip spawning; Rideout et al., 2005) has not been incorporated into the NEFSC six-class scheme as of yet.

In NEFSC stock assessments of winter flounder, maturity is determined from spring survey data using the logistic model. All years in the time series have been pooled because there was little evidence for a change in maturation over time. Three U.S. winter flounder stocks are recognized: southern New England (includes more southern strata offshore of middle Atlantic states [SNE/MA]), Georges Bank, and Gulf of Maine. All three stocks are sampled by the NEFSC spring and fall resource survey; data are also available from the State of Massachusetts' (MDMF) inshore surveys of southern New England and Gulf of Maine stocks.

At SARC 36 (2002), differences in maturity parameters of the inshore stocks were noted when using data from one survey dataset or the other. The MDMF survey consistently estimated a median age at maturity (A_{50}) to be one year older than estimates from the NEFSC survey, as calculated for both the Gulf of Maine and Southern New England stocks. Survey overlap or timing did not seem to explain the difference in the maturity schedule. The more conservative parameters (i.e., older, larger size at maturity) have been used for the inshore stocks. For example, using the MDMF spring data for 1978-2007, the SNE/MA median size at maturity, L_{50}, is 28.4 cm, and the A_{50} is 2.9 years (M. Terceiro, pers. comm.). No alternative data source exists for Georges Bank, and there has been no independent verification of which, if any, parameters are correct.

The purpose of this study was to validate the accuracy of at-sea, macroscopic maturity classifications. Gonad histology was used to independently reexamine the tissue collected from the same fish that were examined at sea. Two-way tables were used to compare agreement of maturity assignments between the two methods. Since the gonad histology method can recognize more cytological details – which can be measured quantitatively and reexamined more than once and by more than one reader – the gonad histology method was expected to produce the correct maturity class with few exceptions (which will be noted below). Sources of error for misidentifications, options for remedy, and the ramifications with regard to defining spawning stock biomass are all discussed.

2.0 Methods

2.1 At-sea collections and ageing

Winter flounder females were collected during routine marine resource surveys conducted by the NEFSC. Collections occurred during 2007-2010 when two research vessels, the *R/V Albatross IV* and the *F/R/V Henry B. Bigelow*, were operating. Biologists were requested to sample one fish from two size groups per station when winter flounder were collected. The size threshold was 25 cm or 28 cm in various years. Very small, immature fish (i.e., < 10 cm) were not collected. A one cubic centimeter piece of fresh tissue was excised from the middle of one of the ovarian lobes and fixed in 10% buffered formalin. Ages were obtained using scales or otoliths following standard NEFSC protocols (Penttila and Dery, 1988).

2.2 Gonad histology

Gonad tissue fixed at sea was later trimmed to an approximately 1 mm thick subsample and preserved in 70% ethyl alcohol. These subsamples were sent in labeled histology cassettes to an outside firm, Mass Histology Service Inc., dehydrated further in increasing ethyl alcohol concentrations, and embedded in wax. Thin sections (5 μm) of tissue were stained using either: 1) Schiffs-Mallory trichrome (SMT) or 2) hematoxylin and eosin (H&E). The use of two different staining methods did not confound interpretation of the samples. A test set (n = 12) of samples were stained using both methods and detailed comparisons have been completed, calibrated, and reported (Rowinski et al. 2010).

2.3 Assignment to maturity class

At sea, macroscopic characters were used to assign maturity. These characters are briefly described in the background section (1.0) and expanded on in Appendix Table 1.

In the lab, histology slides were examined using a Nikon Coolscope II. The majority of material has been examined by two readers, some material has been examined more than twice. The most advanced oocyte stage (MAOS) was recorded as: chromatin nucleolar (CN), perinucleolar (PG), late cortical alveolar (LC), early vitellogenic (V1), late vitellogenic (V2), germinal vesicle migration (GM), nucleus breakdown one (inside the follicle, B1), and nucleus breakdown two (outside the follicle, B2). The absence (0) or presence (some = 1, lots = 2) of postovulatory follicles (POFs) and their relative age (1-3) was recorded. The thickness of the gonad wall (tunica, 1 = thin [< 100 microns], 2 = thick) and gonad stroma were evaluated. Atresia and presence of encysted eggs were also recorded.

Two algorithms were developed in SAS (SAS, 1999) to assign maturity based on gonad histology characters (Appendix Table 2). If the MAOS was CN, then the fish was immature. If the MAOS was PG or LC, then the fish was either immature or it was mature but inactive with regard to spawning. If MAOS was V1, then the gonad was developing, the first sign that a recruit spawner was maturing for the first time or a repeat spawner was redeveloping. Later vitellogenesis (V2) characterized a developing fish, GM and B1 cells indicated oocyte maturation, the B2 was characteristic of active spawning. The presence of POFs and the thickness of the gonad wall and stroma were also diagnostic characters used in the SAS algorithms to indicate recent or past spawning. Some subroutines were season specific to permit assignment of maturing clases as mature or not in a spawning season or calendar year.

A gonad histology scheme was recently developed for winter flounder (Wuenschel et al. 2010), and additional samples collected since and additional discussions have refined this scheme (Fig. 1b). SAS programming code from Wuenschel et al. (2010) was reiteratively modified to match histology-based classifications appropriately with at-sea classifications and to check for outliers or data errors. SAS algorithms assigned histology-based maturity to both the standard I-D-R-U-S-T scheme as well as to an expanded ten-class scheme (Appendix Table 2). The former was used to compare between at-sea and laboratory assignments, whereas the latter was used to investigate oocyte development and maturation processes in greater detail.

2.4 Modeling maturity schedules

All fish not assigned as immature (I, Im, If, Fig. 1) were mature according to both maturity schema. Maturity ogives were fitted to the logistic model using binary coding (0 = immature, 1 = mature) and SAS programming (i.e., PROC LOGISTIC). McBride et al. (2010) compared the logit, probit, and complementary log-log models using the Akaike information criterion. They concluded that the logit model was the most appropriate for parameter estimates of median size at maturity, so this model is used here without further comparison.

3.0 Results and Discussion

3.1 Sample size

A total of 371 winter flounder females were collected on spring and fall cruises from 2007 to 2010 for this analysis (Table 1). Fish were collected aboard the *R/V Albatross IV* in 2007 and 2008 (*n* = 156; Table 2) as well as aboard the *F/R/V Henry B. Bigelow* in 2008, 2009, and 2010 (*n* = 215; Table 2). Fish were collected in all three stock areas managed by U.S. fishery management councils (southern New England [*n* = 177; Table 3], Georges Bank [*n* = 91; Table 3], Gulf of Maine [*n* = 65]; Table 3), as well as on the Scotian Shelf (*n* = 38; Table 3) in Canadian waters. Fish were collected in both survey seasons: spring (*n* = 288; Table 4) and fall (*n* = 83; Table 4).

A total of 362 winter flounder females were aged from southern New England (1, 3, 8 [minimum, median, maximum age], *n* = 176), Georges Bank (1, 3, 14, *n* = 84), Gulf of Maine [1, 4, 8, *n* = 64), and the Scotian Shelf (2, 5, 7, *n* = 38).

3.2 Agreement between methods

A total of 96 of 158 immature fish were correctly identified as immature, and 211 of 213 mature fish were correctly identified as mature. Immature fish smaller than 19 cm were classified correctly, and mature fish larger than 39 cm were classified correctly (Fig. 2). The developing class was consistently classified correctly; > 80% of the time and often >95% of the time by sampling ship, flounder stock, or season (Tables 2-4).

3.3 Minor mismatches between methods

A high rate of exact matches was not expected nor required when the transition between two adjacent maturity classes was subjective. The best example of this was the transition between spent (S) and resting (T) classes. When spent and resting classes were combined the agreement between at-sea and laboratory assignments was consistently > 90%. Such mismatches between separate spent and resting (S,T) classes have little effect to stock assessment results because both classes are mature.

Another source of minor mismatch is when at-sea classification may be more accurate than gonad histology. Although this is unusual, it is not unexpected during certain active classes of spawning, such as when hydrated oocytes first appear but are lightly scattered throughout the gonad (ripe, R) or when they first ovulate and begin to fill the lumen (running ripe, U). The maturity assignment for such fish was best made by examining whole fish and their whole gonad instead of the very small sliver of gonad tissue that was analyzed histologically. Thus, when ripe and running-ripe classes were combined, agreements between the two methods increased to 100% in most cases. Again, such mismatches do not affect the stock assessment because both classes are mature.

3.4 A major mismatch between methods

One particular mismatch was not inconsequential. Specifically, 61 fish identified as immature using gonad histology (i.e., labClass = I), were assigned as resting at sea (i.e., seaClass = T). This occurred on both sampling ships (Table 2), in all stock areas (Table 3), and in both seasons (Table 4). Misclassifying immature females as resting was most common among the largest immature fish (Tables 5, 6; Fig. 2). No females smaller than 19 cm total length were misclassified, but all immature fish larger than 33 cm were misclassified as resting.

All first-developing females were misclassified as resting (Fig. 2). First-developing fish collected in spring were larger (27-34 cm total length [TL]) than other immature fish (Table 6); these fish were preparing to spawn in the next year, 10-12 months ahead of their first spawning event. First-developing fish collected in the fall were the largest of all misidentified immature fish (30-39 cm; Table 6); these fish, many of which had partially yolked oocytes (V1), were preparing to spawn in the next year, 5-6 months ahead. First-developing females are distinguishable from other immature females, based on color of the gonad in particular, but they all had a thin gonad wall as measured from histological preparations of the gonad, and they showed no evidence of past spawning, so first-developing females are immature by definition.

3.5 Preliminary female maturity schedules, by stock

Median length at female maturity (L_{50}) occurred within a narrow length range, 29-30 cm TL, for the inshore stocks (Table 7a). Females from the Georges Bank stock matured at a much larger size, L_{50} = 33.6 cm TL (Table 7a).

These L_{50} values are consistent with another analysis of gonad histology using the fish included here, as well as more material from state surveys (Massachusetts, Rhode Island, Connecticut), totaling nearly 800 females (McBride et al. 2010). Nonetheless, these L_{50} estimates should be considered preliminary. Sampling has continued on NEFSC surveys since spring, 2010, and other valuable material has been collected on state surveys and by cooperating industry research boats (i.e., the study fleet), which can be used in further analysis.

Median age at female maturity (A_{50}) occurred as young as age 2 (2.6-2.7 years for Georges Bank and southern New England) but was 1-2 years older in more northern stocks (3.7 for Gulf of Maine and 4.7 for Scotian Shelf) (Table 7b).

This analysis does not account for the frequency of mature but non-spawning fish (i.e., skip spawners). Skipping may be > 20% in northern stocks of winter flounder but is not typically that high in U.S. stocks in a typical year (McBride et al., 2010; McElroy et al., 2011). Skip spawning has been defined as non-participation in a spawning event among mature fish (Rideout et al., 2005), so in using this definition, skipping rates do not affect the estimation of size or age of maturity.

3.6 Causes of error and options for remedy

Keypunch errors may occur but the touch-screen data entry system used at sea should make keypunch error unlikely. In addition, there are limits to histology and there is ambiguity between certain macroscopic classes, which was evident by mismatches between the ripe (R) and running-ripe (U) classes as well as the spent (S) and resting (T) classes. These examples are minor errors that do not bias the interpretation of spawning stock biomass and do not appear to require any comprehensive remedy.

The misclassification of immature and first-time developing fish as mature, resting fish is more problematic. It inflates the estimate of spawning stock biomass among relatively young but abundant age classes.

This type of error was broadly distributed among NEFSC staff, contractors, and volunteers. Although fish were not assigned randomly to the biologists for sampling, a total of 67 individuals (i.e., 'cutters') made maturity determinations of these 371 winter flounder females. No cutter identified the maturity of more than 30 fish, and the majority of cutters identified the maturity of fewer than five fish. Among this diverse pool of biologists, almost half (n = 31) misclassified at least one of the 61 immature fish as resting. The maximum number of this type of misclassifications per cutter was five.

Early on in the study, we were generally interested in having cutters identify 'difficult-to-identify gonads.' Some cutters may have selected fish that were difficult to classify, which would inflate the magnitude of the error. Again, neither the assignment of the cutters nor the selection of the fish was random, so this report cannot identify the precise nature of the error. Instead it simply notes that this is a specific source of error that affects characterization of spawning stock biomass.

The problem warrants continued training by way of regular maturity workshops using fresh fish. These occur regularly after the first three legs of the spring and the fall resource surveys. The summary statistics presented here suggest that all sea-going biologists will benefit from attending these workshops.

Also, better use of photographic images should be made to standardize maturity classification and reduce misclassification of immature fish as resting, mature fish. Photographs of fish at sea demonstrate the ambiguities between classes and can be used to set standards (Fig. 3), but the quality of images taken at sea is often unsatisfactory. Photographs of fish taken in the laboratory may not be as fresh but they generally can be of higher resolution or compositional quality (Fig. 4).

Displays such as Figure 4 are posted in the NEFSC main building cutting room and have been highlighted during the spring, 2011, maturity workshops. Looking ahead, sampling of gonad tissue should stop this spring and resume in a few years to test the effectiveness of such training.

One alternative to at-sea, macroscopic classifications is to fit maturity ogives based on gonad histology only. This is a costly option if used routinely but it could be done periodically to validate at-sea, macroscopic methods as was done here. If it is done infrequently, so that it only creates parameter estimates for a short time interval, variance around these point estimates can be used to model the effect of uncertainty.

Another alternative is to establish a set of decision rules to appropriately reclassify all or most resting fish as immature from prior spring surveys. This may be a reasonable approach considering that more immature fish are misclassified as resting than there are resting fish during spring (Table 4b). Such a reclassification would assume similar error rates and biases throughout the time series.

A third alternative is to create an age-based decision rule for classifying spawning stock biomass. In such an approach, all fish older than a certain age would be classified as mature. In such a case, macroscopic determination of maturity class at sea would cease and the age-maturity relationship could be periodically validated by gonad histology.

4.0 Acknowledgements

We recognize that all hands going to sea are working diligently and they took extra time to complete our special sampling request. J. Burnett and G. Thornton aged the winter flounder. Our understanding of flounder oogenesis and interpretation of macroscopic and microscopic characters has been improved with support from the Northeast Cooperative Research Program (CRP), from the samples collected by CRP Study Fleet commercial fishing vessels, and from interactions among R.S.M., M.J.W., and the North Atlantic Fisheries Organization (NAFO) Working Group on Reproductive Potential. We thank all the above.

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Table 1. Sample sizes (N = number of fish) by year, season, stock and survey vessel. Survey vessels (SVVESSEL) are the Albatross IV (AL) and the Henry Bigelow (HB).Female winter flounder collected by NEFSC monitoring only.

		stock								
		Georges Bank		Gulf of Maine		Southern New England		Scotian Shelf		
		SVVESSEL		SVVESSEL		SVVESSEL		SVVESSEL		
		AL	HB	AL	HB	AL	HB	AL	HB	All
		N	N	N	N	N	N	N	N	N
EST_YEAR	SEASON									
2007	FALL	8	.	5	.	15	.	8	.	36
	SPRING	8	.	7	.	37	.	9	.	61
2008	FALL	.	6	.	.	.	.	.	.	6
	SPRING	8	.	.	.	38	.	13	.	59
2009	FALL	.	20	.	12	.	9	.	.	41
	SPRING	.	26	.	17	.	39	.	2	84
2010	SPRING	.	15	.	24	.	39	.	6	84
All		24	67	12	53	90	87	30	8	371

Table 2. Survey vessel-specific matches of maturity assignments. A 6-class scheme is used to match at sea (seaClass) and in lab (labClass) assignments. Survey Vessels (SVVESSEL) are the Albatross IV (AL) and the Henry Bigelow (HB). Frequency = number of fish, Col Pct = Percentage of each cell in relation to entire column. Female winter flounder collected by NEFSC monitoring only.

SVVESSEL=AL

seaClas2 / labClas2 (Frequency, Col Pct)	1_I	2_D	3_R	4_U	5_S	6_T	Total
1_I	42 56.00	0 0.00	0 0.00	0 0.00	0 0.00	2 5.71	44
2_D	0 0.00	29 90.63	0 0.00	0 0.00	0 0.00	0 0.00	29
3_R	0 0.00	1 3.13	1 100.00	1 100.00	1 8.33	0 0.00	4
4_U	0 0.00	1 3.13	0 0.00	0 0.00	0 0.00	0 0.00	1
5_S	0 0.00	0 0.00	0 0.00	0 0.00	2 16.67	10 28.57	12
6_T	33 44.00	1 3.13	0 0.00	0 0.00	9 75.00	23 65.71	66
Total	75	32	1	1	12	35	156

SVVESSEL=HB

seaClas2 / labClas2 (Frequency, Col Pct)	1_I	2_D	3_R	4_U	5_S	6_T	Total
1_I	54 65.06	0 0.00	0 0.00	0 0.00	0 0.00	0 0.00	54
2_D	0 0.00	76 93.83	0 0.00	0 0.00	1 4.55	1 3.85	78
3_R	1 1.20	0 0.00	0 0.00	1 50.00	0 0.00	0 0.00	2
4_U	0 0.00	0 0.00	1 100.00	1 50.00	0 0.00	0 0.00	2
5_S	0 0.00	2 2.47	0 0.00	0 0.00	20 90.91	10 38.46	32
6_T	28 33.73	3 3.70	0 0.00	0 0.00	1 4.55	15 57.69	47
Total	83	81	1	2	22	26	215

Table 3. Stock-specific matches of maturity assignments. A 6-class scheme is used to match at sea (seaClass) and in lab (labClass) assignments. Frequency = number of fish, Col Pct = Percentage of each cell in relation to entire column.Female winter flounder collected by NEFSC monitoring only.

------------------------------------ stock=Georges Bank ------------------------------------

seaClas2 labClas2

Frequency Col Pct	1_I	2_D	3_R	4_U	5_S	6_T	Total
1_I	27 75.00	0 0.00	0 0.00	0 0.00	0 0.00	1 8.33	28
2_D	0 0.00	26 81.25	0 0.00	0 0.00	0 0.00	0 0.00	26
3_R	0 0.00	0 0.00	1 50.00	0 0.00	0 0.00	0 0.00	1
4_U	0 0.00	0 0.00	1 50.00	1 100.00	0 0.00	0 0.00	2
5_S	0 0.00	2 6.25	0 0.00	0 0.00	7 87.50	3 25.00	12
6_T	9 25.00	4 12.50	0 0.00	0 0.00	1 12.50	8 66.67	22
Total	36	32	2	1	8	12	91

------------------------------------ stock=Gulf of Maine ------------------------------------

seaClas2 labClas2

Frequency Col Pct	1_I	2_D	5_S	6_T	Total
1_I	17 54.84	0 0.00	0 0.00	0 0.00	17
2_D	0 0.00	27 96.43	0 0.00	0 0.00	27
3_R	1 3.23	1 3.57	0 0.00	0 0.00	2
5_S	0 0.00	0 0.00	4 100.00	1 50.00	5
6_T	13 41.94	0 0.00	0 0.00	1 50.00	14
Total	31	28	4	2	65

Table 3 (cont.). Stock-specific matches of maturity assignments. A 6-class scheme is used to match at sea (seaClass) and in lab (labClass) assignments. Frequency = number of fish, Col Pct = Percentage of each cell in relation to entire column.Female winter flounder collected by NEFSC monitoring only.

---------------------------------- stock=Southern New England ----------------------------------

seaClas2 labClas2

Frequency Col Pct	1_I	2_D	4_U	5_S	6_T	Total
1_I	42 58.33	0 0.00	0 0.00	0 0.00	1 2.38	43
2_D	0 0.00	38 97.44	0 0.00	1 4.55	1 2.38	40
3_R	0 0.00	0 0.00	2 100.00	1 4.55	0 0.00	3
4_U	0 0.00	1 2.56	0 0.00	0 0.00	0 0.00	1
5_S	0 0.00	0 0.00	0 0.00	11 50.00	15 35.71	26
6_T	30 41.67	0 0.00	0 0.00	9 40.91	25 59.52	64
Total	72	39	2	22	42	177

------------------------------------ stock=Scotian Shelf ------------------------------------

The FREQ Procedure

Table of seaClas2 by labClas2

seaClas2 labClas2

Frequency Col Pct	1_I	2_D	6_T	Total
1_I	10 52.63	0 0.00	0 0.00	10
2_D	0 0.00	14 100.00	0 0.00	14
5_S	0 0.00	0 0.00	1 20.00	1
6_T	9 47.37	0 0.00	4 80.00	13
Total	19	14	5	38

Table 4. Season-specific matches of maturity assignments. A 6-class scheme is used to match at sea (seaClass) and in lab (labClass) assignments. Seasons are Spring (March-May) and Fall (September-November). Frequency = number of fish, Col Pct = Percentage of each cell in relation to entire column. Female winter flounder collected by NEFSC monitoring only.

-- SEASON=FALL --

seaClas2 labClas2

Frequency Col Pct	1_I	2_D	6_T	Total
1_I	19 47.50	0 0.00	0 0.00	19
2_D	0 0.00	25 80.65	1 8.33	26
5_S	0 0.00	2 6.45	0 0.00	2
6_T	21 52.50	4 12.90	11 91.67	36
Total	40	31	12	83

--- SEASON=SPRING ---

seaClas2 labClas2

Frequency Col Pct	1_I	2_D	3_R	4_U	5_S	6_T	Total
1_I	77 65.25	0 0.00	0 0.00	0 0.00	0 0.00	2 4.08	79
2_D	0 0.00	80 97.56	0 0.00	0 0.00	1 2.94	0 0.00	81
3_R	1 0.85	1 1.22	1 50.00	2 66.67	1 2.94	0 0.00	6
4_U	0 0.00	1 1.22	1 50.00	1 33.33	0 0.00	0 0.00	3
5_S	0 0.00	0 0.00	0 0.00	0 0.00	22 64.71	20 40.82	42
6_T	40 33.90	0 0.00	0 0.00	0 0.00	10 29.41	27 55.10	77
Total	118	82	2	3	34	49	288

Table 5a. Sample size and proportions of all female winter flounder collected. A 10-class maturity scheme using gonad histology is used; (the 6-class equivalent). The first two classes are immature (never spawned), the other classes are mature (have spawned). Skippers have spawned in the past but are not spawning this year. Female winter flounder collected by NEFSC monitoring only.

TenClass	Frequency	Percent	Cumulative Frequency	Cumulative Percent
(I) Immature - never spawned	147	39.62	147	39.62
(I) Imm., 1st-time developing	11	2.96	158	42.59
(D) Developing - Mature	96	25.88	254	68.46
(D) Oocyte Maturation-Initial	17	4.58	271	73.05
(R) Oocyte Maturation-Hydrated	2	0.54	273	73.58
(U) Oocyte Maturation-Ovulated	3	0.81	276	74.39
(S) Spent - Just spawned	34	9.16	310	83.56
(T) Resting - Has spawned	45	12.13	355	95.69
(T) Re-developing - Mature	15	4.04	370	99.73
(T) Skipper - Has spawned	1	0.27	371	100.00

Table 5b. Simple statistics of fish size for all female winter flounder collected. A 10-class maturity scheme using gonad histology is used; (the 6-class equivalent). The first two classes are immature (never spawned), the other classes are mature (have spawned). Skippers have spawned in the past but are not spawning this year. Female winter flounder collected by NEFSC monitoring only.

Analysis Variable : TL_mm

TenClass	N Obs	N	Mean	Std Dev	Minimum	Maximum
(I) Immature - never spawned	147	147	243.0	52.2	120.0	346.0
(I) Imm., 1st-time developing	11	11	327.7	34.0	268.0	390.0
(D) Developing - Mature	96	96	382.8	70.7	250.0	570.0
(D) Oocyte Maturation-Initial	17	17	364.1	66.4	270.0	540.0
(R) Oocyte Maturation-Hydrated	2	2	480.0	169.7	360.0	600.0
(U) Oocyte Maturation-Ovulated	3	3	495.3	41.1	450.0	530.0
(S) Spent - Just spawned	34	34	373.1	61.3	280.0	560.0
(T) Resting - Has spawned	45	45	345.9	42.6	194.0	440.0
(T) Re-developing - Mature	15	15	385.1	77.6	270.0	556.0
(T) Skipper - Has spawned	1	1	370.0	.	370.0	370.0

Table 6a. Sample size and proportions of immature fish misidentifed as mature, resting. According to the 10-class maturity scheme, these fish are immature and have never spawned. Female winter flounder collected by NEFSC monitoring only.

-- SEASON=FALL --

The FREQ Procedure

TenClass	Frequency	Percent	Cumulative Frequency	Cumulative Percent
(I) Immature - never spawned	16	76.19	16	76.19
(I) Imm., 1st-time developing	5	23.81	21	100.00

-- SEASON=SPRING --

The FREQ Procedure

TenClass	Frequency	Percent	Cumulative Frequency	Cumulative Percent
(I) Immature - never spawned	34	85.00	34	85.00
(I) Imm., 1st-time developing	6	15.00	40	100.00

Table 6b. Simple statistics of fish size of immature fish misidentifed as mature, resting. According to the 10-class maturity scheme, these fish are immature and have never spawned. Female winter flounder collected by NEFSC monitoring only.

-- SEASON=FALL --

Analysis Variable : TL_mm

TenClass	N Obs	N	Mean	Std Dev	Minimum	Maximum
(I) Immature - never spawned	16	16	283.6	37.2	210.0	346.0
(I) Imm., 1st-time developing	5	5	343.4	39.4	297.0	390.0

-- SEASON=SPRING --

Analysis Variable : TL_mm

TenClass	N Obs	N	Mean	Std Dev	Minimum	Maximum
(I) Immature - never spawned	34	34	282.3	35.1	191.0	340.0
(I) Imm., 1st-time developing	6	6	314.7	25.0	268.0	340.0

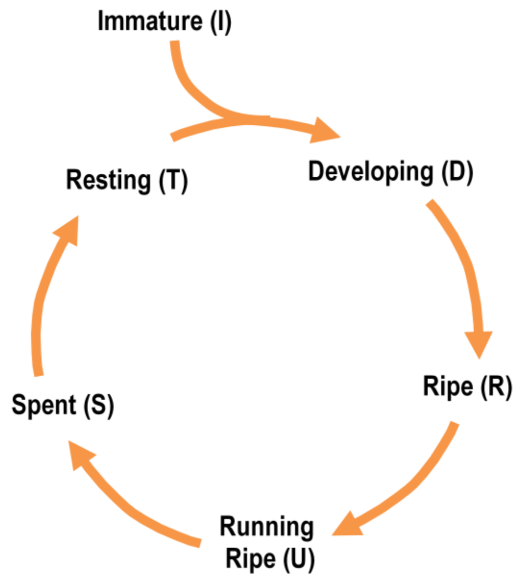
Table 7a. Stock-specific logistic regression of maturity in relation to fish size. Size is measured as total length to the nearest mm (median size at maturity [L50]). Maturity (0=immature, 1=mature) determined by gonad histology. Female winter flounder collected by NEFSC monitoring only.

stock	_LINK_	_STATUS_	Intercept	TL_mm	_LNLIKE_	L50
Georges Bank	LOGIT	0 Converged	22.7450	-0.067756	-11.7151	335.690
Gulf of Maine	LOGIT	0 Converged	13.2772	-0.045413	-21.2714	292.365
Southern New England	LOGIT	0 Converged	13.8801	-0.046448	-53.6985	298.833
Scotian Shelf	LOGIT	0 Converged	14.5187	-0.048414	-16.0243	299.886

Table 7b. Stock-specific logistic regression of maturity in relation to fish age. Age is measured in years (median age at maturity [A50]). Maturity (0=immature, 1=mature) determined by gonad histology. Female winter flounder collected by NEFSC monitoring only.

stock	_LINK_	_STATUS_	Intercept	AGE	_LNLIKE_	A50
Georges Bank	LOGIT	0 Converged	5.10427	-1.98083	-29.6927	2.57683
Gulf of Maine	LOGIT	0 Converged	8.13547	-2.18084	-21.1679	3.73043
Southern New England	LOGIT	0 Converged	5.81909	-2.17224	-62.9812	2.67884
Scotian Shelf	LOGIT	0 Converged	3.52308	-0.75186	-22.3841	4.68581

A)



B)

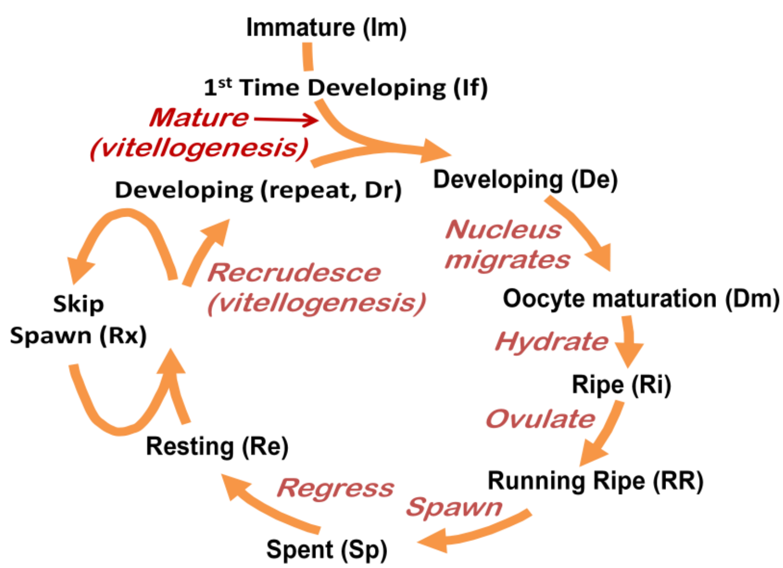


Figure 1. Two complementary maturity schemes for winter flounder (*Pseudopleuronectes americanus*) females. (A) The standard six-class NEFSC maturity scheme used at sea by examining fresh gonads macroscopically, and (B) and an expanded ten-class maturity scheme suitable if gonad histology is available. See also Wuenschel et al. (2010) for comparisons of these two schemes.

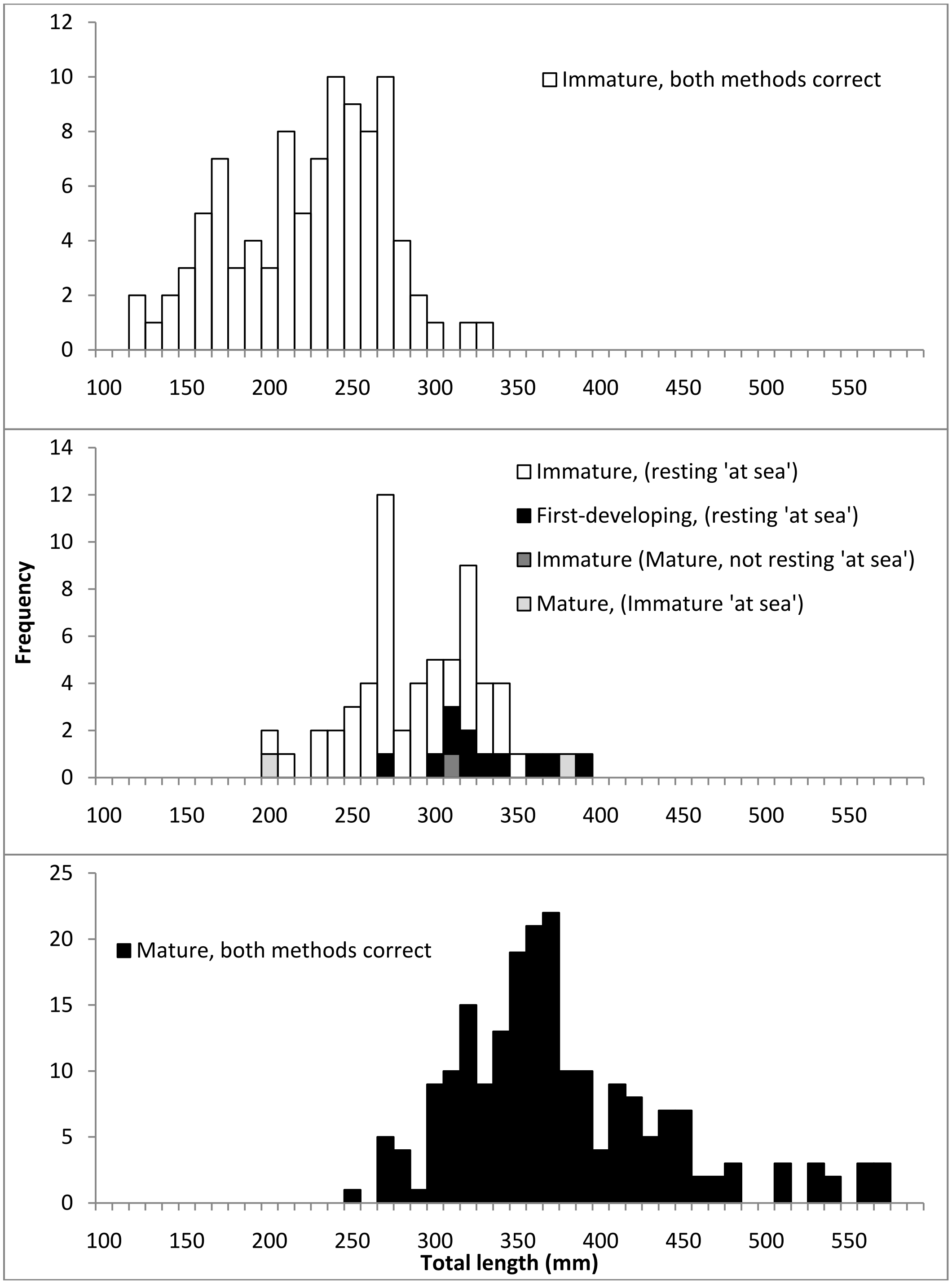


Figure 2. Size distributions of winter flounder (*Pseudopleuronectes americanus*) females. Status of at-sea classifications fall into three groups: immature, correctly identified both at sea and by histology (top panel); incorrect identifications (middle panel, see legend); mature, correctly identified at sea and by histology (bottom panel).

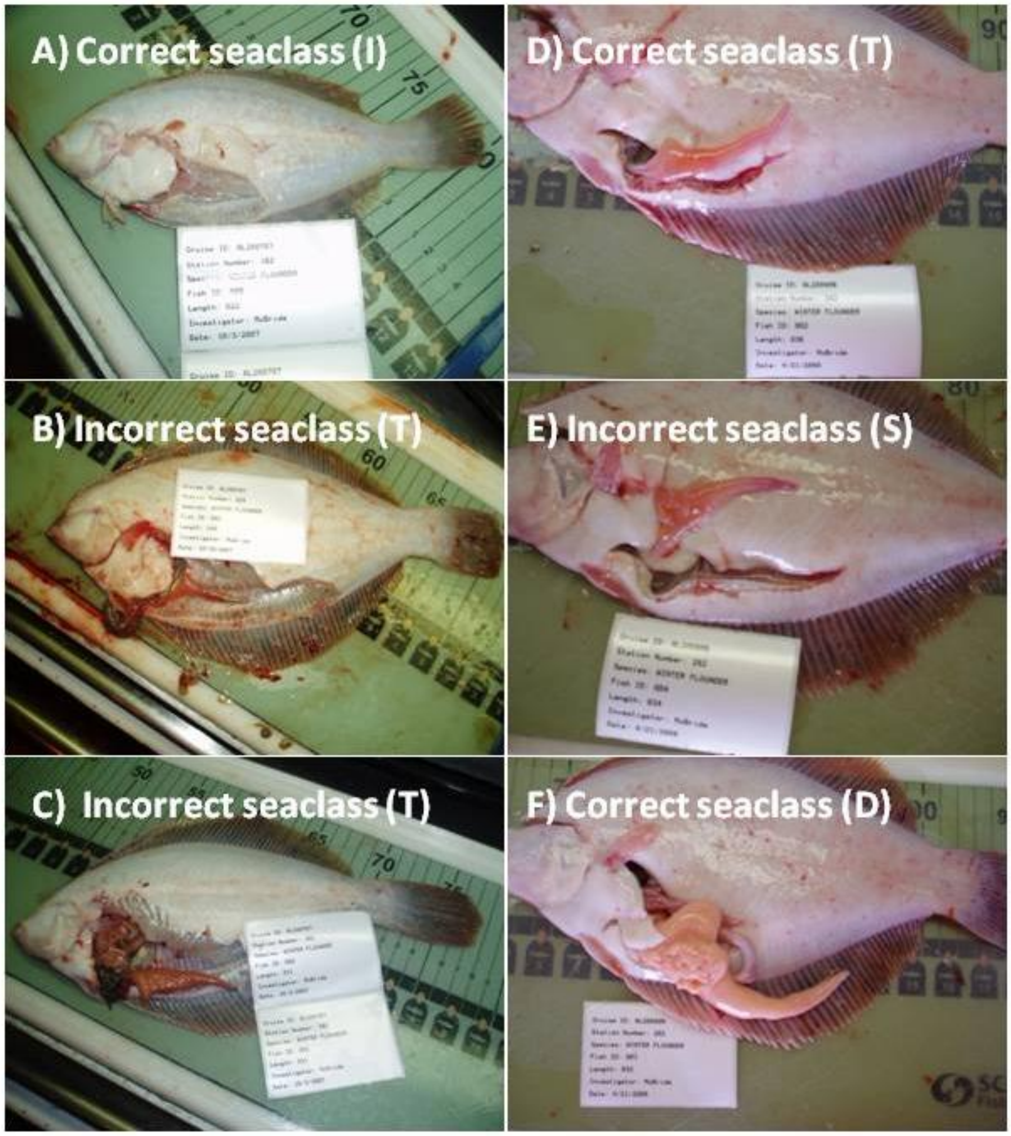


Figure 3. Images of dissected for winter flounder (*Pseudopleuronectes americanus*) females taken aboard NEFSC resource surveys. (A) An immature female collected in southern New England during October; this was correctly assigned at sea. (B) An immature female on Georges Bank in October; this was not correctly assigned at sea. (C) A first-time developing female collected in southern New England in October; this fish was preparing to spawn next spring – and was fairly well along – but it had not spawned before so it was immature. (D) A resting female collected on the Scotian Shelf in April; this was correctly assigned at sea. (E) A re-developing female collected on the Scotian Shelf in April; the gonad is not flaccid so it should not have been called spent, resting would have been correct because the partially-yolked eggs observed by histology are not apparent macroscopically. (F) A developing female collected on the Scotian Shelf in April; this was correctly assigned at sea.

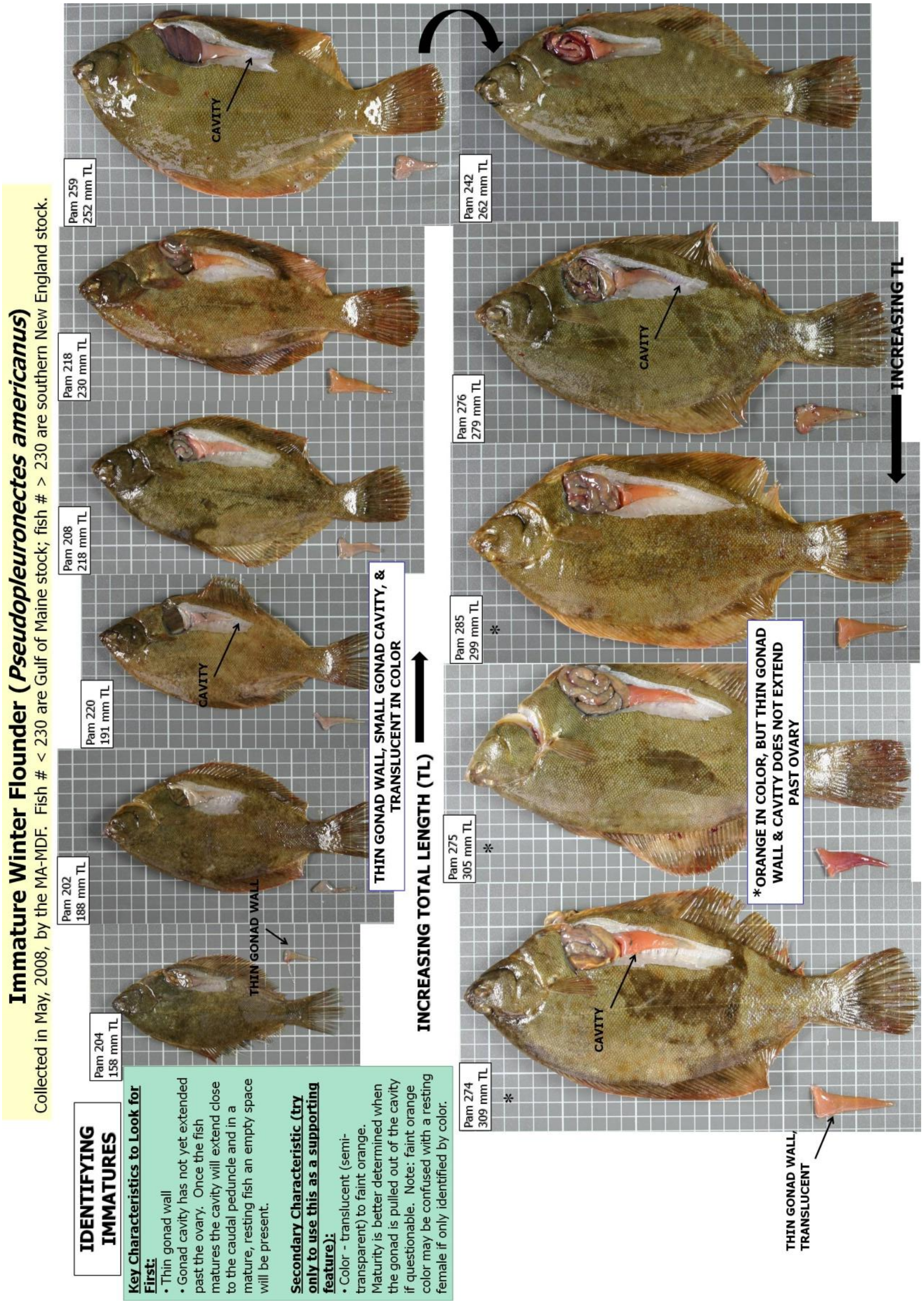


Figure 4. Sample training poster hung in the NEFSC main building cutting room in February, 2011.

Appendix Table 1

Female maturity staging criteria used during NEFSC bottom trawl surveys. Modified from Burnett et al. (1989).

Class	Code	Description and Criteria
Immature	I	Ovary paired, tube-like organ, small relative to body cavity; thin, transparent outer membrane; contains colorless to pink jell-like tissue with no visible eggs
Developing	D	Ovaries enlarge to occupy up to 2/3 of body cavity; if blood vessels present, they become prominent; ovary has granular appearance as yellow to orange yolked eggs develop
Ripe	R	Enlarged ovaries may fill entire body cavity; mixture of yellow to orange yolked eggs and hydrated or "clear" eggs present (50% or more clear eggs denotes ripe ovary, while less than 50% denotes developing ovary) *
Ripe & Running	U	Ripe female with eggs flowing from vent with little or no pressure to abdomen
Spent	S	Ovaries flaccid, sac-like, similar in size to ripe ovary; color red to purple; ovary wall thickening, becoming cloudy and translucent vs. transparent as in ripe ovary; some eggs, either clear or yolked, may still be present, however most adhere to ovary wall; therefore, CUT OPEN OVARY to make sure there is no mass of eggs in center of ovary (as in stages D and R)
Resting	T	Gonad reduced in size relative to ripe ovary, but larger than an immature; interior jell-like with no visible eggs **Flounders**: ovary does not appear to reduce in size relative to body cavity as much as in gadids, and interior usually yellow or orange; apparently, eggs spawned and after a short spent stage, ovary develops up again with yolked eggs which are small and do not get any larger until prior to next spawning season; ovary wall thicker and tougher than ripe ovary wall, and wall is cloudy or translucent, rather than clear as in ripe ovary

* This criterion (in paratheses) is no longer used. Any number of hydrated eggs classifies a fish as ripe, unless they freely flow from the vent, in which case the fish is running-ripe.

Appendix Table 2

Algorithm to assign maturity class to for winter flounder (*Pseudopleuronectes americanus*) females based on evaluation of gonad histology. The first algorithm is used to assign each fish to the standard, six-class scheme (A), the second algorithm is used to assign each fish to an expanded, ten-class scheme (B). Regardless, both schemes assign the same fish to immature versus mature classes when fitting maturity data to a logistic model.

(A)

```
* Assign the laboratory (histology) maturity assignments;

if (MAOS = 'CN' and POFs = 0) then labClass = 'I';

if MAOS = 'PG' then do;
 if POFs = 0 then do;
    if Tuni_thick = 1 then labClass = 'I';
    if Tuni_thick = 2 then labClass = 'T';
   end;
  if POFs > 0 then do;
 if POFage < 3 then labClass = 'S';
 if POFage > 2 then labClass = 'T';
end;
end;

if MAOS ='LC' then do;
 if POFs = 0 then do;
   if Tuni_thick = 1 then labClass = 'I';
   if Tuni_thick = 2 then labClass = 'T';
  end;
  if POFs > 0 then do;
 if POFage < 3 then labClass = 'S';
 if POFage > 2 then labClass = 'T';
end;
end;

if MAOS = 'V1' then do;
 if POFs = 0 then do;
   if Tuni_thick = 1 then labClass = 'I';
   if Tuni_thick = 2 then labClass = 'T';
  end;
 if POFs > 0 then labClass = 'T';
end;

if MAOS = 'V2' then labClass = 'D';

if MAOS = 'GM' then labClass = 'D';

if MAOS = 'B1' then do;
 if POFs = 0 then labClass = 'R';
  if POFs > 0 then labClass = 'U';
end;

if MAOS = 'B2' then do;
 if POFage < 2 then labClass = 'U';
  if POFage > 1 then labClass = 'S';
end;
```

Appendix Table 2 (cont.)

(B)

```
* a more complex subroutine to assign finer maturity scale;

if (MAOS = 'CN' and POFs = 0) then labCla22 = '0Im';

if season = 'FALL' then do;
 if MAOS = 'PG' then do;
  if Tuni_thick = 1 then labCla22 = '0Im';
   if Tuni_thick = 2 then labCla22 = '9Rx';
    if (POFs > 0 ) then labCla22 = '9Rx';
 end;
if MAOS = 'LC' then do;
 if Tuni_thick = 1 then labCla22 = '0Im';
  if Tuni_thick = 2 then labCla22 = '9Rx';
   if (POFs > 0 ) then labCla22 = '9Rx';
 end;
end;

if season = 'SPRING' then do;
if MAOS = 'PG' then do;
 if POFs = 0 then do;
  if Tuni_thick = 1 then labCla22 = '0Im';
   if Tuni_thick = 2 then labCla22 = '7Re';
  end;
if (POFs > 0 ) then do;
 if POFage < 3 then labCla22 = '6Sp';
  if POFage > 2 then labCla22 = '7Re';
 end;
end;
if MAOS = 'LC' then do;
 if POFs = 0 then do;
  if (Tuni_thick = 1 and Stroma ^= 2) then labCla22 = '1If';
  if (Tuni_thick = 2 and Stroma ^= 0) then labCla22 = '8Dr';
   end;
if POFs > 0 then do;
 if POFage < 3 then labCla22 = '6Sp';
  if POFage > 2 then labCla22 = '7Re';
  end;
 end;
end;

if MAOS = 'V1' then do;
 if POFs = 0 then do;
  if (Tuni_thick = 1) then labCla22 = '1If';
   if (Tuni_thick = 2) then labCla22 = '8Dr';
   end;
 if POFs > 0 then labCla22 = '7Re';
end;

if MAOS = 'V2' then labCla22 = '2De';

if MAOS = 'GM' then labCla22 = '3Dm';
```

Appendix Table 2 (cont.)

```
if MAOS = 'B1' then do;
 if POFs = 0 then labCla22 = '4Ri';
  if POFs > 0 then labCla22 = '5RR';
end;

if (MAOS = 'B2') then do;
 if POFage < 2 then labCla22 = '5RR';
 if POFage > 1 then labCla22 = '6Sp';
end;
```

SDWG Background WP#9b

May 2011

VMS Stock Apportionment

SDWG52 WP 9: Validating the stock apportionment of commercial fisheries landings using positional data from Vessel Monitoring Systems (VMS): Impacts on the winter flounder stock allocations

Michael C. Palmer and Susan E. Wigley

**Update of Palmer MC, Wigley SE. 2007. Validating the stock apportionment of commercial fisheries landings using positional data from Vessel Monitoring Systems (VMS). US Dept Commer, Northeast Fisheries Sci Cent Ref Doc. 07-22.*

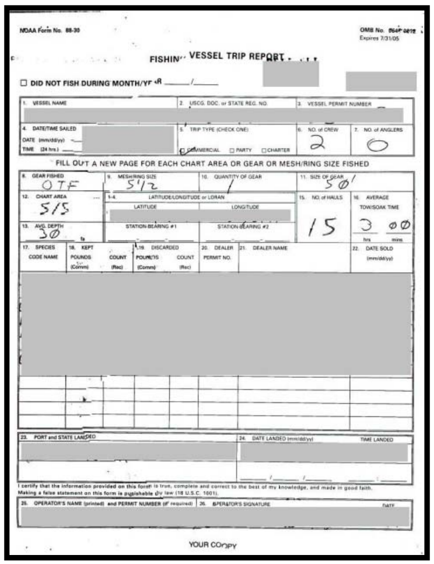
The Problem:

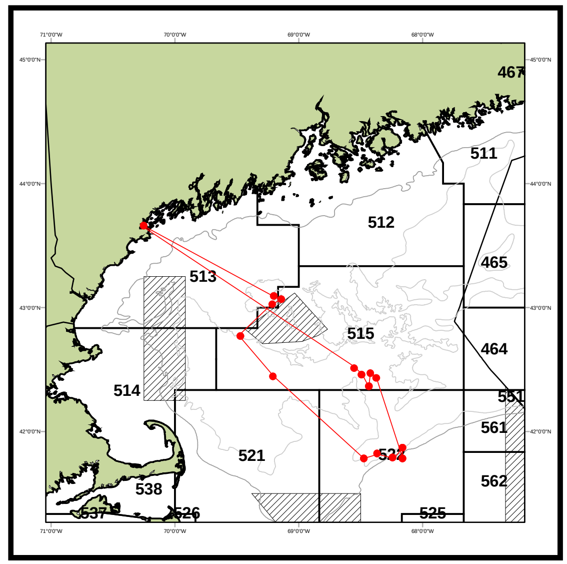
- Eight federally managed fish species are assessed as multiple stocks in Northeast Region.
  - Atlantic cod, haddock, yellowtail flounder, **winter flounder**, windowpane flounder, goosefish, silver hake, red hake.

- Commercial landings are assigned to stock areas using the statistical areas/positions reported on Vessel Trip Reports (VTRs).
  - Trip-level allocation; AA tables (Wigley et al., 2008)

The Problem (cont.):

- VTR misreporting has been previously identified as a problem (Palmer et al., 2007, A. Applegate and T. Nies 2007, Palmer and Wigley 2007).
  - Primarily, fishers under-report the number of statistical areas fished.





** Note: VTR and trip example shown are not from an actual trip. For illustration purposes only!*

- There is a need to assess the potential impacts of VTR misreporting on stock allocations.
  - Earlier studies have used relatively small subsets of the fishery (e.g., Study Fleet, vessels with observer coverage, etc.).
  - Updated the previous Palmer Wigley (2007) analysis to include years 2007and 2008.

Methodology:

- VMS coverage of landings is greater relative to observer data and available real-time.
  - Nearing census coverage in some fleet sectors (e.g., Atlantic scallop, NE groundfish,) as required by recent management measures (e.g., FW 17 Atlantic Scallop FMP, FW 42 NE Multispecies FMP).

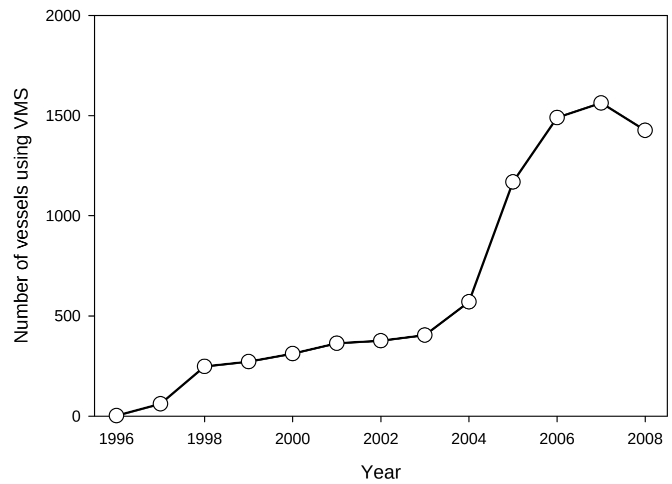


Figure 2

- VMS data have been used in other studies as a proxy for location of NE Region fishing activity (e.g., Murawski et al., 2005; Nies and Applegate, 2007).
  - Used average vessels speeds to categorize activity (e.g., < 3.5 knots = fishing)

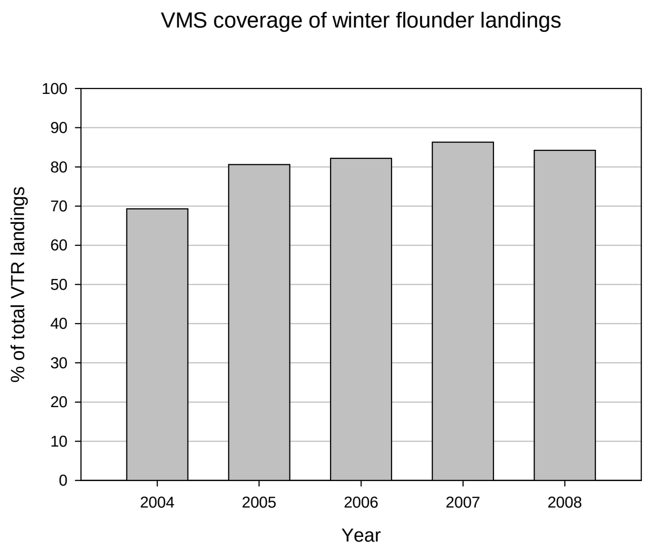
- Used positional information from Vessel Monitoring Systems (VMS) to:
  1. Assess the magnitude of VTR statistical misreporting; and,
  2. Assess the impacts of VTR statistical area misreporting on stock allocations.

Methodology (cont.):

- Examined calendar years 2004 to 2008.

- Included all vessels having reported landing one or more of the eight species and having fished with VTR gear codes of OTF, DRS, GNS and LLB.
  - Accounted for > 96 % of total VTR-reported landings for each of the eight species.

- Matched VTR trips to VMS data using permit number and date sail/land from VTR.
  - Matched trips accounted for 17.6 – 92.0 % of total VTR species landings.
    - **Since 2005 VMS has provided >80% coverage of winter flounder landings.**



Based on Table 11

Methodology (cont.):

- Used average vessel speed from VMS data to classify polled positions into either 'fishing' or 'non-fishing' activity.
- Calculated the statistical area fished from VMS fished positions → compared to VTR.
- Used a constant CPUE model to assign trip landings to stock area based on VMS-indicated locations of fishing activity → compared to VTR-based stock allocations.
- Validated the method against Northeast Fisheries Observer Program (NEFOP) data.

Methodology (cont.):

- Average vessel speed ranges by gear type:
  - **OTF** – fishing = 2.0 to 4.0 knots
    - Accuracy = 99.2 % correct for 'fishing', 31.8 % incorrect for 'non-fishing' – **overestimates fishing activity**.
  - **DRS** – fishing = 2.5 to 6.0 knots
    - Accuracy = 98.3 % correct for 'fishing', 69.3 % incorrect for 'non-fishing' – **overestimates fishing activity**.
  - **GNS** – fishing = 0.1 to 1.3 knots
  - **LLB** – fishing = 0.1 to 1.3 knots

Methodology (cont.):

- Constant CPUE allocation model: $\hat{L}_{sk} = \left(\left(\sum l_{si}\right) + l_{sk}\right) \bullet \left(\frac{t_k}{\left(\sum t_i\right) + t_k}\right)$

where:

$\hat{L}_{sk}$ = VMS prorated trip landings for species *s*, stock *k* (kg)

l_s = Trip landings for species *s* in stock area, *k*, as derived from VTR reports (kg)

l_i = Trip landings for species *s* in stock areas *i*, where $i \neq k$, as derived from VTR reports (kg)

t_k = Time spent fishing in stock area, *k*, as derived from VMS positional data (days)

t_i = Time spent fishing in stock area *i*, where $i \neq k$, as derived form VMS positional data (days)

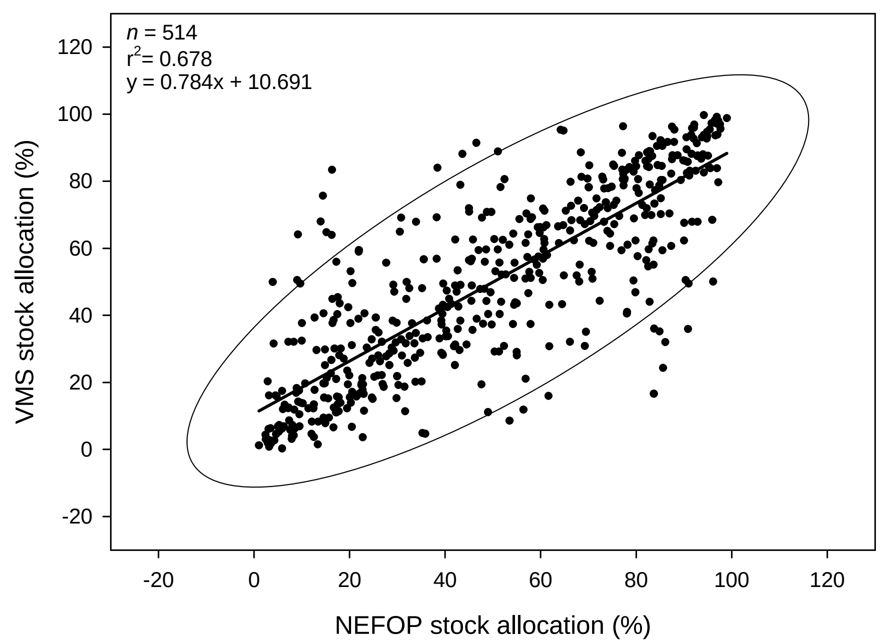


Figure 6

Methodology (cont.):

- Compare VTR statistical area fished to NEFOP data.
  - Accurate reporting for single area trips, underreporting of multi-area trips.

Year	Trip category	Number of trips	Agreement level	Number of trips	Percent of total category trips (%)
2004	Single area	135	Complete	129	95.6
			None	6	4.4
	Multi-area	114	Complete	6	5.3
			None	2	1.8
			Partial	106	93.0
2005	Single area	490	Complete	462	94.3
			None	27	5.5
			Partial	1	0.2
	Multi-area	411	Complete	57	13.9
			None	13	3.2
			Partial	341	83.0
2006	Single area	305	Complete	293	96.1
			None	10	3.3
			Partial	2	0.7
	Multi-area	209	Complete	35	16.7
			None	6	2.9
			Partial	168	80.4
2007	Single area	469	Complete	442	94.6
			None	27	5.4
	Multi-area	302	Complete	46	15.2
			None	9	3.0
			Partial	247	81.8
2008	Single area	385	Complete	367	95.3
			None	17	4.4
			Partial	1	0.3
			Complete	42	15.5

Table 4

Methodology (cont.):

- Compare VMS-determined statistical area fished to NEFOP data.
  - Tends to overestimate number of statistical areas fished, but shows improved gains for multi-area trips.

Year	Area category	Number of trips	Agreement level	Number of trips	Percent of total category trips (%)
2004	Single area	135	Complete	123	91.1
			Partial	12	8.9
	Multi-area	114	Complete	77	67.5
			Partial	37	32.5
2005	Single area	490	Complete	431	88.0
			None	1	0.2
			Partial	58	11.8
	Multi-area	411	Complete	306	74.5
			Partial	105	25.5
2006	Single area	306	Complete	274	89.5
			Partial	32	10.5
	Multi-area	208	Complete	149	71.6
			Partial	59	28.4
2007	Single area	469	Complete	437	93.2
			Partial	32	6.8
	Multi-area	302	Complete	227	75.2
			Partial	75	24.8
2008	Single area	385	Complete	350	90.9
			None	2	0.5
			Partial	33	8.5
	Multi-area	270	Complete	190	70.4
			Partial	80	29.6

Table 5

Results:

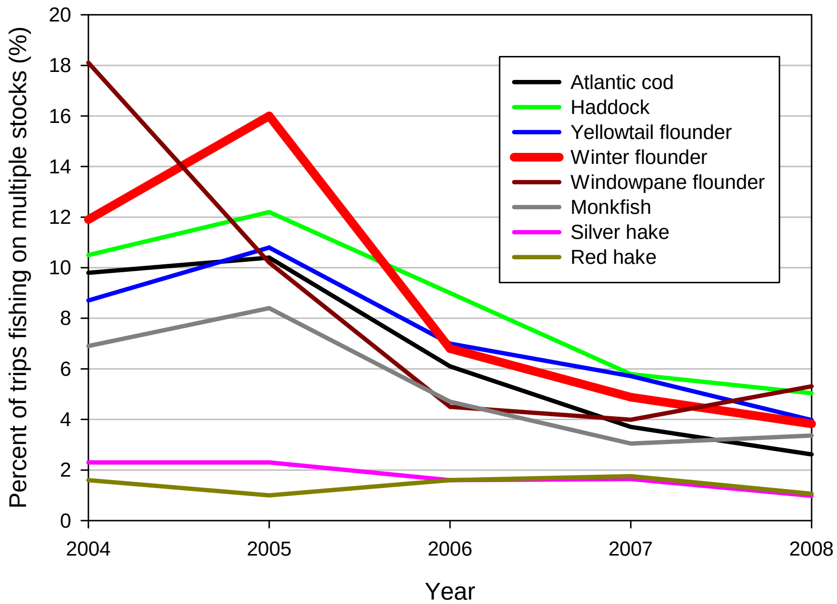
- For winter flounder, the VTR-based allocation has achieved stock allocations closer to NEFOP-based allocations compared to VMS-based methods in the most recent years.
  - **Note: stock allocations do not match actual stock allocations; allocations are contingent on observer coverage and availability of VMS data.*

Year	Stock area	NEFOP-based allocation	VTR-based allocation			VMS-based allocation		
		Stock allocation (%)	Stock allocation (%)	Difference	sum(abs(diff))	Stock allocation (%)	Difference	sum(abs(diff))
2004	GBK	89.1	82.7	-6.4	14.7	**90.3**	**1.2**	**2.3**
	GOM	3.1	2.2	-0.9		**2.3**	**-0.8**	
	SNEMA	7.7	15.1	7.4		**7.4**	**-0.3**	
2005	GBK	84.5	81.3	-3.2	6.4	**83.4**	**-1.1**	**3.0**
	GOM	1.7	4.1	2.4		**1.3**	**-0.4**	
	SNE	13.8	14.6	0.8		**15.3**	**1.5**	
2006	GBK	85.3	83.2	-2.1	4.6	**85.0**	**-0.3**	**1.0**
	GOM	1.6	1.4	-0.2		**1.4**	**-0.2**	
	SNEMA	13.1	15.4	2.3		**13.6**	**0.5**	
2007	GBK	72.7	**69.1**	**-3.7**	**8.3**	65.4	-7.3	**14.7**
	GOM	2.6	**2.1**	**-0.5**		3.4	0.8	
	SNEMA	24.6	**28.8**	**4.2**		31.2	6.5	
2008	GBK	84.6	**84.0**	**-0.6**	**3.0**	78.8	-5.8	**11.9**
	GOM	2.7	**1.8**	**-0.9**		2.6	-0.1	
	SNEMA	12.6	**14.1**	**1.5**		18.6	5.9	

From Tables 6-10

Results:

- Percentage of trips fishing on multiple stocks has declined over time.
  - Not clear whether this is caused by:
    1. A change in the types of trips included in the analytical set.
       - FW 42 (November 2006) required VMS for all limited access NE Multispecies vessels.
       - Prior to FW 42, VMS was only required when fishing in Special Management Programs (offshore).
    2. A true reduction in the frequency of multi-stock area trips.
  - Since 2005, VMS has consistently covered 80-87% of winter flounder landings.
    - VMS coverage has remained consistent since 2006, yet the percentage of multi-stock trips has declined.



Based on Table 18

Methodology (cont.):

- Compare VTR-determined statistical areas fished to VMS-determined statistical area fished for the larger VTR-VMS analytical set.
  - Level of misreporting/underreporting has remained consistent over time.

Year	Trip category	Number of trips	Agreement level	Number of trips	Percent of total category trips (%)
2004	Single area	2,895	Complete	2,688	92.8
			None	194	6.7
			Partial	13	0.4
	Multi-area	2,997	Complete	74	2.5
			None	139	4.6
			Partial	2,784	92.9
2005	Single area	5,630	Complete	5,267	93.6
			None	334	5.9
			Partial	29	0.5
	Multi-area	4,279	Complete	265	6.2
			None	206	4.8
			Partial	3,808	89.0
2006	Single area	13,488	Complete	12,869	95.4
			None	590	4.4
			Partial	29	0.2
	Multi-area	5,677	Complete	234	4.1
			None	221	3.9
			Partial	5,222	92.0
2007	Single area	19,917	Complete	19,104	95.9
			None	785	3.9
			Partial	28	0.1
	Multi-area	6,007	Complete	284	4.7
			None	234	3.9
			Partial	5,489	91.4
2008	Single area	16,797	Complete	16,124	96.0
			None	641	3.8
			Partial	32	0.2
	Multi-area	4,028	Complete	172	4.3
			None	170	4.2
			Partial	3,686	91.5

Table 17

Results:

- VTR and VMS-based allocation differences <5% in majority of years/stocks.
  - Predominance of large differences in recent 2 years, though this corresponds to the period when VTR-based methods appeared to outperform VMS-based methods.

Year	Total species landings (kg)	Stock area	VTR landings allocation (kg)	VMS landings allocation (kg)	Δ landings allocation abs(kg)	VTR stock allocation (%)	VMS Stock allocation (%)	Difference (%)	Relative difference (%)
2004	3,127,781	GBK	2,420,182	2,459,208	39,026	77.4	78.6	-1.2	-1.6
		GOM	94,235	95,648	1,413	3.0	3.1	0.0	0.0
		SNE	**613,364**	**572,925**	**40,439**	**19.6**	**18.3**	**1.3**	**6.6**
2005	2,800,638	GBK	1,976,251	1,985,963	9,712	70.6	70.9	-0.3	-0.4
		GOM	**132,155**	**112,737**	**19,418**	**4.7**	**4.0**	**0.7**	**14.9**
		SNE	692,232	701,939	9,707	24.7	25.1	-0.3	-1.2
2006	2,128,053	GBK	837,904	847,487	9,583	39.4	39.8	-0.5	-1.3
		GOM	151,351	151,497	146	7.1	7.1	0.0	0.0
		SNE	1,138,798	1,129,069	9,729	53.5	53.1	0.5	0.9
2007	2,172,096	**GBK**	**766,057**	**713,963**	**52,094**	**35.3**	**32.9**	**2.4**	**7.3**
		GOM	**193,425**	**204,320**	**10,895**	**8.9**	**9.4**	**-0.5**	**-5.3**
		SNE	1,212,614	1,253,813	41,199	55.8	57.7	-1.9	-3.3
2008	1,875,233	**GBK**	**915,033**	**849,254**	**65,779**	**48.8**	**45.3**	**3.5**	**7.7**
		GOM	187,557	193,399	5,843	10.0	10.3	-0.3	-3.0
		SNE	**772,643**	**832,579**	**59,936**	**41.2**	**44.4**	**-3.2**	**-7.2**

From Tables 20-24

Conclusions:

- In general VTR reporting of statistical areas is problematic - compliance needs to be improved.
    - Scope of the problem is manageable.
        - Of the approx. 2,500 vessels submitting VTRs annually, there are < 300 vessels which frequently under-report statistical areas on their VTRs.
- The impacts of VTR misreporting on the allocation of winter flounder landings are minor (< 5.0 % relative difference) in the majority of instances.
    - Can be significant for some stocks, particularly the smaller stocks.
- For winter flounder VTR misreporting/underreporting is not likely a large source of landings uncertainty; particularly in recent years.

Uncertainties:

- VMS determination of fishing activity – tends to overestimate fishing effort.
- Constant CPUE-model used to allocate landings to stock area violates known groundfish distribution patterns.
- VMS does not provide census coverage of the landings of the eight species examined.
    - For winter flounder, the coverage of the landings is high (>80%).

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VMS Stock Apportionment

Using positional data from vessel monitoring systems (VMS) to validate the logbook-reported area fished and the stock allocation of commercial fisheries landings, 2004-2008[1]

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Abstract

Vessel monitoring system (VMS) positional data from northeast United States fisheries were used to validate the statistical area fished and stock allocation of commercial landings derived from mandatory logbooks. A gear-specific speed algorithm was applied to VMS positions collected between 2004 and 2008 from the otter trawl, scallop dredge, sink gillnet and benthic longline fisheries to estimate the location of fishing activity. Estimated fishing locations were used to re-allocate the stock area landings of eight federally managed groundfish species. The accuracy of the VMS method relative to the mandatory logbooks was assessed using haul locations and catch data recorded by at-sea observers. VMS-based allocations generally outperformed VTR-based allocations; VMS methods achieved stock allocations more similar to observer-based allocations in 58 of the 90 cases examined (18 stocks over 5 years). The VMS algorithm tended to overestimate the number of statistical areas fished such that when a trip's fishing activity occurred in a single statistical area, logbooks more accurately reflected the true fishing location. On trips where fishing activity occurred in multiple statistical areas, the VMS algorithm showed appreciable gains relative to logbook data. VMS-based methods show promise as a means of validating the VTR-based allocations. However, given the limited extent of VMS both over time and in breadth of fisheries covered, it is not an acceptable surrogate for VTR-based allocations.

Introduction

Among the federally managed fish species in the northeast United States (U.S.), eight species are managed and assessed as two or more discrete stocks. The eight species are: Atlantic cod (*Gadus morhua*), haddock (*Melanogrammus aeglefinus*), yellowtail flounder (*Limanda ferruginea*), winter flounder (*Pseudopleuronectes americanus*), windowpane flounder *(Scophthalmus aquosus*), goosefish (*Lophius americanus*), silver hake (*Merluccius bilinearis*) and red hake (*Urophycis chuss*). Stock units are comprised of statistical area groupings (Fig. 1) with stocks defined by divisions that, in most cases, relate to oceanographic features (e.g., Gulf of Maine, Georges Bank; Table 1). All of the species are managed under the Northeast Multispecies Fisheries Management Plan (NEFMC, 1985), with the exception of goosefish which is managed under the Monkfish Fisheries Management Plan (NEFMC, 1998).

In the northeast U.S., dealer weighout data are assumed to be a census of commercial landings amounts. Commercial landings are allocated to management stocks using the statistical areas reported on the mandatory paper logbooks (Wigley et al., 1998). These logbooks are referred to as vessel trip reports (VTRs). Current VTR regulations require that on completion of a fishing trip, a logbook report must be submitted which documents the total catch by species for each statistical area in which fishing occurred (Title 50 of the U.S. Congressional Federal Register, Part 648.7). Despite the regulations, it is known that misreporting of statistical area occurs, most frequently in the form of underreporting the number of statistical areas fished when fishing occurs in more than one area (Palmer et al., 2007; A. Applegate and T. Nies pers. comm.). While, underreporting of statistical areas does not necessarily translate to the misclassification of commercial landings to stock areas, the potential exists and the magnitude of these effects on the allocation of commercial landings is unknown.

The most reliable source of fisheries-dependent catch and effort data in the northeast U.S. are available from the information collected by at-sea fisheries observers. However, because these data are limited in their coverage (e.g., generally < 5% of all certain fisheries in a given year, Wigley et al., 2007) they cannot provide the synoptic coverage necessary to allocate commercial landings to stock area with any regularity. Vessel monitoring systems (VMS) in the northeast were first implemented for the limited-access scallop fisheries in 1998 (NEFMC, 1993). The use of VMS has increased over time (Fig. 2) and expanded to cover many fisheries (Table 2). Historically the larger off-shore vessels participating in the limited-access scallop and special-access groundfish fisheries were more likely to be equipped with VMS compared to the smaller near-shore vessels. With the passage of Framework 17 to the Atlantic sea scallop Fishery Management Plan (FMP; NEFMC, 2005) and Framework 42 to the Multispecies FMP (NEFMC, 2006), VMS is now required for a greater proportion of the smaller near-shore scallop and groundfish fleets. While VMS does not provide census coverage of these fleets, it does provide census coverage of trips taken by those vessels equipped with VMS. Given the increasing use of VMS in the region, this represents a potential tool to conduct large-scale validation of the statistical areas reported on VTRs.

Vessel positions obtained from VMS have been used as a proxy for the location of fishing effort in prior work (Deng et al., 2005; Murawski et al., 2005; Mills et al., 2007). Commonly, the average vessel speed is used to differentiate fishing activity from non fishing activity (Deng et al., 2005; Murawski et al., 2005). Many VMS programs do not require the transmission of instantaneous vessels speeds; only a vessel position and a date and time stamp. This has changed recently in some fisheries (Mills et al. 2007); however, most users of VMS data must infer vessel speed and course from averages calculated from successive positions. Northeast U.S. VMS regulations only require the transmission of the position and the associated date and time. Positions are typically collected once per 30 min from vessels participating in the limited access scallop fishery and once per 60 min from vessels participating in the groundfish fishery (Table 2). The classification error will also depend on whether the vessels speeds available to the analysis represent instantaneous vessels speeds or averaged vessels speeds calculated from the distance traveled between VMS polling events. As the VMS polling frequency increases, the relative accuracy of the calculated speeds decreases (Figure 3). The average vessel speed method can achieve accuracy levels as great as 99%, however it can also result in the incorrect classification of non-trawling activity (Mills et al., 2007) leading to an overestimation of fishing intensity. A more complex method utilizing both vessel speed and directionality has been attempted (Mills et al., 2007); however, this method did not improve the detection of fishing activity and reduced the inclusion of false positives only slightly (0.7%).

When using the vessel-speed method, the amount of classification error is sensitive to the VMS polling rate (Figure 3, Palmer, 2008), the speed ranges used to define fishing activity and the practices of the fishery under observation (e.g., how much overlap exists between the vessel-speed signals of fishing and non-fishing activity, how long are individual hauls). With the exception of Mills et al. (2007) much of the work so far published in the fisheries literature has utilized VMS data without a quantitative assessment of the classification error of fishing vs. non-fishing activity when the vessel-speed method is used. This paper assesses the ability of the VMS vessel-speed method to detect the statistical area fished and allocate fishery landings to stock area by comparing results to matching NEFOP trips. The method is then applied to assess VTR area reporting compliance and its impacts on the current VTR-based allocation method used in the northeast US.

Materials and methods

Data sources

VTR logbook trip, gear and species catch data were extracted from the VTR logbook reports from calendar years 2004 to 2008; prior to 2004, fewer than 500 vessels were equipped with VMS units in the Northeast Region, thus limiting the scope of a VMS-based allocation (Fig. 2). The analytical datasets were post-processed to remove any overlapping trips (i.e., trips taken by the same vessel with a date of sail occurring before the date of landing of a previous trip). Overlaps occur because of VTR reporting and/or data entry errors. This process resulted in the removal of between 1.2% and 2.2% of the total annual reported VTR trips from 2004 and 2008. Of the remaining trips, only those trips where at least one of the eight study species were reported as retained catch were retained in the dataset (Atlantic cod, haddock, yellowtail flounder, winter flounder, windowpane flounder, monkfish, silver hake, and red hake). Because the focus was on assessing the impact of statistical area misreporting on the proration of commercial landings, discards were not included in these analyses. All species weights were converted to live weight in kilograms (kg) using standard species conversion factors established by the Northeast Fisheries Science Center (NEFSC). The VTR dataset was further restricted to include only the four major gear types responsible for species landings in the region: fish bottom otter trawl (OTF), scallop dredge (DRS), sink gillnet (GNS) and benthic longline (LLB). VTR species landings were then assigned to a stock area based on the statistical area fished reported on the logbook (Palmer and Wigley, 2007; Table 1). The final VTR subsets used in this analysis contained between 32,000 and 34,000 trips per year (Table 3).

All available VMS data were extracted from the VMS database for each vessel and assigned to the appropriate VTR trip by matching on the vessel and assigning all VMS point locations with dates between the VTR date of sailing and date landed to the respective trip. The average vessel speed was calculated by dividing the haversine distance (Sinnott, 1984) by the time difference between consecutive VMS positions. All positions were assigned to a National Marine Fisheries Service (NMFS) statistical area (Fig. 1). Summaries of the number of VMS-VTR matched trips by year are included in Table 3.

In the northeast U.S., at-sea fisheries observers are coordinated by the NEFSC's Northeast Fisheries Observer Program (NEFOP). All NEFOP trips which could be matched to the list of VMS-VTR matched trips were extracted from the observer database. Matches were established using the vessel, date of sailing and date landed as reported on the VTR; trips with multiple matches were removed from the analyses. For all matched trips the associated haul duration, statistical area fished, species and retained catch weights were also extracted; retained catch weights were converted to live weight in kilograms (kg) using standard NEFSC conversion factors. Summaries of the number of matches by year are included in Table 3.

Method development and application

Past research using northeast U.S. VMS data have differentiated fishing activity from non-fishing activity by using only upper-speed bounds; < 3.5 knots for bottom trawl vessels (Murawski et al., 2005) and < 5.0 knots for scallop dredge vessels (Rago and McSherry, 2001). To our knowledge no attempt has been made to identify fishing activity from the VMS signals of fixed-gear vessels (i.e., sink gillnet, benthic longline). We attempted to improve vessel-speed classifications and extend the application to fixed-gear vessels through a combination of visual examination of the percent frequency distributions of VMS-derived average speeds, knowledge of fishing operations and observations from high-frequency polled GPS data.

Percent frequency distributions of VMS average vessel speed were plotted for all gear types (Fig. 4). These were then compared to percent frequency distributions of activity-specific (fishing vs. non-fishing) instantaneous vessel speeds from high-frequency polled GPS data (1 fix/10 seconds) collected from vessels involved in NMFS Cooperative Research projects (Fig. 5). These data sets included precise observations of the dates and times of fishing activity. Six trips taken by five separate vessels were analyzed; two groundfish bottom trawl trips, two scallop dredge trips and two gillnet trips. Individual vessel speed observations from all trips were combined by gear type and activity was classified as either 'fishing' or 'other'. For mobile gear, 'fishing' was defined as the period from winch brake lock to winch brake release; presumably the period when the gear is actually in contact with the bottom. For fixed gillnet gear, 'fishing' was defined as the period when gear is being hauled back. Unfortunately, high frequency polling data were not available for benthic longline activity. It is assumed that fixed gears such as sink gillnet and benthic longline gear are likely to be fished in very specific and limited geographic areas on a given trip, thus it is unlikely fishing is occurring on multiple fish stocks on a single trip. If this assumption is true, these analyses will not be as sensitive to misclassification of fixed gear activity relative to mobile gear activity.

VMS-based bottom otter trawl activity exhibits a very pronounced bi-modal distribution of vessel speeds. It was assumed that the first mode (2.8 knots) represented fishing activity and the second mode (8.0 knots) was indicative of steaming activity. Fishing activity falls within a very narrow range from approximately 2.0 to 5.0 knots as evidenced by the distributions observed from the high-frequency GPS data. A fishing speed window of 2.0 knots < fishing activity < 4.0 knots was used. This window fits the high-frequency polled GPS well, correctly classifying 99.2% of fishing activity. However, it also incorrectly categorizes 31.8% of non-fishing activity as fishing activity (Fig. 5). It is expected, that a portion of the non-fishing activity falling inside the window of fishing speed represents activity associated with the hauling and setting of the gear, which suggests that the impact of false-positives on statistical area fished estimation may not be as great as the 31.8% figure implies.

The VMS-based average-vessel-speed distribution of scallop dredge activity has a nearly tri-modal distribution (Fig. 4). Unlike bottom otter trawl speed distributions there is a high percentage of activity close to 0.0 knots. This may be indicative of shucking activity when vessels are drifting and allowing the crew to shuck scallops and clear the deck. The primary mode (4.2 knots) was assumed to represent fishing activity and the 8.2 knot mode was assumed to represent steaming activity. Scallop dredge fishing activity occurs over a broader range compared to trawl activity, falling between approximately 2 to 7 knots as evidenced by the distributions observed from the high-frequency GPS data (Fig. 5). A fishing speed window of 2.5 knots < fishing activity < 6.0 knots was used. This window fit the high-frequency polled GPS well, correctly classifying 98.3% of fishing activity; however, it incorrectly categorized 69.3% of non-fishing activity.

Like scallop dredge activity, VMS-observed sink gillnet average speed distributions have a tri-modal distribution (Fig. 4). Based on personal knowledge of gillnet operations, the first mode (0.6 knots) was interpreted as representing the hauling of gillnet gear, the second mode (3.0 knots) as re-setting the nets and the third mode (8.2 knots) as steaming activity. The majority of presumed hauling activity occurred between the speeds of 0.1 and 1.3 knots. This window did not fit the high-frequency polled GPS well. Only 50.0 % of the fishing activity was correctly identified. Conversely, this speed window incorrectly classified only 25.3% of non-fishing activity. Given the limited scope of the high frequency polling data (i.e., 2 trips taken by 1 vessel) and the likelihood that the geographic extent of fixed gear vessels is somewhat limited, a decision was made to use the 0.1 and 1.3 knot speed window.

Benthic longline average speed distributions have a bimodal distribution (Fig. 4). The first mode (0.8 knots) was interpreted as representing the hauling and setting of the longline gear and the second mode (10.0 knots) as steaming to and from the fishing grounds. For benthic longline gear the same speed used for gillnet gear was used (0.1 < fishing activity < 1.3 knots).

Those VMS locations identified as representative of fishing activity were then used to determine the statistical areas in which fishing occurred. Statistical areas fished were compared across data sources to assess whether the statistical areas derived from VMS-defined fishing activity represented an improvement over VTR reported statistical areas relative to NEFOP data. Trips were broken into two categories: single area trips (fishing occurs in only one statistical area per trip) and multi-area trips (fishing occurs in more than one statistical area per trip). Because all stock boundaries are divided along statistical area boundaries, correct reporting of multi-area trips are of the greatest concern. These are the trips having the potential to fish on multiple stocks of fish in a single trip and where misreporting of statistical area(s) may lead to incorrect estimates of stock removals. For each trip, the levels of agreement between the NEFOP, VMS and VTR statistical areas were categorized as in agreement ('Complete'), not in agreement ('None') or in partial agreement ('Partial'; at least one statistical area was in agreement, but not all). Agreement levels were contingent on agreement among both the number of statistical areas reported and the identity of those statistical areas. For example, if a VTR reports that fishing occurred in statistical areas 515 and 521 and VMS positions indicate that fishing occurred in 515 and 521 then the trip would be considered to be in agreement (‘Complete’). If the VTR reported fishing in 515, and the VMS data suggests fishing occurred in 515 and 521, then the trip would be considered to be in partial agreement (‘Partial’). If the VTR reported fishing in 515, and the VMS data suggests fishing occurred only in 521, then the trip would not be considered to be in agreement (‘None’). The same analysis was repeated on the larger set of VMS and VTR matched trips.

A VMS-based allocation algorithm was devised using the statistical areas fished from the VMS data to re-allocate VTR-reported landings to stock area. Fishing activity was assigned to stock area based on the species landed and statistical area in which the fishing activity was occurring. The time spent fishing in each stock area was estimated as the sum of fishing activity blocks occurring in each stock area. The duration of one activity block is contingent on the VMS polling frequency which is variable, but generally once per 30 minutes for scallop vessels and once per hour for groundfish vessels. Total VTR trip landings for each species (*s*) were allocated to stock area (*k*) based on the ratio of time spent fishing in each stock area as determined from VMS locations (Equation 1).

$$(1) \qquad \hat{L}_{sk} = \left(\left(\sum l_{si}\right) + l_{sk}\right) \bullet \left(\frac{t_k}{\left(\sum t_i\right) + t_k}\right)$$

where:

$\hat{L}_{sk}$ = VMS prorated trip landings for species *s*, stock *k* (kg)

l_s = trip landings for species *s* in stock area, *k*, as derived from VTR reports (kg)

l_i = trip landings for species *s* in stock areas *i*, where $i \neq k$, as derived from VTR reports (kg)

t_k = time spent fishing in stock area, *k*, as derived from VMS positional data (days)

t_i = time spent fishing in stock area *i*, where $i \neq k$, as derived form VMS positional data (days)

The results of the VMS-based allocation were compared to landings allocation derived from both NEFOP and VTR data sources to assess the relative accuracy of the VTR-based allocation and determine if the VMS-based algorithm resulted in improved estimates of landings by stock area. VTR and NEFOP species landings were prorated by assigning landings to stock area based on the reported statistical area. All comparisons were performed through an examination of the percent allocation to stock area as opposed to absolute landings because percent allocations derived from the traditional VTR source are used to allocate the amounts of commercial landings as determined through dealer weighout data (Wigley et al., 1998). The same analysis was performed on the larger VMS-VTR matched data set.

The VMS-based allocation method assumes a constant species catch-per-unit-effort (CPUE) at all fishing locations (i.e., species catch is distributed only as a function of the time spent fishing in each stock area). This assumption neglects species habitat preferences (e.g., sediment composition, water depth and temperature, etc.) which would result in species being more likely to be caught in some locales and not others. To assess the degree to which this assumption was violated, individual species trip allocations from the VMS-method were compared to the same allocations as determined from NEFOP observations using linear regression.

Results

Method validation using NEFOP data

Statistical area agreement between NEFOP and VTR was > 94% for single area trips across all years between 2004 and 2008, but less than 17% for multi-area trips (Table 4). Nearly all disagreements among the 'partial' multi-area trips matches (> 98%) are due to under-reporting of statistical areas (fewer statistical areas reported on the VTR compared to NEFOP); 105 trips in 2004, 337 in 2005, 166 in 2006, 247 in 2007 and 219 in 2008. There was a general trend towards improved VTR reporting of multi-area trips between 2004 and 2006, though the level of accurate reporting has remained constant at approximately 15% since 2007. Given the small sample size, limited number of years of NEFOP comparisons and potential for observer-type effects on VTR-reporting, caution should be taken in inferring any meaningful conclusion based on these apparent trends.

The statistical area agreement between NEFOP and VMS-based statistical areas was lower (≥ 88.0%) for single-area trips compared to the NEFOP-VTR comparisons (Table 5). The cause of disagreement among single-area trips is primarily due to the overestimation of statistical areas fished by the VMS-based method. The overestimation results from the VMS-based method misclassifying non-fishing activity as fishing activity. Agreement among multi-area trips is greater (> 67%) when using the VMS-method compared to the VTR-reported statistical area trips, with no complete disagreement among any of the trips. Among statistical areas in partial agreement there was a tendency for the VMS-method to overestimate the number of statistical areas fished (59.5% of partial matches in 2004, 53.3% in 2005, 50.8% in 2006, 57.3% in 2007, and 56.3% in 2008). The performance of the VMS-based method in detecting statistical areas fished is not equivalent for all gear types; a closer examination of the VMS-NEFOP statistical area comparison in 2005 showed that 80.3% (535 of 666) of trawl trips, 65.4% (17 of 26) of dredge trips, 83.8% (88 of 105) of gillnet trips and 97.1% (101 of 104) of longline trips have agreement levels of 'Complete'. This finding supports the assumption that the misclassification of the location of fixed gear fishing activity is less likely compared to mobile gear activity.

The VMS-based allocation method arrived at annual stock allocations closer to NEFOP allocations relative to the VTR-based allocations for 58 of the 90 stock comparisons examined (eighteen stocks over five years; Tables 6 – 10). There were no species allocations for which the VMS-based allocation under-performed the VTR allocation in all five years. There was a general improvement in the VMS-based allocation between 2004 and 2006 with the number of species for which it under-performed the VTR allocation decreasing from three in 2004 to only one in 2006. However, the VMS method did not outperform the VTR method in 2007 and only marginally better in 2008. Of all species, goosefish, silver hake and red hake had the greatest percent difference relative to the NEFOP allocation. Comparisons of the individual trip stock allocations between the VMS-based method and NEFOP allocation showed strong agreement between VMS and NEFOP stock allocations ($r = 0.823$, $p < 0.001$, $n=514$; Fig. 6), however there was considerable spread in residuals. There are large differences in the NEFOP landings compared to VTR landings shown in Tables 6 – 10 for some species, most notably monkfish (e.g., in 2004 NEFOP estimated 380 mt compared to the VTR estimate of 71 mt). The exact reasons for these discrepancies are unknown, however there is a tendency for self-reported hail weights to be biased low (Palmer et al., 2007). Additionally, monkfish tails constitute a large proportion of monkfish landings and these are often incorrectly reported on VTRs as whole monkfish (Palmer et al., 2007). A conversion factor of 3.32 is applied to monkfish tail landings to convert these to whole weights; incorrect reporting of monkfish tails as whole monkfish will results in the underestimation of VTR monkfish landings by approximately a factor of 3.

Extrapolation to larger VMS-VTR matched dataset

The NEFOP-VMS-VTR subset of data used to validate the VMS-based method is relatively small compared to the total population of VTR-recorded trips (Table 3). The validation results suggest that for some trips monitored through VMS, the VMS-based allocation method can be used to gauge the accuracy of the stock allocations as determined through VTR reports. The VMS-VTR matched set is a much larger dataset. The subset of VTR reports examined (eight species caught using the four gear types) account for only approximately a quarter of the total VTR reports in a given year (Table 3), however this dataset accounts for greater than 95% of the landings of all the study species across the time series (Table 11). Similarly, VMS coverage is available for only 5,892 to 19,165 of the VTR trips in a given year (Table 3), but these trips account for 17.6 to 98.1% of the total landings of individual species (Table 11). By 2006, VMS data were available for trips responsible for landing greater than 70% of all species but goosefish; coverage of goosefish landings is low because there are no specific VMS requirements for the goosefish fishery (Table 2). In 2008 there was a slight decline in the number of vessels covered by VMS (Fig. 2), which appears to have led to a decrease in the percentage of landings covered by VMS.

All demersal species examined in this analysis are primarily caught by the otter trawl fishery except goosefish where gillnet gear is responsible for the majority of the landings. Gillnet is the secondary gear type for all species with the exception of haddock and silver hake which are secondarily targeted by benthic longline (Tables 12 -16). VMS coverage of the landings by most gear types is highly variable, though generally increasing with time; there is a general pattern of low gillnet coverage for landings of most species during the time series.

Examination of the VTR statistical area reporting using VMS-based statistical areas fished showed similar patterns to those observed in the NEFOP-VMS-VTR comparisons. Agreement levels of single-area trips exceeded 92% in all years and was always less than 6.5% for multi-area trips (Table 17). This level of agreement is less than that observed in the NEFOP-VTR comparison. It is unclear whether these lower rates of agreement are due to the overestimation of the number of statistical areas fished by the VMS method, an observer-effect, or some other factor. Closer examination of the partial matches revealed that the number of vessels apparently under-reporting the number of statistical areas fished was 397 in 2004, 477 in 2005 and 629 in 2006. Those vessels that likely frequently under-report trips (> 5 trips in a year) are responsible for the majority of the potentially under-reported trips. In 2004 there were

179 vessels that appeared to frequently under-report accounting for 1,876 of 2,797 of partial agreement trips (67.1%). In 2005, there were 221 vessels in this category, accounting for 2,787 of the 3,837 partial agreement trips (72.6%) and in 2006 there were 268 vessels which potentially under-reported the number of areas fished, accounting for 3,815 of the 5,251 partial agreement trips (72.7%). The number of vessels in this category increased in 2007 to 307 vessels accounting for 4,485 of the 5,489 partial agreement trips (81.7%) before falling in 2008 to 199 vessels accounting for 2,747 of 3,686 partial agreement trips (74.5%).

It is important to consider the implications of the matched trip set composition when interpreting the performance of the VMS-based method. The performance relative to the VTR method is contingent on the number of multi-area trips and the gear composition of the matched data set. For example; a higher proportion of multi-area trips in the examined dataset would appear to improve the performance of the method. The percentage of multi-stock trips recorded by VMS increased in 2005 followed by a decline in 2006 to levels below 2004 values for all but windowpane, silver hake and red hake trips (Table 18). The declines generally continued in 2007 and 2008, with only 1 species (windowpane flounder) having > 5% of trips fishing on multi-stock trips by 2008. Those trips fishing on multiple stocks are predominantly (≥ 99.0%) mobile-gear vessels (Table 19), implying that fixed-gear fishing effort occurs primarily in localized geographic areas such that landings from fixed-gear trips are unlikely to have come from multiple stocks. This supports the prior assumption that the misinterpretation of the VMS speed signals from fixed-gear trips is unlikely to result in the misallocation of landings.

The perceived under-reporting of statistical areas in the VTR data led to minor (< 5%) differences in the overall species allocations; only nine stocks in the five year time-series exhibited differences in stock allocations exceeding 2.0% (2004: northern and southern silver hake, ± 3.0%; 2006: northern and southern windowpane flounder, ± 4.7%; 2007: Georges Bank winter flounder, 2.4%; 2008: Georges Bank winter flounder, 2.4%, southern New England winter flounder, -3.2%, and northern and southern windowpane flounder, ± 3.4%; Tables 20 – 24). These figures are similar to the total proportion of species landings potentially misallocated, which was < 5% for all species-years examined; again with the exception of 2004 silver hake, 2006 and 2008 windowpane flounder, and 2008 winter flounder. However, these small differences in percent allocation have a disproportionate effect on the less abundant stock such as such as Gulf of Maine haddock, southern New England yellowtail, southern windowpane and northern silver hake. For these, stocks, minor differences can be large (≥ 5.0%) relative to the percent of the total species landings allocated to that stock (Tables 20 – 24). These impacts are most notable in the stock allocations of the southern New England/mid-Atlantic yellowtail flounder. Stock allocation differences between the VTR and VMS methods were ≤ 1.6% for all years, however commercial landings of this stock were ≤ 6.4% of the total stock landings as estimated from the VTR reports resulting in relative differences of 53.8, 61.9 and 25.0% for the years 2004, 2005 and 2006 respectively. In 2007 and 2008 the relative differences were < 2%. Of the 90 stock/year combinations analyzed the VMS-based method stock allocations had ≥ 5.0% relative difference compared to the VTR-based allocations for 25 of the comparisons.

There was a tendency for the VTR-method to over-allocate the predominant Atlantic cod and haddock stocks (i.e., Georges Bank) relative to the VMS method (2004 haddock was an exception). There were no consistent trends in the over/under-allocation of Georges Bank yellowtail and winter flounder stocks and under/over-allocate the Gulf of Maine and southern New England stocks. The direction of stock allocation differences for goosefish, windowpane flounder, silver hake and red hake was variable from year to year.

Discussion

The underreporting of statistical areas on VTR logbooks is a problem that affects greater than 80% of the multi-area trips examined. The VTR underreporting rates from this study agree closely with past studies that have used both NEFOP and haul-by-haul self reported data (Palmer et al., 2007). While the impacts of this underreporting are relatively small in regards to overall stock allocation percentages, the relative impacts on less abundant stocks such as southern New England/mid-Atlantic yellowtail can be substantial. This is in agreement with the findings of other studies that have examined this issue using more restrictive data sets (A. Applegate and T. Nies pers. comm.). These discrepancies have implications on the estimation of fishery removals and the assessment of these stocks. While the impacts are minimal for the majority of stocks examined, the extent of the impacts on those few stocks that are significantly affected (e.g., southern New England yellowtail flounder) suggests that this is a problem deserving of attention.

Many of the stock assessments of these eight species use finer stratification of commercial landings (e.g., quarter and market category) to estimate landings at age numbers used in virtual population analysis (VPA), or similar assessment models (Mayo and Terceiro, 2005). This paper does not consider the impacts of statistical area reporting patterns on these finer scale stratifications of commercial landings, however the accuracy of finer-scale allocations would be sensitive to the number of multi-area trips included in each strata. It is possible that the effects of statistical area mis-reporting on stock allocations are reduced due to offsetting errors (i.e., a trip that misallocates 1,100 kg to the Georges Bank cod stock would be largely offset by a trip that misallocates 1,200 kg to the Gulf of Maine cod stock). However, the spatial accuracy of VTR reports is critical not only for the assessment of fish species, but also of protected species such as sea turtles (e.g., Murray, 2004, 2005, 2006; Orphanides and Bisak, 2006) and marine mammals (Belden et al., 2006). When these data are used at finer spatial scales the accuracy of VTR reports becomes increasingly important.

It is important to consider that the results of these analyses apply only to the trips monitored by VMS; however by 2006, trips responsible for more than 70% of the species landings examined were monitored by VMS (Table 11). VMS coverage of some fisheries such as the Northeast multispecies complex is nearing a census, with all vessels required to use a VMS unit when fishing on a Multispecies Days-At-Sea (DAS) (NEFMC, 2010). The increased coverage improves the utility of VMS data as a validation tool for managers and as a data set of spatial fishing patterns for analysts. The number of vessels responsible for the landings of the eight species examined has remained constant at slightly less than 1,200 (Table 3), however the number of these vessels monitored by VMS has increased from 38.5% (453 of 1,176) in 2004 to 86.8% (957 of 1,102) by 2007. The increase in VMS usage appears to have occurred primarily among the smaller-nearshore fleet in response to VMS requirements to participate in the general category scallop fishery (NEFMC, 2005) and the NE multispecies fishery (NEFMC, 2006) as indicated by the drop in percentage of multi-stock area trips recorded by VMS from 2004 to 2008 (Table 13). There was a decrease in the number of multiple stock area trips from 2005 to 2008 which may explain the improved performance of VTR-based allocations in 2007 and 2008 (Tables 9 and 10).

The results are sensitive to the accuracy of average VMS vessel-speeds in differentiating fishing activity from non-fishing activity as well as the validity of the VMS-based allocation. This study defines fishing activity using narrower speed ranges than have been used in past studies which should lead to more conservative estimates of fishing effort. The speed range used for the mobile gears agree closely with the speeds obtained from high-frequency polling of vessels GPS units suggesting that these ranges are reasonable. The speed ranges used for gillnet gear did not correspond all that well with the high frequency GPS polling data; however, given the low percentage of fixed gear trips fishing on multiple stock areas (Table 19), the lack of agreement should not negatively impact these analyses. Additionally, this study relied on average vessel speeds not instantaneous vessel speeds, which are more analogous to the speeds estimated from high-frequency GPS polling. The averaging process blurs activity from observation to observation, potentially leading to an incorrect determination of fishing activity (Fig. 3; Deng et al., 2005; Palmer, 2008). These impacts were not explicitly considered in this study and represent an area of uncertainty.

The speed ranges adequately classify fishing activity (> 98% success for mobile gear, ≥ 50% success for gillnet gear), but tend to overestimate the amount of fishing by incorrectly classifying non-fishing effort as fishing (69.3% misclassification of non-fishing scallop activity). The overestimation was apparent in the comparisons of statistical areas fished between VMS and NEFOP data (Table 5). Future work should focus on the use of more advanced statistical procedures such as mixture distribution models (e.g., Marin et al., 2005) to decompose the mixed distributions of vessels speed. The fine scale observations taken from cooperative research vessels could be used identify likely parameterization of the underlying probability density functions.

VMS data indicate where it is likely that fishing effort is occurring but provide no information on catch composition. A critical assumption of the VMS-based allocation is that the proportion of species caught across multiple stock areas on a fishing trip is only a function of the time spent fishing in each stock area. In the Gulf of Mexico penaeid shrimp fishery, this assumption has generally held true (Cole et al., 2006), however, it may not be appropriate in a multispecies groundfish fishery where the species habitat preference is variable and the target species changes from trip to trip. While the relationship between VMS and NEFOP allocations was significant suggesting that an assumption of constant CPUE is valid, there was a considerable amount of variability (Fig. 6). However, the use of groundfish habitat models (e.g., Rooper et al., 2005) could be used to improve the catch allocation used in this paper. The large degree of variability in this relationship is not independent of overestimating the time spent in an area by the VMS method; disproportionate overestimation of time spent fishing in a particular stock area will have a direct affect on the VMS-based allocation.

The various uncertainties and shortcomings of the VMS allocation method point out that this is not a replacement for a VTR-based allocation. Additionally, the low vessel coverage of historical VMS data (Fig. 2) limits its use as a tool to correct historical misreporting. However, the results do show that VMS data can be used as a tool to monitor the accuracy and completeness of VTRs and guide efforts to improve VTR compliance. The number of vessels which are potentially under-reporting statistical areas on a frequent basis is small (< 350 vessels) relative to the total number of vessels submitting VTRs (> 2,000; Table 3). Improvements are needed in the compliance of VTR reporting regulations, particularly among those vessels likely to be fishing on multiple fish stocks. Given the manageable size of the problem and availability of tools to monitor these data, the quality of self-reported data should be monitored and improved through targeted outreach and education activities.

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Tables

Table 1. Statistical areas used to define species stock units for eight species examined.

Species	Stock area	Statistical areas
Atlantic cod *(Gadus morhua)*	Georges Bank (GBK)	521, 522, 525, 526, 533, 534, 537 - 539, 541 - 543, 551, 552, 561, 562, 611 - 616, 621 - 629, 631 - 639
	Gulf of Maine (GOM)	464, 465, 467, 511 - 515
Haddock *(Melanogrammus aeglefinus)*	Georges Bank (GBK)	521, 522, 525, 526, 533, 534, 537 - 539, 541 - 543, 551, 552, 561, 562, 611 - 616, 621 - 629, 631 - 639
	Gulf of Maine (GOM)	464, 465, 467, 511 - 515
Yellowtail flounder *(Limanda ferruginea)*	Georges Bank (GBK)	522, 525, 551, 552, 561, 562
	Cape Cod/Gulf of Maine (GOM)	464, 465, 467, 511, 512, 513, 514, 515, 521
	Southern New England/ Mid-Atlantic (SNE)	526, 533, 534, 537 - 539, 541 - 543, 611 - 616, 621 - 629, 631 - 639
Winter flounder *(Pseudopleuronectes americanus)*	Georges Bank (GBK)	522, 525, 551, 552, 561, 562
	Gulf of Maine (GOM)	464, 465, 467, 511, 512, 513, 514, 515
	Southern New England/ Mid-Atlantic (SNE)	521, 526, 533, 534, 537 - 539, 541 - 543, 611 - 616, 621 - 629, 631 - 639
Windowpane flounder *(Scophthalmus aquosus)*	North (NOR)	464, 465, 467, 511 - 515, 521, 522, 525, 542, 543, 551, 552, 561, 562
	South (SOU)	526, 533, 534, 537 - 539, 541, 611 - 616, 621 - 629, 631 - 639
Goosefish *(Lophius americanus)*	North (NOR)	464, 465, 467, 511 - 515, 521, 522, 551, 561
	South (SOU)	525, 526, 533, 534, 537 - 539, 541 - 543, 552, 562, 611 - 616, 621 - 629, 631 - 639
Silver hake *(Merluccius bilinearis)*	North (NOR)	464, 465, 467, 511 - 515, 521, 522, 551, 561
	South (SOU)	525, 526, 533, 534, 537 - 539, 541 - 543, 552, 562, 611 - 616, 621 - 629, 631 - 639
Red hake *(Urophycis chuss)*	North (NOR)	464, 465, 467, 511 - 515, 521, 522, 551, 561
	South (SOU)	525, 526, 533, 534, 537 - 539, 541 - 543, 552, 562, 611 - 616, 621 - 629, 631 - 639

Table 2. Fishery management plan (FMP) actions passed by the Northeast Fisheries Management Council (NEFMC) and Mid-Atlantic Fisheries Management Council (MAFMC) affecting the use of Vessel Monitoring System (VMS) in the northeast United States through December 31, 2006. Note: if a vessel is subject to VMS regulations from multiple programs, the most restrictive regulation applies.

Date effective	Fishery	Measure	Description	Reference
May 1998	Atlantic scallop	Amendment 4	Required VMS for all limited access full- and part-time vessels (hourly polling). **Note: Amendment 4 effective March 1994, but VMS implementation delayed by NMFS until May 1998.*	NEFMC 1993
May 1999	Atlantic herring	Original FMP	Required VMS for all category 1 vessels (hourly polling).	NEFMC 1999
May 2001	Atlantic scallop	Framework Adjustment 14	Required VMS for all limited access occasional-category vessels when participating in area access programs (half-hourly polling).	NEFMC 2001
May 2004	Northeast multispecies	Amendment 13	Required VMS for all vessels accessing the US/Canada shared resource area (half-hour polling within US/Canada area, hourly polling outside).	NEFMC 2003
November 2004	Atlantic scallop	Framework Adjustment 16	Required VMS for all general category vessels participating in area access programs (half-hour polling).	NEFMC 2004a
November 2004	Northeast multispecies	Framework Adjustment 40A	Required VMS for all vessels participating in special access programs (SAP) and when fishing under the Regular B Days-at-Sea (DAS) Program (hourly polling).	NEFMC 2004b
October 2005	Atlantic scallop	Framework Adjustment 17	Required VMS for all general category vessels landing > 40 lb scallop meats (half-hour polling).	NEFMC 2005
November 2006	Northeast multispecies	Framework Adjustment 42	Required VMS for all limited access NE multispecies DAS vessels using multispecies DAS (hourly polling).	NEFMC 2006
May 2010	Northeast multispecies	Amendment 16	Required VMS for all limited access NE multispecies DAS vessels using multispecies DAS or on a sector trip (hourly polling).	NEFMC 2010

Table 3. Summary of the Vessel Trip Report (VTR), Vessel Monitoring System (VMS), and Northeast Fisheries Observer Program (NEFOP) 2004 to 2008 data sets, by number of trips and number of vessels.

Year	Category	Number of trips	Number of Vessels
2004	VTR dataset	114,491	2,629
	VTR subset	32,272	1,176
	VMS-VTR matched set	5,892	453
	NEFOP-VMS-VTR matched set	249	150
2005	VTR dataset	121,442	2,599
	VTR subset	33,090	1,161
	VMS-VTR matched set	9,909	622
	NEFOP-VMS-VTR matched set	901	252
2006	VTR dataset	118,548	2,497
	VTR subset	32,431	1,155
	VMS-VTR matched set	19,165	886
	NEFOP-VMS-VTR matched set	514	255
2007	VTR dataset	112,902	2,404
	VTR subset	33,288	1,102
	VMS-VTR matched set	25,924	957
	NEFOP-VMS-VTR matched set	771	328
2008	VTR dataset	105,352	2,271
	VTR subset	33,645	1,064
	VMS-VTR matched set	20,825	845
	NEFOP-VMS-VTR matched set	655	316

Table 4. Summary of the agreement levels between statistical areas fished recorded by the Northeast Fisheries Observer Program (NEFOP) and the statistical areas fished reported on Vessel Trip Reports (VTR) from matched fishing trips from 2004 to 2006. Trip subcategories are based on the NEFOP-reported number of statistical areas fished. *Note: percentages may not sum to 100 due to rounding.*

Year	Trip category	Number of trips	Agreement level	Number of trips	Percent of total category trips (%)
2004	Single area	135	Complete	129	95.6
			None	6	4.4
	Multi-area	114	Complete	6	5.3
			None	2	1.8
			Partial	106	93.0
2005	Single area	490	Complete	462	94.3
			None	27	5.5
			Partial	1	0.2
	Multi-area	411	Complete	57	13.9
			None	13	3.2
			Partial	341	83.0
2006	Single area	305	Complete	293	96.1
			None	10	3.3
			Partial	2	0.7
	Multi-area	209	Complete	35	16.7
			None	6	2.9
			Partial	168	80.4
2007	Single area	469	Complete	442	94.6
			None	27	5.4
	Multi-area	302	Complete	46	15.2
			None	9	3.0
			Partial	247	81.8
2008	Single area	385	Complete	367	95.3
			None	17	4.4
			Partial	1	0.3
	Multi-area	270	Complete	42	15.5
			None	5	1.9
			Partial	223	82.6

Table 5. Summary of the agreement levels between statistical areas fished recorded by the Northeast Fisheries Observer Program (NEFOP) and the statistical areas fished as determined using Vessel Monitoring System (VMS) positional data from matched fishing trips from 2004 to 2006. Trip subcategories are based on the NEFOP-reported number of statistical areas fished. **Note: percentages may not sum to 100 due to rounding.*

Year	Area category	Number of trips	Agreement level	Number of trips	Percent of total category trips (%)
2004	Single area	135	Complete	123	91.1
			Partial	12	8.9
	Multi-area	114	Complete	77	67.5
			Partial	37	32.5
2005	Single area	490	Complete	431	88.0
			None	1	0.2
			Partial	58	11.8
	Multi-area	411	Complete	306	74.5
			Partial	105	25.5
2006	Single area	306	Complete	274	89.5
			Partial	32	10.5
	Multi-area	208	Complete	149	71.6
			Partial	59	28.4
2007	Single area	469	Complete	437	93.2
			Partial	32	6.8
	Multi-area	302	Complete	227	75.2
			Partial	75	24.8
2008	Single area	385	Complete	350	90.9
			None	2	0.5
			Partial	33	8.5
	Multi-area	270	Complete	190	70.4
			Partial	80	29.6

Table 6. Comparison of the Northeast Fisheries Observer Program (NEFOP), Vessel Trip Reports (VTR), and Vessel Monitoring System (VMS) stock allocations of 2004 commercial landings based on 249 matched trips. Bold text is used to indicate which method, VTR or VMS, achieve results closest to NEFOP allocations. Stock areas are Gulf of Maine (GOM), Georges Bank (GBK), southern New England/mid-Atlantic (SNE), northern (NOR), and southern (SOU). Note: allocations may not sum to 100 due to rounding.

Species	Total Observer species landings (kg)	Total VTR species landings (kg)	Stock area	NEFOP landings allocation (kg)	VTR landings allocation (kg)	VMS landings allocation (kg)	NEFOP stock allocation (%)	VTR stock allocation (%)	*VTR difference (%)*	VMS stock allocation (%)	*VMS difference (%)*
Atlantic cod *(Gadus morhua)*	134,732	121,281	GBK	121,143	110,140	109,975	89.9	90.8	-0.9	**90.7**	**-0.8**
			GOM	13,588	11,141	11,306	10.1	9.2	0.9	**9.3**	**0.8**
Haddock *(Melanogrammus aeglefinus)*	507,806	501,287	GBK	499,955	493,985	494,177	98.5	**98.5**	**-0.1**	98.6	-0.1
			GOM	7,851	7,302	7,110	1.5	**1.5**	**0.1**	1.4	0.1
Yellowtail flounder *(Limanda ferruginea)*	252,865	281,582	GBK	247,173	271,682	274,809	97.7	96.5	1.3	**97.6**	**0.2**
			GOM	5,582	9,900	6,684	2.2	3.5	-1.3	**2.4**	**-0.2**
			SNE	109		88	0.0	0.0	0.0	**0.0**	**0.0**
Winter flounder *(Pseudopleuronectes americanus)*	170,741	203,914	GBK	152,184	168,733	184,100	89.1	82.7	6.4	**90.3**	**-1.2**
			GOM	5,362	4,452	4,727	3.1	2.2	1.0	**2.3**	**0.8**
			SNE	13,194	30,729	15,087	7.7	15.1	-7.3	**7.4**	**0.3**
Windowpane flounder *(Scophthalmus aquosus)*	153	66	NOR	144	66	42	94.4	**100.0**	**-5.6**	64.3	30.0
			SOU	9	0	23	5.6	**0.0**	**5.6**	35.7	-30.0
Goosefish *(Lophius americanus)*	380,531	71,311	NOR	335,799	54,720	55,942	88.2	76.7	11.5	**78.4**	**9.8**
			SOU	44,732	16,591	15,369	11.8	23.3	-11.5	**21.6**	**-9.8**
Silver hake *(Merluccius bilnearis)*	24,840	23,280	NOR	4,614	3,685	5,031	18.6	**15.8**	**2.7**	21.6	-3.0
			SOU	20,226	19,595	18,250	81.4	**84.2**	**-2.7**	78.4	3.0
Red hake *(Urophycis chuss)*	2,869	2,655	NOR	1,252	797	850	43.6	30.0	13.6	**32.0**	**11.6**
			SOU	1,617	1,858	1,805	56.4	70.0	-13.6	**68.0**	**-11.6**

Table 7. Comparison of the Northeast Fisheries Observer Program (NEFOP), Vessel Trip Reports (VTR), and Vessel Monitoring System (VMS) stock allocations of 2005 commercial landings based on 901 matched trips. Bold text is used to indicate which method, VTR or VMS, achieve results closest to NEFOP allocations. Stock areas are Gulf of Maine (GOM), Georges Bank (GBK), southern New England/mid-Atlantic (SNE), northern (NOR), and southern (SOU). Note: allocations may not sum to 100 due to rounding.

Species	**Total Observer species landings (kg)**	**Total VTR species landings (kg)**	**Stock area**	**NEFOP landings allocation (kg)**	**VTR landings allocation (kg)**	**VMS landings allocation (kg)**	**NEFOP stock allocation (%)**	**VTR stock allocation (%)**	***VTR difference (%)***	**VMS stock allocation (%)**	***VMS difference (%)***
Atlantic cod *(Gadus morhua)*	653,066	593,995	GBK	599,457	545,989	541,523	91.8	**91.9**	**-0.1**	91.2	0.6
			GOM	53,609	48,006	52,472	8.2	**8.1**	**0.1**	8.8	-0.6
Haddock *(Melanogrammus aeglefinus)*	1,456,503	1,481,989	GBK	1,431,364	1,440,899	1,433,354	98.3	**97.2**	**1.0**	96.7	1.6
			GOM	25,139	41,090	48,635	1.7	**2.8**	**-1.0**	3.3	-1.6
Yellowtail flounder *(Limanda ferruginea)*	780,959	817,279	GBK	758,539	773,181	791,561	97.1	94.6	2.5	**96.9**	**0.3**
			GOM	21,652	23,010	24,687	2.8	2.8	0.0	**3.0**	**-0.2**
			SNE	768	21,088	1,030	0.1	2.6	-2.5	**0.1**	**0.0**
Winter flounder *(Pseudopleuronectes americanus)*	548,666	640,737	GBK	463,772	520,883	534,598	84.5	81.3	3.2	**83.4**	**1.1**
			GOM	9,403	26,073	8,308	1.7	4.1	-2.4	**1.3**	**0.4**
			SNE	75,491	93,781	97,831	13.8	14.6	-0.9	**15.3**	**-1.5**
Windowpane flounder *(Scophthalmus aquosus)*	16,477	13,851	NOR	16,460	13,398	13,780	99.9	96.7	3.2	**99.5**	**0.4**
			SOU	16	454	71	0.1	3.3	-3.2	**0.5**	**-0.4**
Goosefish *(Lophius americanus)*	1,277,812	268,890	NOR	898,895	166,563	172,457	70.3	61.9	8.4	**64.1**	**6.2**
			SOU	378,917	102,327	96,433	29.7	38.1	-8.4	**35.9**	**-6.2**
Silver hake *(Merluccius bilnearis)*	75,370	72,752	NOR	23,266	26,305	26,140	30.9	36.2	-5.3	**35.9**	**-5.1**
			SOU	52,104	46,447	46,612	69.1	63.8	5.3	**64.1**	**5.1**
Red hake *(Urophycis chuss)*	4,165	3,877	NOR	3,139	2,592	2,769	75.4	66.9	8.5	**71.4**	**3.9**
			SOU	1,025	1,285	1,107	24.6	33.1	-8.5	**28.6**	**-3.9**

Table 8. Comparison of the Northeast Fisheries Observer Program (NEFOP), Vessel Trip Reports (VTR), and Vessel Monitoring System (VMS) stock allocations of 2006 commercial landings based on 514 matched trips. Bold text is used to indicate which method, VTR or VMS, achieve results closest to NEFOP allocations. Stock areas are Gulf of Maine (GOM), Georges Bank (GBK), southern New England/mid-Atlantic (SNE), northern (NOR), and southern (SOU). Note: allocations may not sum to 100 due to rounding.

Species	**Total Observer species landings (kg)**	**Total VTR species landings (kg)**	**Stock area**	**NEFOP landings allocation (kg)**	**VTR landings allocation (kg)**	**VMS landings allocation (kg)**	**NEFOP stock allocation (%)**	**VTR stock allocation (%)**	***VTR difference (%)***	**VMS stock allocation (%)**	***VMS difference (%)***
Atlantic cod	234,013	207,562	GBK	201,266	176,561	177,335	86.0	85.1	0.9	**85.4**	**0.6**
(Gadus morhua)			GOM	32,747	31,001	30,227	14.0	14.9	-0.9	**14.6**	**-0.6**
Haddock	312,195	286,961	GBK	304,139	268,746	275,605	97.4	93.7	3.8	**96.0**	**1.4**
(Melanogrammus aeglefinus)			GOM	8,056	18,215	11,356	2.6	6.3	-3.8	**4.0**	**-1.4**
Yellowtail flounder	270,492	288,175	GBK	256,683	277,142	275,958	94.9	96.2	-1.3	**95.8**	**-0.9**
(Limanda ferruginea)			GOM	12,548	10,029	10,530	4.6	3.5	1.2	**3.7**	**1.0**
			SNE	1,261	1,004	1,686	0.5	0.3	0.1	**0.6**	**-0.1**
Winter flounder	193,511	202,203	GBK	165,082	168,158	171,834	85.3	83.2	2.1	**85.0**	**0.3**
(Pseudopleuronectes americanus)			GOM	3,109	2,827	2,834	1.6	1.4	0.2	**1.4**	**0.2**
			SNE	25,321	31,219	27,535	13.1	15.4	-2.4	**13.6**	**-0.5**
Windowpane flounder	11,167	8,308	NOR	10,964	7,745	8,026	98.2	93.2	5.0	**96.6**	**1.6**
(Scophthalmus aquosus)			SOU	204	563	282	1.8	6.8	-5.0	**3.4**	**-1.6**
Goosefish	697,289	150,874	NOR	450,096	105,992	110,857	64.5	**70.3**	**-5.7**	73.5	-8.9
(Lophius americanus)			SOU	247,193	44,883	40,017	35.5	**29.7**	**5.7**	26.5	8.9
Silver hake	67,997	57,500	NOR	30,157	23,221	23,584	44.4	40.4	4.0	**41.0**	**3.3**
(Merluccius bilnearis)			SOU	37,840	34,278	33,916	55.6	59.6	-4.0	**59.0**	**-3.3**
Red hake	5,318	4,354	NOR	3,888	2,908	3,328	73.1	66.8	6.3	**76.4**	**-3.3**
(Urophycis chuss)			SOU	1,431	1,447	1,027	26.9	33.2	-6.3	**23.6**	**3.3**

Table 9. Comparison of the Northeast Fisheries Observer Program (NEFOP), Vessel Trip Reports (VTR), and Vessel Monitoring System (VMS) stock allocations of 2007 commercial landings based on 771 matched trips. Bold text is used to indicate which method, VTR or VMS, achieve results closest to NEFOP allocations. Stock areas are Gulf of Maine (GOM), Georges Bank (GBK), southern New England/mid-Atlantic (SNE), northern (NOR), and southern (SOU). Note: allocations may not sum to 100 due to rounding.

Species	Total Observer species landings (kg)	Total VTR species landings (kg)	Stock area	NEFOP landings allocation (kg)	VTR landings allocation (kg)	VMS landings allocation (kg)	NEFOP stock allocation (%)	VTR stock allocation (%)	*VTR difference (%)*	VMS stock allocation (%)	*VMS difference (%)*
Atlantic cod			GBK	406,039	389,822	383,746	88.5	**88.8**	**-0.2**	87.4	1.1
(Gadus morhua)	458,590	439,098	GOM	52,552	49,276	55,352	11.5	**11.2**	**0.2**	12.6	-1.1
Haddock			GBK	420,707	427,180	423,005	96.7	**95.9**	**0.8**	95.0	1.7
(Melanogrammus aeglefinus)	434,982	445,240	GOM	14,275	18,060	22,235	3.3	**4.1**	**-0.8**	5.0	-1.7
Yellowtail flounder			GBK	177,581	189,671	191,276	89.1	**89.4**	**-0.3**	90.1	-1.0
(Limanda ferruginea)			GOM	17,868	19,131	17,445	9.0	**9.0**	**0.0**	8.2	0.7
	199,270	212,210	SNE	3,821	3,408	3,489	1.9	**1.6**	**0.3**	1.6	0.3
Winter flounder			GBK	153,281	170,371	161,318	72.7	**69.1**	**3.7**	65.4	7.3
(Pseudopleuronectes americanus)			GOM	5,526	5,257	8,429	2.6	**2.1**	**0.5**	3.4	-0.8
	210,757	246,681	SNE	51,951	71,053	76,934	24.6	**28.8**	**-4.2**	31.2	-6.5
Windowpane flounder			NOR	13,637	10,286	10,329	94.5	93.7	0.8	**94.1**	**0.4**
(Scophthalmus aquosus)	14,428	10,979	SOU	792	693	650	5.5	6.3	-0.8	**5.9**	**-0.4**
Goosefish			NOR	327,731	69,999	70,227	70.4	70.1	0.3	**70.3**	**0.1**
(Lophius americanus)	465,492	99,856	SOU	137,761	29,857	29,629	29.6	29.9	-0.3	**29.7**	**-0.1**
Silver hake			NOR	26,292	37,105	34,143	35.5	37.1	-1.6	**34.1**	**1.4**
(Merluccius bilnearis)	74,105	100,047	SOU	47,813	62,942	65,905	64.5	62.9	1.6	**65.9**	**-1.4**
Red hake			NOR	8,698	7,163	7,051	63.0	**51.0**	**12.1**	50.2	12.9
(Urophycis chuss)	13,803	14,055	SOU	5,105	6,892	7,005	37.0	**49.0**	**-12.1**	49.8	-12.9

Table 10. Comparison of the Northeast Fisheries Observer Program (NEFOP), Vessel Trip Reports (VTR), and Vessel Monitoring System (VMS) stock allocations of 2008 commercial landings based on 655 matched trips. Bold text is used to indicate which method, VTR or VMS, achieve results closest to NEFOP allocations. Stock areas are Gulf of Maine (GOM), Georges Bank (GBK), southern New England/mid-Atlantic (SNE), northern (NOR), and southern (SOU). Note: allocations may not sum to 100 due to rounding.

Species	Total Observer species landings (kg)	Total VTR species landings (kg)	Stock area	NEFOP landings allocation (kg)	VTR landings allocation (kg)	VMS landings allocation (kg)	NEFOP stock allocation (%)	VTR stock allocation (%)	*VTR difference (%)*	VMS stock allocation (%)	*VMS difference (%)*
Atlantic cod			GBK	351,095	315,830	311,392	87.5	88.3	-0.8	**87.1**	**0.4**
(Gadus morhua)	401,344	357,702	GOM	50,249	41,872	46,310	12.5	11.7	0.8	**12.9**	**-0.4**
Haddock			GBK	743,721	725,050	719,921	98.8	**98.3**	**0.5**	97.6	1.2
(Melanogrammus aeglefinus)	752,855	737,893	GOM	9,134	12,843	17,971	1.2	**1.7**	**-0.5**	2.4	-1.2
Yellowtail flounder			GBK	197,165	218,113	215,660	93.1	93.9	-0.9	**92.9**	**0.2**
(Limanda ferruginea)			GOM	12,527	11,436	12,813	5.9	4.9	1.0	**5.5**	**0.4**
	211,839	232,198	SNE	2,147	2,649	3,725	1.0	**1.1**	**-0.1**	1.6	-0.6
Winter flounder			GBK	229,437	273,771	256,775	84.6	**84.0**	**0.6**	78.8	5.8
(Pseudopleuronectes americanus)			GOM	7,419	5,975	8,527	2.7	**1.8**	**0.9**	2.6	0.1
	271,056	325,728	SNE	34,201	45,982	60,426	12.6	**14.1**	**-1.5**	18.6	-5.9
Windowpane flounder			NOR	7,265	7,096	6,942	88.7	**86.9**	**1.8**	85.0	3.7
(Scophthalmus aquosus)	8,190	8,169	SOU	926	1072	1226	11.3	**13.1**	**-1.8**	15.0	-3.7
Goosefish			NOR	180,968	32,766	35,171	53.5	51.5	2.0	**55.3**	**-1.8**
(Lophius americanus)	338,356	63,624	SOU	157,388	30,857	28,453	46.5	48.5	-2.0	**44.7**	**1.8**
Silver hake			NOR	9,805	13,200	13,130	21.2	27.3	-6.0	**27.1**	**-5.9**
(Merluccius bilnearis)	46,151	48,412	SOU	36,346	35,212	35,282	78.8	72.7	6.0	**72.9**	**5.9**
Red hake			NOR	11,410	7,531	7,536	76.8	68.0	8.7	**68.1**	**8.7**
(Urophycis chuss)	14,864	11,068	SOU	3,454	3,538	3,532	23.2	32.0	-8.7	**31.9**	**-8.7**

Table 11. Species-level summary of the Vessel Monitoring System (VMS) dataset and Vessel Trip Reports (VTR) subset compared to total VTR landings (kg) from 2004 to 2008.

Year	Species	Total VTR landings (kg)	VTR subset (kg)	Percent of total (%)	VMS matched set (kg)	Percent of total (%)
2004	Atlantic cod *(Gadus morhua)*	5,611,244	5,432,809	96.8	1,874,015	33.4
	Haddock *(Melanogrammus aeglefinus)*	6,919,871	6,837,521	98.8	5,096,088	73.6
	Yellowtail flounder *(Limanda ferruginea)*	6,954,627	6,899,760	99.2	5,378,986	77.3
	Winter flounder *(Pseudopleuronectes americanus)*	4,515,996	4,483,488	99.3	3,127,780	69.3
	Windowpane flounder *(Scophthalmus aquosus)*	92,640	91,522	98.8	18,217	19.7
	Goosefish *(Lophius americanus)*	7,561,854	7,440,979	98.4	1,332,178	17.6
	Silver hake *(Merluccius bilinearis)*	7,454,395	7,392,633	99.2	2,071,931	27.8
	Red hake *(Urophycis chuss)*	875,228	863,357	98.6	236,830	27.1
2005	Atlantic cod *(Gadus morhua)*	5,072,510	4,983,113	98.2	2,754,687	54.3
	Haddock *(Melanogrammus aeglefinus)*	6,198,222	6,155,937	99.3	5,700,737	92.0
	Yellowtail flounder *(Limanda ferruginea)*	3,925,078	3,922,078	99.9	3,475,993	88.6
	Winter flounder *(Pseudopleuronectes americanus)*	3,473,132	3,457,729	99.6	2,800,639	80.6
	Windowpane flounder *(Scophthalmus aquosus)*	81,693	81,532	99.8	45,771	56.0
	Goosefish *(Lophius americanus)*	7,377,131	7,259,875	98.4	2,129,989	28.9
	Silver hake *(Merluccius bilinearis)*	7,526,280	7,522,877	100.0	3,531,069	46.9
	Red hake *(Urophycis chuss)*	549,641	547,200	99.6	154,666	28.1
2006	Atlantic cod *(Gadus morhua)*	4,623,801	4,546,055	98.3	3,428,790	74.2
	Haddock *(Melanogrammus aeglefinus)*	2,810,657	2,713,290	96.5	2,513,767	89.4
	Yellowtail flounder *(Limanda ferruginea)*	1,891,367	1,867,650	98.7	1,681,115	88.9
	Winter flounder *(Pseudopleuronectes americanus)*	2,589,643	2,583,503	99.8	2,128,052	82.2
	Windowpane flounder *(Scophthalmus aquosus)*	87,187	87,012	99.8	61,654	70.7
	Goosefish *(Lophius americanus)*	6,109,614	6,026,365	98.6	3,246,832	53.1
	Silver hake *(Merluccius bilinearis)*	5,331,664	5,327,921	99.9	4,606,490	86.4
	Red hake *(Urophycis chuss)*	559,679	553,489	98.9	458,731	82.0
2007	Atlantic cod *(Gadus morhua)*	6,278,969	6,171,416	98.3	5,838,287	93.0
	Haddock *(Melanogrammus aeglefinus)*	3,071,154	3,054,852	99.5	3,013,511	98.1
	Yellowtail flounder *(Limanda ferruginea)*	1,675,883	1,668,462	99.6	1,623,035	96.8
	Winter flounder *(Pseudopleuronectes americanus)*	2,517,944	2,499,538	99.3	2,172,096	86.3
	Windowpane flounder *(Scophthalmus aquosus)*	180,091	179,389	99.6	144,231	80.1
	Goosefish *(Lophius americanus)*	4,797,261	4,677,828	97.5	2,969,033	61.9
	Silver hake *(Merluccius bilinearis)*	6,198,030	6,179,560	99.7	5,749,198	92.8
	Red hake *(Urophycis chuss)*	614,724	606,624	98.7	544,902	88.6
2008	Atlantic cod *(Gadus morhua)*	7,026,980	6,942,829	98.8	4,987,617	71.0
	Haddock *(Melanogrammus aeglefinus)*	5,213,529	5,190,698	99.6	4,072,033	78.1
	Yellowtail flounder *(Limanda ferruginea)*	1,624,491	1,616,847	99.5	1,239,577	76.3
	Winter flounder *(Pseudopleuronectes americanus)*	2,226,518	2,210,008	99.3	1,875,233	84.2
	Windowpane flounder *(Scophthalmus aquosus)*	117,138	116,527	99.5	59,340	50.7
	Goosefish *(Lophius americanus)*	4,189,612	4,046,358	96.6	1,791,932	42.8
	Silver hake *(Merluccius bilinearis)*	5,767,216	5,583,469	96.8	3,801,904	65.9
	Red hake *(Urophycis chuss)*	754,050	716,744	95.1	535,823	71.1

Table 12. 2004 summary of the Vessel Monitoring System (VMS) data subsets compared to the subset of Vessel Trip Reports (VTR) landings (kg), by species and gear type (bottom otter trawl gear = OTF, scallop dredge gear = DRS, sink gillnet = GNS, and benthic longline = LLB).

		VTR			VMS			
Species	**VTR gear code**	**Number of Vessels**	**Number of trips**	**VTR landings (kg)**	**Number of Vessels**	**Number of trips**	**VMS landings (kg)**	**Percent of VTR landings (%)**
Atlantic cod *(Gadus morhua)*	OTF	444	9,167	3,507,919	189	2,724	1,829,688	52.2
	DRS	6	9	535	3	3	14	2.5
	GNS	171	6,972	1,726,238	4	116	25,959	1.5
	LLB	67	1,221	198,117	21	253	18,355	9.3
Haddock *(Melanogrammus aeglefinus)*	OTF	384	6,323	5,908,548	187	2,472	4,619,014	78.2
	DRS	1	1	0	0	0	0	*N/A*
	GNS	137	3,313	133,401	3	86	9,789	7.3
	LLB	55	986	795,572	21	261	467,285	58.7
Yellowtail flounder *(Limanda ferruginea)*	OTF	404	7,337	6,749,688	181	2,061	5,373,053	79.6
	DRS	36	62	4,346	33	48	4,072	93.7
	GNS	93	1,541	145,727	2	31	1,862	1.3
	LLB	0	0	0	0	0	0	*N/A*
Winter flounder *(Pseudopleuronectes americanus)*	OTF	471	9,866	4,393,835	184	2,314	3,125,651	71.1
	DRS	18	37	750	16	26	660	87.9
	GNS	129	3,029	88,606	2	57	1,433	1.6
	LLB	9	67	298	2	10	37	12.3
Windowpane flounder *(Scophthalmus aquosus)*	OTF	158	1,291	90,880	46	105	18,217	20.0
	DRS	0	0	0	0	0	0	*N/A*
	GNS	12	63	642	0	0	0	0.0
	LLB	0	0	0	0	0	0	*N/A*
Goosefish *(Lophius americanus)*	OTF	555	9,467	1,870,948	208	2,325	880,759	47.1
	DRS	226	1,226	381,761	214	1,179	380,203	99.6
	GNS	268	8,119	5,186,982	4	118	70,362	1.4
	LLB	26	146	1,288	16	75	854	66.3
Silver hake *(Merluccius bilinearis)*	OTF	234	3,212	7,334,373	68	721	2,069,807	28.2
	DRS	0	0	0	0	0	0	*N/A*
	GNS	63	415	21,948	2	7	1,976	9.0
	LLB	4	17	36,311	2	4	148	0.4
Red hake *(Urophycis chuss)*	OTF	172	2,226	769,215	56	510	235,494	30.6
	DRS	0	0	0	0	0	0	*N/A*
	GNS	26	353	93,767	1	33	1,044	1.1
	LLB	7	21	376	3	7	292	77.6

Table 13. 2005 summary of the Vessel Monitoring System (VMS) data subsets compared to the subset of Vessel Trip Reports (VTR) landings (kg), by species and gear type (bottom otter trawl gear = OTF, scallop dredge gear = DRS, sink gillnet = GNS, and benthic longline = LLB).

Species	VTR gear code	VTR			VMS			
		Number of Vessels	**Number of trips**	**VTR landings (kg)**	**Number of Vessels**	**Number of trips**	**VMS landings (kg)**	**Percent of VTR landings (%)**
Atlantic cod *(Gadus morhua)*	OTF	381	9,005	3,201,456	229	4,415	2,491,742	77.8
	DRS	8	11	1,209	7	10	100	8.3
	GNS	157	6,711	1,574,496	21	697	164,299	10.4
	LLB	89	1,373	205,952	45	638	98,546	47.8
Haddock *(Melanogrammus aeglefinus)*	OTF	342	6,471	5,246,396	217	3,670	5,036,560	96
	DRS	3	4	15	2	3	14	93.9
	GNS	125	3,054	59,757	15	292	4,494	7.5
	LLB	80	1257	849,769	44	650	659,669	77.6
Yellowtail flounder *(Limanda ferruginea)*	OTF	352	7,138	3,815,235	218	3,175	3,473,828	91.1
	DRS	30	45	2,059	28	42	1,883	91.5
	GNS	77	1,180	104,756	5	30	259	0.2
	LLB	5	19	28	3	16	23	83.6
Winter flounder *(Pseudopleuronectes americanus)*	OTF	413	9,225	3,407,204	229	3,458	2,786,325	81.8
	DRS	37	65	13,237	36	64	12,772	96.5
	GNS	118	2,530	36,739	12	189	1,069	2.9
	LLB	11	84	549	6	66	473	86.1
Windowpane flounder *(Scophthalmus aquosus)*	OTF	158	1,057	80,999	78	227	45,762	56.5
	DRS	0	0	0	0	0	0	*N/A*
	GNS	9	77	523	0	0	0	0.0
	LLB	4	9	10	3	8	9	91.3
Goosefish *(Lophius americanus)*	OTF	493	9,197	1,857,280	260	3,603	1,359,021	73.2
	DRS	317	2,722	335,072	266	1,498	321,271	95.9
	GNS	246	8,736	5,065,683	34	801	448,437	8.9
	LLB	36	212	1,841	30	182	1,260	68.4
Silver hake *(Merluccius bilinearis)*	OTF	193	2,689	7,391,321	96	1197	3,489,085	47.2
	DRS	2	2	365	2	2	365	100.0
	GNS	41	255	20,219	1	8	4,400	21.8
	LLB	7	30	110,972	5	20	37,219	33.5
Red hake *(Urophycis chuss)*	OTF	143	1,838	482,879	69	757	152,655	31.6
	DRS	1	1	125	1	1	125	100.0
	GNS	24	239	64,020	2	25	1,810	2.8
	LLB	4	10	176	2	6	76	43.3

Table 14. 2006 summary of the Vessel Monitoring System (VMS) data subsets compared to the subset of Vessel Trip Reports (VTR) landings (kg), by species and gear type (bottom otter trawl gear = OTF, scallop dredge gear = DRS, sink gillnet = GNS, and benthic longline = LLB).

Species	VTR gear code	VTR			VMS			
		Number of Vessels	Number of trips	VTR landings (kg)	Number of Vessels	Number of trips	VMS landings (kg)	Percent of VTR landings (%)
Atlantic cod *(Gadus morhua)*	OTF	350	7,493	2,913,548	301	5,799	2,680,732	92.0
	DRS	5	8	420	4	7	184	43.8
	GNS	153	6,764	1,427,295	95	2739	656,843	46.0
	LLB	80	1,154	204,792	42	511	91,031	44.5
Haddock *(Melanogrammus aeglefinus)*	OTF	296	4,938	2,242,491	252	3,994	2,186,209	97.5
	DRS	5	5	1,303	4	4	1,299	99.7
	GNS	122	2,964	65,539	75	1275	26,864	41.0
	LLB	76	1091	403,958	42	496	299,395	74.1
Yellowtail flounder *(Limanda ferruginea)*	OTF	319	6,402	1,772,976	282	4,938	1,674,672	94.5
	DRS	24	36	4,098	23	35	4,076	99.4
	GNS	67	1,293	90,562	32	244	2,355	2.6
	LLB	5	12	14	4	11	13	96.7
Winter flounder *(Pseudopleuronectes americanus)*	OTF	381	8,460	2,534,691	310	5,530	2,115,716	83.5
	DRS	36	73	4,951	34	71	4,926	99.5
	GNS	109	2,825	43,398	64	979	6,983	16.1
	LLB	8	57	463	7	42	428	92.5
Windowpane flounder *(Scophthalmus aquosus)*	OTF	151	1,246	86,897	117	607	61,621	70.9
	DRS	1	2	7	1	2	7	100.0
	GNS	9	37	107	3	7	24	22.6
	LLB	1	1	2	1	1	2	100.0
Goosefish *(Lophius americanus)*	OTF	459	8,032	1,574,844	380	5,747	1,417,361	90.0
	DRS	336	3,917	323,214	333	3,650	317,777	98.3
	GNS	261	8,050	4,127,303	114	2910	1,510,988	36.6
	LLB	22	113	1,004	20	99	706	70.3
Silver hake *(Merluccius bilinearis)*	OTF	197	3,098	5,294,681	162	2242	4,590,130	86.7
	DRS	1	3	14	1	3	14	100.0
	GNS	37	251	18,600	22	98	11,729	63.1
	LLB	4	13	14,628	3	5	4,616	31.6
Red hake *(Urophycis chuss)*	OTF	152	1,983	525,546	119	1346	447,917	85.2
	DRS	2	2	29	2	2	29	100.0
	GNS	22	257	27,383	10	112	10,260	37.5
	LLB	4	6	531	3	5	524	98.7

Table 15. 2007 summary of the Vessel Monitoring System (VMS) data subsets compared to the subset of Vessel Trip Reports (VTR) landings (kg), by species and gear type (bottom otter trawl gear = OTF, scallop dredge gear = DRS, sink gillnet = GNS, and benthic longline = LLB).

Species	VTR gear code	VTR Number of Vessels	VTR Number of trips	VTR landings (kg)	VMS Number of Vessels	VMS Number of trips	VMS landings (kg)	Percent of VTR landings (%)
Atlantic cod	OTF	333	7,166	3,722,919	322	6,538	3,592,723	96.5
(Gadus morhua)	DRS	6	11	122	6	11	122	100.0
	GNS	145	7,724	2,224,006	135	7059	2,038,677	91.7
	LLB	62	1,048	224,369	54	952	206,764	92.2
Haddock	OTF	273	4,508	2,623,998	270	4,220	2,603,164	99.2
(Melanogrammus aeglefinus)	DRS	3	5	29	3	5	29	100.0
	GNS	113	2,985	60,006	113	2851	58,541	97.6
	LLB	60	1007	370,818	55	946	351,777	94.9
Yellowtail flounder	OTF	306	6,360	1,592,293	298	5,718	1,558,752	97.9
(Limanda ferruginea)	DRS	21	34	991	21	34	991	100.0
	GNS	78	2,089	73,751	76	1872	63,226	85.7
	LLB	6	8	1,427	5	7	66	4.6
Winter flounder	OTF	360	8,748	2,442,367	327	6,449	2,120,496	86.8
(Pseudopleuronectes americanus)	DRS	37	76	6,369	37	76	6,369	100.0
	GNS	124	3,877	50,230	104	3474	44,687	89.0
	LLB	6	45	572	5	43	545	95.3
Windowpane flounder	OTF	182	1,865	179,240	159	1133	144,127	80.4
(Scophthalmus aquosus)	DRS	1	1	5	1	1	5	100.0
	GNS	7	51	144	4	46	99	68.9
	LLB	0	0	0	0	0	0	*N/A*
Goosefish	OTF	412	6,928	811,850	367	5,586	782,931	96.4
(Lophius americanus)	DRS	330	3,458	421,485	323	3,223	417,292	99.0
	GNS	249	7,546	3,444,297	169	5152	1,768,626	51.3
	LLB	16	53	195	16	51	184	94.2
Silver hake	OTF	201	3,830	6,112,602	180	3023	5,685,483	93.0
(Merluccius bilinearis)	DRS	3	3	8	3	3	8	100.0
	GNS	50	562	24,962	45	538	23,987	96.1
	LLB	5	32	41,988	5	31	39,720	94.6
Red hake	OTF	157	2,637	590,951	130	2043	531,345	89.9
(Urophycis chuss)	DRS	0	0	0	0	0	0	*N/A*
	GNS	18	247	15,673	14	235	13,557	86.5
	LLB	0	0	0	0	0	0	*N/A*

Table 16. 2008 summary of the Vessel Monitoring System (VMS) data subsets compared to the subset of Vessel Trip Reports (VTR) landings (kg), by species and gear type (bottom otter trawl gear = OTF, scallop dredge gear = DRS, sink gillnet = GNS, and benthic longline = LLB).

Species	VTR gear code	VTR Number of Vessels	VTR Number of trips	VTR landings (kg)	VMS Number of Vessels	VMS Number of trips	VMS landings (kg)	Percent of VTR landings (%)
Atlantic cod	OTF	319	8,051	3,980,275	283	5,545	2,782,826	69.9
(Gadus morhua)	DRS	3	3	20	1	1	9	45.5
	GNS	145	9,193	2,776,208	130	6811	2,052,888	73.9
	LLB	59	871	186,327	47	652	151,893	81.5
Haddock	OTF	250	4,469	4,740,122	230	3,129	3,667,918	77.4
(Melanogrammus aeglefinus)	DRS	1	2	41	1	2	41	100.0
	GNS	111	3,128	55,863	106	2402	42,170	75.5
	LLB	56	657	394,672	46	540	361,904	91.7
Yellowtail flounder	OTF	290	6,869	1,499,440	257	4,825	1,163,165	77.6
(Limanda ferruginea)	DRS	14	35	1,301	14	34	1,251	96.2
	GNS	90	2,725	111,067	84	1773	74,741	67.3
	LLB	6	59	5,039	4	9	420	8.3
Winter flounder	OTF	346	8,642	2,150,549	294	5,328	1,832,963	85.2
(Pseudopleuronectes americanus)	DRS	24	41	2,139	19	30	1,424	66.6
	GNS	125	4,402	56,329	100	3149	40,113	71.2
	LLB	8	102	992	6	49	733	73.9
Windowpane flounder	OTF	167	1,863	115,475	127	796	58,557	50.7
(Scophthalmus aquosus)	DRS	1	1	1	0	0	0	0.0
	GNS	19	80	1,051	8	33	782	74.4
	LLB	0	0	0	0	0	0	*N/A*
Goosefish	OTF	378	5,872	614,655	300	3,595	405,446	66.0
(Lophius americanus)	DRS	323	2,800	304,618	290	1,971	233,700	76.7
	GNS	237	6,226	3,126,971	147	3362	1,152,723	36.9
	LLB	7	24	114	4	15	62	54.4
Silver hake	OTF	205	3,518	5,541,597	164	2186	3,767,703	68.0
(Merluccius bilinearis)	DRS	0	0	0	0	0	0	*N/A*
	GNS	62	804	41,852	54	690	34,181	81.7
	LLB	3	4	20	3	4	20	100.0
Red hake	OTF	161	2,558	708,281	124	1532	527,891	74.5
(Urophycis chuss)	DRS	1	1	16	0	0	0	0.0
	GNS	19	298	8,284	14	257	7,783	94.0
	LLB	3	5	163	2	4	149	91.6

Table 17. Summary of the agreement levels between statistical areas recorded on Vessel Trip Reports (VTR) and the statistical areas fished as determined using Vessel Monitoring System (VMS) positional data from matched fishing trips from 2004 to 2008. Trip subcategories are based on the VMS determined number of statistical areas fished. Note: percentages may not sum to 100 due to rounding.

Year	Trip category	Number of trips	Agreement level	Number of trips	Percent of total category trips (%)
2004	Single area	2,895	Complete	2,688	92.8
			None	194	6.7
			Partial	13	0.4
	Multi-area	2,997	Complete	74	2.5
			None	139	4.6
			Partial	2,784	92.9
2005	Single area	5,630	Complete	5,267	93.6
			None	334	5.9
			Partial	29	0.5
	Multi-area	4,279	Complete	265	6.2
			None	206	4.8
			Partial	3,808	89.0
2006	Single area	13,488	Complete	12,869	95.4
			None	590	4.4
			Partial	29	0.2
	Multi-area	5,677	Complete	234	4.1
			None	221	3.9
			Partial	5,222	92.0
2007	Single area	19,917	Complete	19,104	95.9
			None	785	3.9
			Partial	28	0.1
	Multi-area	6,007	Complete	284	4.7
			None	234	3.9
			Partial	5,489	91.4
2008	Single area	16,797	Complete	16,124	96.0
			None	641	3.8
			Partial	32	0.2
	Multi-area	4,028	Complete	172	4.3
			None	170	4.2
			Partial	3,686	91.5

Table 18. Frequency of trips fishing on multiple stocks based on Vessel Monitoring System (VMS) data from 2004 to 2008.

Species	2004			2005			2006			2007			2008		
	Total trips	Multiple stock area trips	Percent (%)	Total trips	Multiple stock area trips	Percent (%)	Total trips	Multiple stock area trips	Percent (%)	Total trips	Multiple stock area trips	Percent (%)	Total trips	Multiple stock area trips	Percent (%)
Atlantic cod *(Gadus morhua)*	3,096	304	9.8	5,760	600	10.4	9,056	555	6.1	14,560	539	3.7	13,009	340	2.6
Haddock *(Melanogrammus aeglefinus)*	2,819	295	10.5	4,615	562	12.2	5,769	517	9	8,022	464	5.8	6,073	306	5.0
Yellowtail flounder *(Limanda ferruginea)*	2,140	186	8.7	3,263	352	10.8	5,228	367	7	7,631	436	5.7	6,641	264	4.0
Winter flounder *(Pseudopleuronectes americanus)*	2,407	286	11.9	3,777	604	16	6,622	453	6.8	10,042	490	4.9	8,556	327	3.8
Windowpane flounder *(Scophthalmus aquosus)*	105	19	18.1	236	24	10.2	617	28	4.5	1180	47	4.0	829	44	5.3
Goosefish *(Lophius americanus)*	3,697	254	6.9	6,084	511	8.4	12,406	580	4.7	14,012	426	3.0	8,943	300	3.4
Silver hake *(Merluccius bilinearis)*	732	17	2.3	1,227	28	2.3	2,348	38	1.6	3,595	59	1.6	2,880	28	1.0
Red hake *(Urophycis chuss)*	550	9	1.6	789	8	1	1,465	23	1.6	2,278	40	1.8	1,793	19	1.1

Table 19. Frequency of fixed (sink gillnet, benthic longline) and mobile (bottom otter trawl, scallop dredge) gear types used on trips fishing on multiple stocks based on Vessel Monitoring System (VMS) positional data from 2005.

Species	Number of total trips	Number of multiple stock area trips	Percent of total trips (%)	Gear category	Number of Trips	Percent of multiple stock area trips (%)
Atlantic cod *(Gadus morhua)*	5,760	600	10.4	Fixed	6	1.0
				Mobile	594	99.0
Haddock *(Melanogrammus aeglefinus)*	4,615	562	12.2	Fixed	4	0.7
				Mobile	558	99.3
Yellowtail flounder *(Limanda ferruginea)*	3,263	352	10.8	Fixed	0	0.0
				Mobile	352	100.0
Winter flounder *(Pseudopleuronectes americanus)*	3,777	604	16.0	Fixed	1	0.2
				Mobile	603	99.8
Windowpane flounder *(Scophthalmus aquosus)*	236	24	10.2	Fixed	0	0.0
				Mobile	24	100.0
Goosefish *(Lophius americanus)*	6,084	511	8.4	Fixed	0	0.0
				Mobile	511	100.0
Silver hake *(Merluccius bilinearis)*	1,227	28	2.3	Fixed	0	0.0
				Mobile	28	100.0
Red hake *(Urophycis chuss)*	789	8	1.0	Fixed	0	0.0
				Mobile	8	100.0

Table 20. Results of the Vessel Monitoring System (VMS) based stock area allocation compared to the stock area allocation based on the Vessel Trip Reports (VTR) reported statistical area for 2004. Relative difference is determined as % difference/VTR stock allocation; allocations ≥ 5.0% relative differences are italicized. Stock areas are Gulf of Maine (GOM), Georges Bank (GBK), southern New England/mid-Atlantic (SNE), northern (NOR), and southern (SOU). Note: allocations may not sum to 100 due to rounding.

Species	Total species landings (kg)	Stock area	VTR landings allocation (kg)	VMS landings allocation (kg)	Δ landings allocation abs(kg)	$\sum\Delta_i$/total species landings (%)	VTR stock allocation (%)	VMS Stock allocation (%)	Difference (%)	Relative difference (%)
Atlantic cod (*Gadus morhua*)	1,874,015	GBK	1,384,752	1,375,601	9,151	0.98	73.9	73.4	0.5	0.7
		GOM	489,263	498,414	9,151		26.1	26.6	-0.5	-1.9
Haddock (*Melanogrammus aeglefinus*)	5,096,088	GBK	4,763,038	4,806,095	43,057	1.69	93.5	94.3	-0.8	-0.9
		GOM	333,050	289,993	43,057		6.5	5.7	0.8	*12.3*
Yellowtail flounder (*Limanda ferruginea*)	5,378,987	GBK	5,094,590	5,176,798	82,208	3.06	94.7	96.2	-1.5	-1.6
		GOM	215,710	172,386	43,324		4.0	3.2	0.8	*20.0*
		SNE	68,687	29,802	38,885		1.3	0.6	0.7	*53.8*
Winter flounder (*Pseudopleuronectes americanus*)	3,127,781	GBK	2,420,182	2,459,208	39,026	2.59	77.4	78.6	-1.2	-1.6
		GOM	94,235	95,648	1,413		3.0	3.1	0.0	0.0
		SNE	613,364	572,925	40,439		19.6	18.3	1.3	*6.6*
Windowpane flounder (*Scophthalmus aquosus*)	18,217	NOR	16,807	16,725	82	0.90	92.3	91.8	0.5	0.5
		SOU	1,410	1,492	82		7.7	8.2	-0.5	*-6.5*
Goosefish (*Lophius americanus*)	1,332,178	NOR	787,572	801,448	13,876	2.08	59.1	60.2	-1.0	-1.7
		SOU	544,606	530,730	13,876		40.9	39.8	1.0	2.4
Silver hake (*Merluccius bilinearis*)	2,071,930	NOR	404,972	343,720	61,252	*5.91*	19.5	16.6	3.0	*15.4*
		SOU	1,666,958	1,728,210	61,252		80.5	83.4	-3.0	-3.7
Red hake (*Urophycis chuss*)	236,830	NOR	61,461	64,355	2,894	2.44	26.0	27.2	-1.2	-4.6
		SOU	175,369	172,475	2,894		74.0	72.8	1.2	1.6

Table 21. Results of the Vessel Monitoring System (VMS) based stock area allocation compared to the stock area allocation based on the Vessel Trip Reports (VTR) reported statistical area for 2005. Relative difference is determined as % difference/VTR stock allocation; allocations ≥ 5.0% relative differences are italicized. Stock areas are Gulf of Maine (GOM), Georges Bank (GBK), southern New England/mid-Atlantic (SNE), northern (NOR), and southern (SOU). Note: allocations may not sum to 100 due to rounding.

Species	Total species landings (kg)	Stock area	VTR landings allocation (kg)	VMS landings allocation (kg)	Δ landings allocation abs(kg)	$\sum\Delta_i$/total species landings (%)	VTR stock allocation (%)	VMS stock allocation (%)	Difference (%)	Relative difference (%)
Atlantic cod (*Gadus morhua*)	2,754,687	GBK	1,920,110	1,879,800	40,310	2.93	69.7	68.2	1.5	2.2
		GOM	834,577	874,887	40,310		30.3	31.8	-1.5	*-5.0*
Haddock (*Melanogrammus aeglefinus*)	5,700,737	GBK	5,319,329	5,285,374	33,955	1.19	93.3	92.7	0.6	0.6
		GOM	381,408	415,363	33,955		6.7	7.3	-0.6	*-9.0*
Yellowtail flounder (*Limanda ferruginea*)	3,475,993	GBK	3,115,140	3,164,191	49,051	2.82	89.6	91.0	-1.4	-1.6
		GOM	286,276	281,958	4,318		8.2	8.1	0.1	1.2
		SNE	74,577	29,844	44,733		2.1	0.9	1.3	*61.9*
Winter flounder (*Pseudopleuronectes americanus*)	2,800,638	GBK	1,976,251	1,985,963	9,712	1.39	70.6	70.9	-0.3	-0.4
		GOM	132,155	112,737	19,418		4.7	4.0	0.7	*14.9*
		SNE	692,232	701,939	9,707		24.7	25.1	-0.3	-1.2
Windowpane flounder (*Scophthalmus aquosus*)	45,772	NOR	43,740	44,337	597	2.61	95.6	96.9	-1.3	-1.4
		SOU	2,032	1,435	597		4.4	3.1	1.3	*29.5*
Goosefish (*Lophius americanus*)	2,129,989	NOR	1,188,433	1,223,924	35,491	3.33	55.8	57.5	-1.7	-3.0
		SOU	941,556	906,065	35,491		44.2	42.5	1.7	3.8
Silver hake (*Merluccius bilinearis*)	3,531,070	NOR	400,744	380,084	20,660	1.17	11.3	10.8	0.6	*5.3*
		SOU	3,130,326	3,150,986	20,660		88.7	89.2	-0.6	-0.7
Red hake (*Urophycis chuss*)	154,666	NOR	39,360	37,097	2,263	2.93	25.4	24.0	1.5	*5.9*
		SOU	115,306	117,569	2,263		74.6	76.0	-1.5	-2.0

Table 22. Results of the Vessel Monitoring System (VMS) based stock area allocation compared to the stock area allocation based on the Vessel Trip Reports (VTR) reported statistical area for 2006. Relative difference is determined as % difference/VTR stock allocation; allocations ≥ 5.0% relative differences are italicized. Stock areas are Gulf of Maine (GOM), Georges Bank (GBK), southern New England/mid-Atlantic (SNE), northern (NOR), and southern (SOU). Note: allocations may not sum to 100 due to rounding.

Species	Total species landings (kg)	Stock area	VTR landings allocation (kg)	VMS landings allocation (kg)	Δ landings allocation abs(kg)	$\sum\Delta_i$/total species landings (%)	VTR stock allocation (%)	VMS Stock allocation (%)	Difference (%)	Relative difference (%)
Atlantic cod (*Gadus morhua*)	3,428,790	GBK	2,012,366	2,009,838	2,528	0.15	58.7	58.6	0.1	0.2
		GOM	1,416,424	1,418,952	2,528		41.3	41.4	-0.1	-0.2
Haddock (*Melanogrammus aeglefinus*)	2,513,766	GBK	2,175,084	2,171,158	3,926	0.31	86.5	86.4	0.2	0.2
		GOM	338,682	342,608	3,926		13.5	13.6	-0.2	-1.5
Yellowtail flounder (*Limanda ferruginea*)	1,681,115	GBK	1,253,693	1,283,732	30,039	3.57	74.6	76.4	-1.8	-2.4
		GOM	319,177	315,714	3,463		19.0	18.8	0.2	1.1
		SNE	108,245	81,669	26,576		6.4	4.9	1.6	*25.0*
Winter flounder (*Pseudopleuronectes americanus*)	2,128,053	GBK	837,904	847,487	9,583	0.91	39.4	39.8	-0.5	-1.3
		GOM	151,351	151,497	146		7.1	7.1	0.0	0.0
		SNE	1,138,798	1,129,069	9,729		53.5	53.1	0.5	0.9
Windowpane flounder (*Scophthalmus aquosus*)	61,653	NOR	36,421	39,349	2,928	*9.50*	59.1	63.8	-4.7	*-8.0*
		SOU	25,232	22,305	2,927		40.9	36.2	4.7	*11.5*
Goosefish (*Lophius americanus*)	3,246,832	NOR	1,591,261	1,624,922	33,661	2.07	49.0	50.0	-1.0	-2.0
		SOU	1,655,571	1,621,910	33,661		51.0	50.0	1.0	2.0
Silver hake (*Merluccius bilinearis*)	4,606,490	NOR	876,514	950,975	74,461	3.23	19.0	20.6	-1.6	*-8.4*
		SOU	3,729,976	3,655,515	74,461		81.0	79.4	1.6	2.0
Red hake (*Urophycis chuss*)	458,731	NOR	142,190	145,968	3,778	1.65	31.0	31.8	-0.8	-2.6
		SOU	316,541	312,763	3,778		69.0	68.2	0.8	1.2

Table 23. Results of the Vessel Monitoring System (VMS) based stock area allocation compared to the stock area allocation based on the Vessel Trip Reports (VTR) reported statistical area for 2007. Relative difference is determined as % difference/VTR stock allocation; allocations ≥ 5.0% relative differences are italicized. Stock areas are Gulf of Maine (GOM), Georges Bank (GBK), southern New England/mid-Atlantic (SNE), northern (NOR), and southern (SOU). Note: allocations may not sum to 100 due to rounding.

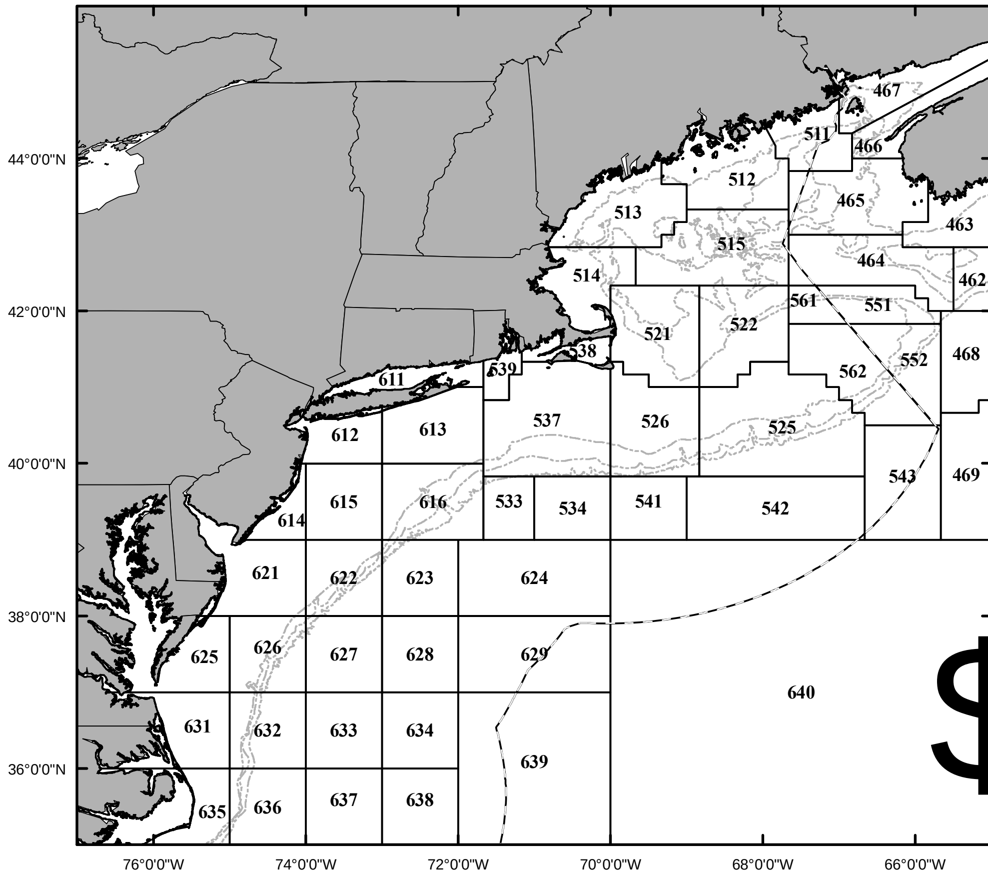
Species	Total species landings (kg)	Stock area	VTR landings allocation (kg)	VMS landings allocation (kg)	Δ landings allocation abs(kg)	$\sum\Delta_i$/total species landings (%)	VTR stock allocation (%)	VMS Stock allocation (%)	Difference (%)	Relative difference (%)
Atlantic cod	5,838,287	GBK	2,971,618	2,948,151	23,466	0.8	50.9	50.5	0.4	0.8
(*Gadus morhua*)		GOM	2,866,669	2,890,135	23,466		49.1	49.5	-0.4	-0.8
Haddock	3,013,511	GBK	2,475,073	2,471,087	3,985	0.3	82.1	82.0	0.1	0.2
(*Melanogrammus aeglefinus*)		GOM	538,438	542,423	3,985		17.9	18.0	-0.1	-0.7
Yellowtail flounder	1,623,035	GBK	1,107,416	1,128,478	21,062	2.6	68.2	69.5	-1.3	-1.9
(*Limanda ferruginea*)		GOM	376,016	356,443	19,574		23.2	22.0	1.2	*5.5*
		SNE	139,603	138,114	1,488		8.6	8.5	0.1	1.1
Winter flounder	2,172,096	GBK	766,057	713,963	52,094	4.8	35.3	32.9	2.4	*7.3*
(Pseudopleuronectes americanus)		GOM	193,425	204,320	10,895		8.9	9.4	-0.5	*-5.3*
		SNE	1,212,614	1,253,813	41,199		55.8	57.7	-1.9	-3.3
Windowpane flounder	144,231	NOR	110,327	110,067	260	0.4	76.5	76.3	0.2	0.2
(Scophthalmus aquosus)		SOU	33,904	34,164	260		23.5	23.7	-0.2	-0.8
Goosefish	2,969,033	NOR	1,106,535	1,094,480	12,056	0.8	37.3	36.9	0.4	1.1
(*Lophius americanus*)		SOU	1,862,497	1,874,553	12,056		62.7	63.1	-0.4	-0.6
Silver hake	5,749,198	NOR	1,045,749	1,065,613	19,865	0.7	18.2	18.5	-0.3	-1.9
(*Merluccius bilinearis*)		SOU	4,703,449	4,683,584	19,865		81.8	81.5	0.3	0.4
Red hake	544,902	NOR	106,960	105,305	1,655	0.6	19.6	19.3	0.3	1.6
(*Urophycis chuss*)		SOU	437,942	439,597	1,655		80.4	80.7	-0.3	-0.4

Table 24. Results of the Vessel Monitoring System (VMS) based stock area allocation compared to the stock area allocation based on the Vessel Trip Reports (VTR) reported statistical area for 2008. Relative difference is determined as % difference/VTR stock allocation; allocations ≥ 5.0% relative differences are italicized. Stock areas are Gulf of Maine (GOM), Georges Bank (GBK), southern New England/mid-Atlantic (SNE), northern (NOR), and southern (SOU). Note: allocations may not sum to 100 due to rounding.

Species	Total species landings (kg)	Stock area	VTR landings allocation (kg)	VMS landings allocation (kg)	Δ landings allocation abs(kg)	$\sum\Delta_i$/total species landings (%)	VTR stock allocation (%)	VMS Stock allocation (%)	Difference (%)	Relative difference (%)
Atlantic cod	4,987,617	GBK	1,977,321	1,964,655	12,666	0.5	39.6	39.4	0.3	0.6
(*Gadus morhua*)		GOM	3,010,296	3,022,962	12,666		60.4	60.6	-0.3	-0.4
Haddock	4,072,033	GBK	3,801,155	3,748,015	53,140	2.6	93.3	92.0	1.3	1.4
(*Melanogrammus aeglefinus*)		GOM	270,879	324,018	53,140		6.7	8.0	-1.3	*-16.4*
Yellowtail flounder	1,239,577	GBK	772,304	770,172	2,132	0.3	62.3	62.1	0.2	0.3
(*Limanda ferruginea*)		GOM	358,242	358,411	169		28.9	28.9	0.0	0.0
		SNE	109,030	110,993	1,963		8.8	9.0	-0.2	-1.8
Winter flounder	1,875,233	GBK	915,033	849,254	65,779	7.0	48.8	45.3	3.5	*7.7*
(Pseudopleuronectes americanus)		GOM	187,557	193,399	5,843		10.0	10.3	-0.3	-3.0
		SNE	772,643	832,579	59,936		41.2	44.4	-3.2	*-7.2*
Windowpane flounder	59,340	NOR	33,564	31,550	2,014	6.8	56.6	53.2	3.4	*6.4*
(Scophthalmus aquosus)		SOU	25,776	27,789	2,014		43.4	46.8	-3.4	*-7.2*
Goosefish	1,791,932	NOR	428,672	445,051	16,379	1.8	23.9	24.8	-0.9	-3.7
(*Lophius americanus*)		SOU	1,363,260	1,346,881	16,379		76.1	75.2	0.9	1.2
Silver hake	3,801,904	NOR	616,304	633,309	17,005	0.9	16.2	16.7	-0.4	-2.7
(*Merluccius bilinearis*)		SOU	3,185,600	3,168,595	17,005		83.8	83.3	0.4	0.5
Red hake	535,765	NOR	105,091	105,101	10	0.0	19.6	19.6	0.0	0.0
(*Urophycis chuss*)		SOU	430,673	430,664	10		80.4	80.4	0.0	0.0

Figures

Palmer and Wigley - Figure 1.



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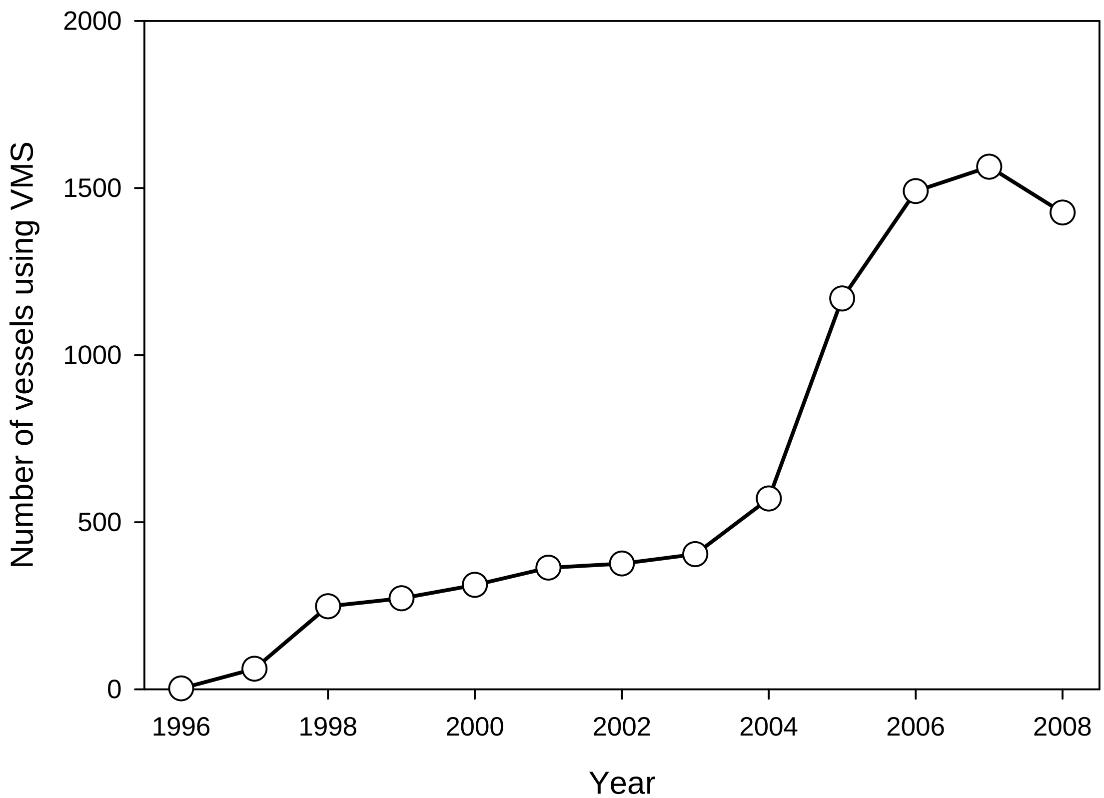

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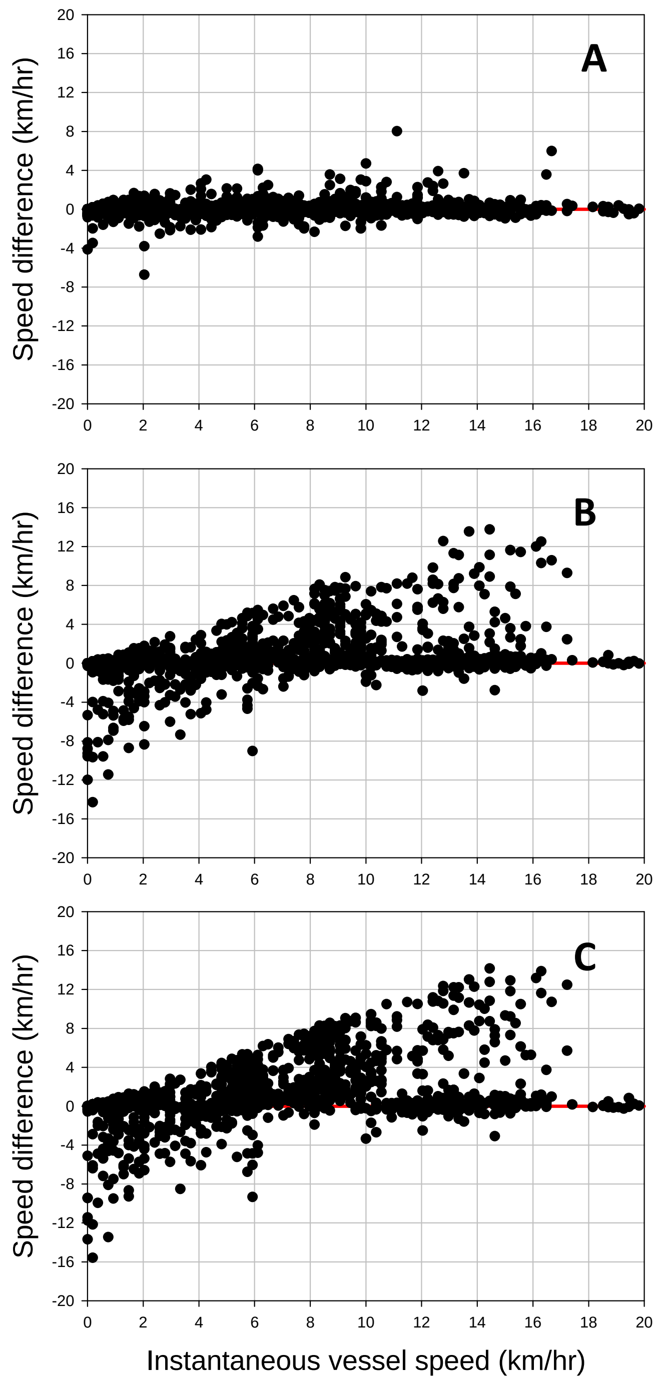

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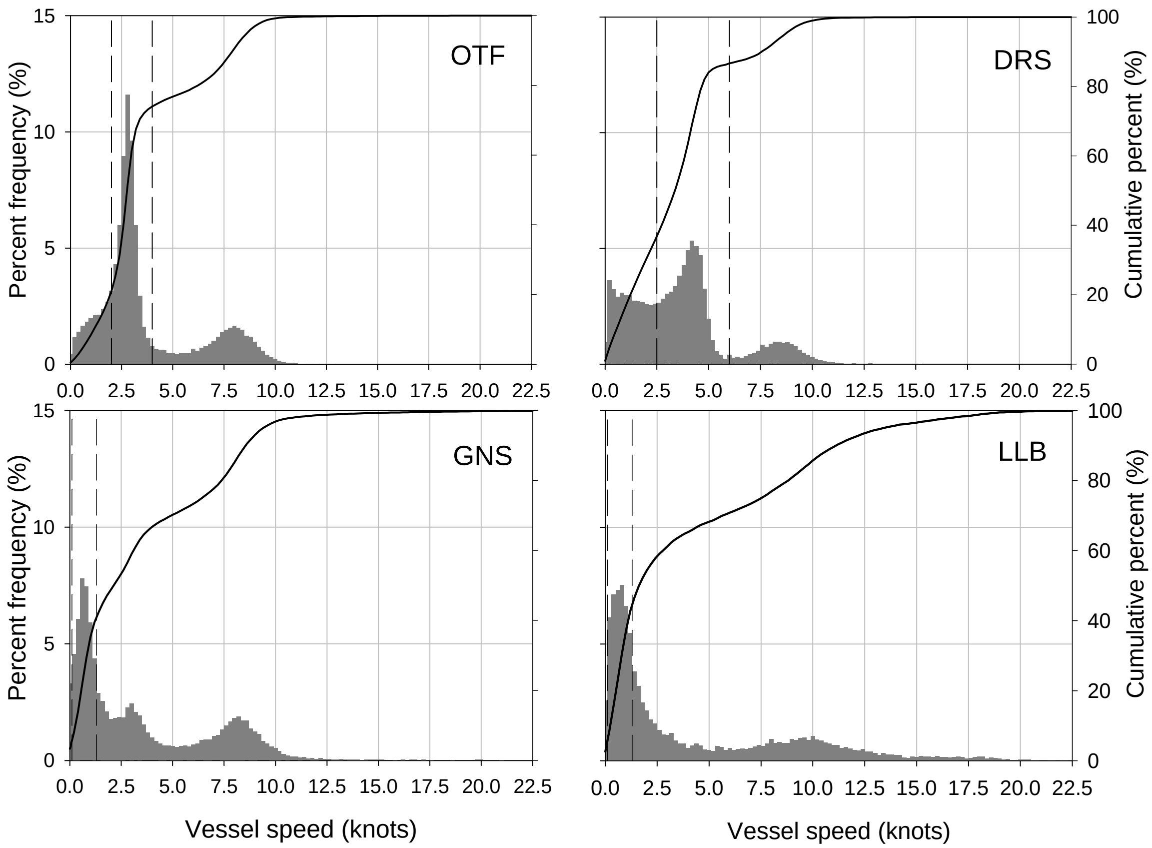

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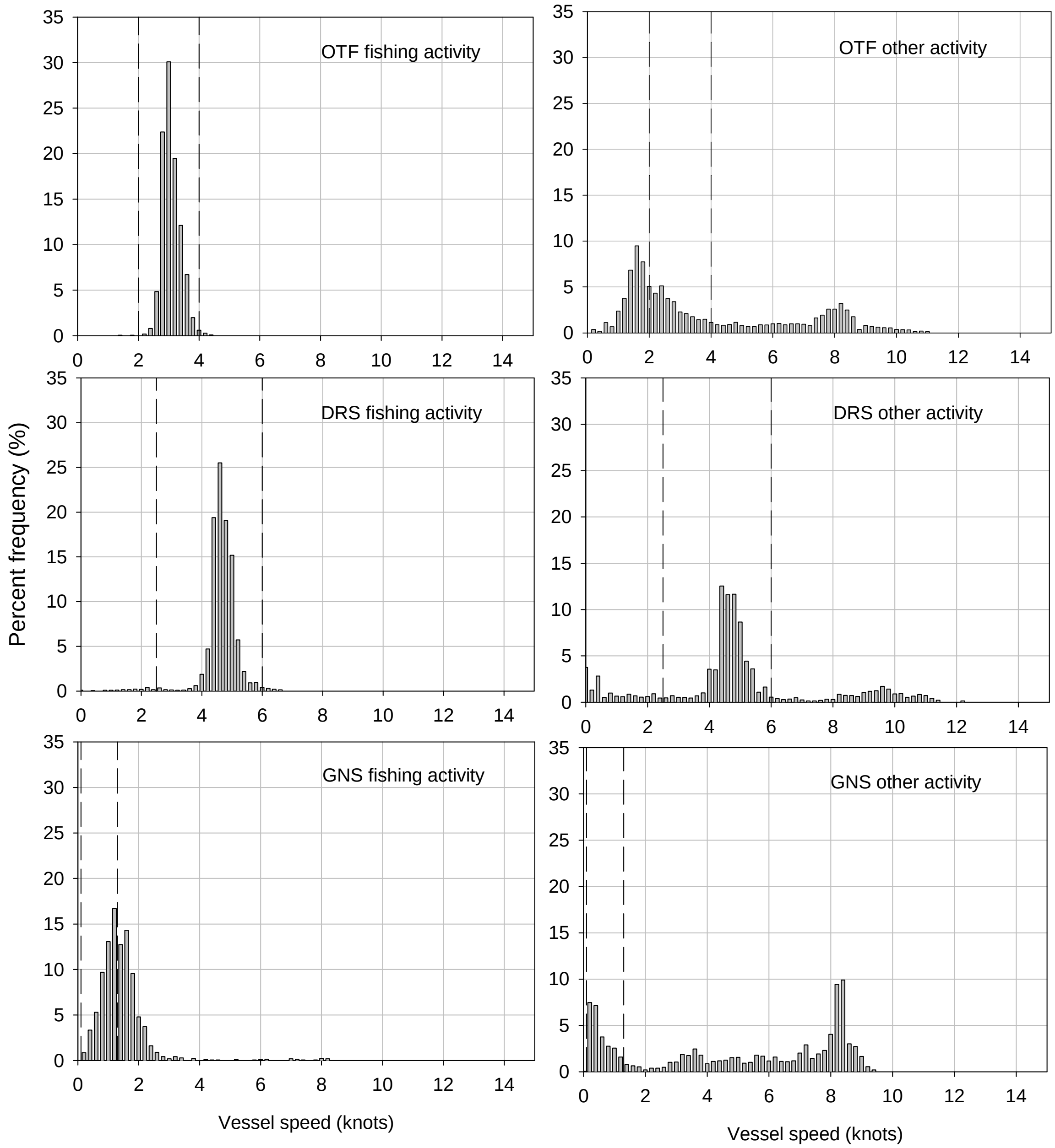

Palmer and Wigley - Figure 6.

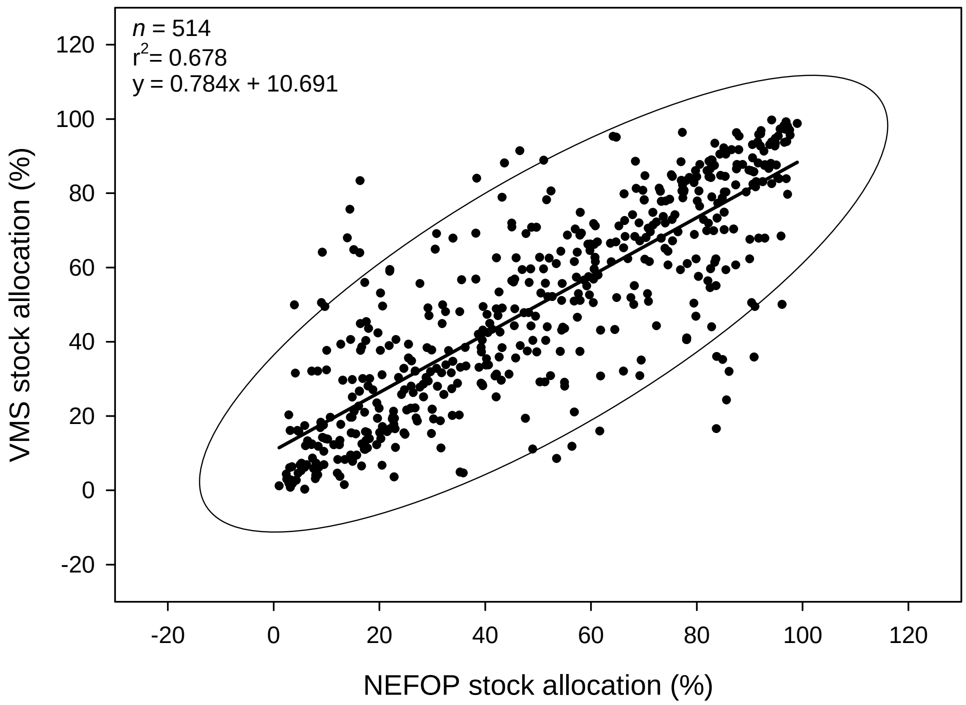

Figure 1. Statistical areas used for commercial fisheries data collection by the National Marine Fisheries Service in the Northeast Region. The 50, 100 and 500 fa bathymetric lines are shown in light gray and the U.S. Exclusive Economic Zone is indicated by the dashed black line.

Figure 2. Number of vessels using Vessel Monitoring System (VMS) in the northeast United States between 1998 and 2006.

Figure 3. Vessel speeds calculated from sequential GPS polling positions to the compared to a vessel's instantaneous speed recorded directly from the GPS unit. Plot A shows the comparison of the calculated average speed of a fishing vessel compared to the vessel's instantaneous speed when the VMS polling frequency is 1 position/minute. Plot B shows the effect when the VMS polling frequency is 1 position/30 minutes. Plot C shows the effect when the VMS polling frequency is 1 position/hour.

Figure 4. Percent frequency and cumulative percent distributions of average vessel speed (knots) as determined from Vessel Monitoring System (VMS) positions for vessels fishing fish bottom otter trawl (OTF), scallop dredge (DRS), sink gillnet (GNS) and benthic longline (LLB). The dashed lines represent the bounds used in this study to define fishing activity (OTF = 2.0 – 4.0 knots, DRS = 2.5 – 6.0 knots, GNS = 0.1 – 1.3 knots, LLB = 0.1 – 1.3 knots).

Figure 5. Percent frequency distribution of instantaneous vessel speed (knots) of vessels fishing fish bottom otter trawl gear (OTF), scallop dredge gear (DRS) and sink gillnet (GNS) characterized by both 'fishing' and 'other' activity. These data were collected using high-frequency polling of the vessel's global positioning unit (>1 observation/20 seconds) and represent the aggregate of multiple fishing trips. The dashed lines represent the bounds used in this paper to define fishing activity (OTF = 2.0 – 4.0 knots, DRS = 2.5 – 6.0 knots, GNS = 0.1 – 1.3 knots).

Figure 6. Comparison of 2005 Vessel Monitoring System (VMS) – Northeast Fisheries Observer Program (NEFOP) species stock allocations at the trip-level and associated 95 % confidence ellipse. Only those species-trip allocations where VMS and NEFOP-based methods agreed on the number of stock areas fished and the number of stock areas fished > 1 were compared.

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Industry-based Surv (GSCh)

Results of an Industry-Based Survey for Winter Flounder in the Great South Channel

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Introduction

Between June and October of 2010, scientists at the School for Marine Science and Technology (SMAST) collaborated with members of the New Bedford otter trawl fleet to conduct an industry-based survey for winter flounder in the Great South Channel. The survey was composed of two components; biological survey and a mark-recapture experiment. The goals of the survey component were to provide better information on the relative abundance, geographical distribution, and demographic information for winter flounder in the Great South Channel. The goals of the tagging experiment were to utilize a robust design mark-recapture model to calculate an absolute estimate of winter flounder abundance and survival in the Great South Channel. The industry-based survey was designed to help inform the winter flounder stock assessment during a period when fishery dependent data sources may be limited for this resource. Another goal of the industry-based survey was to allow fishermen to actively participate in the research that influences the management of their fisheries.

Prior to the survey, a series of meetings was held with SMAST scientists and members of the New Bedford otter trawl fleet. During the meetings, fishermen identified areas within the Great South Channel where winter flounder are currently, and have historically, been abundant. Input from fishermen was used to define a study area for the survey (Figure 1), and to determine the best time of year to conduct the survey. SMAST scientists, fishermen, and net manufacturers collaborated to design a survey net that was suitable to fish for winter flounder in the Great South Channel.

Five vessels with experience fishing for winter flounder in the Great South Channel were chosen to participate in the industry-based survey. The characteristics of each vessel were considered, and measures were taken to select vessels with similar attributes (i.e., length, horsepower, gross registered tonnage).

Methods

Survey Planning and Design

The design of the survey was established between January and May of 2010, using input from members of the New Bedford otter trawl fleet. The study area ranged from just offshore of Chatham, MA, southward to the northeast portion of the Nantucket Lightship Closed Area. The eastern boundary of the survey area was Closed Area 1. Depth within the study area ranged from approximately 10 to 90 meters. The study area was divided into 132, nine square nautical mile grid cells (Figure 1), and the study site had a total area of 4,057.48 km^2.

Five survey trips were completed between June and October of 2010, and each trip ranged from nine to ten days in duration. A target of 64 survey tows was set for each trip. The survey was designed to enable the use of a robust design mark-recapture tagging model, to estimate winter flounder abundance and survival. Each survey trip was the primary sampling event, and there were four secondary sampling events within a trip. Each secondary sampling event consisted of 16 survey tows. Of the 16 tows, the location of 12 tows was chosen at random, and the location of four tows was chosen by the captain (Figure 2). For each secondary sampling event, the random point generation software of the Hawth's Tools extension for ArcGIS was used to generate 12 random points within the study site. The grid cells containing these 12 random points were then selected, and a tow was completed in each of the 12 grid cells during that secondary sampling event. A total of 64 survey tows were completed during each trip in June, July and August. On each trip, 48 tow locations were chosen at random, and 16 tow locations were selected by the captain. During the final two survey trips in September and October, three secondary sampling events (48 tows) were completed. During these months, 36 tow locations were chosen at random, and 12 tow locations were selected by the captain.

Each secondary sampling event was completed by traveling from north to south, and the captain and scientists worked together to determine the optimal order to complete the tows within a secondary sampling period. After each secondary sampling period was completed, the vessel steamed to the northern portion of the study area, and completed the next secondary sampling period, proceeding in a north to south direction.

Vessels

Five vessels with experience fishing for winter flounder in the Great South Channel were chosen to participate in the industry-based survey. Effort was taken to select vessels with similar characteristics, to ensure that survey results would be comparable between months. The characteristics of each vessel are shown below in Table 1.

Table 1. Characteristics of vessels that participated in the SMAST industry-based survey for winter flounder.

Vessel Name	Survey Month	Horsepower	Length (ft)	Gross Registered Tonnage	USCG Doc. Number
Seel	June	560	87	144	646423
Sasha Lee	July	678	82.3	129	909149
Sea Siren	August	520	70	140	600188
Iberia II	September	520	86	129	594749
United States	October	550	76.4	144	618882

Survey Tows

The captain chose the starting location of each survey tow within the designated grid cell, and the direction of the tow was left to the discretion of the captain. The tow time and vessel position were recorded using FLDRS, the Northeast Fisheries Science Center study fleet software, connected to a handheld GPS. The start of the tow was marked when the net was deployed and the winches were locked. The end of the tow was recorded when the winches were engaged to retrieve the net. Captains were instructed to complete tows in a straight line, without turning the vessel, whenever possible. The captain was asked to maintain a tow speed of roughly 3 knots, although this speed was not always attainable due to strong currents in the study site. The captain determined the amount of warp set on each tow. The amount of warp set during each tow was recorded in an Access database.

The target duration for a survey tow was 30 minutes, and the minimum acceptable tow duration was 20 minutes. On some occasions, tows were cut short due to gear problems (i.e., net hanging down) or excessive amounts of spiny dogfish bycatch.

Survey tows that were less than 20 minutes in duration were repeated within the same grid cell. Multiple attempts were made to complete each survey tow within the assigned grid cell. However, when it was not possible to complete a survey tow within the designated grid cell, an adjacent grid cell was chosen, and the survey tow was completed within that cell. If damage to the net occurred during a tow (i.e. hole in the net), the tow was repeated within the same grid cell. If a tow was not able to be completed in a grid because of the presence of fixed gear, another grid cell in close proximity was selected.

Excessive amounts of spiny dogfish bycatch were a problem during some survey tows. In some instances, the net had to be opened to release spiny dogfish, before the net could be brought on board. It is likely that a portion of the flounder captured during these tows were also released from the net along with the dogfish. Therefore, the exact weight of winter flounder caught during the tow was unknown. Of the 288 survey tows that were completed, the net had to be opened due to dogfish bycatch on 18 tows. Data from these 18 tows were not included in the analysis of winter flounder catch, distribution, or area swept biomass estimates.

Catch Sampling Protocols

After the survey tow was completed, the net was brought on board and the catch was dumped into a checker pen. All winter flounder were sorted from the catch by hand, and placed in holding tanks with fresh seawater. The weight of all other species caught in each tow was estimated by SMAST technicians, and recorded in an Access database. All species except winter flounder were thrown overboard as quickly as possible to minimize mortality.

The total length of each winter flounder was measured to the nearest centimeter, and any relevant comments were recorded for each flounder. The biomass of winter flounder (kg) caught on each survey tow was calculated by using the length-weight relationship for winter flounder captured on the NEFSC annual spring bottom trawl survey (Wigley et al., 2003):

$$\ln \text{weight (kg)} = -11.4718 + (3.0431 * \ln \text{length (cm)})$$

Survey tows ranged from 20 to 40 minutes in duration. In order to account for this variability, a tow duration ratio was calculated and winter flounder catches were adjusted to a standard tow length of 30 minutes. The tow duration ratio was calculated as follows:

$$\text{Tow duration ratio} = 30 \text{ minutes/observed tow time in minutes}$$

For each survey tow, winter flounder catches were standardized to a 30 minute tow duration using the tow duration ratio as follows:

$$\text{Standardized winter flounder catch (kg)} = \text{Observed winter flounder catch (kg)} * \text{tow duration ratio}$$

Tagging Protocols

The condition of each winter flounder was assessed using the protocols developed by Cadrin (2006). Each flounder that was deemed to be in “good” or “excellent” condition was double tagged with individually numbered plastic t-bar anchor tags (Figure 3), or tagged using a Peterson disc tag. Following tagging, each flounder was quickly released back to the water. A total of 50 dead winter flounder were retained during each survey trip, and brought back to the lab at SMAST for use in a stock composition analysis study.

The tagging experiment was designed to enable the use of a 'robust design' mark-recapture model (Pollock, 1982), to estimate winter flounder abundance and survival in the Great South Channel. The robust design involves a series of short-term, closed population experiments, which are used to estimate abundance. The short-term experiments are nested within open population models that are used to calculate survival using Jolly-Seber estimation (Figure 4). Each survey trip constituted the primary sampling event, and four groups of 16 survey tows were used as the secondary sampling event. The population was assumed to be closed during each survey trip, and open during the periods between survey trips. Prior to the start of the survey, a series of model simulations were performed to determine the appropriate number of survey trips and tag releases that would be needed to support the analysis.

Survey Nets

Two survey nets were constructed by Reidar's Manufacturing in Fairhaven, MA (Figure 5). The nets were 2-seam "flat" nets designed for targeting winter flounder in hard bottom. The nets were constructed with 4 mm euroline netting, with 4.5 inch mesh in the net body and codend. The fishing line was 80 feet, and the headrope was 60 feet. The groundgear was constructed with rock hopper discs with floppies in-between the rock hoppers. The center portion of the groundgear had 21 inch rock hopper discs that tapered to 18 inches and then 16 inch discs at the wings. There were 60 eight inch center hole floats on the headrope. The bridles were 30 feet in length. The top bridle was wire and the bottom bridle was chain. No groundcables were used on the study nets, which is consistent with the net configuration used by New Bedford fishermen in the study area. The dimensions of the net were designed to be appropriate for the size and horsepower of the vessels that participated in the survey.

A model of the survey net was tested in the flume tank at Memorial University in Newfoundland. The performance of the net was evaluated in the flume tank, and slight modifications to the original net design were made. The configuration of the net was monitored during survey tows using e-Sonar and Netmind net mensuration equipment. The equipment measured the doorspread, wingspread, and headrope height during each survey tow. If the net was not fishing at an optimal configuration, the captain could modify the tow speed or amount of warp to adjust the dimensions of the survey net. Placement of sensors was consistent with recommendations from the ICES Study Group on Survey Trawl Standarisation (ICES, 2006). The headrope sensor was placed in the center of the headrope, the wing sensors were placed in front of the wings tips attached to the upper bridge, and the door sensors were typically welded to the center of the doors, although the position of the door sensors varied depending on type of door used.

Length Frequency

The size structure of winter flounder captured during each leg of the survey was examined. The length frequency of winter flounder captured on the industry-based survey was compared to the length frequency of winter flounder captured on the NEFSC spring and fall survey in strata 1250 and 3550 between 2000 and 2009. A Kolmogorov-Smirnov test was conducted to look for differences in the size structure of winter flounder caught on the two surveys (Sokal and Rohlf, 2001).

The fishermen participating in the survey stated that they typically catch larger winter flounder in the deeper waters of the Great South Channel. To test this hypothesis, the length frequency distributions of winter flounder caught on "shallow" and "deep" tows was examined. The average depth sampled during the survey was 52 meters. The size distribution of winter flounder caught during tows conducted in waters < 52 meters were included in the "shallow" group, and flounder caught in tows > 52 meters were included in the "deep" group. A Kolmogorov-Smirnov test was conducted to look for differences in the size structure of winter flounder in deep and shallow tows (Sokal and Rohlf, 2001).

Area Swept Calculations

Estimates of winter flounder density (kg/km^2) and winter flounder biomass were calculated by examining the catch of winter flounder and the area sampled by the survey net, for the 270 valid tows that were completed during the industry-based survey. The net mensuration data from these 270 survey tows were audited for outliers and data properties were examined. Net mensuration data was audited based on recommendations from the ICES Study Group on Survey Trawl Standarisation (ICES, 2006). Data was excluded based on quantiles and observed values from a test model put in the flume tank at Memorial University. Headrope data was trimmed to between the 0% quantile and the 75% quantile. The 0% quantile was used because the sensor's minimum reading is 2.2 meters. Wing data was trimmed to the 25% quantile and 21 meters, which was the optimal wingspread observed in the flume tank for the net. The door data was trimmed to between the 25% and the 75% quantiles. The mean doorspread, wingspread and headrope values were calculated for each tow. The mean doorspread and wingspread measurements were converted from meters to kilometers. Estimates of doorspread and wingspread were not available for every tow, due to technical problems with the net mensuration equipment. In these cases, the mean doorspread or wingspread value observed during that trip was used in the area swept calculation because there were significant differences in the mean value on the trip level. During the fourth survey trip, completed in September, the wing sensors were not properly attached to the survey net. For all survey tows that were conducted in September (n=35), the mean wingspread observed during trips 1, 2, 3 and 5 (mean = 0.014 km) was used to calculate area swept.

Throughout each trip, the vessel position (latitude and longitude), speed and course of were recorded electronically every 30 seconds using the GPS polling function of the FLDRS fishery monitoring software. Fishing activity was assumed to occur when the vessel speed was between 2.0 and 4.0 knots, based on the results of Palmer and Wigley (2007), which found that 99.2% of otter trawl fishing activities occur at this range of speed. Therefore, the tow speed data was trimmed and observations <2.0 knots or >4.0 knots were excluded from the analysis. The trimmed data were used to calculate the mean speed (km/hour) for each survey tow. The duration of each tow was converted from minutes to a fraction of an hour for area swept calculations.

The total area swept (km^2) by the trawl doors was calculated for each tow using the following formula:

$$\textbf{Area swept (km}^2\textbf{) = doorspread (km) * tow duration (hr) * tow speed (km/hr)}$$

Similarly, the total area swept by the wings of the net during each survey tow was calculated using the following formula:

$$\textbf{Area swept (km}^2\textbf{) = wingspread (km) * tow duration (hr) * tow speed (km/hr)}$$

Area swept calculations were used to calculate the density of winter flounder (kg/km^2) observed during each survey tow. The following formula was used to calculate the density of winter flounder observed during each tow. The mean density of winter flounder observed during each survey trip was also calculated:

$$\textbf{Winter flounder density (kg/km}^2\textbf{) = winter flounder catch (kg)/area swept (km}^2\textbf{)}$$

Each grid cell in the study area had an area of 30.74 km^2, and a total of 132 grid cells were present within the study area. The study site encompassed a total area of 4,057.48 km^2. Estimates of winter flounder density were used to derive an estimate of the winter flounder biomass sampled during each tow, using the following equation:

$$\textbf{Winter flounder biomass (kg) = winter flounder density (kg/km}^2\textbf{) * 4,057.48 km}^2$$

The biomass estimate derived for each survey tow was then used to calculate a mean biomass estimate for each of the five trips. The biomass estimate for each trip was converted from kilograms to metric tons.

The catchability (q) of the survey net is unknown. To investigate the effect of catchability on estimates of winter flounder density and biomass, a series of calculations were made using catchability estimates ranging from 0.1 to 1.0. The density of winter flounder was calculated using the following equation:

$$\textbf{Winter flounder density (kg/ km}^2\textbf{) = winter flounder catch (kg)/area swept (km}^2\textbf{) * (1/q)}$$

The exploitable biomass of winter flounder within the study area was estimated. For these estimations, the biomass of winter flounder $\geq$ 30cm captured during each survey tow was calculated. The exploitable biomass of winter flounder in the study area was estimated using both the doorspread and wingspread to estimate area swept.

$$\textbf{Density of exploitable winter flounder (kg/km}^2\textbf{) = catch of winter flounder} \geq \textbf{30cm / area swept (km}^2\textbf{)}$$

$$\textbf{Exploitable biomass (kg) = Density of exploitable flounder (kg/km}^2\textbf{) * 4,057.48 km}^2$$

Depletion Experiments

During the final two survey trips, in September and October, a series of depletion experiments were conducted. The goal of the depletion experiments was to calculate an estimate of the survey net catchability, and to estimate the biomass of winter flounder in the survey area.

Winter flounder catch rates from the first survey trips suggested that catchability was greater at night than during the day. Captains also indicated that the winter flounder fishery in the study area is typically conducted at night. Therefore, depletion experiments were conducted both during the day and night to examine diel differences in catchability. Depletion experiments during the day were completed between sunrise and sunset, and experiments conducted at night were completed between sunset and sunrise.

Depletion experiments could be conducted in grid cells that had been previously sampled during survey tows on that trip, or in a cell that the captain selected based on experience. The experiments were conducted in grid cells that were observed to have high abundances of winter flounder, and which appeared to have suitable bottom to conduct multiple tows while limiting the bycatch of certain species like spiny dogfish. Tows completed during depletion experiments had a target duration of 20 minutes. However, actual tow durations varied between 7 and 34 minutes. Therefore, winter flounder catch rates were standardized (# of flounder caught per minute) to facilitate comparisons of catch rates between tows. Captains were instructed to tow the net over the same bottom as accurately as possible during each tow in a depletion experiment, and each tow was made in the same direction during a depletion experiment if possible. The direction of the tidal current would occasionally prohibit returning to the starting point of a depletion tow. When this occurred, the vessel began the next depletion tow at the end point of the previous tow. Between four and eight tows were completed during each depletion experiment. Protocols determining when to stop depletion experiments differed between trips four and five. During the fourth trip, the protocol dictated that the depletion experiment should be ended when a significant linear regression was found between the catch rate (# flounder per minute) and the cumulative catch. On the fifth trip, the protocol was adjusted to account for the potential effect of the tidal current. The protocol for the fifth trip was to complete as many tows as possible during each depletion experiment.

During depletion experiments, the number of winter flounder caught on each tow was counted, and each flounder was measured to the nearest centimeter. As time permitted, winter flounder were either double or single tagged with individually numbered plastic t-bar tags. The catches of winter flounder were plotted, with the number of winter flounder caught per minute on the y-axis and cumulative winter flounder catch on the x-axis. Linear regression was used to determine if there was a significant relationship between catch rates and the cumulative catch. During depletion experiments, the slope of the regression line can be used to generate an estimate of the catchability of the net.

Results

Winter Flounder Catches

A total of 270 valid survey tows were completed during the five trips between June and October (Figure 6). Observed winter flounder catches were analyzed to investigate the monthly distribution of winter flounder in the Great South Channel. The standardized mean winter flounder catch (kg) per survey tow is shown in Table 2.

Table 2. Mean standardized winter flounder catches (kg) for survey tows conducted between June and October of 2011.

	Number of tows	Mean catch per tow (kg)	St. Dev.	Maximum catch (kg)	# of tows with no winter flounder
Trip 1	64	36.76	43.89	189.15	3
Trip 2	61	22	50.27	308.44	8
Trip 3	64	45.79	58.59	276.24	2
Trip 4	35	33.31	76.11	405.51	9
Trip 5	46	28.88	61.13	382.38	5
Survey Mean		**33.35**			

The largest mean winter flounder catches were observed during the month of August. Winter flounder were widely distributed throughout the study area during this time, and flounder were captured during 62 of the 64 survey tows that were conducted. The smallest mean winter flounder catches were observed in July, when an average of 22.0 kg of winter flounder was captured per 30 minute tow. The single largest catch of winter flounder occurred in September, when 405.5 kg of winter flounder were caught during a survey tow.

During each trip, 75% of all survey tows occurred in grid cells that were chosen at random, and 25% were conducted in grid cells were chosen by the captain. Generally, winter flounder catches were greater when the location of the tow was selected by the captain. The mean winter flounder catches observed for random and fishermen selected tow locations is shown below in Table 3.

Table 3. Mean standardized catch of winter flounder (kg) observed during random and fishermen selected tows for each trip during the winter flounder industry-based survey.

	Random tows		Fishermen selected tows	
	n	mean	n	mean
Trip 1	48	23.66	16	76.06
Trip 2	46	17.71	15	35.17
Trip 3	48	29.03	16	96.08
Trip 4	29	21.43	6	90.72
Trip 5	35	26.79	11	35.55
Survey Mean		**23.72**		**66.71**

During the survey, 129 tows were completed during the day, and 141 tows were completed at night. Winter flounder catches were typically higher during the nighttime than during the day. The average catch of winter flounder was greater at night than during the day in each month, with the exception of August. The average winter flounder catch observed during the day and night for each survey trip is shown below in Table 4.

Table 4. The mean standardized catch of winter flounder (kg) observed during the day and at night during each of the survey trips that was completed.

	Day		Night	
	n	mean	n	mean
Trip 1	38	27.31	26	50.58
Trip 2	32	10.83	29	34.33
Trip 3	33	55.43	31	35.54
Trip 4	13	18.11	22	42.29
Trip 5	13	22.26	33	31.49
Survey Mean		**26.79**		**38.85**

The distribution of standardized winter flounder catches observed during each survey trip is shown in Figures 6 though 10. In June (Figure 7), winter flounder are most numerous in the western portion of the study site. During July (Figure 8), winter flounder were again numerous in the western portion of the study site. The distribution of winter flounder appeared to shift slightly eastward between June and July. By August (Figure 9), winter flounder are most abundant in the eastern portion of the study area. The biomass of winter flounder appears to have shifted substantially between June and August, as very few flounder were captured in the western portion of the study area in August. The distribution of winter flounder in September (Figure 10) is similar to the distribution observed in August. Winter flounder are most numerous in the deeper waters, near the eastern boundary of the study area. However, fewer survey tows were made in September (n=35) relative to other months (n= 46 to 64). Finally, in October (Figure 11), winter flounder were again numerous in the eastern portion of the study area. In October, the center of distribution appears to have shifted slightly to the north.

Area Swept Calculations

The number of tows in which actual net mensuration data was used to calculate the mean doorspread and wingspread is shown in Table 5. Problems with the net mensuration equipment were common during the survey. Problems with the door sensors arose during the first survey trip in June. The wing sensors were damaged during the fourth tow of trip 3, and wingspread data was unavailable for tows 4 through 64. In addition, the wing sensors were not properly placed on the survey net during trip 4.

Table 5. Number of tows during each survey trip where the actual doorspread and wingspread was calculated from observations recorded by the net mensuration equipment.

		Doorspread			Wingspread		
Trip	n	# tows with actual data	# of tows with estimated data	% of tows with actual data	# tows with actual data	# of tows with estimated data	% of tows with actual data
1	64	11	53	17.2%	62	2	96.9%
2	61	50	11	82.0%	43	18	70.5%
3	64	47	17	73.4%	3	61	4.7%
4	35	21	14	60.0%	0	35	0.0%
5	46	31	15	67.4%	27	19	58.7%
Total	270	160	110	**59.3%**	135	135	**50.0%**

The average area swept by the net during each survey tow is shown below in Table 6. Mean estimates of the area swept by the wings of the net were calculated for each survey. The mean area swept per tow observed during the industry-based survey

(0.0110 nm^2) is in close agreement to the average area swept per tow by the R/V Albatross during the NEFSC spring and fall groundfish surveys (0.0112 nm^2; Groundfish Plan Development Team, 2010). The mean area swept per tow observed on the industry-based survey (0.110 nm^2) was greater than the mean area swept per tow by the R/V Bigelow during the NEFSC spring and fall groundfish surveys (0.007 nm^2; Groundfish Plan Development Team, 2010).

Table 6. Mean area swept per tow during the industry-based survey for winter flounder in the Great South Channel. Estimates of area swept were calculated using both the actual and averaged wingspread values for each survey tow.

	Mean area swept/tow (km^2)	Mean area swept/tow (nm^2)	Tow area/tow footprint
Trip 1	0.039	0.011	103797
Trip 2	0.041	0.012	99737
Trip 3	0.043	0.012	95174
Trip 4	0.033	0.010	124390
Trip 5	0.034	0.010	119739
Survey Mean	**0.038**	**0.011**	**107392**

The mean density (kg/km^2) and biomass (kg) of winter flounder estimated to be present in the study area during each month of the survey was calculated. Density and biomass estimates were made using both the doorspread and wingspread to estimate the area swept during each survey tow. A conservative catchability coefficient (q) of 1 was assumed during the calculations. The results are shown below in Table 7.

Table 7. Mean estimates of winter flounder density (kg/km^2) and biomass (kg) for each of the five survey trips that were completed between June and October, 2010. Density and biomass estimates were calculated using both the doorspread and wingspread for each tow.

	Doorspread			Wingspread		
Trip	Density (kg/km^2)	Biomass (kg)	Biomass (mt)	Density (kg/km^2)	Biomass (kg)	Biomass (mt)
1	571.5	2318809.9	2281.7	1027.8	4170209.0	4103.5
2	299.0	1213008.2	1193.6	551.8	2238787.9	2203.0
3	632.5	2566400.1	2525.3	1089.5	4420512.9	4349.8
4	557.1	2260306.3	2224.1	1007.0	4085776.0	4020.4
5	507.1	2057692.5	2024.8	937.5	3803968.5	3743.1
Survey Mean	511.5	2083243.4	**2049.9**	922.7	3743850.9	**3683.9**

The mean density (kg/km^2) of winter flounder that was observed during each trip is shown below in Table 8. In these calculations, the mean doorspread observed during each tow was used to calculate the area swept during the tow. A range of catchability coefficients were used to determine the sensitivity of winter flounder density estimates to the catchability coefficient that was assumed for the survey net.

Table 8. Estimates of winter flounder density (kg/km^2) assuming a range of catchability values. The mean doorspread observed during each tow was used in area swept calculations.

	Density of winter flounder (kg/km^2)									
	q=1	q=0.9	q=0.8	q=0.7	q=0.6	q=0.5	q=0.4	q=0.3	q=0.2	q=0.1
Trip 1	571.5	635.0	714.4	816.4	952.5	1143.0	1428.7	1905.0	2857.4	5714.9
Trip 2	299.0	332.2	373.7	427.1	498.3	597.9	747.4	996.5	1494.8	2989.6
Trip 3	632.5	702.8	790.6	903.6	1054.2	1265.0	1581.3	2108.4	3162.6	6325.1
Trip 4	557.1	619.0	696.3	795.8	928.5	1114.1	1392.7	1856.9	2785.4	5570.7
Trip 5	507.1	563.5	633.9	724.5	845.2	1014.3	1267.8	1690.5	2535.7	5071.4
Survey Mean	**513.4**	**570.5**	**641.8**	**733.5**	**855.7**	**1026.9**	**1283.6**	**1711.4**	**2567.2**	**5134.3**

The mean biomass of winter flounder that was observed during each trip is shown below in Table 9. A range of catchability values were used to determine the sensitivity of biomass calculations to the catchability coefficient that was assumed for the survey net.

Table 9. Estimates of winter flounder biomass (kg) assuming a range of catchability values. The mean doorspread observed during each tow was used in area swept calculations.

	Biomass (mt)									
	q=1	q=0.9	q=0.8	q=0.7	q=0.6	q=0.5	q=0.4	q=0.3	q=0.2	q=0.1
Trip 1	2281.7	2535.2	2852.1	3259.6	3802.8	4563.4	5704.3	7605.7	11408.5	22817.1
Trip 2	1193.6	1326.2	1492.0	1705.1	1989.3	2387.2	2984.0	3978.7	5968.0	11936.0
Trip 3	2525.3	2805.9	3156.7	3607.6	4208.9	5050.7	6313.3	8417.8	12626.7	25253.4
Trip 4	2224.1	2471.3	2780.2	3177.3	3706.9	4448.3	5560.4	7413.8	11120.7	22241.4
Trip 5	2024.8	2249.7	2531.0	2892.5	3374.6	4049.5	5061.9	6749.2	10123.8	20247.7
Survey Mean	**2049.9**	**2277.7**	**2562.4**	**2928.4**	**3416.5**	**4099.8**	**5124.8**	**6833.0**	**10249.6**	**20499.1**

Estimates of mean winter flounder density (kg/km^2) calculated for each trip is shown below in Table 10. The calculations were made using the mean wingspread observed during each tow to calculate area swept. A range of catchability values were used to determine the sensitivity of winter flounder density estimates to the assumed catchability.

Table 10. Estimates of winter flounder density assuming a range of catchability values. The mean wingspread observed during each tow was used in area swept calculations.

	Density of winter flounder (kg/km^2)									
	q=1	q=0.9	q=0.8	q=0.7	q=0.6	q=0.5	q=0.4	q=0.3	q=0.2	q=0.1
Trip 1	1027.8	1142.0	1284.7	1468.3	1713.0	2055.6	2569.5	3425.9	5138.9	10277.8
Trip 2	551.8	613.1	689.7	788.2	919.6	1103.5	1379.4	1839.2	2758.8	5517.7
Trip 3	1089.5	1210.5	1361.8	1556.4	1815.8	2178.9	2723.7	3631.6	5447.4	10894.7
Trip 4	1007.0	1118.9	1258.7	1438.5	1678.3	2013.9	2517.4	3356.6	5034.9	10069.7
Trip 5	937.5	1041.7	1171.9	1339.3	1562.5	1875.0	2343.8	3125.1	4687.6	9375.2
Survey Mean	**922.7**	**1025.2**	**1153.4**	**1318.1**	**1537.8**	**1845.4**	**2306.8**	**3075.7**	**4613.5**	**9227.0**

Estimates of mean winter flounder biomass calculated for each trip are shown below in Table 11. These calculations were made using the mean wingspread observed during each tow to calculate area swept. A range of catchability values were used to determine the sensitivity of winter flounder biomass estimates to the assumed catchability.

Table 11. Estimates of winter flounder biomass assuming a range of catchability values. The mean wingspread observed during each tow was used in area swept calculations.

	Biomass (mt)									
	q=1	q=0.9	q=0.8	q=0.7	q=0.6	q=0.5	q=0.4	q=0.3	q=0.2	q=0.1
Trip 1	4103.5	4559.4	5129.4	5862.1	6839.1	8207.0	10258.7	13678.3	20517.4	41034.9
Trip 2	2203.0	2447.7	2753.7	3147.1	3671.6	4405.9	5507.4	7343.2	11014.8	22029.7
Trip 3	4349.8	4833.1	5437.2	6214.0	7249.6	8699.6	10874.5	14499.3	21748.9	43497.8
Trip 4	4020.4	4467.1	5025.5	5743.4	6700.7	8040.8	10051.0	13401.3	20102.0	40204.0
Trip 5	3743.1	4159.0	4678.9	5347.3	6238.5	7486.2	9357.8	12477.0	18715.5	37431.1
Survey Mean	**3683.9**	**4093.3**	**4604.9**	**5262.8**	**6139.9**	**7367.9**	**9209.9**	**12279.8**	**18419.7**	**36839.5**

The exploitable biomass of winter flounder within the study area was estimated. The weight of winter flounder ≥ 30cm caught during each tow was used in the biomass calculations. The density of exploitable biomass was calculated using both the doorspread and wingspread to estimate area swept. Estimates of total biomass and exploitable biomass are shown in Table 12. Between 90.44% and 94.97% of the winter flounder biomass in the study area is composed of winter flounder which are considered to be exploitable by the fishery (≥ 30cm). The catchability of the survey net was assumed to be 100% (q =1) in these calculations.

Table 12. Estimates of exploitable and total biomass of winter flounder for each survey trip. Biomass was estimated using both the doorspread and the wingspread in area swept calculations. Calculations were made assuming a catchability coefficient of 1.

	Doorspread		Wingspread		
	Exploitable biomass (mt)	Total biomass (mt)	Exploitable biomass (mt)	Total biomass (mt)	% Exploitable Biomass
Trip 1	2086.0	2281.7	3755.2	4103.5	91.47%
Trip 2	1084.8	1193.6	2002.1	2203.0	90.88%
Trip 3	2398.3	2525.3	4130.8	4349.8	94.97%
Trip 4	2010.6	2224.1	3637.5	4020.4	90.44%
Trip 5	1909.9	2024.8	3535.2	3743.1	94.39%
Survey Mean	**1897.9**	**2049.9**	**3412.2**	**3683.9**	**92.60%**

Estimates of exploitable biomass were calculated assuming a range of catchability values between 0.1 and 1.0. Exploitable biomass estimates were calculated using both the doorspread (Table 13) and wingspread (Table 14) to calculate the area swept during each tow.

Table 13. Estimates of exploitable biomass assuming a range of values for q. The doorspread observed during each tow was used to calculate of area swept.

	Exploitable Biomass (mt)									
	q=1	q=0.9	q=0.8	q=0.7	q=0.6	q=0.5	q=0.4	q=0.3	q=0.2	q=0.1
Trip 1	2086.0	2317.8	2607.5	2980.0	3476.6	4172.0	5215.0	6953.3	10429.9	20859.8
Trip 2	1084.8	1205.4	1356.0	1549.8	1808.0	2169.7	2712.1	3616.1	5424.1	10848.3
Trip 3	2398.3	2664.8	2997.9	3426.1	3997.1	4796.6	5995.7	7994.3	11991.4	23982.9
Trip 4	2010.6	2234.0	2513.2	2872.3	3351.0	4021.2	5026.5	6702.0	10052.9	20105.9
Trip 5	1909.9	2122.1	2387.4	2728.5	3183.2	3819.8	4774.8	6366.4	9549.6	19099.2
Survey Mean	**1897.9**	**2108.8**	**2372.4**	**2711.3**	**3163.2**	**3795.8**	**4744.8**	**6326.4**	**9489.6**	**18979.2**

Table 14. Estimates of exploitable biomass assuming a range of values for q. The wingspread observed during each tow was used to calculate of area swept.

	Exploitable Biomass (mt)									
	q=1	q=0.9	q=0.8	q=0.7	q=0.6	q=0.5	q=0.4	q=0.3	q=0.2	q=0.1
Trip 1	3755.2	4172.4	4694.0	5364.6	6258.6	7510.4	9388.0	12517.3	18775.9	37551.9
Trip 2	2002.1	2224.6	2502.6	2860.2	3336.9	4004.2	5005.3	6673.7	10010.6	20021.1
Trip 3	4130.8	4589.8	5163.6	5901.2	6884.7	8261.7	10327.1	13769.5	20654.2	41308.4
Trip 4	3637.5	4041.6	4546.8	5196.4	6062.4	7274.9	9093.6	12124.9	18187.3	36374.6
Trip 5	3535.2	3928.0	4419.0	5050.3	5892.0	7070.4	8838.0	11784.0	17676.0	35351.9
Survey Mean	**3412.2**	**3791.3**	**4265.2**	**4874.5**	**5686.9**	**6824.3**	**8530.4**	**11373.9**	**17060.8**	**34121.6**

The exploitable biomass of winter flounder (mt) that was estimated to be present in the study area during each month of the survey was compared to the spawning stock biomass of the entire SNE/MA winter flounder stock, which was last assessed in 2008. The spawning stock biomass of winter flounder in the SNE/MA stock in 2007 was estimated to be 3,368mt (NEFSC, 2008). Estimates of the exploitable biomass of winter flounder biomass were calculated using both the doorspread and the wingspread to calculate area swept. Table 15 depicts the estimates of exploitable winter flounder biomass in the study area, using doorspread to calculate area swept. A range of catchability coefficients were used to derive the biomass estimates.

Table 15. Estimates of exploitable biomass in the survey area, using a range of values to represent catchability. Biomass estimates were derived using the doorspread to calculate area swept.

	q=1.0		q=0.8		q=0.6		q=0.4	
	Biomass (mt)	% of SNE/MA biomass	Biomass (mt)	% of SNE/MA biomass	Biomass (mt)	% of SNE/MA biomass	Biomass (mt)	% of SNE/MA biomass
Trip 1	2086.0	61.9%	2607.5	77.4%	3476.6	103.2%	5215.0	154.8%
Trip 2	1084.8	32.2%	1356.0	40.3%	1808.0	53.7%	2712.1	80.5%
Trip 3	2398.3	71.2%	2997.9	89.0%	3997.1	118.7%	5995.7	178.0%
Trip 4	2010.6	59.7%	2513.2	74.6%	3351.0	99.5%	5026.5	149.2%
Trip 5	1909.9	56.7%	2387.4	70.9%	3183.2	94.5%	4774.8	141.8%
Survey Mean	**1897.9**	**56.4%**	**2372.4**	**70.4%**	**3163.2**	**93.9%**	**4744.8**	**140.9%**

Table 16 depicts the estimates of exploitable biomass present in the study area, using the wingspread to calculate area swept. A range of catchability values were used to calculate the biomass estimates. The results show that using a conservative catchability of 1 (100% efficiency of the survey net) yields an exploitable biomass estimate of 3412.2 mt, which is greater than the total spawning stock biomass that was estimated to be present in the SNE/MA stock area in 2007 (3,368mt; NEFSC, 2008). As the assumed catchability coefficient is decreased, the estimates of exploitable biomass increase substantially.

Table 16. Estimates of exploitable biomass in the survey area, using a range of values to represent catchability. Biomass estimates were derived using the wingspread to calculate area swept.

	q=1.0		q=0.8		q=0.6		q=0.4	
	Biomass (mt)	% of SNE/MA biomass	Biomass (mt)	% of SNE/MA biomass	Biomass (mt)	% of SNE/MA biomass	Biomass (mt)	% of SNE/MA biomass
Trip 1	3755.2	111.5%	4694.0	139.4%	6258.6	185.8%	9388.0	278.7%
Trip 2	2002.1	59.4%	2502.6	74.3%	3336.9	99.1%	5005.3	148.6%
Trip 3	4130.8	122.6%	5163.6	153.3%	6884.7	204.4%	10327.1	306.6%
Trip 4	3637.5	108.0%	4546.8	135.0%	6062.4	180.0%	9093.6	270.0%
Trip 5	3535.2	105.0%	4419.0	131.2%	5892.0	174.9%	8838.0	262.4%
Survey Mean	**3412.2**	**101.3%**	**4265.2**	**126.6%**	**5686.9**	**168.9%**	**8530.4**	**253.3%**

Length Frequency

The length frequency of winter flounder that were captured during survey tows was examined to provide better information on the size structure of winter flounder present in the Great South Channel. The observed length frequency of winter flounder captured during each survey trip is shown below in Table 17, and is also shown in Figure 12.

The length frequency of winter flounder captured during the industry-based survey was compared to the length frequency of winter flounder captured in survey strata 1250 and 3550 on the R/V Albatross during the NEFSC spring and fall surveys between 2000 and 2009. The length frequency distributions observed during each survey are shown in Figure 13. The NEFSC survey caught a larger size range winter flounder (5-60 cm) than the industry-based survey (16-54 cm). The results of the Kolmogorov-Smirnov test ($p < 0.001$) indicated that there was a significant difference in the size structure of winter flounder captured by the two surveys.

Larger winter flounder were present in the deeper stations of the study site (Figure 14). The length frequency distributions observed during shallow (< 52 meters) and deep water (> 52 meters) tows were found to be significantly different using a Kolmogorov-Smirnov test ($p<0.001$). The results confirmed the fishermen's hypothesis that larger winter flounder are present in the deeper waters of the Great South Channel.

Table 17. Length frequency distribution of winter flounder observed during each trip of the industry-based survey.

	Trip 1		Trip 2		Trip 3		Trip 4		Trip 5	
Length	# caught	Relative Proportion	# caught	Relative Proportion	# caught	Relative Proportion	# caught	Relative Proportion	# caught	Relative Proportion
16	1	0.02%	0	0.00%	0	0.00%	0	0.00%	0	0.00%
17	2	0.04%	0	0.00%	0	0.00%	0	0.00%	0	0.00%
18	2	0.04%	1	0.03%	0	0.00%	0	0.00%	1	0.06%
19	4	0.08%	1	0.03%	0	0.00%	0	0.00%	1	0.06%
20	10	0.21%	3	0.10%	1	0.02%	2	0.08%	4	0.24%
21	18	0.37%	8	0.27%	3	0.06%	0	0.00%	2	0.12%
22	20	0.41%	19	0.65%	3	0.06%	3	0.11%	6	0.36%
23	35	0.73%	33	1.13%	11	0.21%	5	0.19%	6	0.36%
24	59	1.22%	49	1.68%	22	0.42%	24	0.91%	12	0.72%
25	71	1.47%	62	2.13%	59	1.13%	62	2.36%	27	1.61%
26	121	2.51%	82	2.82%	78	1.49%	127	4.84%	47	2.81%
27	206	4.27%	111	3.81%	124	2.37%	161	6.14%	66	3.95%
28	217	4.50%	138	4.74%	171	3.26%	140	5.34%	74	4.42%
29	236	4.90%	162	5.57%	191	3.64%	147	5.60%	66	3.95%
30	361	7.49%	265	9.10%	263	5.02%	136	5.18%	91	5.44%
31	443	9.19%	317	10.89%	375	7.15%	167	6.36%	115	6.87%
32	588	12.20%	308	10.58%	414	7.90%	171	6.52%	135	8.07%
33	463	9.60%	300	10.31%	540	10.30%	192	7.32%	124	7.41%
34	484	10.04%	274	9.41%	516	9.84%	219	8.35%	165	9.86%
35	384	7.97%	228	7.83%	464	8.85%	256	9.76%	147	8.79%
36	275	5.70%	149	5.12%	466	8.89%	200	7.62%	106	6.34%
37	240	4.98%	123	4.23%	417	7.95%	191	7.28%	111	6.63%
38	187	3.88%	80	2.75%	356	6.79%	123	4.69%	80	4.78%
39	119	2.47%	67	2.30%	251	4.79%	113	4.31%	82	4.90%
40	90	1.87%	46	1.58%	185	3.53%	74	2.82%	77	4.60%
41	72	1.49%	38	1.31%	132	2.52%	52	1.98%	52	3.11%
42	43	0.89%	20	0.69%	76	1.45%	23	0.88%	30	1.79%
43	31	0.64%	9	0.31%	57	1.09%	14	0.53%	14	0.84%
44	18	0.37%	5	0.17%	23	0.44%	12	0.46%	16	0.96%
45	8	0.17%	5	0.17%	17	0.32%	6	0.23%	7	0.42%
46	5	0.10%	3	0.10%	12	0.23%	1	0.04%	3	0.18%
47	5	0.10%	2	0.07%	5	0.10%	2	0.08%	0	0.00%
48	1	0.02%	0	0.00%	7	0.13%	0	0.00%	5	0.30%
49	0	0.00%	0	0.00%	2	0.04%	1	0.04%	1	0.06%
50	0	0.00%	2	0.07%	0	0.00%	0	0.00%	0	0.00%
51	1	0.02%	1	0.03%	1	0.02%	0	0.00%	0	0.00%
52	0	0.00%	0	0.00%	0	0.00%	0	0.00%	0	0.00%
53	1	0.02%	0	0.00%	1	0.02%	0	0.00%	0	0.00%
54	0	0.00%	0	0.00%	0	0.00%	0	0.00%	0	0.00%
Total	**4821**		**2911**		**5243**		**2624**		**1673**	

Tagging

During the industry-based survey, a total of 23,187 winter flounder were measured and tagged, making the industry-based survey one of the largest tagging experiments ever conducted for winter flounder. Aside from Howe and Coates (1975), no tagging studies have been completed for winter flounder in the Great South Channel. Therefore, long-term recaptures from the commercial fishery will be important for learning more about the movements of winter flounder in this region.

Winter flounder captured on both survey tows and during depletion experiments were measured and tagged with individually numbered plastic t-bar anchor tags or Peterson discs. In some instances, fish were tagged with both a t-bar anchor tag and a

Peterson disc tag in an attempt to estimate tag retention. The number of tags released on survey tows is shown below in Table 18.

Table 18. Number of tags released on survey tows during each trip of the industry-based survey.

	# of tags released
Trip 1	4715
Trip 2	2395
Trip 3	4842
Trip 4	2344
Trip 5	2461
Total	**16757**

The greatest number of tags were released on survey tows in August, while the fewest tags were released in September.

As time permitted, winter flounder captured during depletion experiments were tagged with t-bar plastic anchor tags. Depletion experiments were conducted during survey trips four and five. A total of 6,430 winter flounder were tagged during the depletion experiments. The distribution of tags released during the depletion experiments is shown below in Table 19.

Table 19. The number of tags released during depletion experiments on survey trips 4 and 5 of the industry-based survey.

	Survey Trip	
Depletion Experiment	4	5
1	1256	515
2	1884	614
3	866	453
4	381	461
Trip Total	**4387**	**2043**

Tag Recaptures

Only two tagged winter flounder were recaptured during survey tows. The lack of recaptures was unexpected. One flounder was tagged and released in June on the third tow of the survey. This flounder was then recaptured during the following tow. Similarly, a tagged winter flounder was recaptured during a survey tow on trip four, but the flounder had also been released during the previous tow. In both instances, these recaptures could not be used to estimate the population size or survival, since the flounder were released and recaptured within the same secondary sampling event. The low number of recaptures during the survey tows precluded the use of the robust design tagging model. Therefore, we were unable to calculate absolute estimates of winter flounder abundance and survival rates using the tagging data from the industry-based survey.

Sixty tagged winter flounder which were tagged and released during depletion experiment tows were later recaptured on subsequent tows of the same depletion experiment. Eight winter flounder were recaptured during depletion experiments in September. All eight of these flounder had been tagged during the same depletion experiment. Fifty two tagged winter flounder were recaptured during depletion experiments in October. Again, all of the winter flounder which were recaptured had been released during an earlier tow within the same depletion tow experiment.

Despite considerable outreach efforts to alert the fishing industry about the industry-based survey, thus far, only one tagged winter flounder has been recaptured and reported by the commercial fishery. A winter flounder that was tagged on 6/22/2010 was later recaptured on 10/3/2010, in the waters of the Great South Channel. The low number of recaptures from the commercial fishery may be attributed to the lack of effort on winter flounder in the SNE/MA stock area. Under Amendment 16 to the Northeast Multispecies FMP, commercial fishermen are prohibited from retaining any flounder caught in the SNE/MA stock area. Therefore, all winter flounder caught in this region are discarded by commercial fishermen, and it is likely that tagged flounder may be overlooked as the fish are being discarded.

There are several potential reasons why so few tagged winter flounder were recaptured during the survey. The most parsimonious explanation is that there was a large abundance of winter flounder present in the Great South Channel. Although over 23,000 winter flounder were tagged during the survey, these tagged flounder may represent a very small proportion of the population that was present in the region. Similarly, the survey was conducted over a very large geographic area, and the average area sampled by the survey net during each tow represented only 0.0009% of the total study area. In addition, the survey net may have also had a low catchability. Therefore, the probability of recapturing a tagged flounder may have been very low.

Another explanation for the low recapture rate could have been tag shedding. Two holding studies were conducted at SMAST, and tagged winter flounder held in the laboratory displayed a tag retention rate of 100%. The Rhode Island Department of Fish and Wildlife used similar t-bar anchor tags on winter flounder in Narragansett Bay, and observed high recapture rates for tagged individuals (12.9%; Powell, 1989). Therefore, a high level of tag shedding appears to be an unlikely explanation for the low number of recaptures. However, the one fish recaptured from the commercial fishery had shed one of the two tags. Another explanation for the low recapture rates is possible emigration of tagged fish from the study area. However, given the relatively sedentary nature of winter flounder, a large-scale emigration of tagged flounder from the study area seems unreasonable. Finally, the low recapture rate may be due to behavioral changes in the winter flounder following tagging. For example, tagged flounder may bury in the sediment following tagging, making them unavailable to the survey net. While this behavior may explain the lack of recaptures in the short term, the survey was conducted over a fairly long period of time. Therefore, it seems unlikely that tagged flounder would remain buried for months following tagging.

Depletion experiments

Four depletion experiments were completed during each of the survey trips in September and October. The results from the depletion experiments completed during September are shown in Figures 15-18. During the first depletion experiment (Figure 15), which was conducted at night, the catch rates increased continually as additional tows were made. The position of the vessel during each of the six tows completed during the experiment is shown in Figure 19. The tow tracks show that the vessel did not cover the exact same fishing grounds during each tow, which may explain why the catch rates increased as subsequent tows were made. The strong tidal currents in the Great South Channel made it difficult for the captain to maintain the same tow course during each tow.

During the second depletion experiment in September (Figure 16), catch rates declined as additional tows were made. However, catch rates remained high during the last tow of the experiment (11 flounder/minute), suggesting that the area had not been depleted completely. Catch rates during the third depletion experiment conducted in September (Figure 17) were highly variable. Generally, the catch rates declined as additional tows were completed. The best results were observed during the final depletion experiment completed in September (Figure 18). Catch rates decreased steadily as additional tows were made.

The results of the four depletion experiments conducted in October are shown in Figures 20-23. During the first depletion experiment (Figure 20), the catch rates decreased steadily during the first four tows. However, the catch rate increased dramatically during the fifth tow. The increase in catch may be attributed to a change in the tide, which occurred between the fourth and the fifth tow. The fishermen who participated in the survey commented that winter flounder catches in the Great South Channel can vary dramatically depending upon the tide.

Catch rates during the second depletion experiment (Figure 21) were variable, and generally increased as additional survey tows were made. The catch rates observed during the third depletion experiment (Figure 22) were also highly variable, and there was no discernable trend in catch rates during the experiment. The results of the fourth depletion experiment are shown in Figure 23. The catch rates decreased steadily during the first three tows. However, during the fourth tow, the tide changed direction, and the catch rates increased again. Catch rates subsequently declined between the fourth and seventh tows.

Further analysis is needed to better understand the results of these depletion tows. One approach may be to examine the tow tracks for regions of overlap during each of the depletion experiments, as was done for the cooperative monkfish survey conducted by the Northeast Fisheries Science Center (NEFSC, 2010). This will allow the catch rates to be corrected for instances where the tow paths differed between tows made within a single depletion experiment. Further work is also needed to generate estimates of the catchability of the survey net.

Vessel Effect

A vessel effect can exist when multiple vessels are used during a survey even though the same net is utilized, and vessel characteristics are similar. A vessel effect was examined for by testing for differences in tow speed, scope ratio, and net dimensions between vessels. The mean vessel tow speed was generally around three knots, which was consistent with survey protocols. However, there was a significant difference in the mean tow speed between vessels (Figure 24). A ranked ANOVA was used to test for differences in the mean tow speed by vessel after the assumptions of normality and homogeneity of variances were not met (Sokal and Rholf, 2001). Weinberg and Kotwicki (2008) found a significant difference in tow speed among vessels that participated in the eastern Bering Sea survey. There were also significant differences in the scope ratio between vessels, although the vessels followed a similar pattern of the amount of warp set compared to the depth (Figure 25). An analysis of covariance was used to test for differences in the slope between vessels (Sokal and Rholf, 2001). The F/V Iberia II and the F/V United States tended to set more discrete amounts of warp over larger depth ranges than the other vessels. For net dimensions measured, there was a significant difference in the mean value by vessel for headline readings. There was no significant difference in the mean value for the wing or door sensors. A ranked anova was also used to test for differences in the mean value by sensor between vessels after parametric assumptions were not met (Sokal and Rholf, 2001). The degrees of freedom were corrected after testing for serial independence (Sokal and Rholf, 2001). The effective degrees of freedom were calculated following the method described in McIntyre and McKitrick (2009). Trip three had the highest headline height. The distance between the wings was relatively consistent between trips with the exception of trip five, which had a smaller wing spread. The door spread was also relatively similar among trips with slight deviations in the values for trips three and five.

Table 20. Mean value for the headline, wing and door measurements by trip in meters.

Trip	Headline Mean (m)	Wing Mean (m)	Door Mean (m)
1	2.69	13.74	24.21
2	2.67	14.06	24.27
3	3.16	14.45	23.88
4	2.56	N/A	24.11
5	2.69	12.96	23.85

Acknowledgements

We are indebted to the many people whose hard work made it possible to complete this survey. We would like to thank Adam Barkley and Doug Zemeckis, who completed survey trips and helped with data collection. We are grateful to the captains and crews of each vessel that participated in the survey for their hard work under difficult conditions. We are especially grateful to the captains who were willing to share their knowledge about winter flounder with us. Their practical experience was a great asset to the scientists at SMAST. We would also like to thank the members of the SMAST groundfish steering committee for their helpful feedback. Their input was invaluable in designing the survey, and their perspective helped us better understand the results. We would like to thank Reidar's Manufacturing, especially Hans and Tor Bendiksen, for their help in transporting the survey nets to and from each vessel. We thank Vin Malkoski with the Massachusetts Division of Marine Fisheries for giving us a place to store the survey nets in between trips. Janice Plante and Commercial Fisheries News did an excellent job publicizing this project. This survey was generously funded through a grant by the National Oceanic and Atmospheric Administration, and the Massachusetts Marine Fisheries Institute.

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Figures

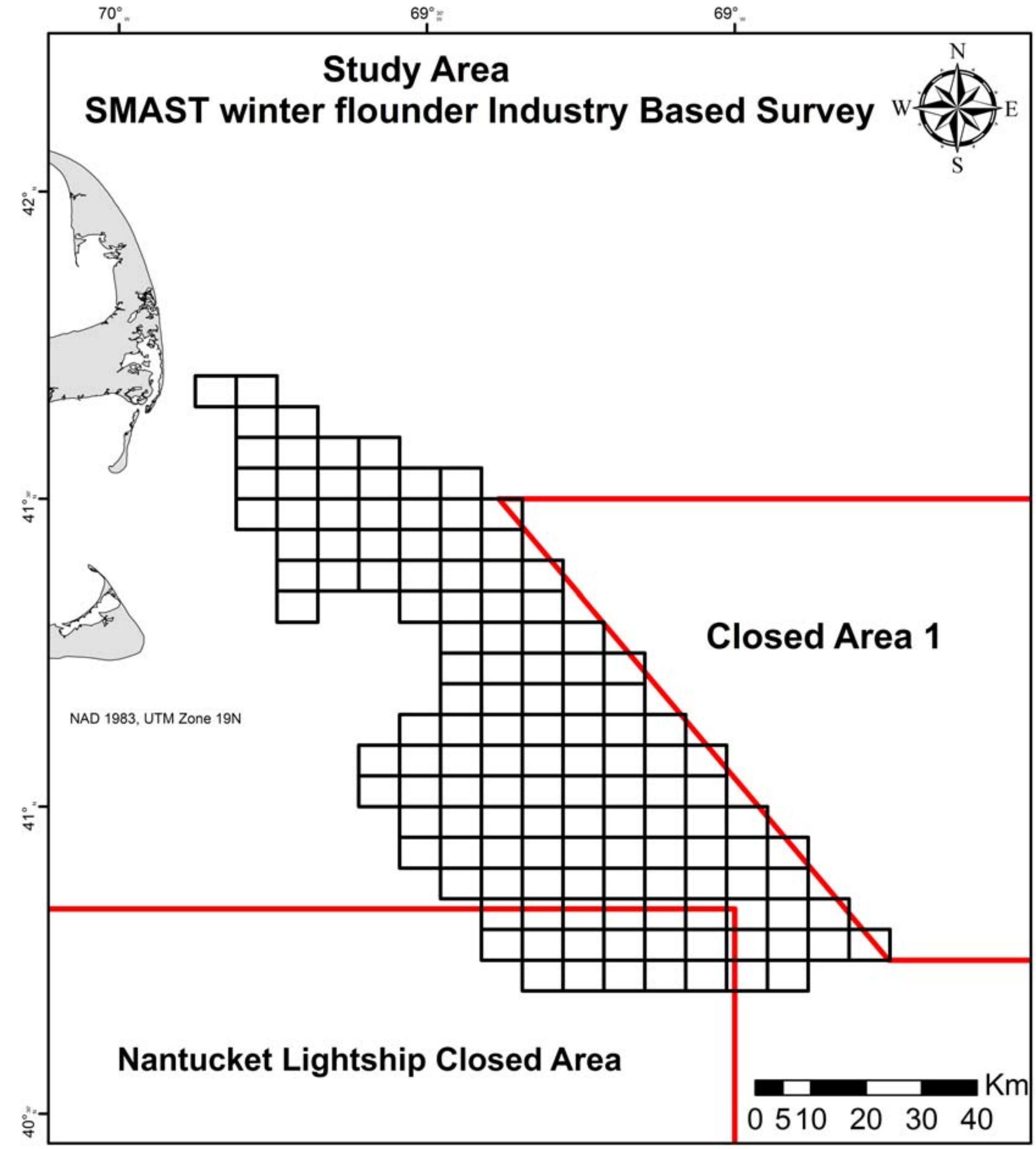

Figure 1. Map of the study site that was sampled during the industry-based survey. The study site was divided into 132 nine square nautical mile grid cells.

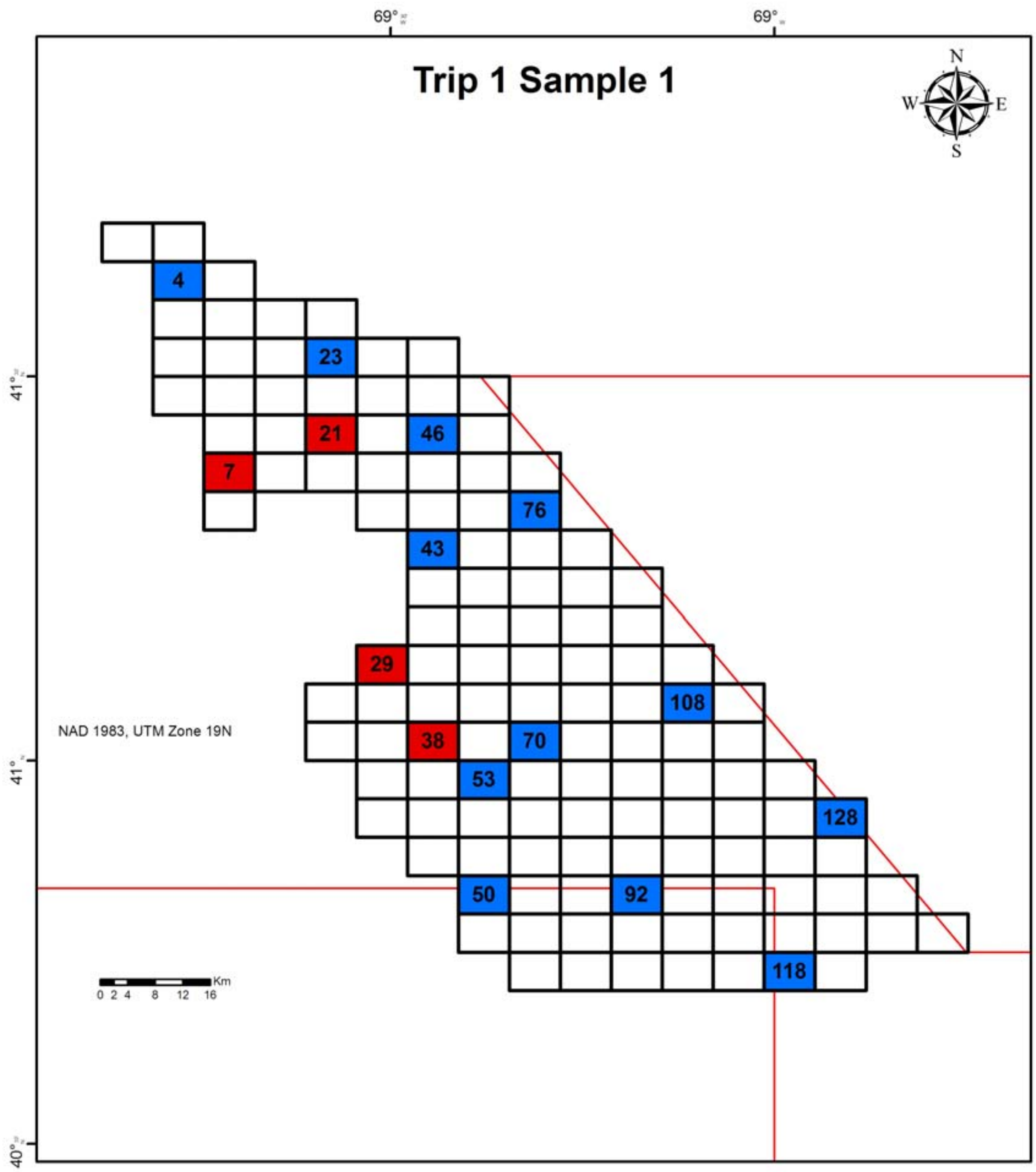

Figure 2. Example of survey tows that were completed during a secondary sampling event. The grid cells selected that were selected at random are shown in blue, and the grid cells selected by the captain are shown in red. The secondary sampling event was conducted by completing a survey tow in each grid cell, in a north to south direction.

Figure 3. Each winter flounder was tagged with two individually numbered plastic t-bar anchor tags. The tags were attached to each flounder in the dorsal musculature.

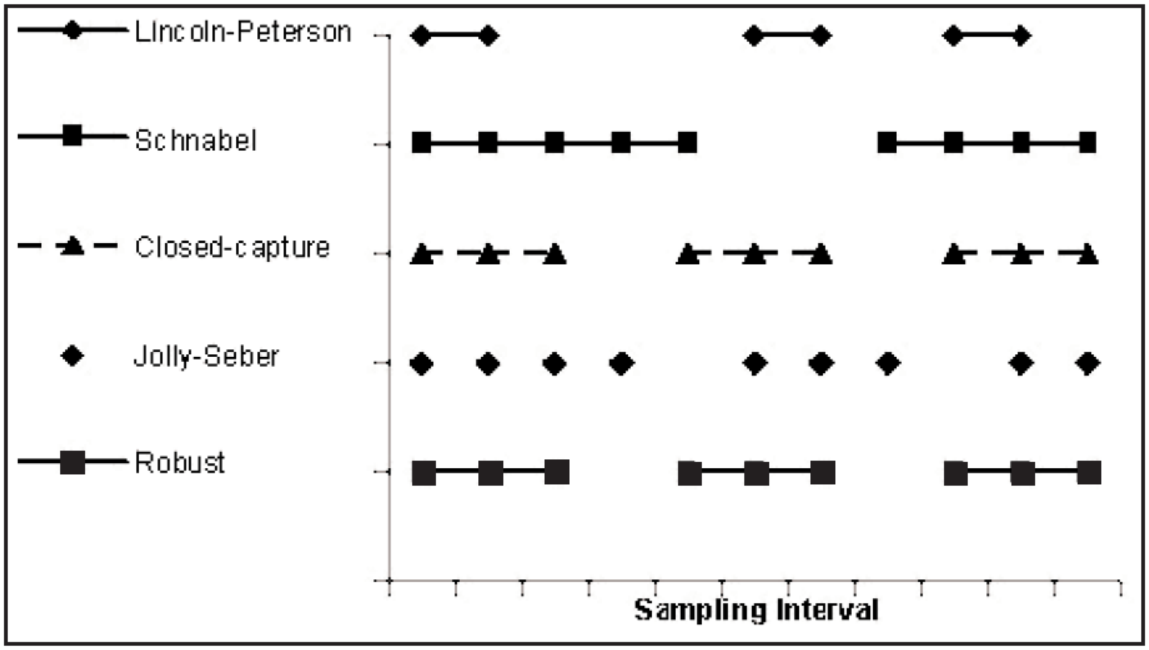

Figure 4. Diagram demonstrating assumptions about capture probabilities for each type of capture-recapture model. Each marker represents a sampling event. The solid lines connecting markers indicate closed populations with equal capture probabilities. Dashed lines between samples indicate closed populations with unequal capture probabilities. Gaps represent intervals where populations are open (from Pine et al. 2003).

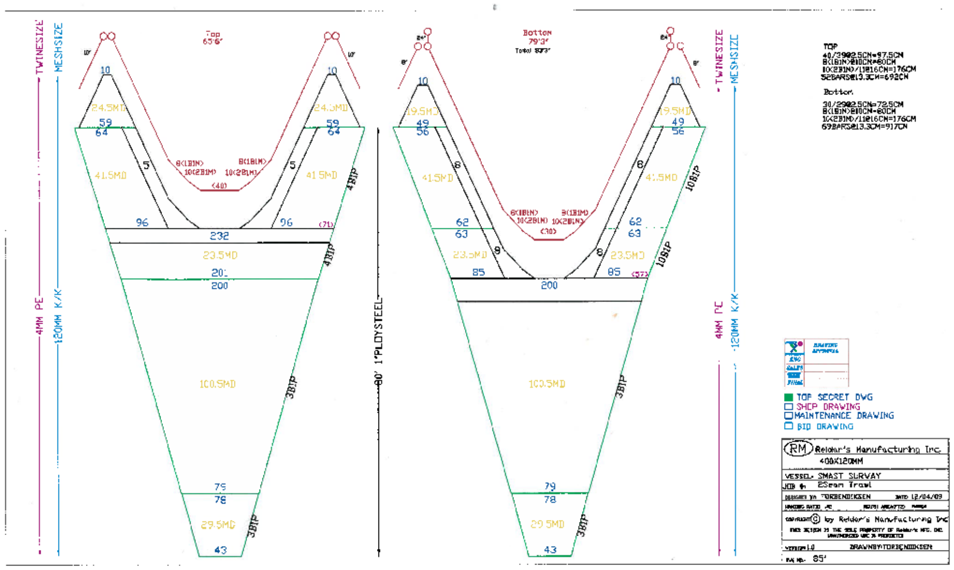

Figure 5. Diagram of the survey nets that were constructed by Reidar's Manufacturing for the industry-based survey in the Great South Channel.

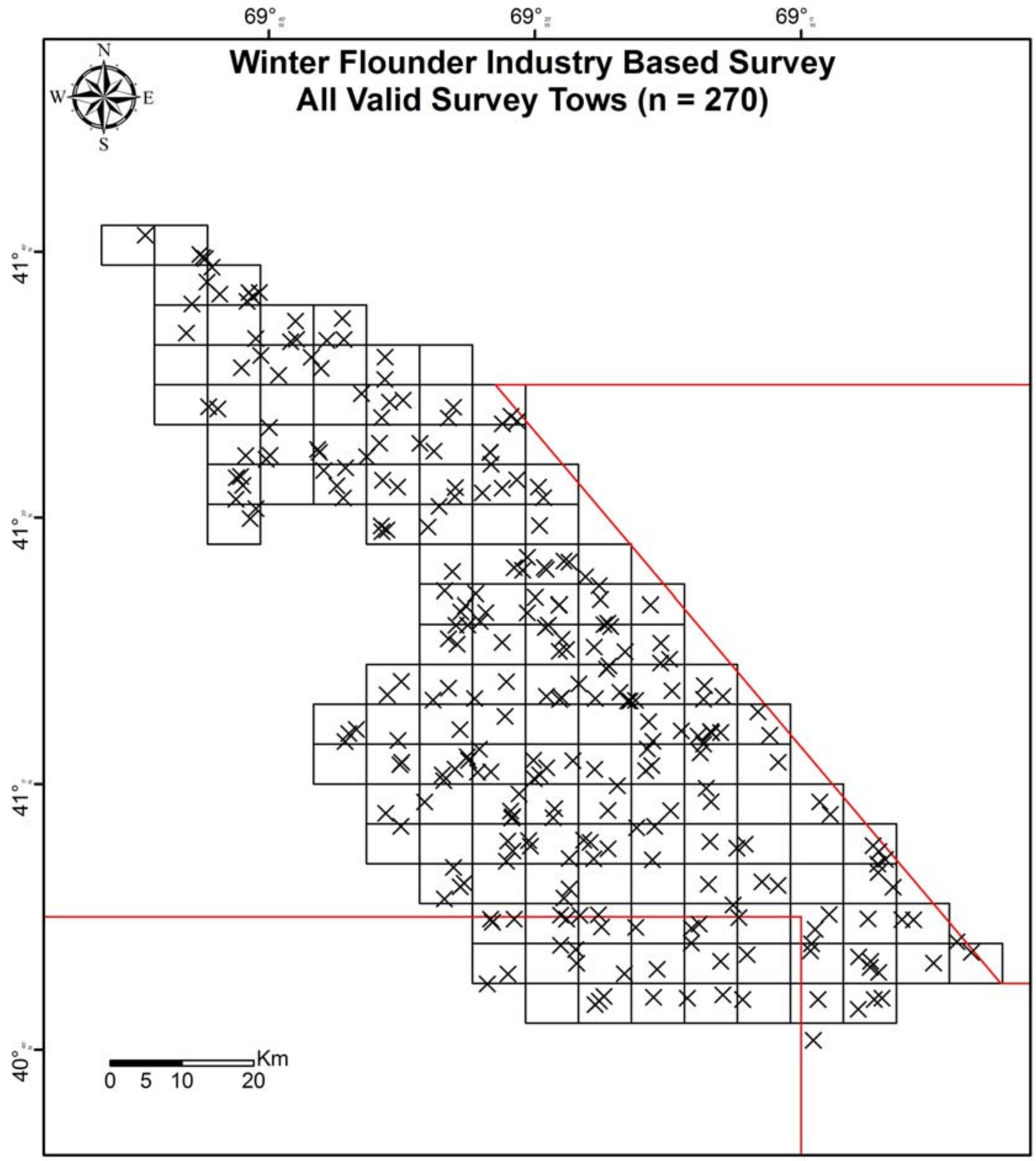

Figure 6. End locations of the 270 valid survey tows that were completed during the industry-based survey for winter flounder in the Great South Channel.

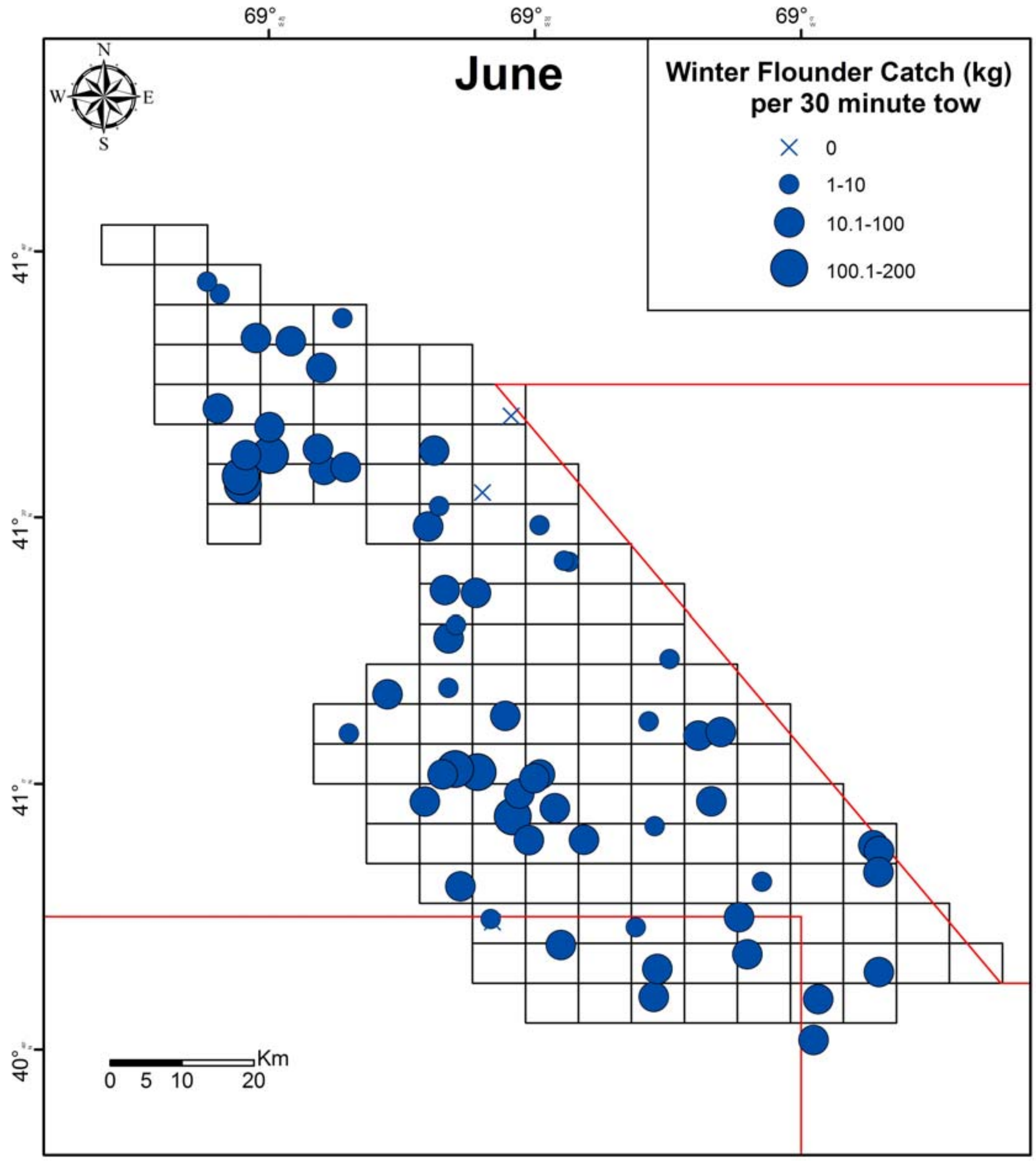

Figure 7. Distribution of standardized winter flounder catches (kg) observed during the month of June.

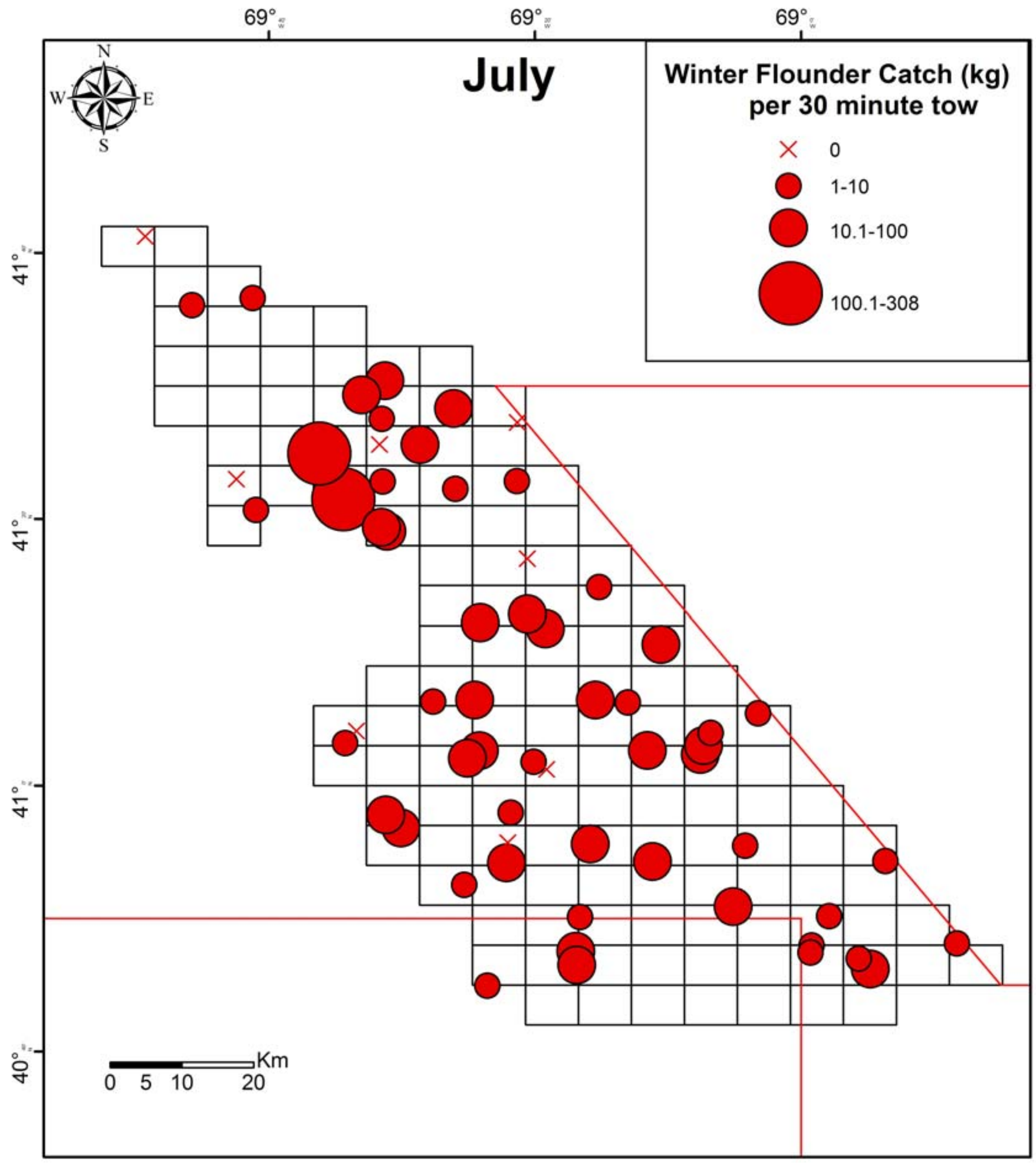

Figure 8. Distribution of standardized winter flounder catches (kg) observed during the month of July.

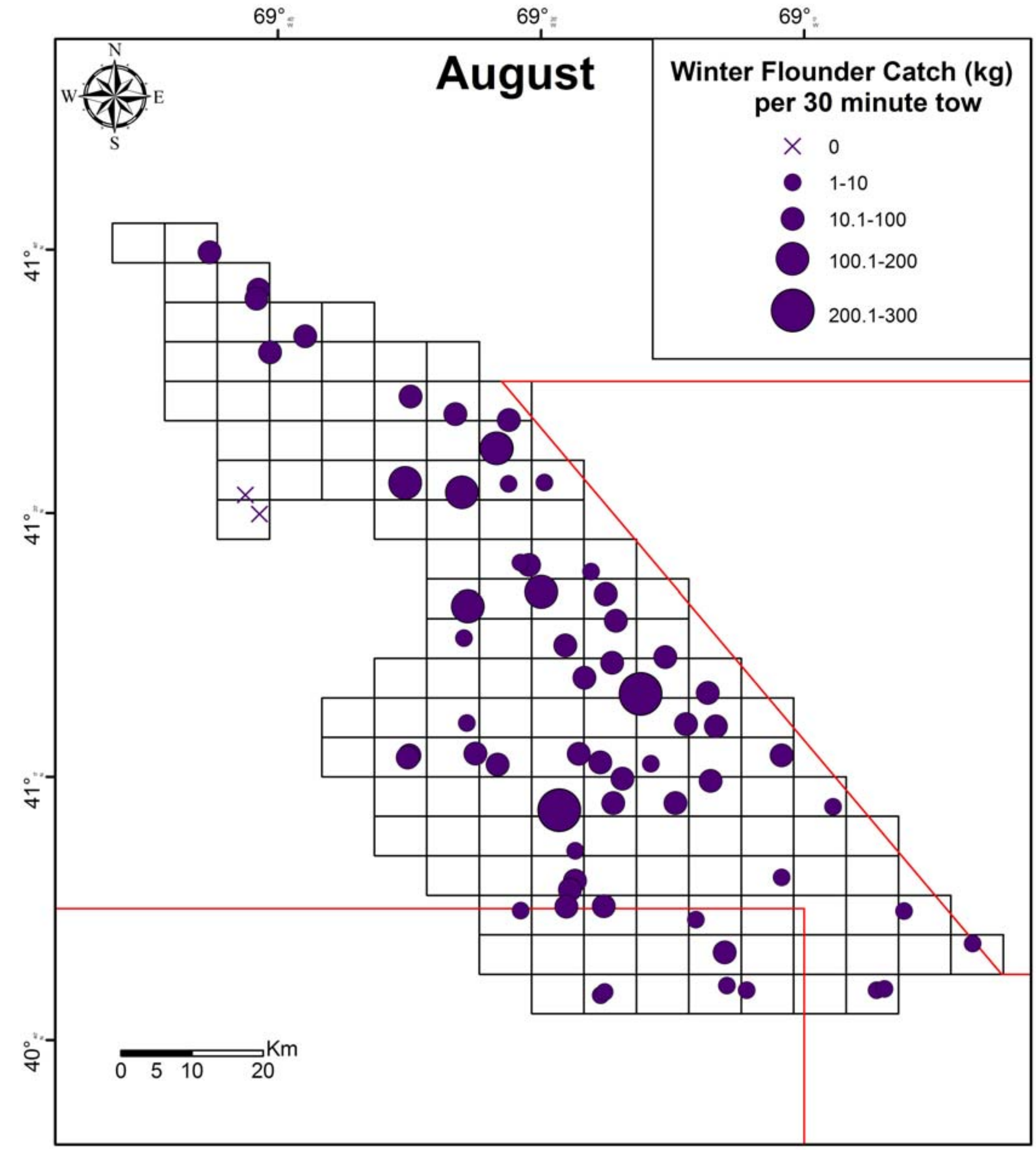

Figure 9. Distribution of standardized winter flounder catches (kg) observed during the month of August.

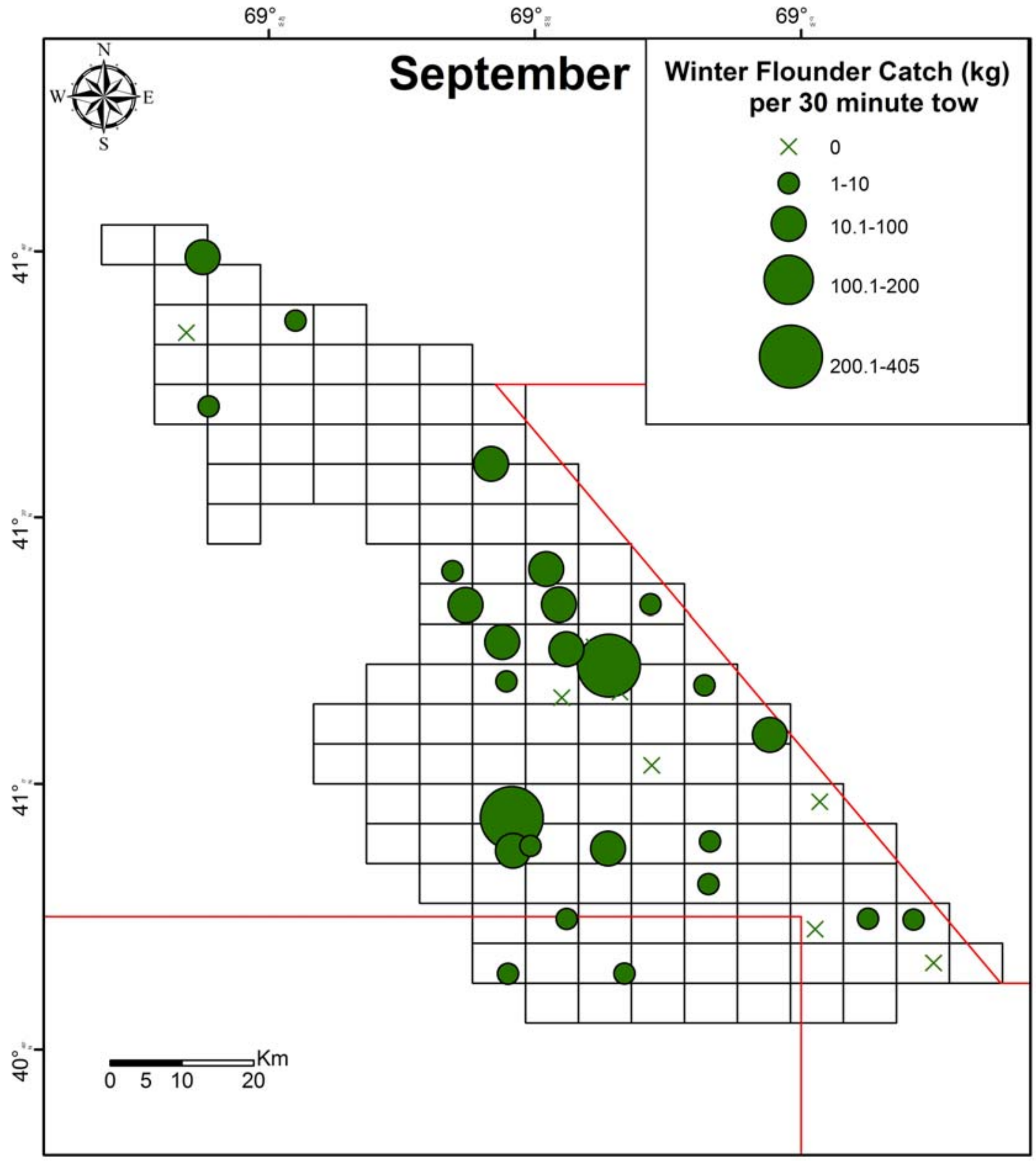

Figure 10. Distribution of standardized winter flounder catches (kg) observed during the month of September.

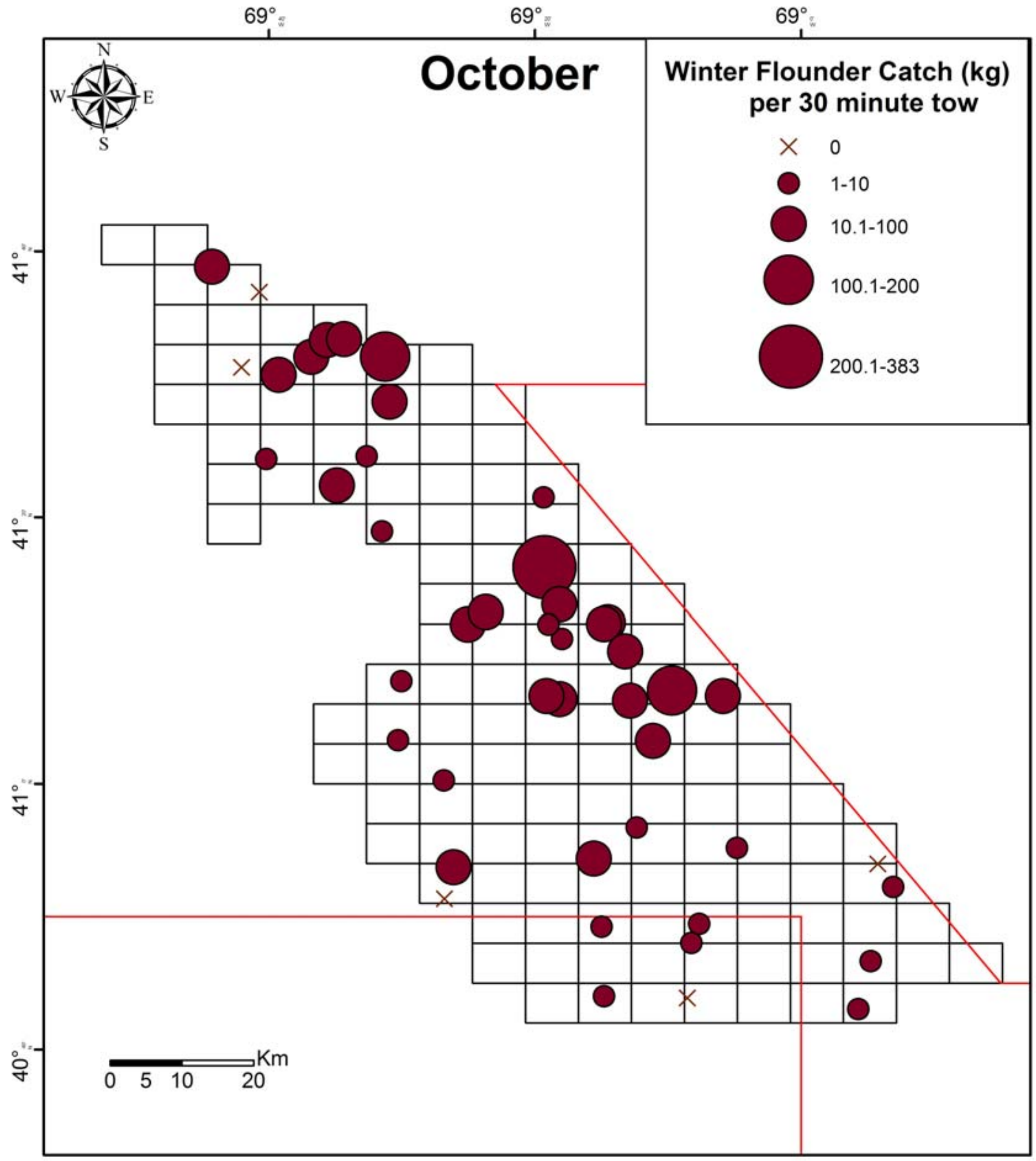

Figure 11. Distribution of standardized winter flounder catches (kg) observed during the month of October.

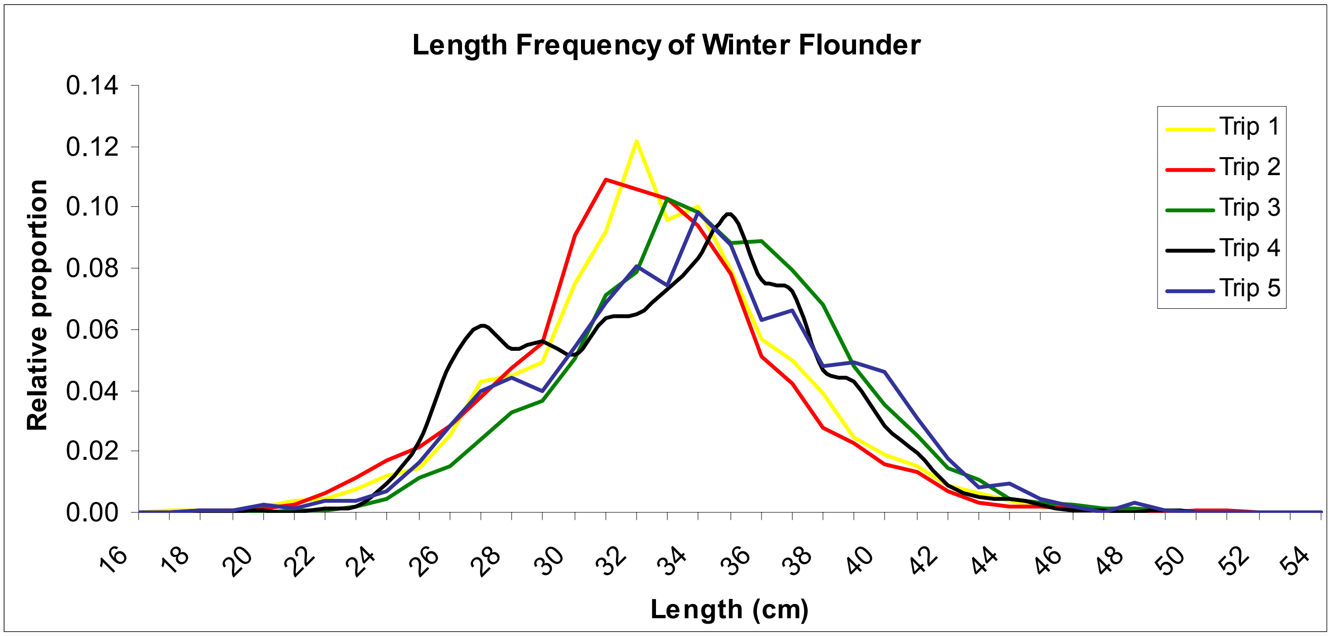

Figure 12. Length frequency of winter flounder observed on survey tows during each trip of the industry-based survey.

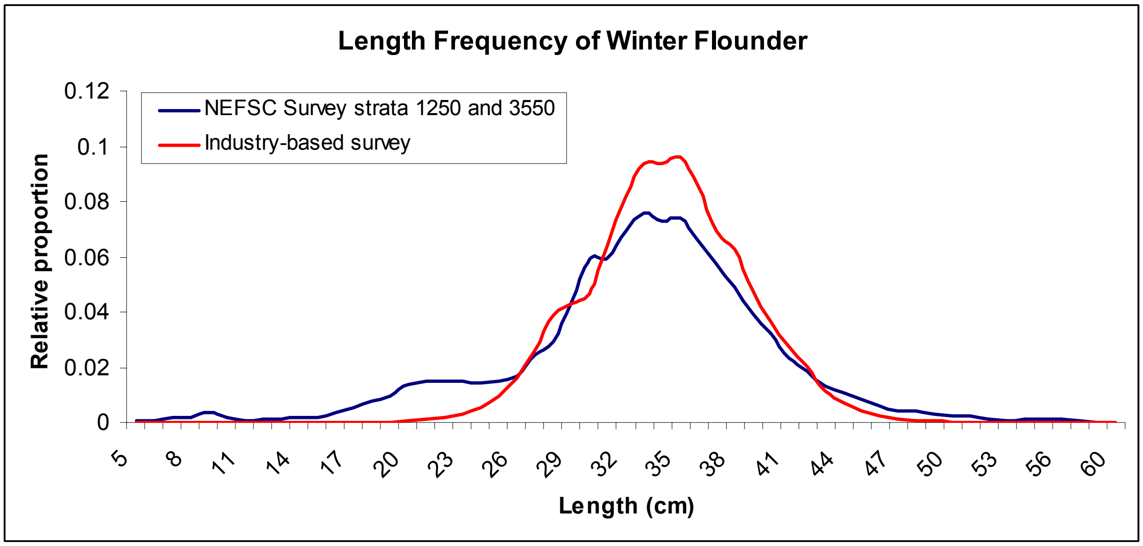

Figure 13. Length frequency distribution of winter flounder observed during the industry-based survey and the NEFSC spring and fall survey strata 1250 and 3550 between 2000 and 2009.

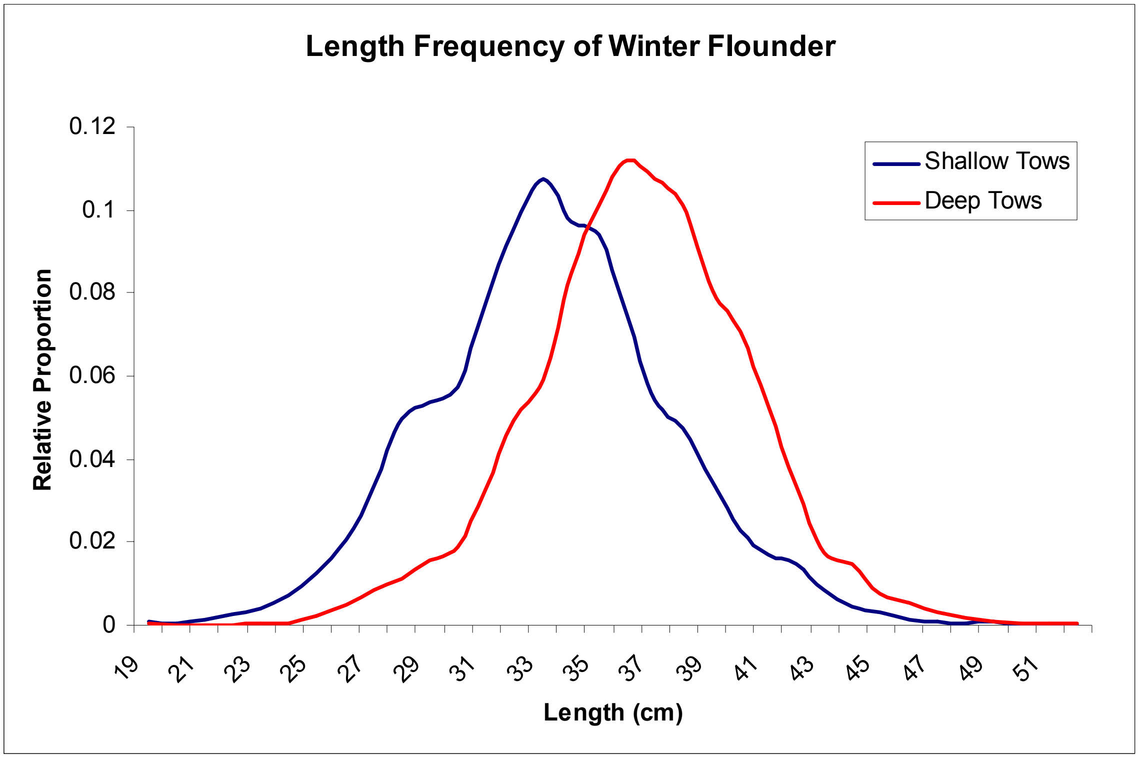

Figure 14. Length frequency of winter flounder caught on shallow (<52 meters) and deep (>52 meters) survey tows during the industry-based survey.

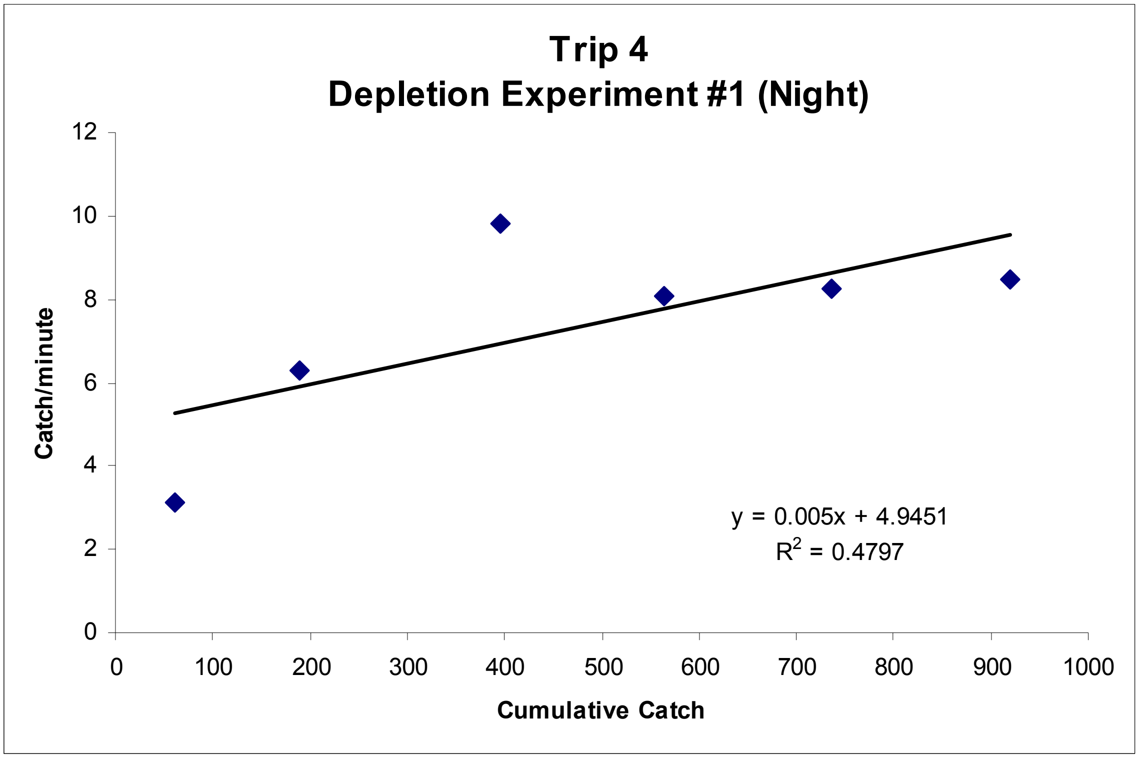

Figure 15. Results from depletion experiment #1 conducted in September.

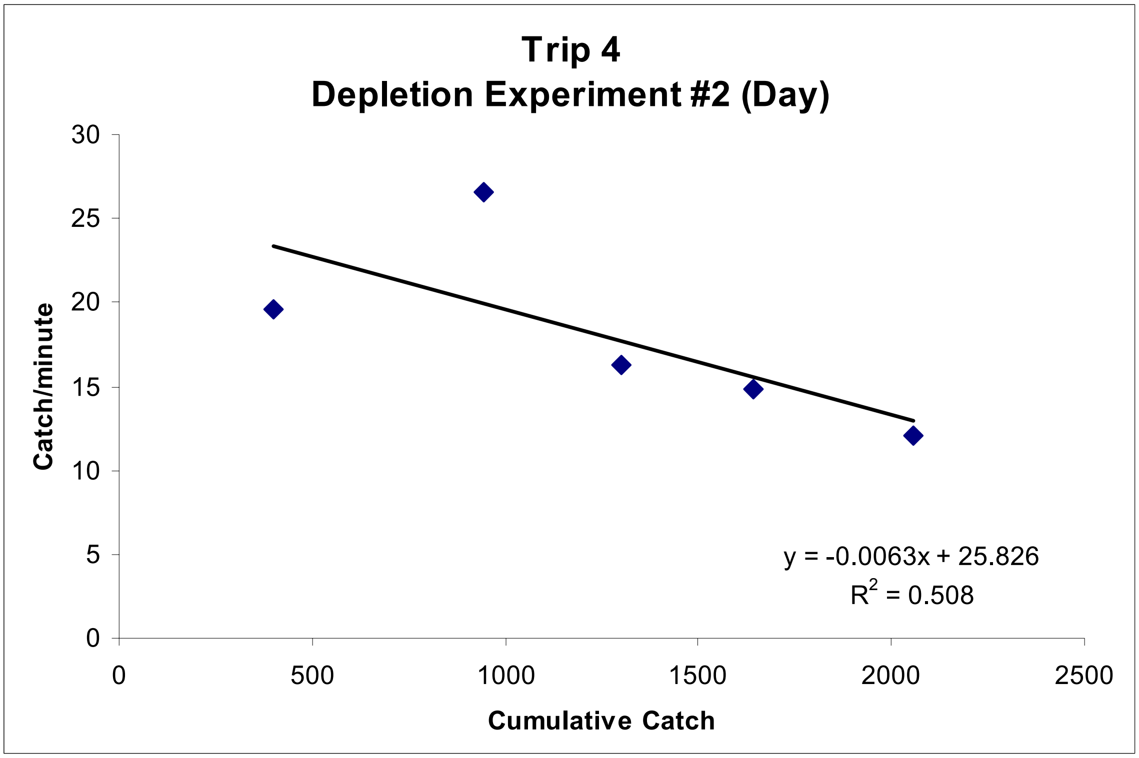

Figure 16. Results from depletion experiment #2 conducted in September.

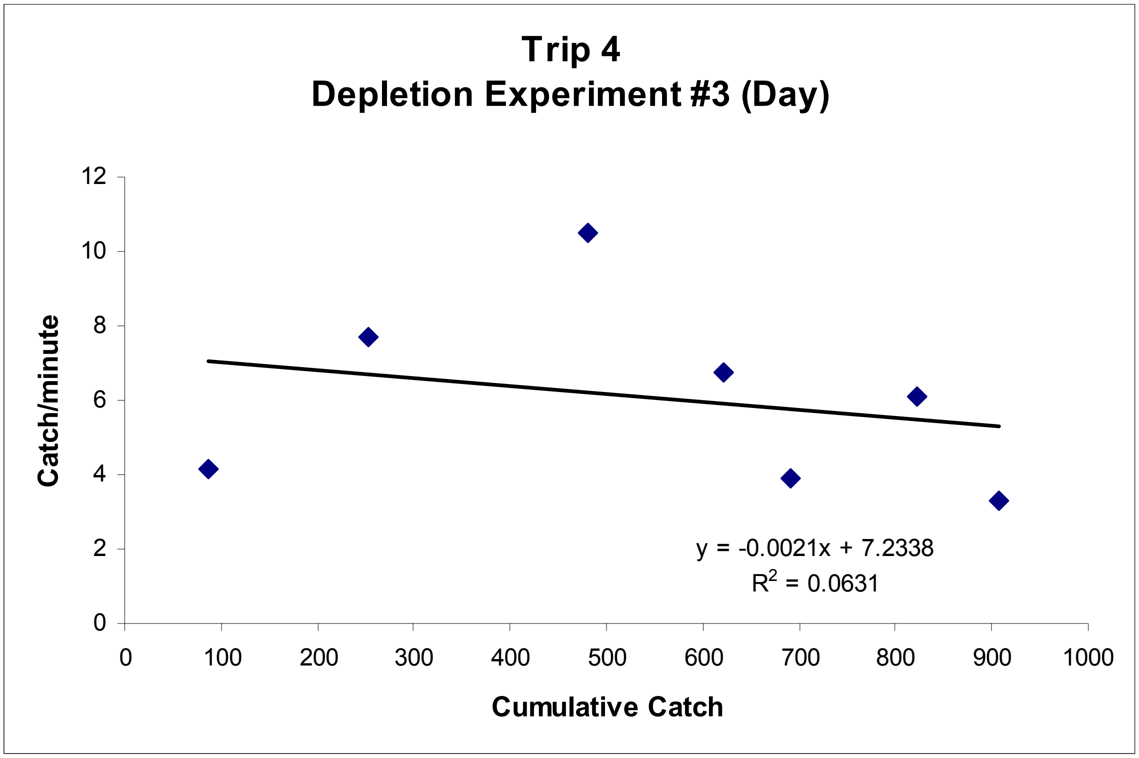

Figure 17. Results from depletion experiment #3 conducted in September.

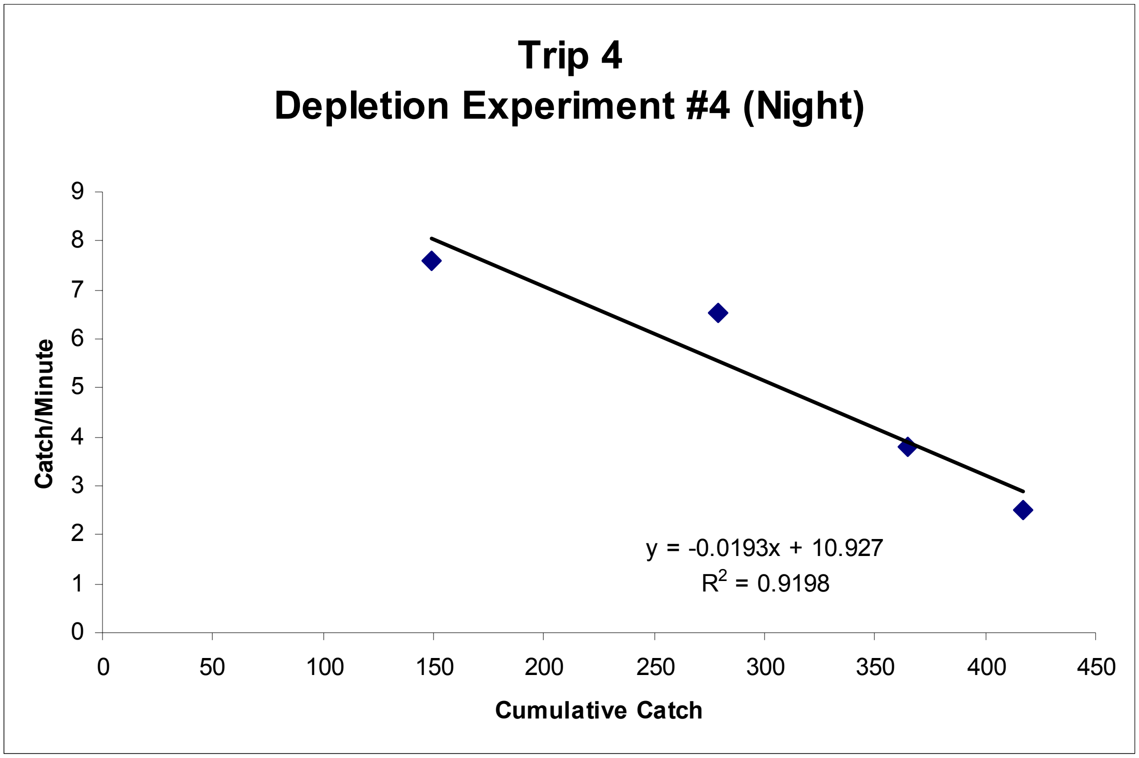

Figure 18. Results from depletion experiment #4 conducted in September.

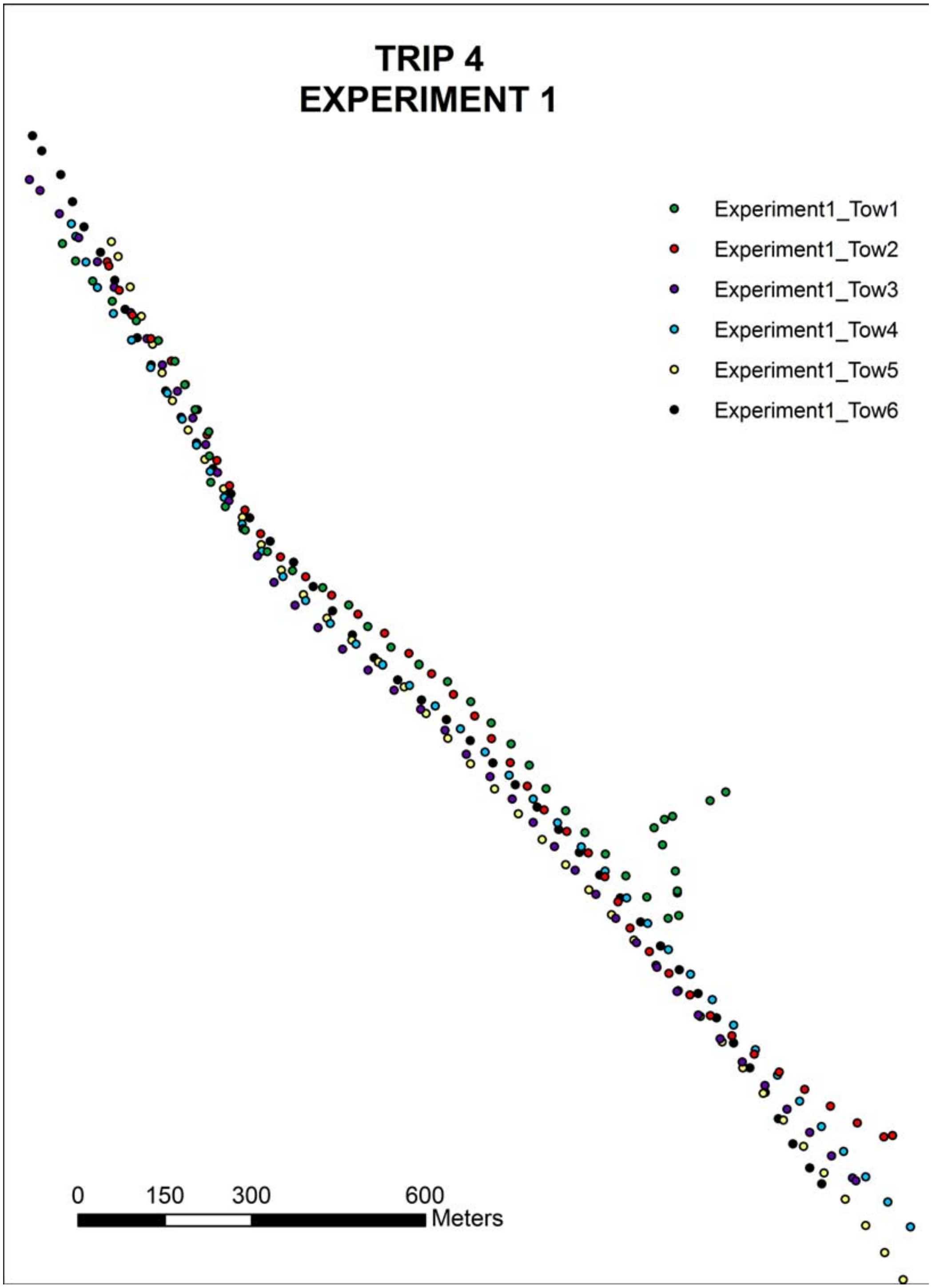

Figure 19. Position of the vessel during each of the tows made during depletion experiment #1 in September. The position of the vessel was recorded every 30 seconds during the tow.

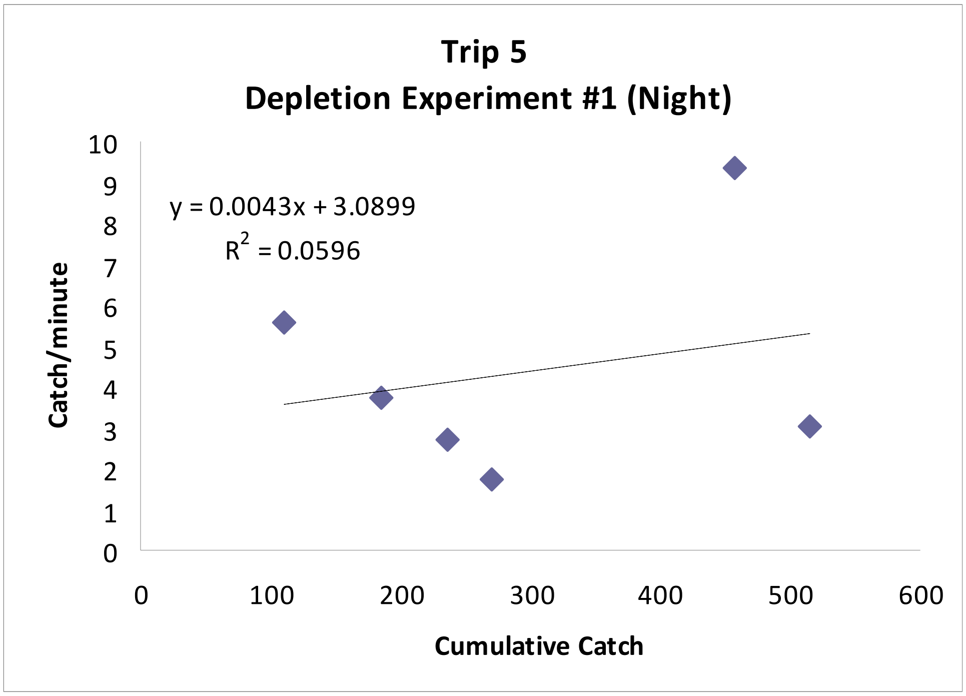

Figure 20. Results from depletion experiment #1 completed in October.

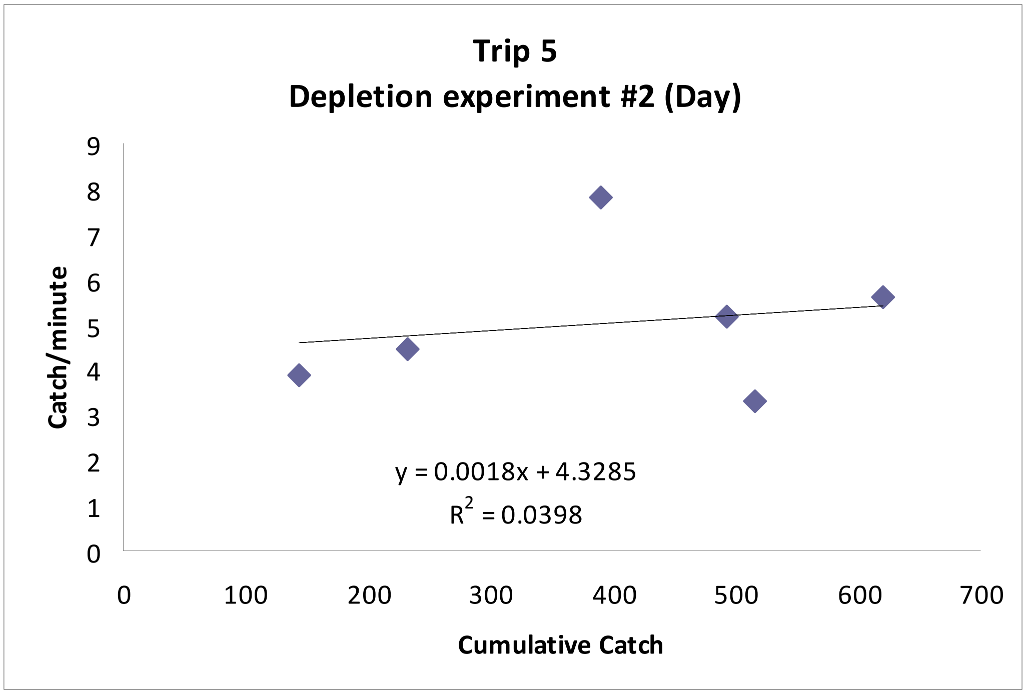

Figure 21. Results from depletion experiment #2 completed in October.

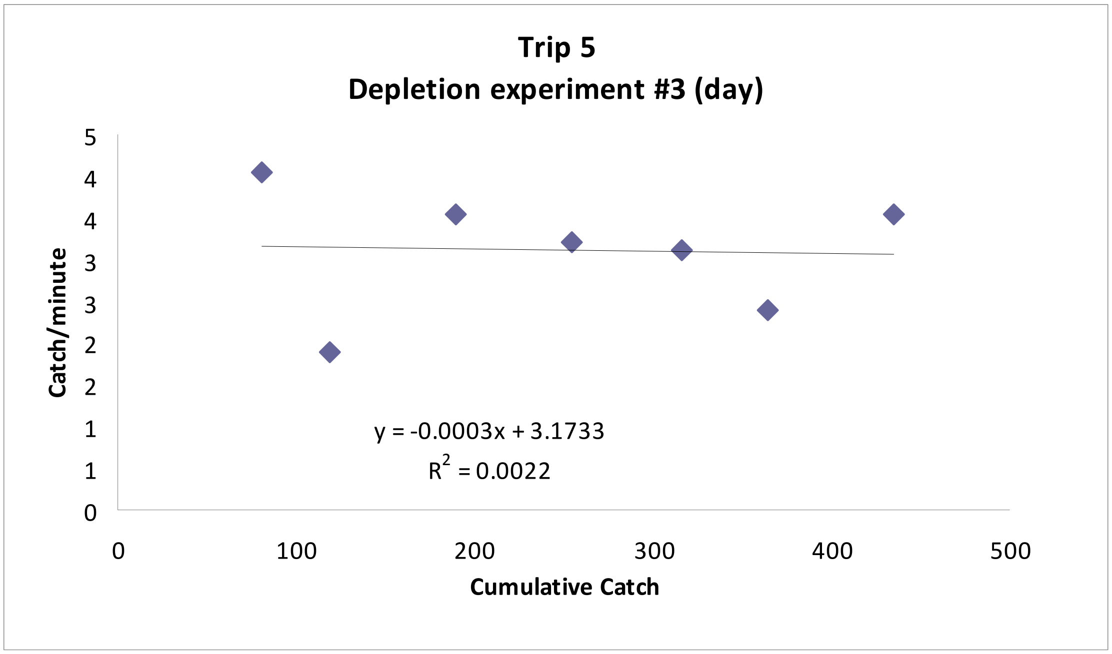

Figure 22. Results from depletion experiment #3 completed in October.

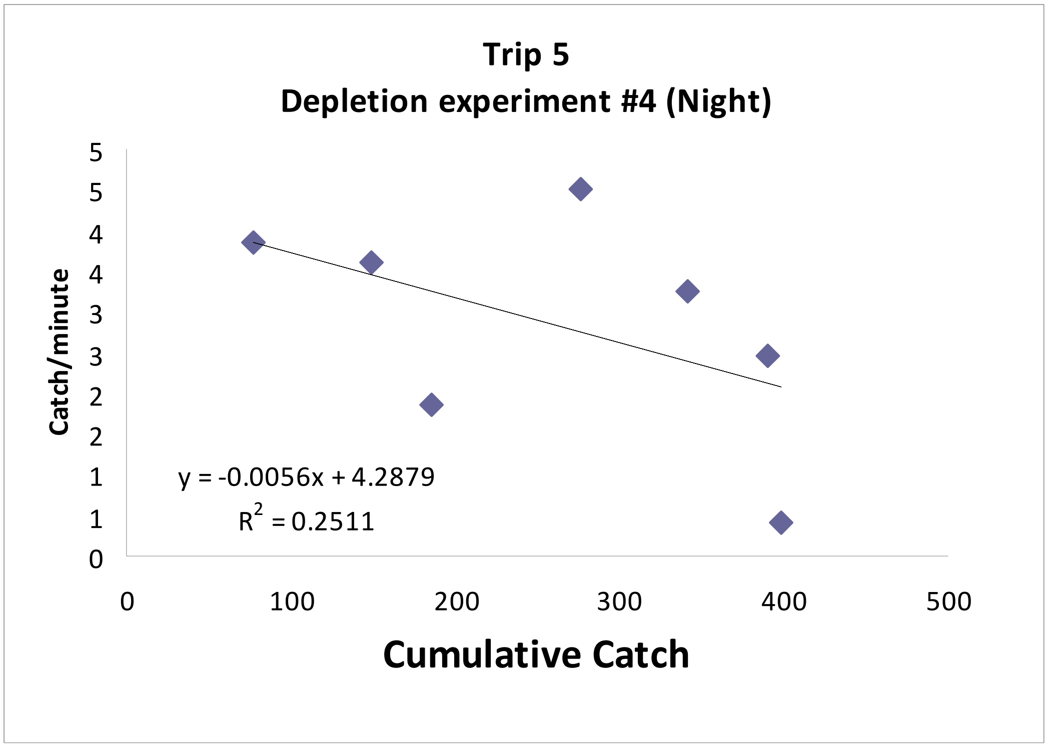

Figure 23. Results from depletion experiment #4 completed in October.

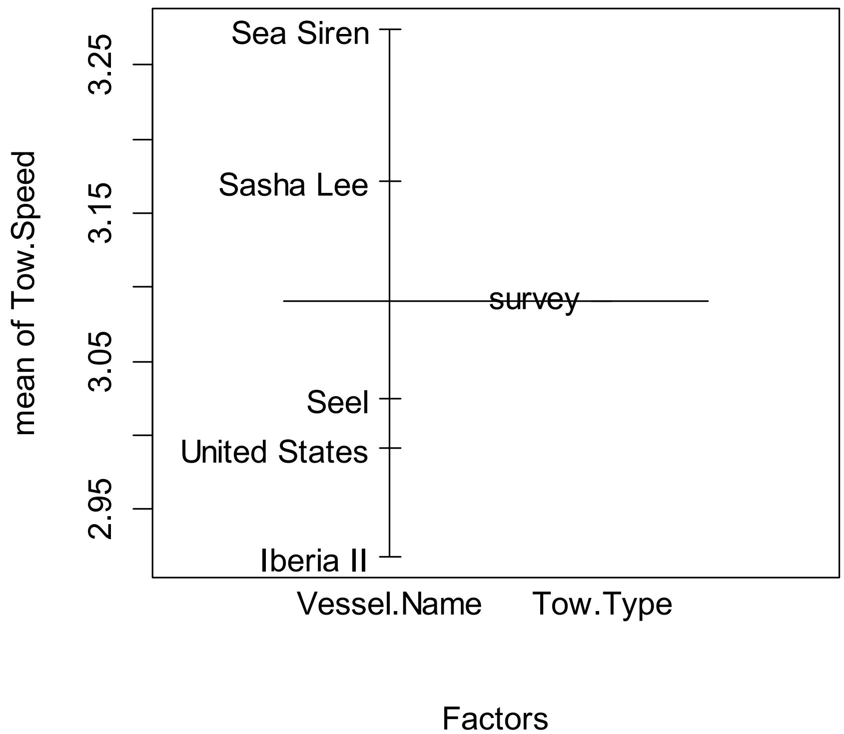

Figure 24. Plot of mean tow speed in knots by vessel for survey tows for the winter flounder industry-based survey.

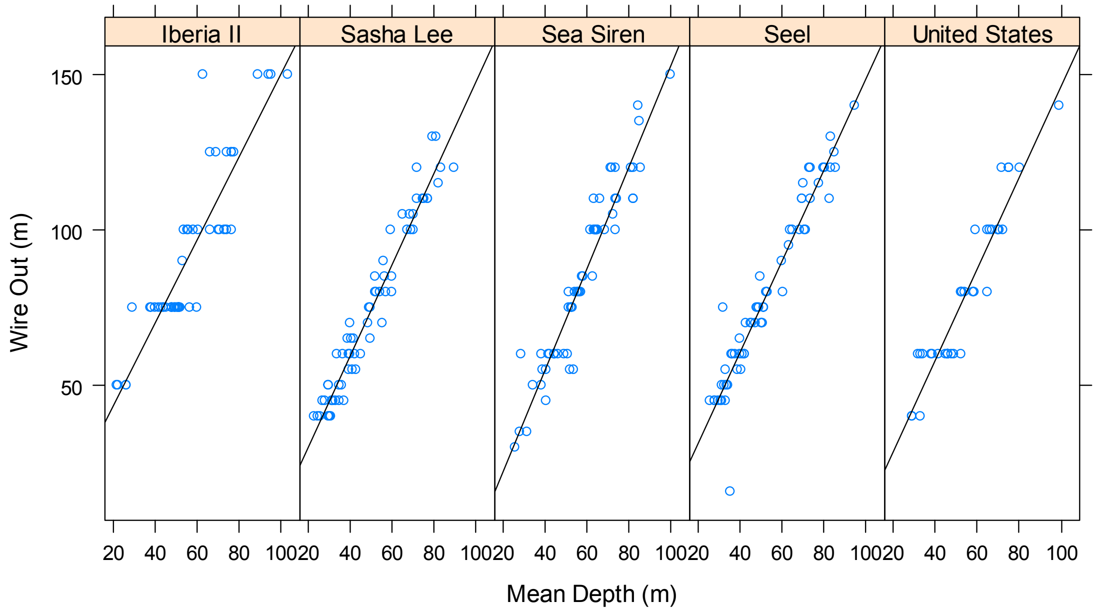

Figure 25. Plot of wire out (meters) against mean depth (meters) by vessel for the winter flounder industry-based survey.

SDWG Background WP#11
May 2011
TOR1-discard rate estimates

A Working Paper in support of SARC 52 Winter Flounder TOR 1:"Estimate catch from all sources including landings and discards. Characterize the uncertainty in these sources of data."

A Comparison of Discard Rates Derived from At-Sea Monitoring and Observer Trips

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April 2011

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Introduction

- The Northeast Fishery Observer Program (NEFOP; NEFOP 2010a; NEFOP 2010b) implemented a new data collection program called At-Sea Monitoring (ASM; NEFOP 2010c) on May 1, 2010.
- This sampling program was required by Amendment 16 to Northeast Multispecies Fishery Management Plan (FMP) for compliance monitoring of NE groundfish trips in fishing year 2010.
- ASM sampling program uses similar sampling protocols as the observer program (slightly less biological sampling – no age structure
- Deployment of monitors and observers are through the Pre-Trip Notification System (PTNS; Palmer et al. In-prep).
- Coverage of New England groundfish fleets, trips using gear that target groundfish include: longline, handline, longline, otter trawl, and gillnet. The otter trawl includes three types of trawl: bottom trawl for fish, Ruhle trawl and haddock separator trawl.
- Funding available to provide approximately 30% coverage of NE groundfish trips with ASM and 8% coverage with Observer.
- Useful to know if the two programs are sampling the same population of groundfish trips before pooling these data together for discard estimation of various species.
- This report summarizes the number of trips and compares the discard rates using the first 10 months of data collection May 1, 2010 to December 31, 2010) by NEFOP ASM and observers (OB).

Methods

- NEFOP data from May through December
- Partitioned data into two sets based on program codes
    - ASM included program codes: 230, 231, 232, 233, and 234
    - OB included program codes: 000, 010, 130, 146, 147, and 150
    - Weight was converted to live pounds
    - Only observed hauls used
    - Each dataset was stratified by calendar quarter and 7 gear/mesh: Longline, Handline, Otter trawl, Ruhle trawl, Haddock Separator trawl, Gillnet (large; extra-large);
- To identify groundfish trips, used the *link1* in the Oracle table used for Quota-Monitor of Sector's annual catch entitlements.
- Summarized trips by dataset and calendar quarter to identify temporal coverage patterns

- Summarized trips by dataset and statistical area and three regions (Gulf of Maine statistical areas 511-515; Georges Bank statistical areas 521-526, 561-562; and Southern England statistical areas 537-539, 611-639)
- Derived discard rates and associated variance for 18 species (8 species with multiple stock components) and all species combined using Equations 1 and 2;
    - Species include: American plaice, Atlantic cod, Atlantic halibut, Atlantic wolffish, haddock, ocean pout, pollock, redfish, white hake, windowpane flounder, winter flounder, witch flounder, yellowtail flounder, monkfish, fluke, silver hake, red hake, and scallops
- Calculated the difference between dataset discard rate and the variance of the difference between discard rate using Equations 3 and 4

Eq 1.
$$\hat{R}_{jh} = \frac{\sum_{i=1}^{n_h} d_{ijh}}{\sum_{i=1}^{n_h} k_{ih}}$$

Eq 2.
$$V\left(\hat{R}_{jh}\right) = \frac{1}{n_h \bar{k}_h^2} \left[\frac{\left(\sum_{i=1}^{n_h} d_{ijh}^2\right) + \hat{R}_{jh}^2 \left(\sum_{i=1}^{n_h} k_{ih}^2\right) - 2\hat{R}_{jh}\left(\sum_{i=1}^{n_h} d_{ijh} k_{ih}\right)}{(n_h - 1)} \right]$$

Eq 3.
$$\hat{R}_{diff} = \hat{R}_{jhASM} - \hat{R}_{jhOB}$$

Eq. 4
$$V(\hat{R}_{diff}) = V(\hat{R}_{jhASM}) + V(\hat{R}_{jhOB})$$

where,
R_{jh} is the discard rate of stock j in stratum h;
d_{ijh} is the discard weight of the stock j within trip i in stratum h;
k_{ih} is the kept weight of all species within trip i in stratum h;
n_h is the number of observed trips in stratum h;
k_h bar is the mean kept of all species within the stratum;
Rdiff is the difference between ASM and OB discard rates for stock j in stratum h;
Stratum h represents gear/mesh and calendar quarter;

- 95% confidential intervals were derived for each difference between discard rates (cell)
- Cells were excluded from analysis if sample size (number of trips) in either dataset was equal to 1
- Difference between discard rates were compared against zero

Results

- There were 513 OB groundfish trips and 2,171 ASM groundfish trips during the May through December 2010 period (Table 1).
- Percentage of groundfish trips by dataset and calendar quarter reveals some temporal variability (Figure 1).
- ASM and OB sea days used and groundfish trip activity, by week, provide insight into quarterly patterns (Figures 2 and 3)
- Percentage of groundfish trips by dataset and statistical area reveals some spatial variability (Figure 4a), but when aggregated by region, less variability is evident (Figure 4b).
- 435 cells (differences between ASM and OB discard rates by species/stock, gear/mesh and calendar quarter) were compared against zero
- 90% of the cells overlapped zero (392 of 435)
- 10% of the cells did not overlap zero (43 of 435)
- Some cells had very small sample sizes
- 21 of the 43 non-overlapping cells had discards < 10 lbs (small quantities of discards)

- Specific to Winter flounder
    - GOM Winter flounder: all 11 cells overlap zero (Figure 5)
    - GB winter flounder: all 9 cells overlap zero (Figure 6)
    - SNE winter flounder: 11 of 12 cells overlap zero (Figure 7)
- Other species/stocks (Figures 9 to 33)

Conclusions

- Expectation: 5% of cells will not overlap zero if there is no statistical difference between the OB and ASM discard rates
- No major differences between discard rates from OB and ASM trips
- Confirms assumption that OB and ASM programs are sampling same population of groundfish trips

Literature

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Northeast Fisheries Observer Program. 2010b. Norheast Fisheries Observer Program Biological Sampling Manual 2010. Northeast Fisheries Science Center, Woods Hole, MA 02543. 84 p. Available on-line at: http://www.nefsc.noaa.gov/femad/fishsamp/fsb/Manuals/JANUARY%202010%20MANUALS/NEFBSM%2001-01-10_BOOKMARKS%28Compressed%29.pdf

Northeast Fisheries Observer Program. 2010c. Northeast Fisheries At-Sea Monitor Program Biological Sampling Manual 2010. Northeast Fisheries Science Center, Woods Hole, MA 02543. 42 p. Available on-line at: http://www.nefsc.noaa.gov/femad/fishsamp/fsb/Manuals/JANUARY%202010%20MANUALS/ASM_Biosampling_Manual_2010.pdf

Palmer, MC, Hersey,P, Marotta,H, Shield,G, Cierpich, S and VanAtten, A. (In-prep). The design, implementation and monitoring of an observer pre-trip notification system (PTNS) for the fisheries of the northeast United States.

Table 1. Summary of Northeast Fisheries Observer Program ‘s program names, program codes, number of groundfish trips and observed hauls, by observer (OB) and at-sea monitoring (ASM) dataset for NEFOP collected from May through December 2010.

Program Name	OB PROGRAM Code	OB DATA		ASM DATA		ASM PROGRAM Code
		Trips	Hauls	Trips	Hauls	
STANDARD SEA SAMPLING TRIPS	000	373	1,595	1,983	7,583	230
TRAINING TRIPS	010	64	249			
US/CANADA MANAGEMENT AREA	130	74	1,684	141	3,016	231
CLOSED AREA I HADDOCK HOOK SAP	146			41	399	233
CLOSED AREA II YELLOWTAIL FLOUNDER/HADDOCK SAP	147	2	59	6	147	234
TOTAL TRIPS		513		2,171		

Figure 1. Percentage of NEFOP trips, by dataset (observer, OB and at-sea monitoring ASM) and calendar quarter for groundfish trips from May through December, 2010.

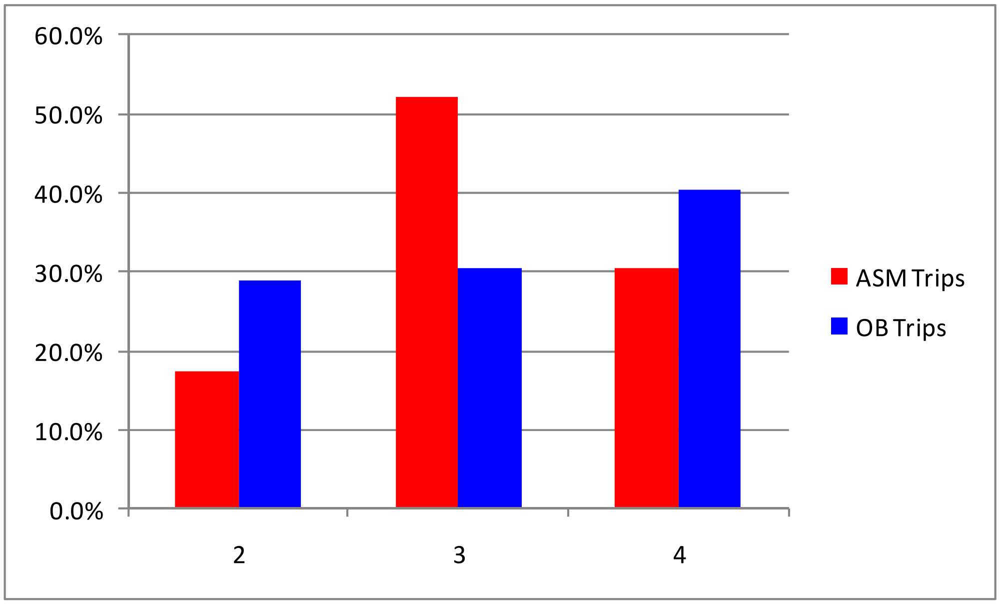


Figure 2. Number of ASM sea days used and trip activity of groundfish trips during May 2010 through early April 2011.

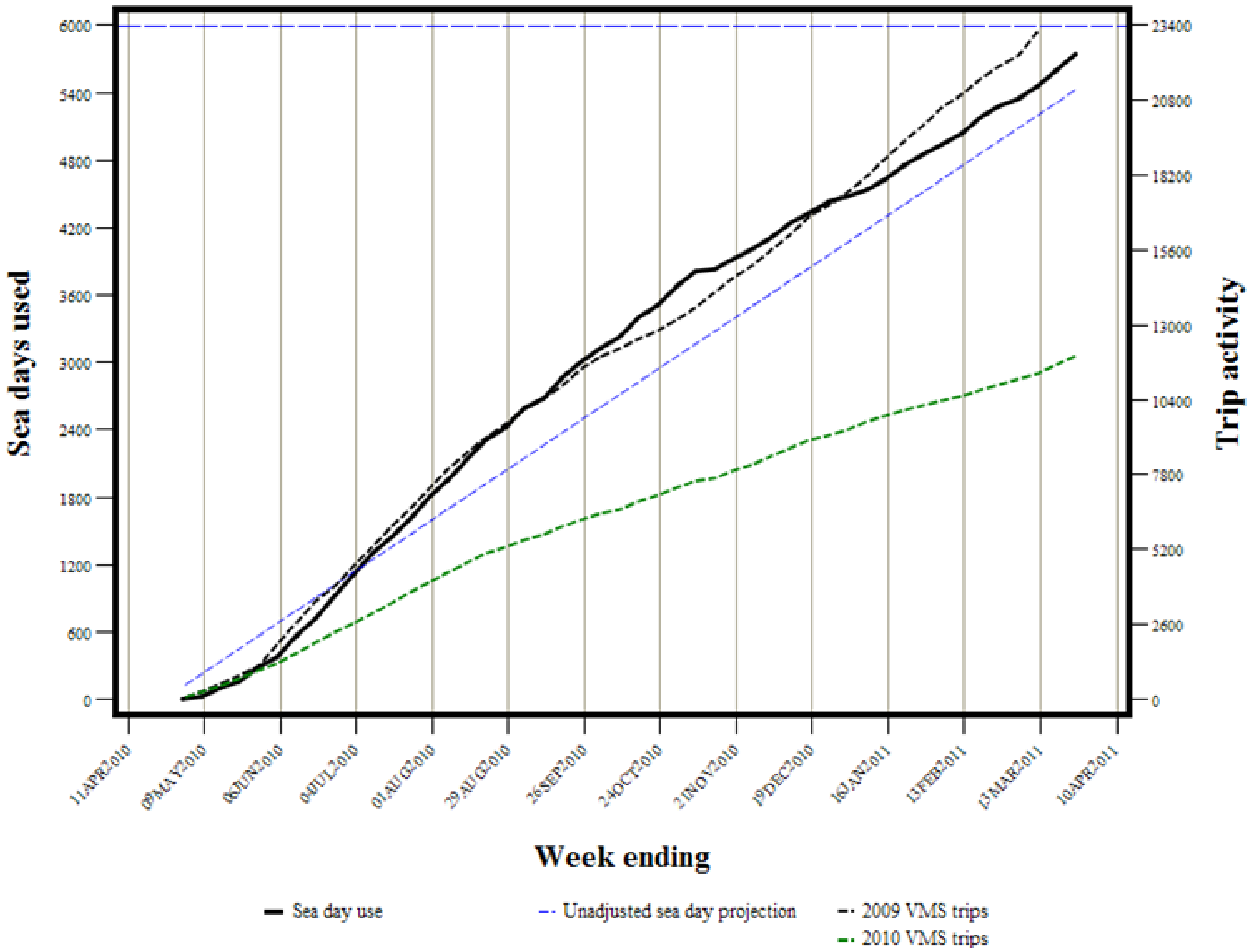


Figure 3. Number of OB sea days used and trip activity of groundfish trips during May 2010 through early April 2011.

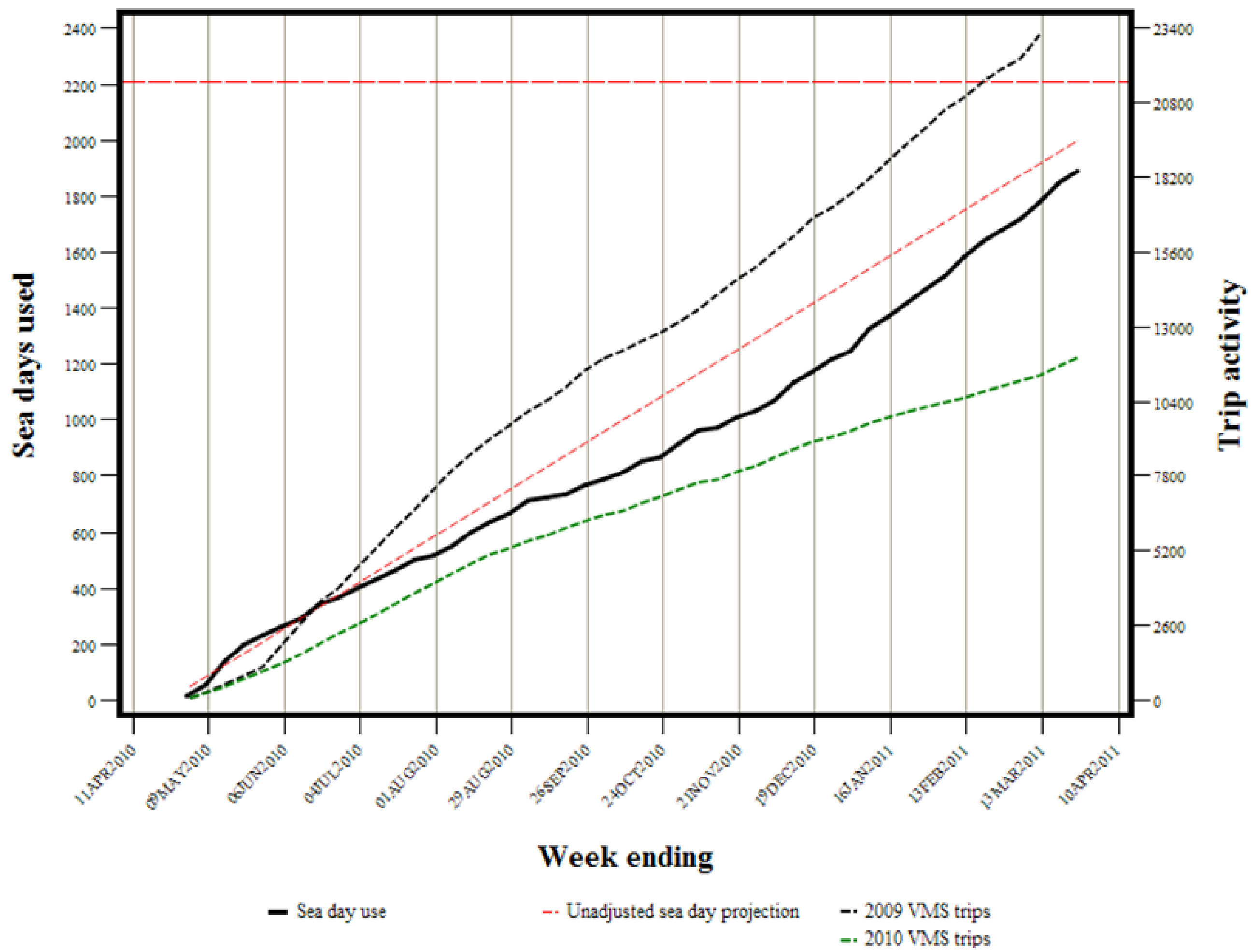
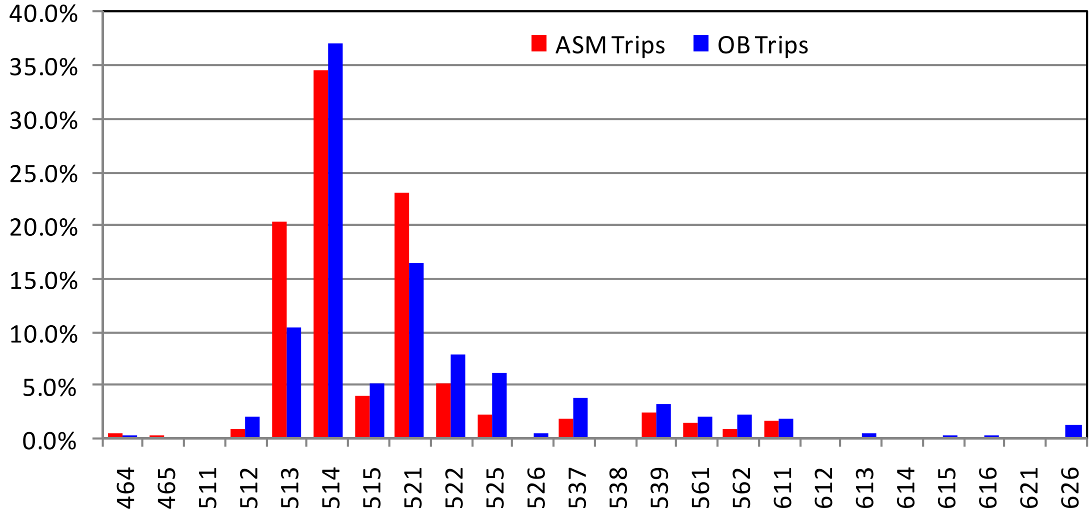


Figure 4. Percentage of NEFOP trips, by dataset (observer, OB and at-sea monitoring ASM) and statistical area (A) and region (B) for groundfish trips from May through December, 2010.



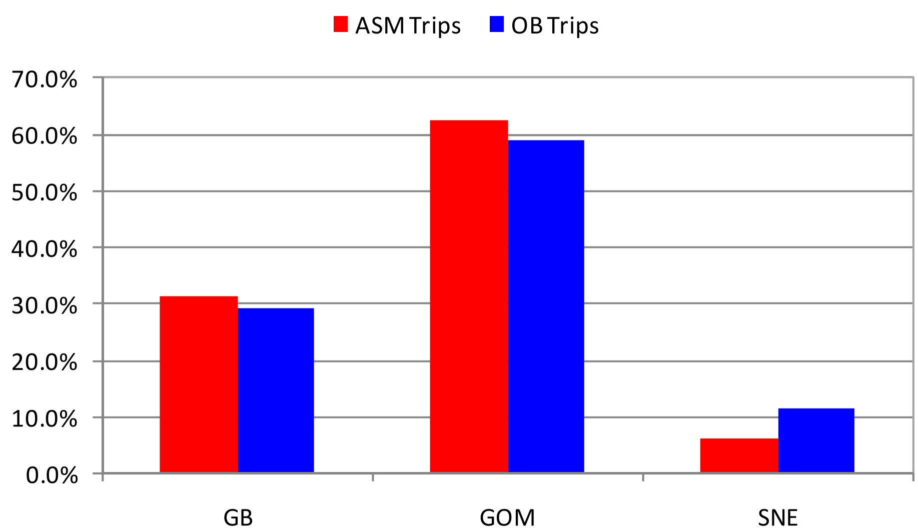


Figure 5. Difference between ASM and Observer discard rates, with 95% confidential interval, for **Gulf of Maine winter flounder** for NEFOP data collection from May through December 2010. Eleven gear/mesh and quarter combinations were evaluated; samples sizes are given by ASM and OB data set.

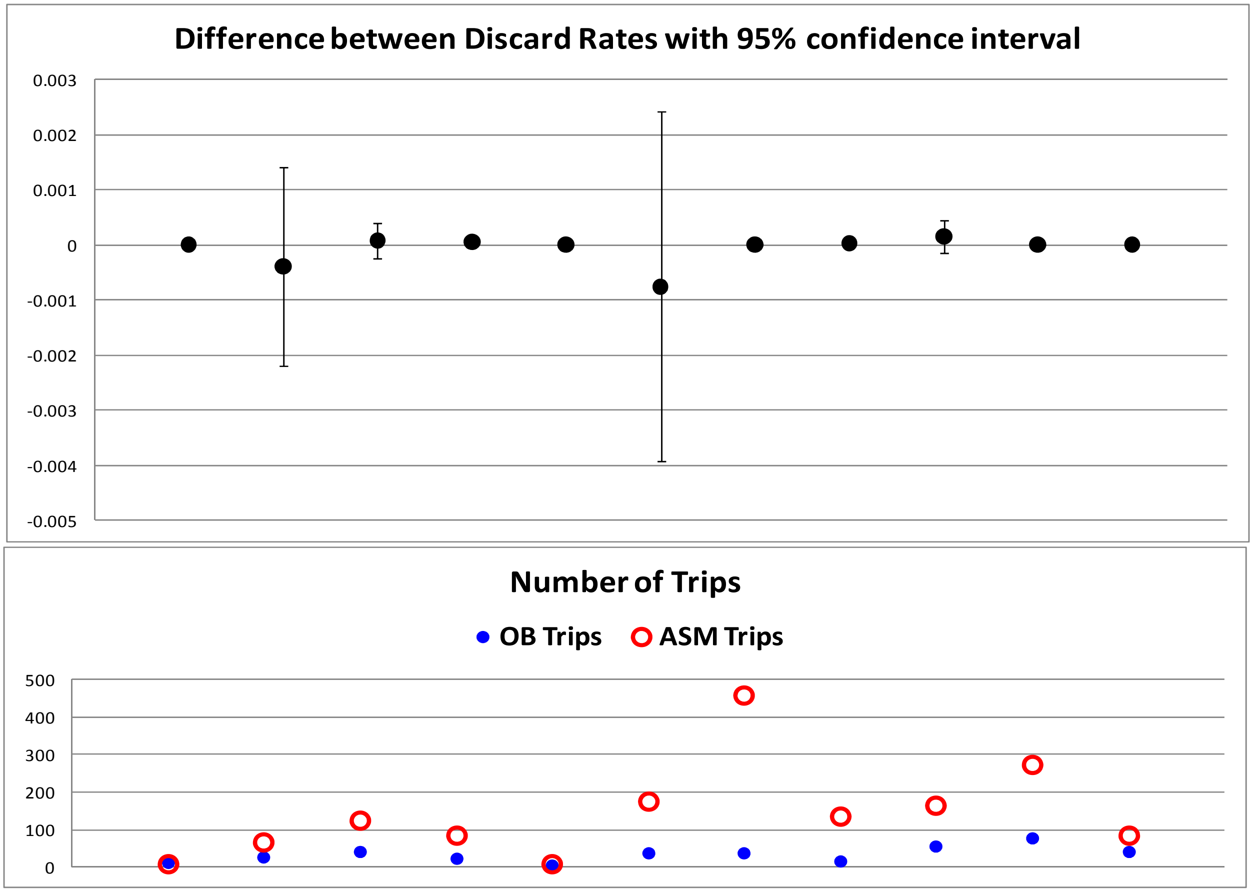


Figure 6. Difference between ASM and Observer discard rate, with 95% confidential interval, for **Georges Bank winter flounder** for NEFOP data collection from May through December 2010. Nine gear/mesh and quarter combinations were evaluated; samples sizes are given by ASM and OB data set.

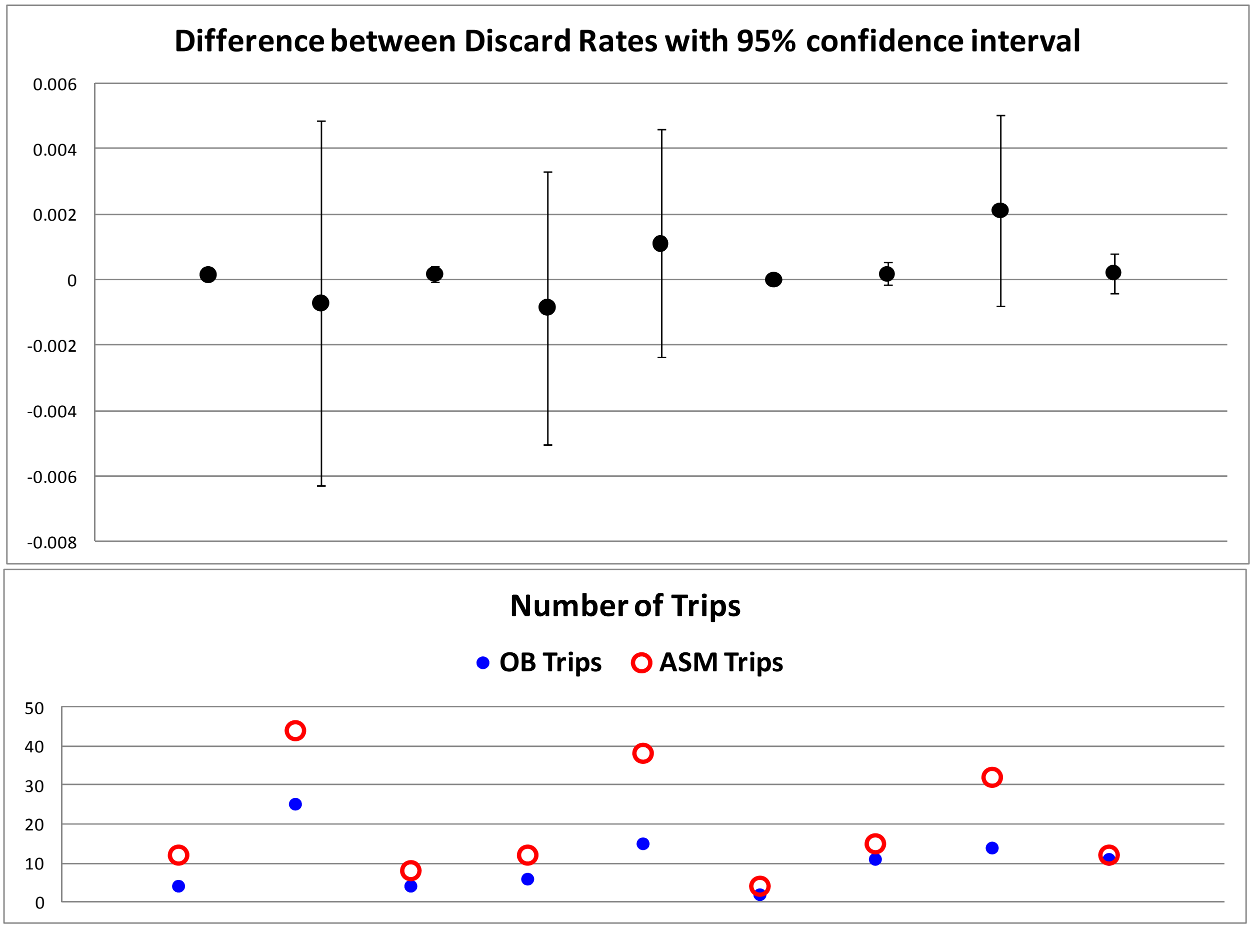


Figure 7. Difference between ASM and Observer discard rate, with 95% confidential interval, for **Southern New England winter flounder** for NEFOP data collection from May through December 2010. Twelve gear/mesh and quarter combinations were evaluated; samples sizes are given by ASM and OB data set.

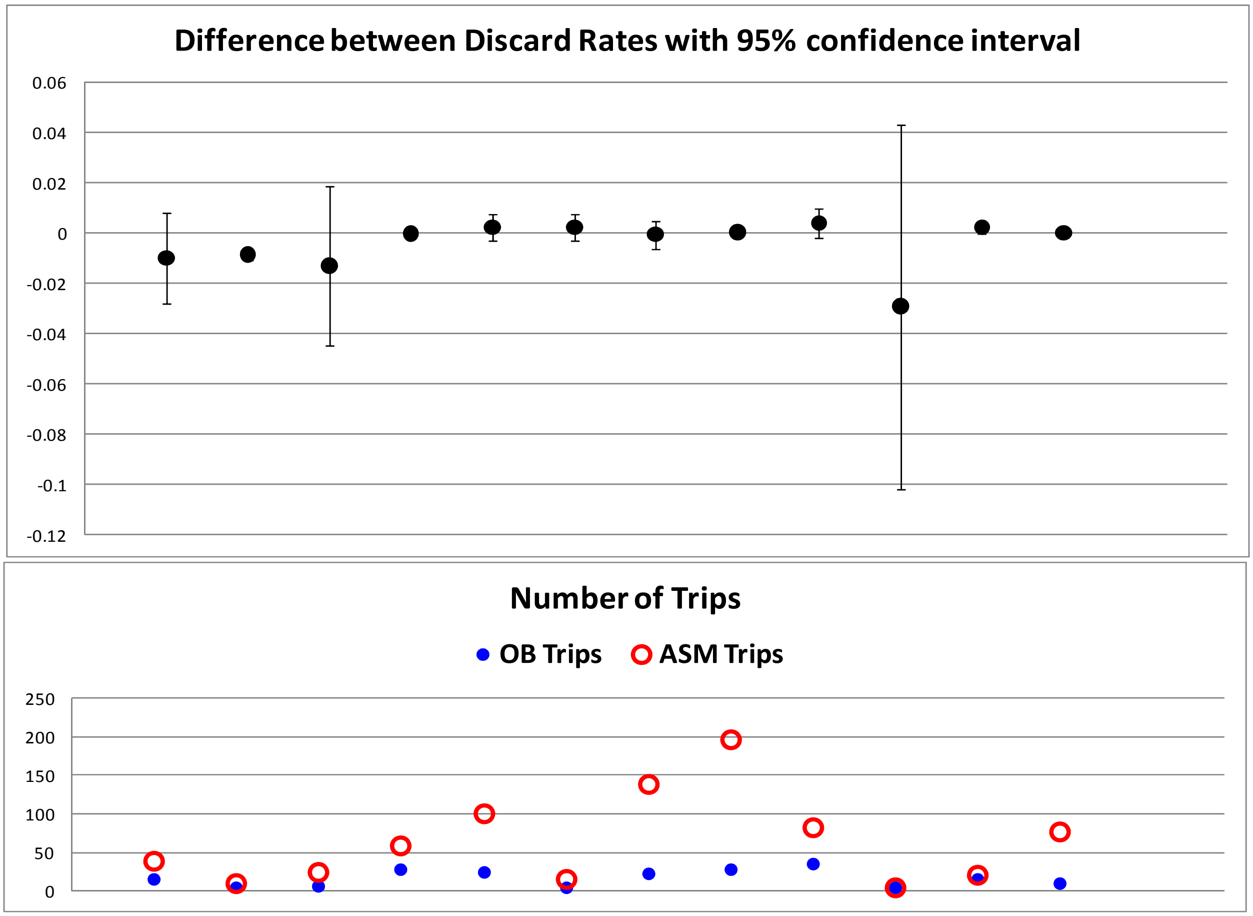


Figure 8. Difference between ASM and Observer discard rate, with 95% confidential interval, for **American plaice** for NEFOP data collection from May through December 2010. Fourteen gear/mesh and quarter combinations were evaluated; samples sizes are given by ASM and OB data set.

15 of 18 cells overlapped zero

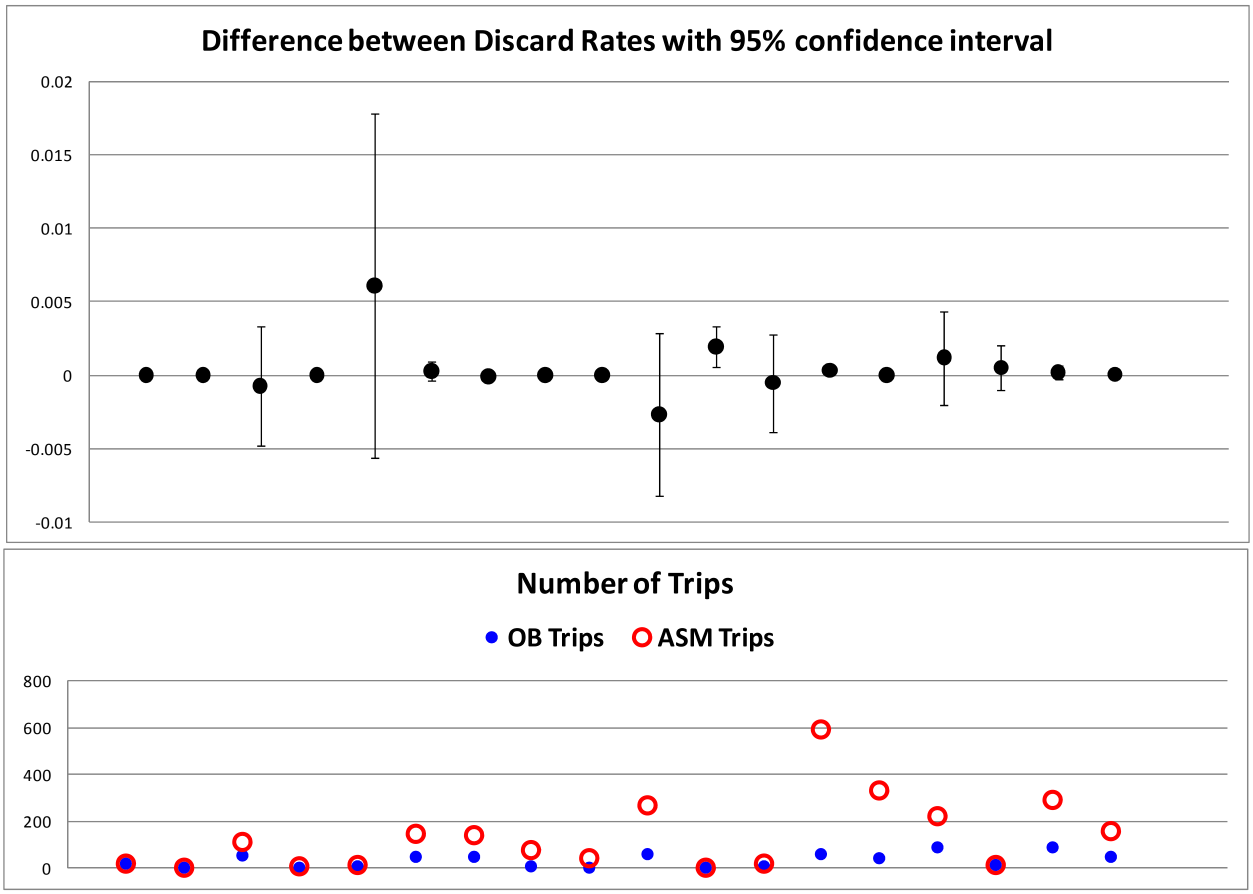


Figure 9. Difference between ASM and Observer discard rate, with 95% confidential interval, for **Gulf of Maine Cod** for NEFOP data collection from May through December 2010. Eleven gear/mesh and quarter combinations were evaluated; samples sizes are given by ASM and OB data set.

10 of 11 cells overlapped zero

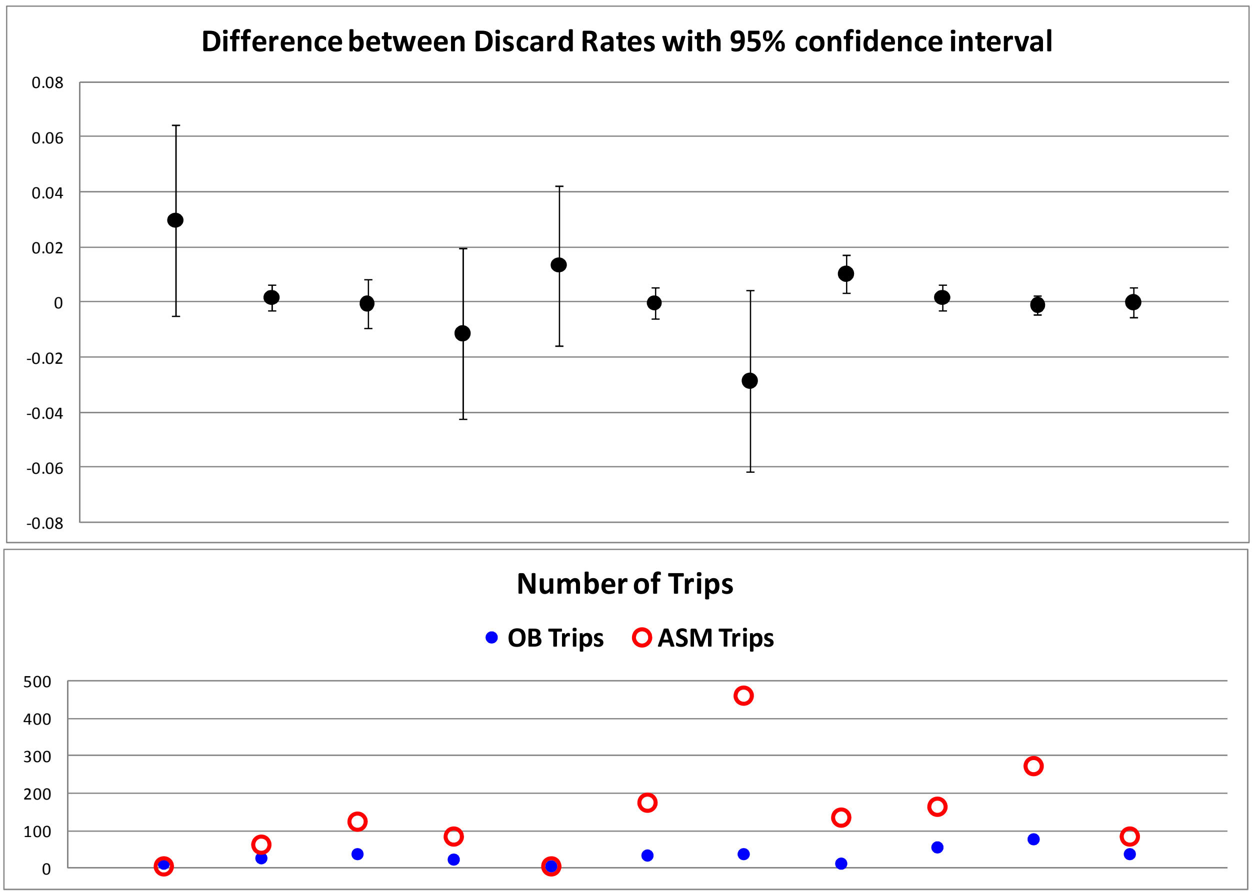


Figure 10. Difference between ASM and Observer discard rate, with 95% confidential interval, for **Eastern Georges Bank Cod** for NEFOP data collection from May through December 2010. Five gear/mesh and quarter combinations were evaluated ; samples sizes are given by ASM and OB data set.

All 5 overlapped zero

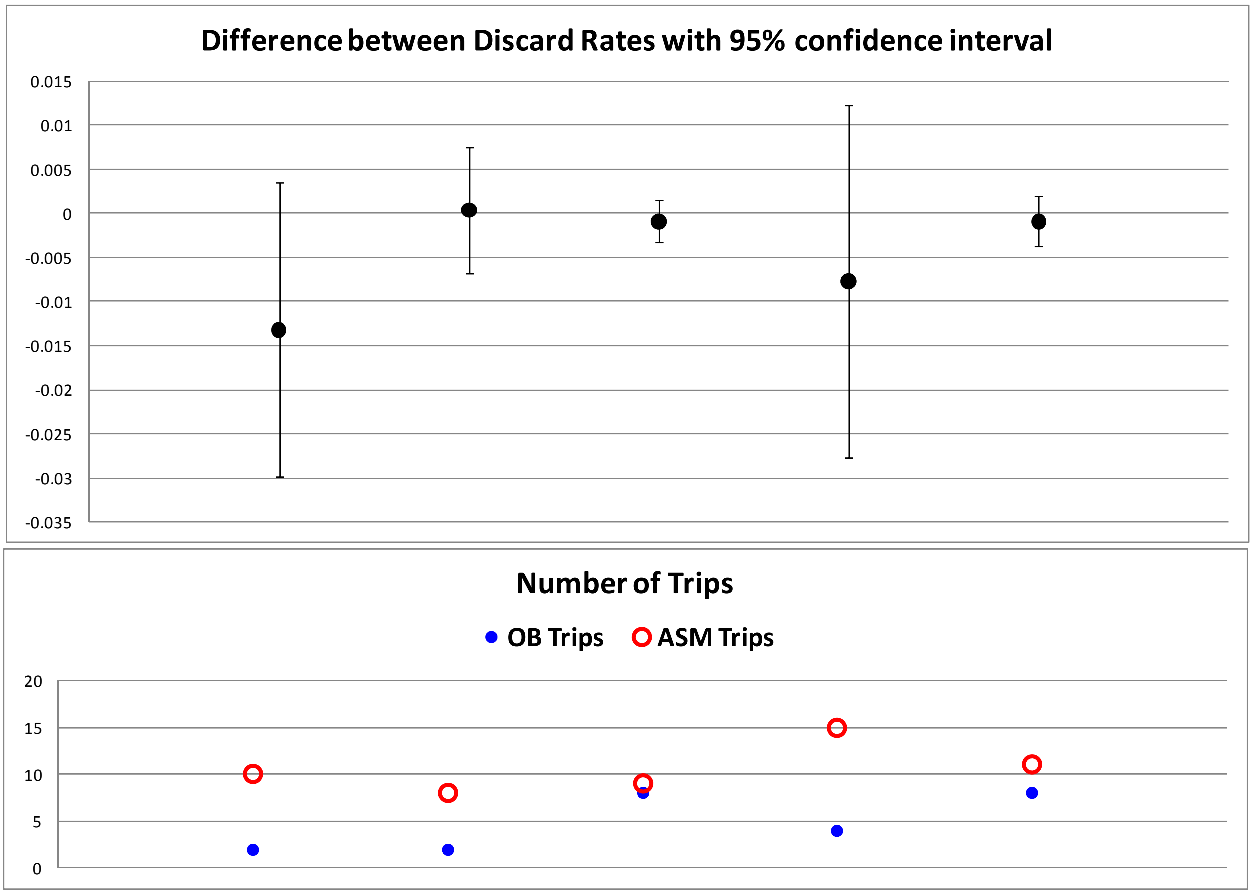


Figure 11 . Difference between ASM and Observer discard rate, with 95% confidential interval, for **Western Georges Bank Cod** for NEFOP data collection from May through December 2010. Fourteen gear/mesh and quarter combinations were evaluated ; samples sizes are given by ASM and OB data set.

13 of 14 cells overlapped zero

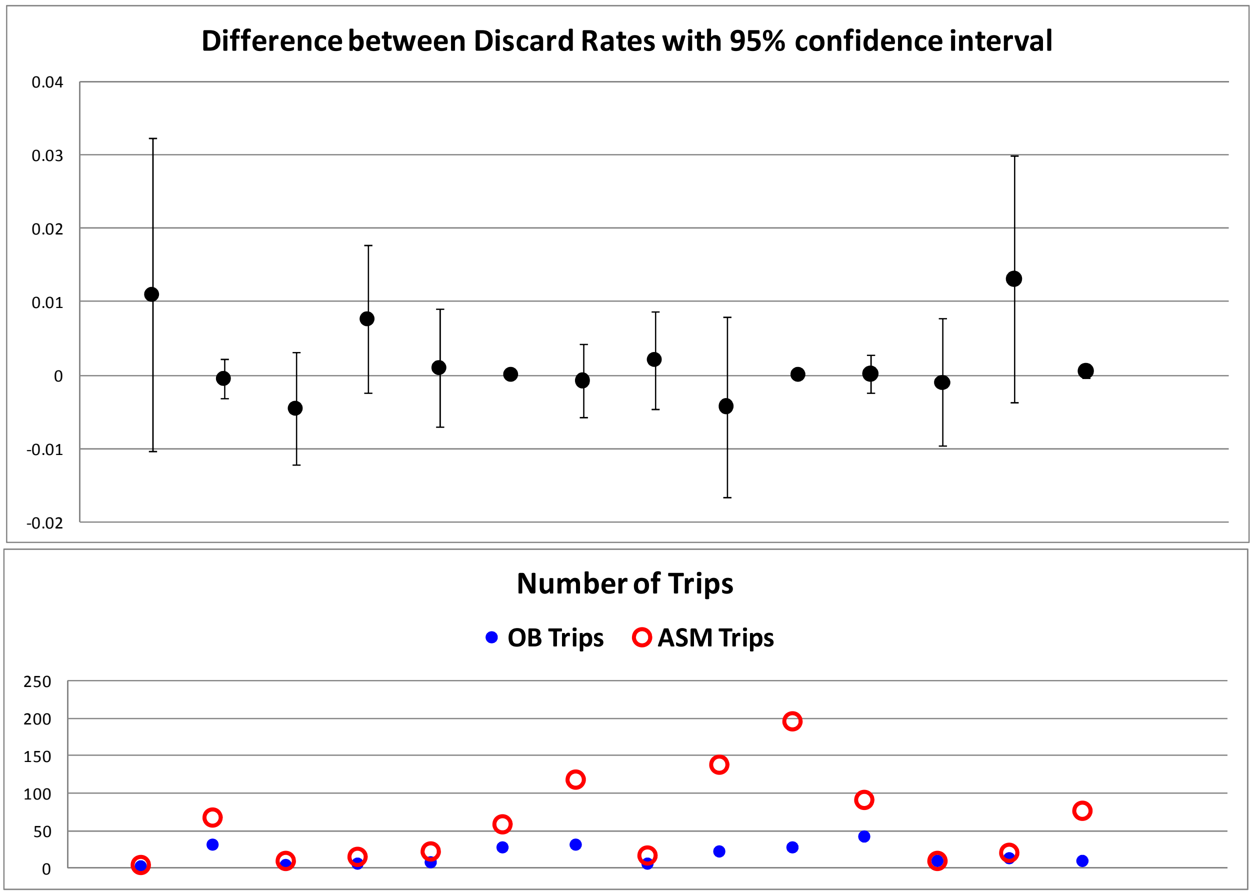


Figure 12. Difference between ASM and Observer discard rate, with 95% confidential interval, for **Gulf of Maine Haddock** for NEFOP data collection from May through December 2010. Eleven gear/mesh and quarter combinations were evaluated ; samples sizes are given by ASM and OB data set.

9 of 11 cells overlapped zero

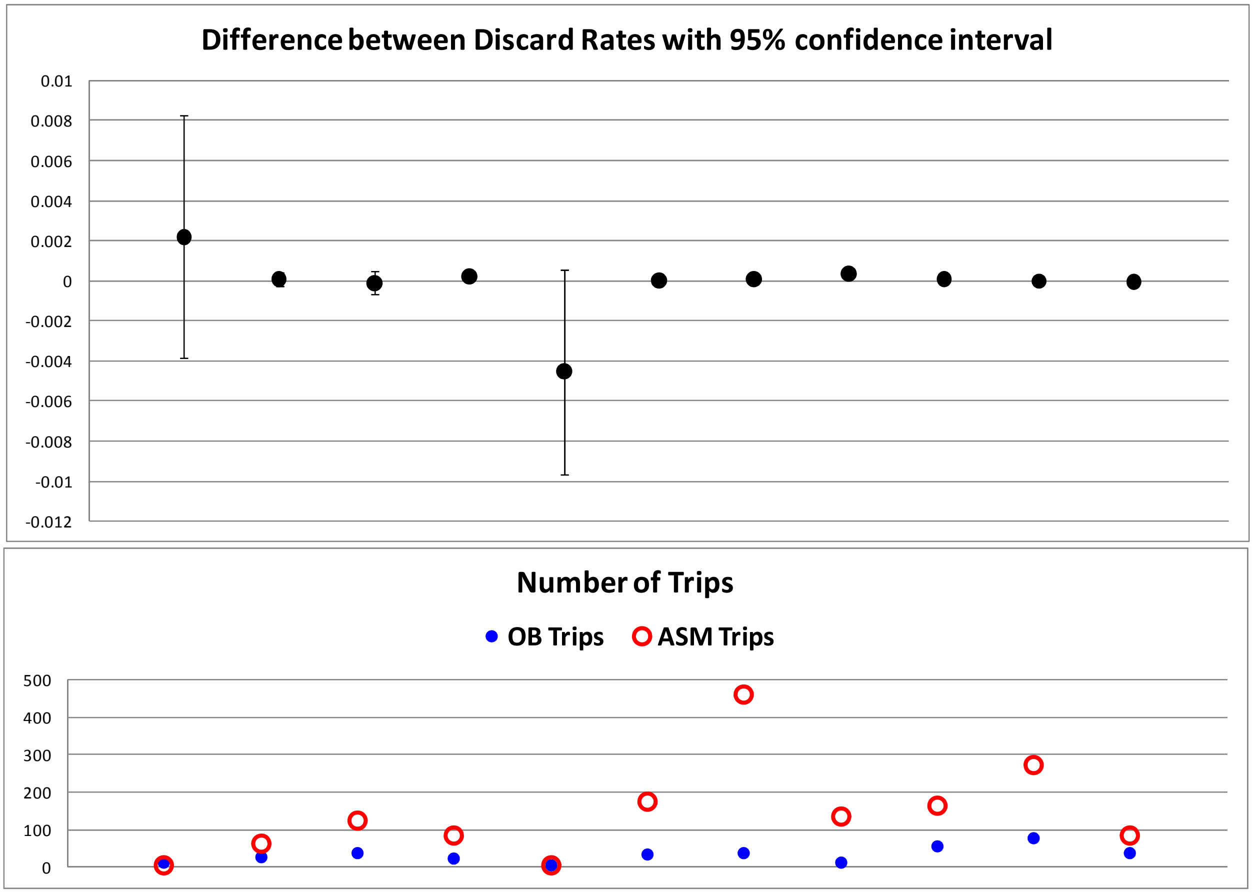


Figure 13. Difference between ASM and Observer discard rate, with 95% confidential interval, for **Eastern Georges Bank Haddock** for NEFOP data collection from May through December 2010. Five gear/mesh and quarter combinations were evaluated ; samples sizes are given by ASM and OB data set.

All 5 cells overlapped zero

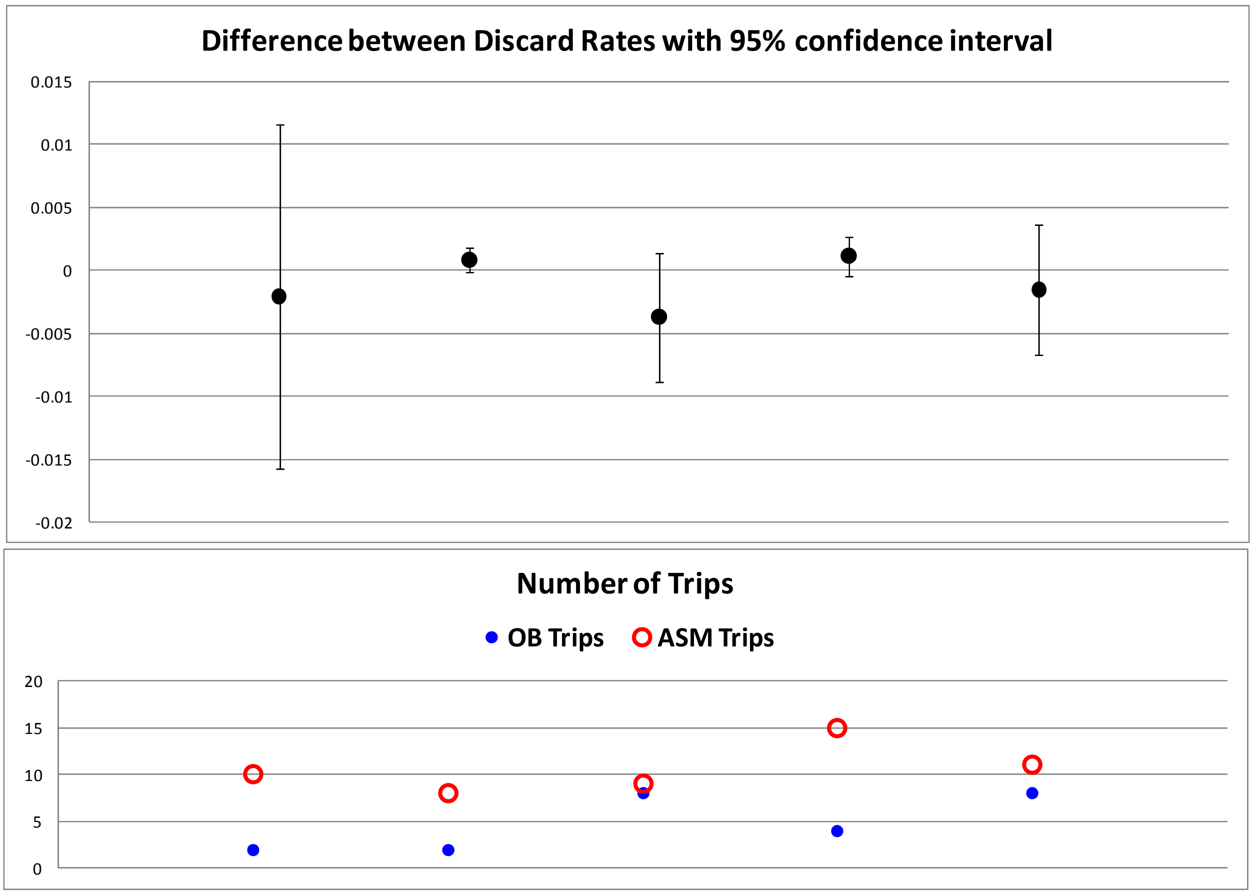


Figure 14. Difference between ASM and Observer discard rate, with 95% confidential interval, for **Western Georges Bank Haddock** for NEFOP data collection from May through December 2010. Fourteen gear/mesh and quarter combinations were evaluated ; samples sizes are given by ASM and OB data set.

12 of 14 cells overlapped zero

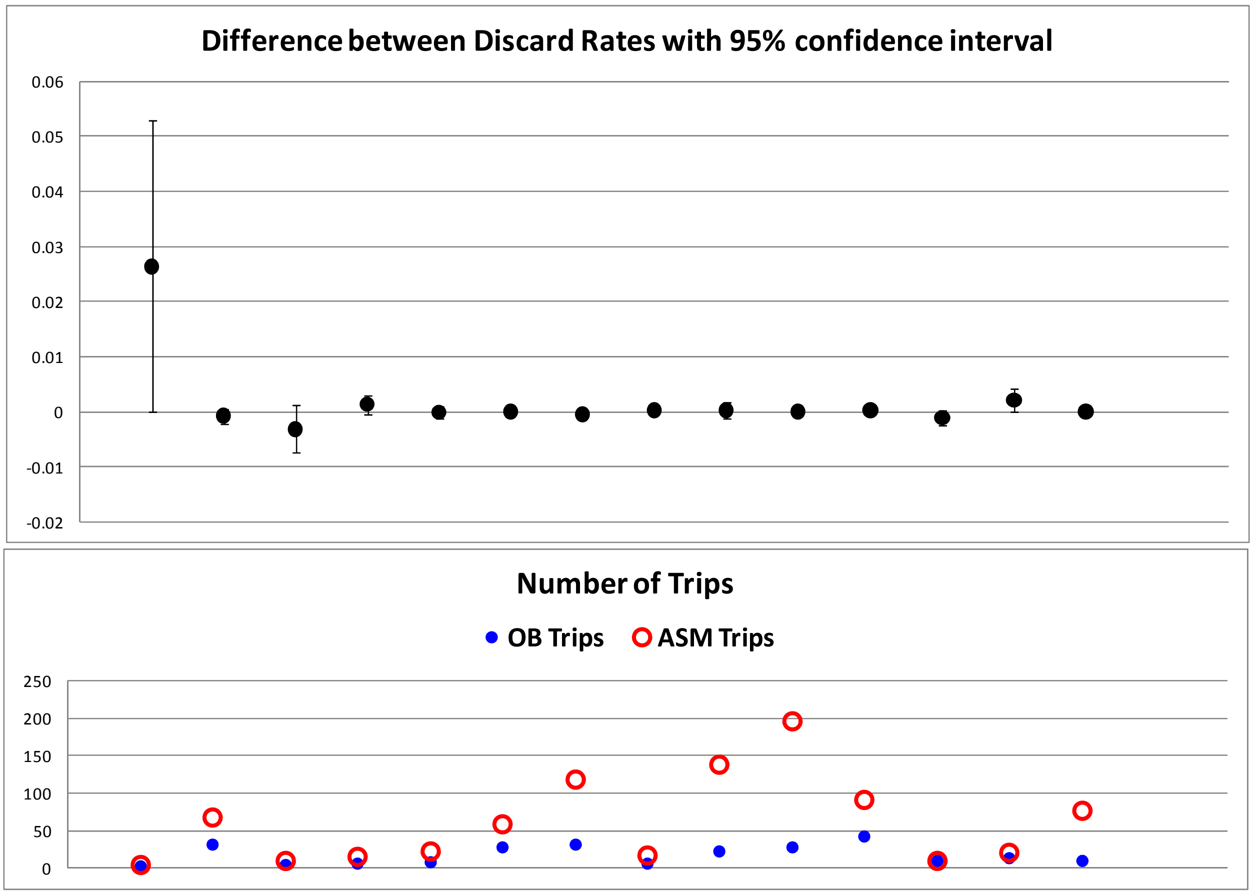
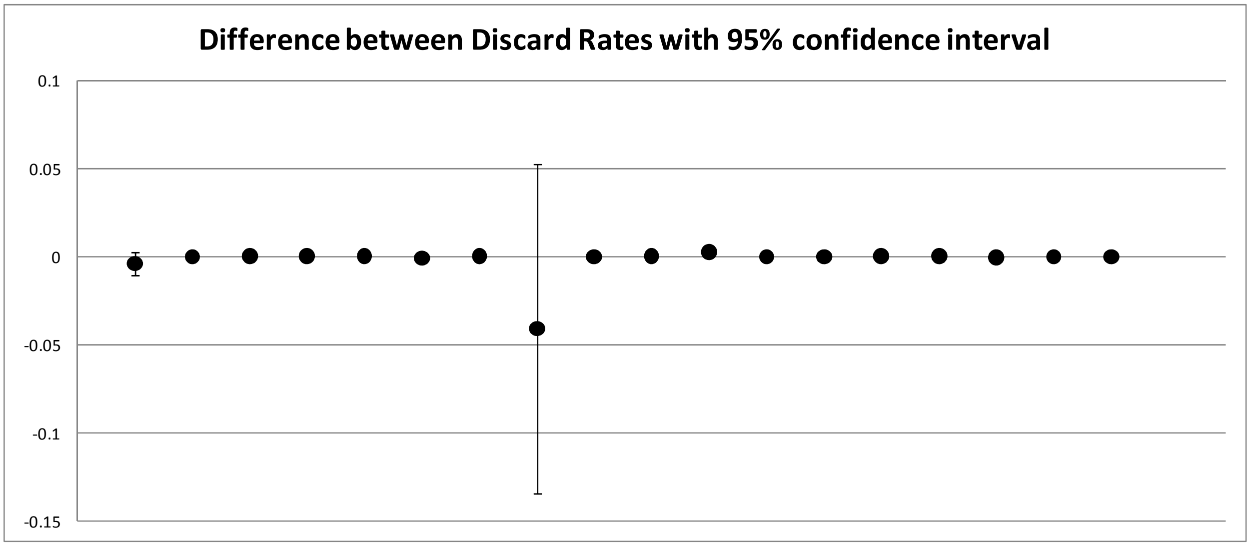


Figure15. Difference between ASM and Observer discard rate, with 95% confidential interval, for **Atlantic halibut** for NEFOP data collection from May through December 2010. Eighteen gear/mesh and quarter combinations were evaluated; samples sizes are given by ASM and OB data set.

14 of 18 cells overlapped zero



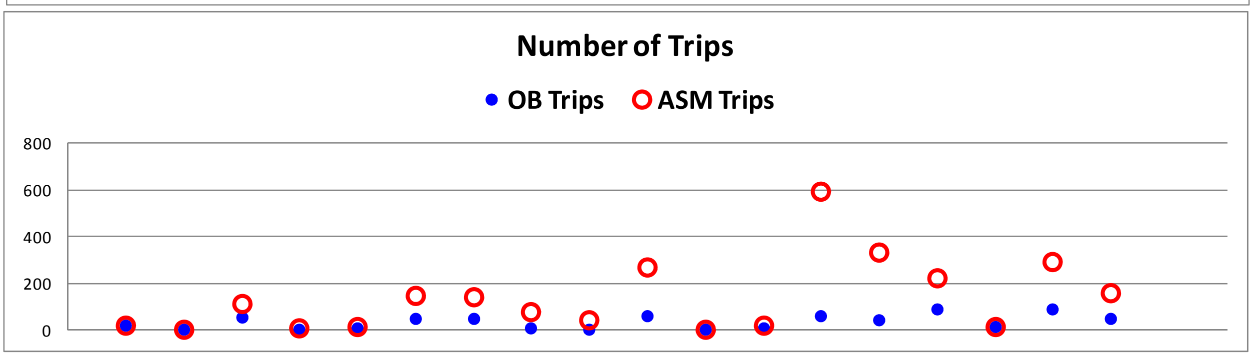


Figure 16. Difference between ASM and Observer discard rate, with 95% confidential interval, for **Southern monkfish** for NEFOP data collection from May through December 2010. Ten gear/mesh and quarter combinations were evaluated; samples sizes are given by ASM and OB data set.

All 10 cells overlapped zero

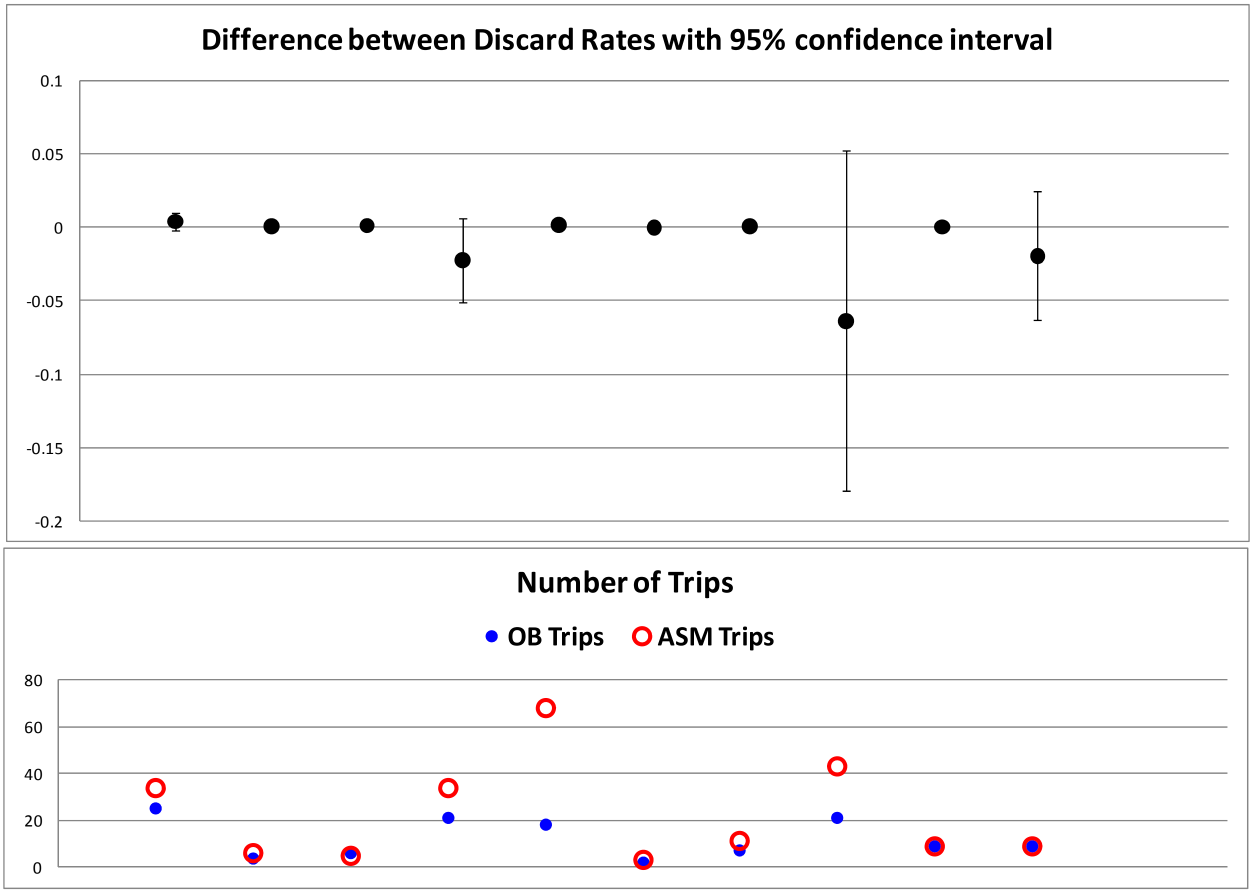
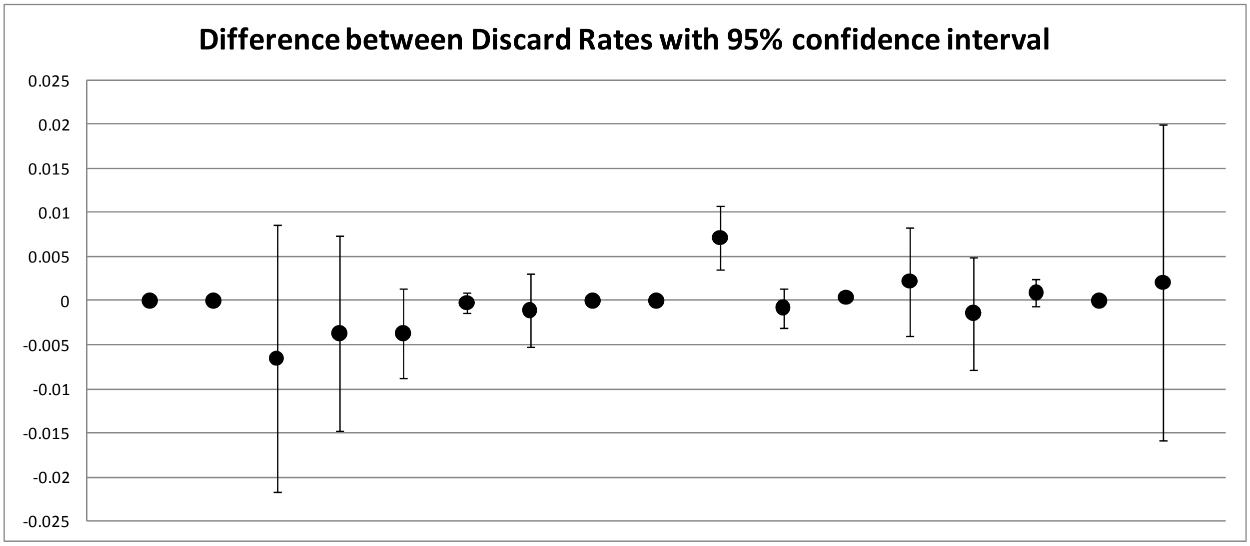


Figure 17. Difference between ASM and Observer discard rate, with 95% confidential interval, for **Northern monkfish** for NEFOP data collection from May through December 2010. Seventeen gear/mesh and quarter combinations were evaluated; samples sizes are given by ASM and OB data set.

16 of 17 cells overlapped zero



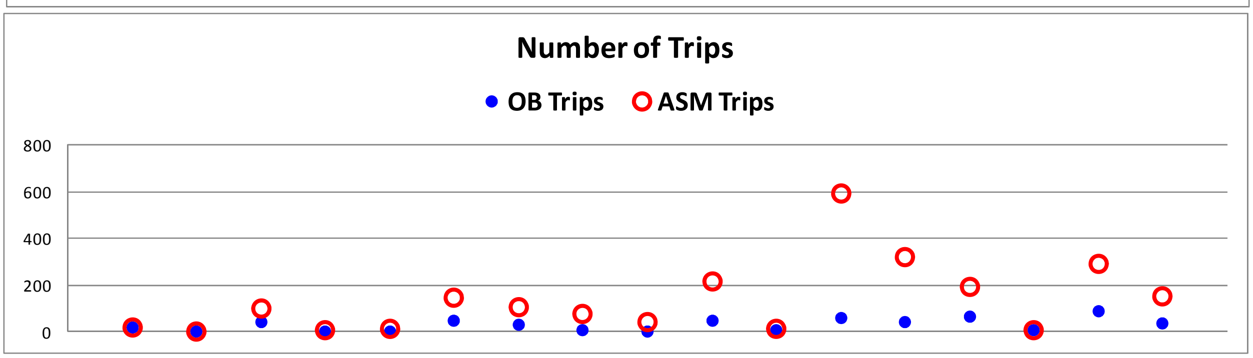


Figure 18. Difference between ASM and Observer discard rate, with 95% confidential interval, for **ocean pout** for NEFOP data collection from May through December 2010. eighteen gear/mesh and quarter combinations were evaluated; samples sizes are given by ASM and OB data set.

All 18 cells overlapped zero

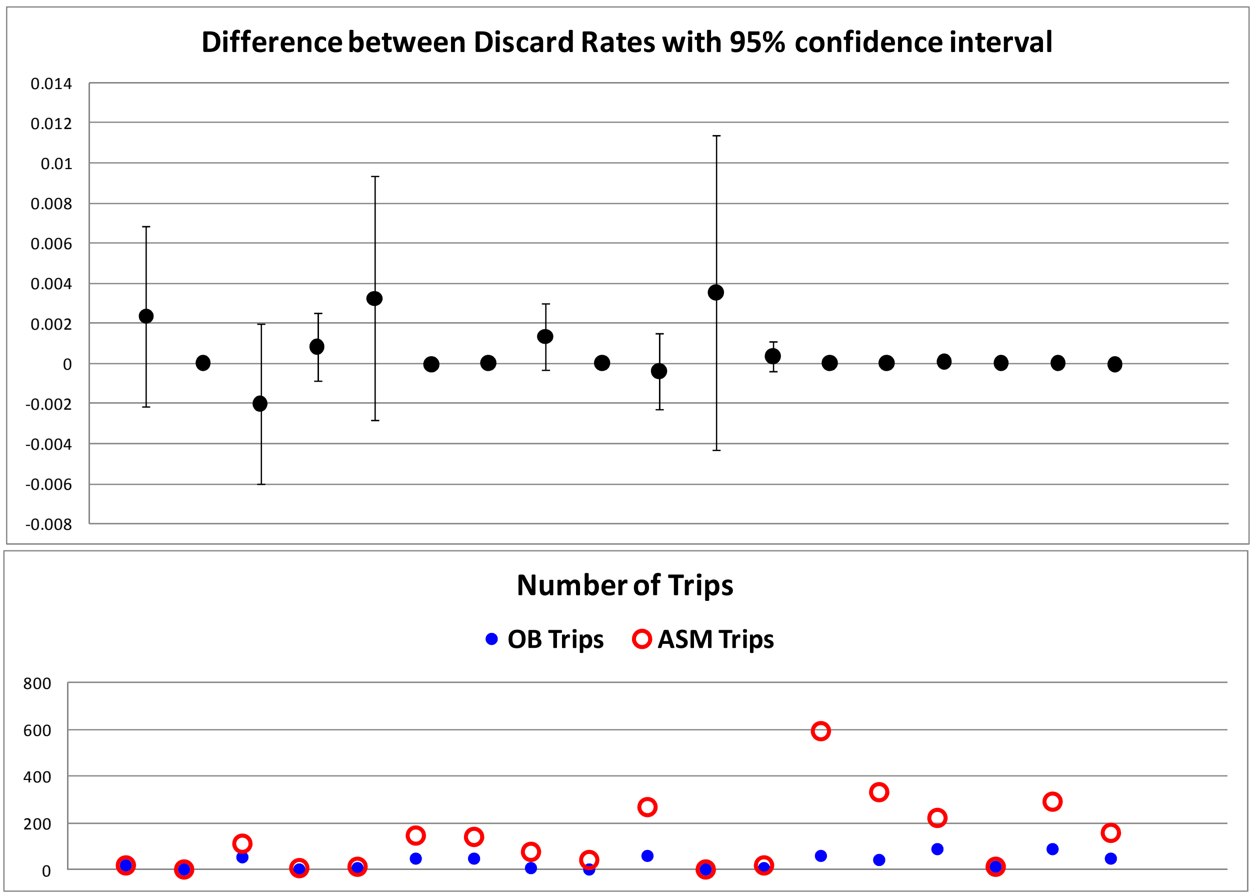
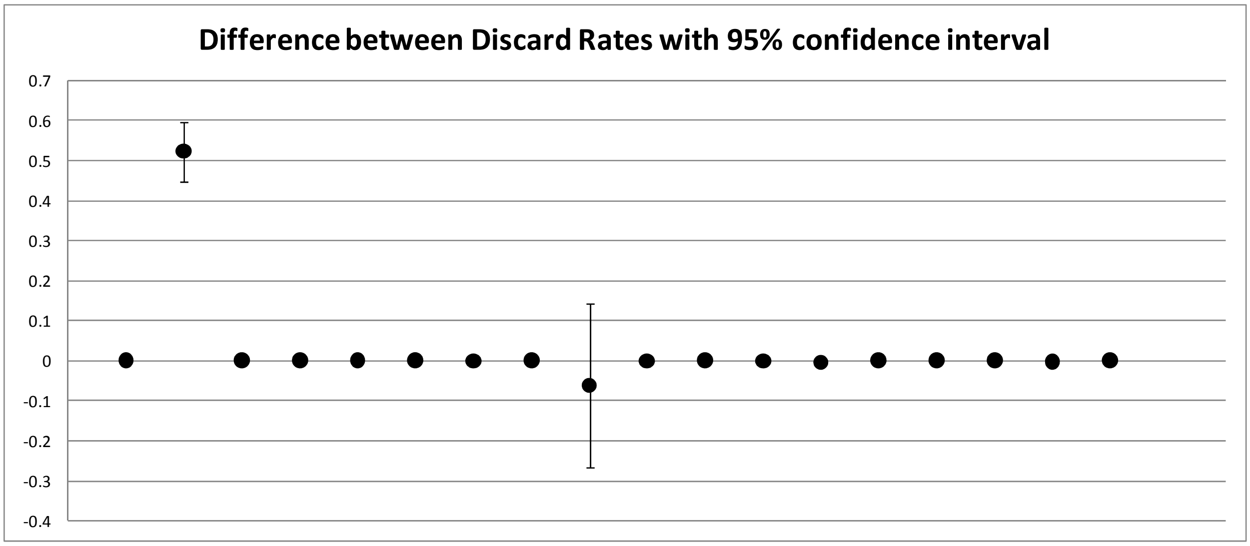


Figure 19. Difference between ASM and Observer discard rate, with 95% confidential interval, for **pollock** for NEFOP data collection from May through December 2010. Eighteen gear/mesh and quarter combinations were evaluated; samples sizes are given by ASM and OB data set.

15 of 18 cells overlapped zero



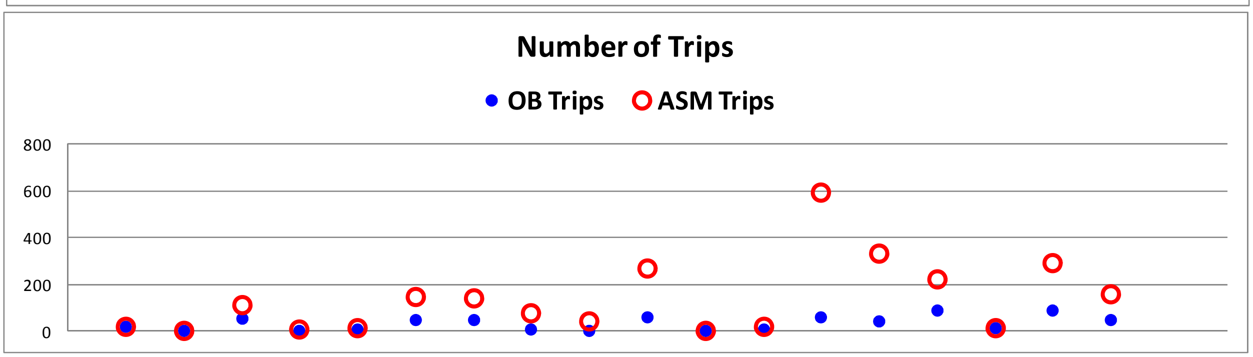


Figure 20. Difference between ASM and Observer discard rate, with 95% confidential interval, for **redfish** for NEFOP data collection from May through December 2010. Eighteen gear/mesh and quarter combinations were evaluated; samples sizes are given by ASM and OB data set.

17of 18 cells overlapped zero

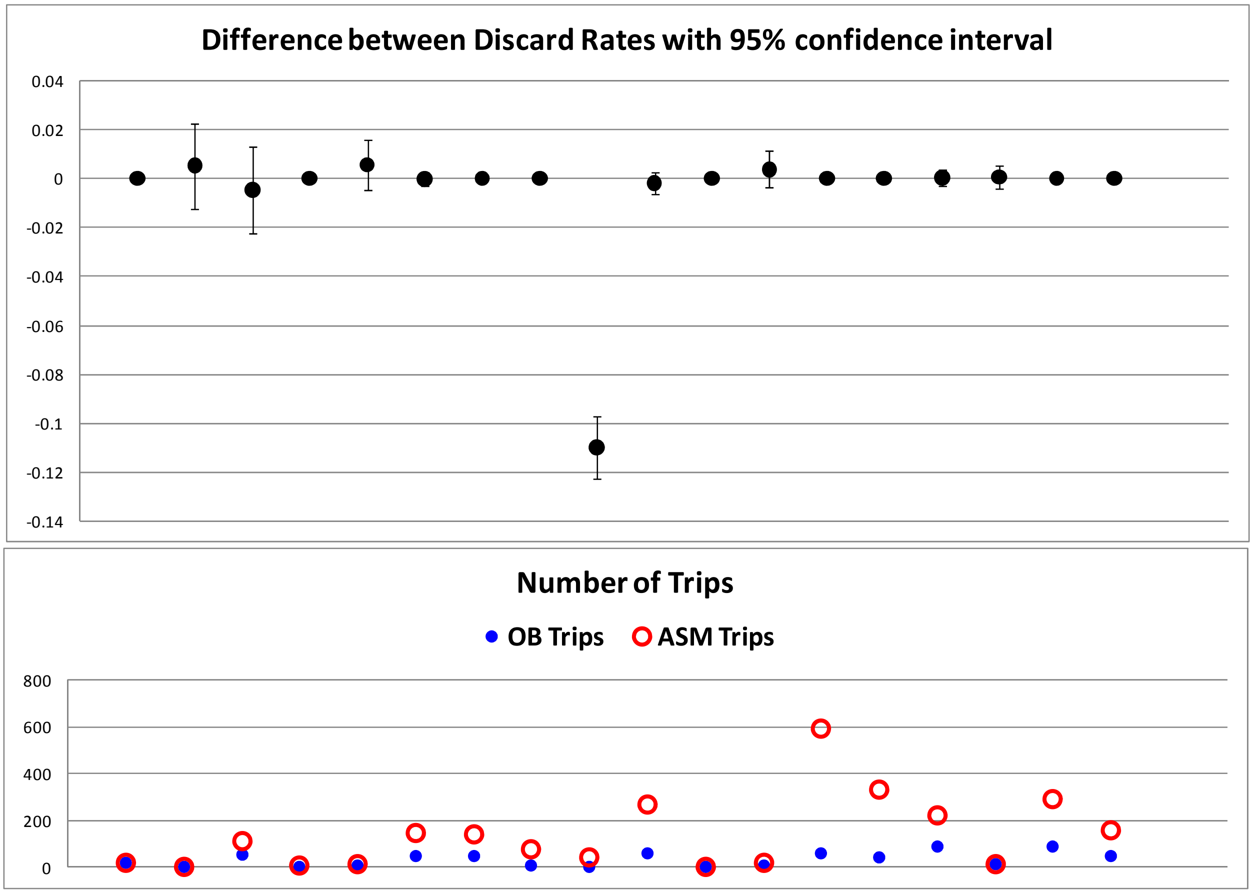


Figure 21. Difference between ASM and Observer discard rate, with 95% confidential interval, for **northern red hake** for NEFOP data collection from May through December 2010. Seventeen gear/mesh and quarter combinations were evaluated; samples sizes are given by ASM and OB data set.

14 of 17 cells overlapped zero

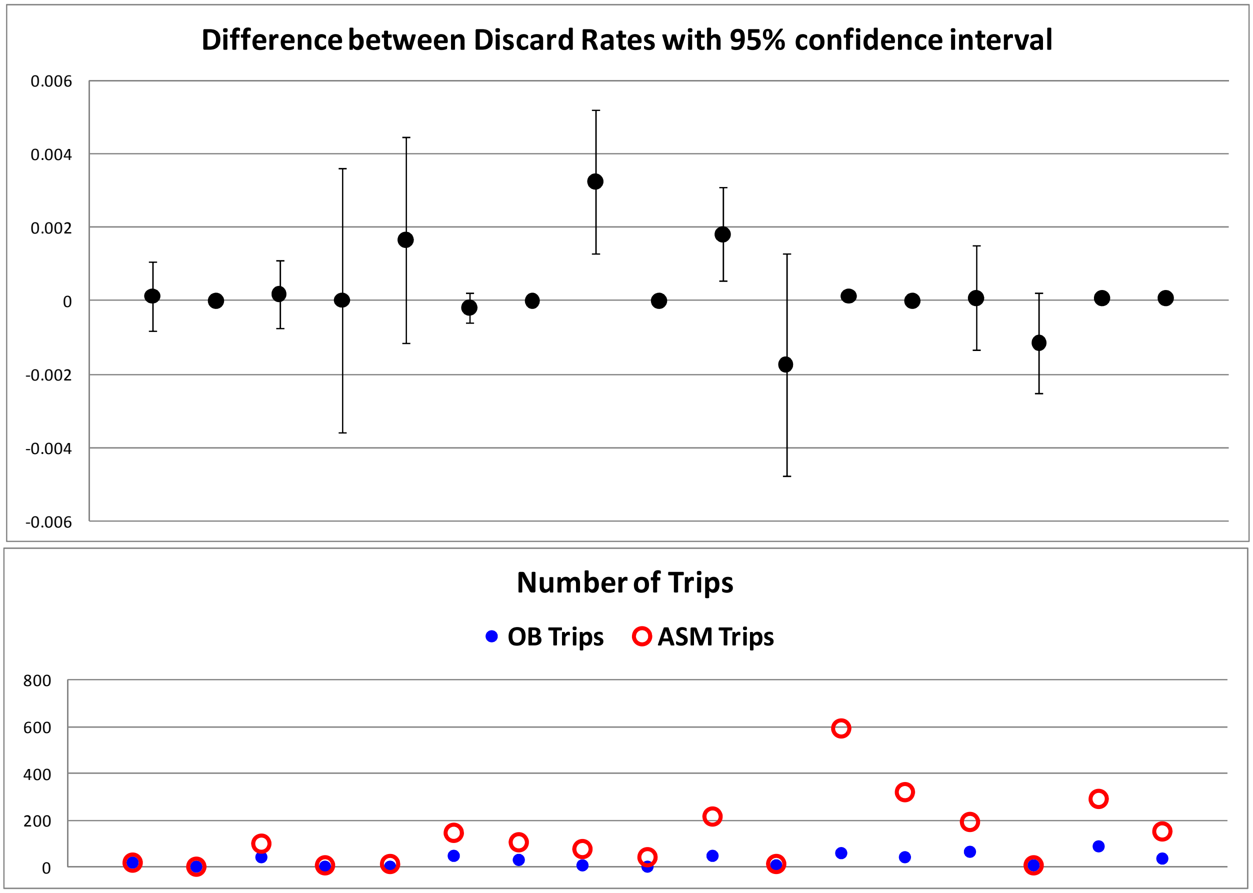
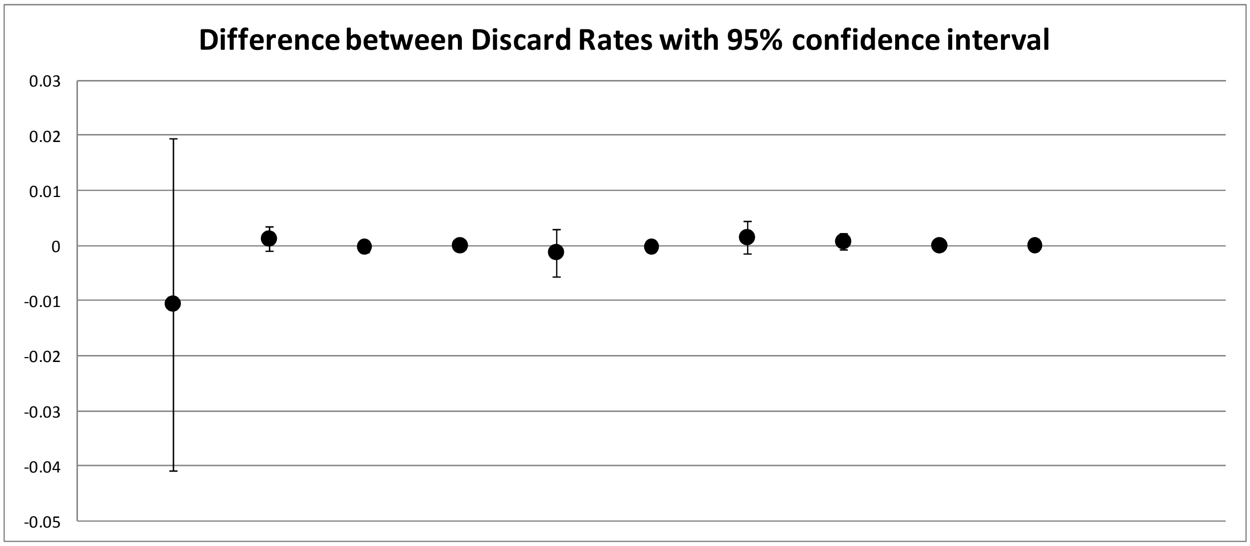


Figure22 . Difference between ASM and Observer discard rate, with 95% confidential interval, for **southern red hake** for NEFOP data collection from May through December 2010. Ten gear/mesh and quarter combinations were evaluated; samples sizes are given by ASM and OB data set.

9 of 10 cells overlapped zero



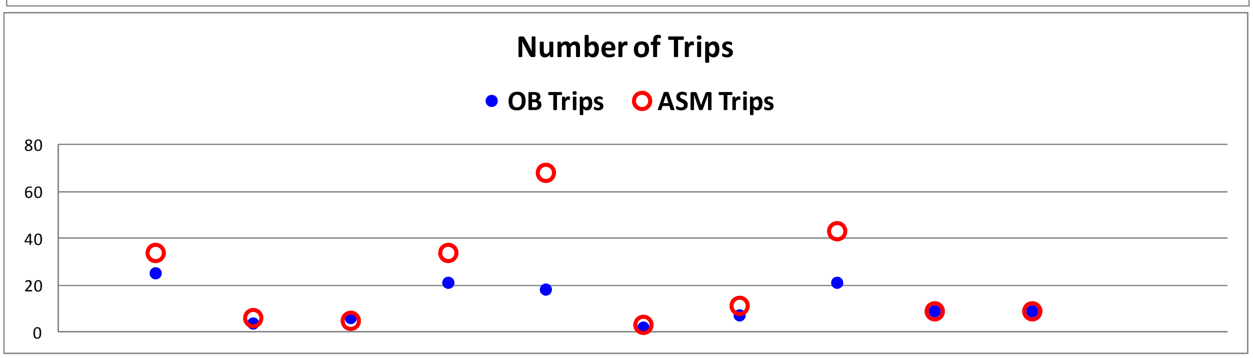
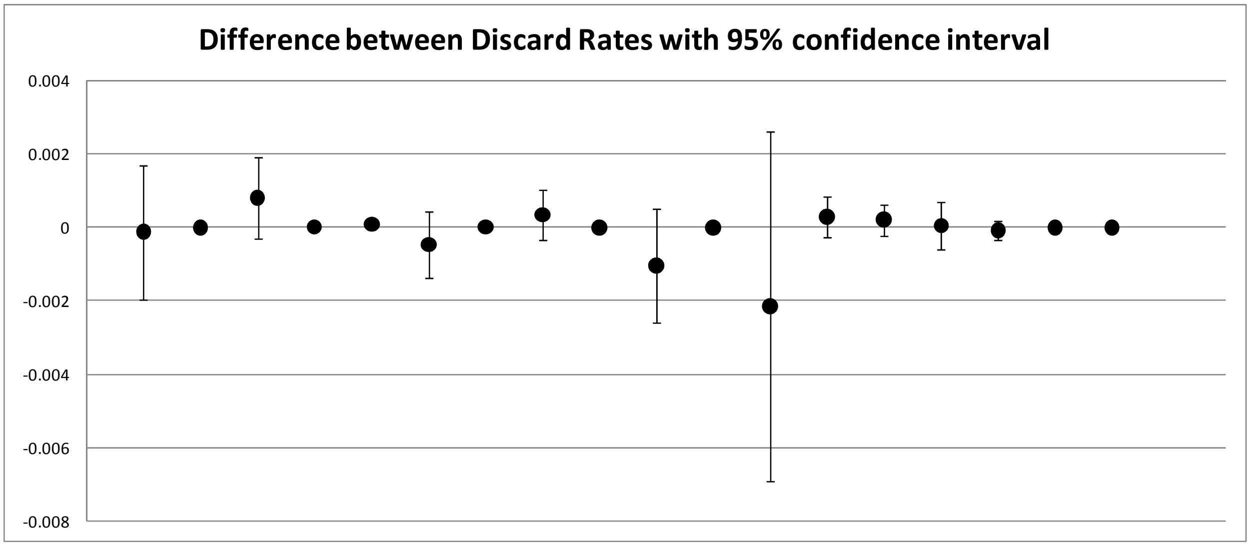


Figure 23. Difference between ASM and Observer discard rate, with 95% confidential interval, for **sea scallop** for NEFOP data collection from May through December 2010. Eighteen gear/mesh and quarter combinations were evaluated; samples sizes are given by ASM and OB data set.

all 18 cells overlapped zero



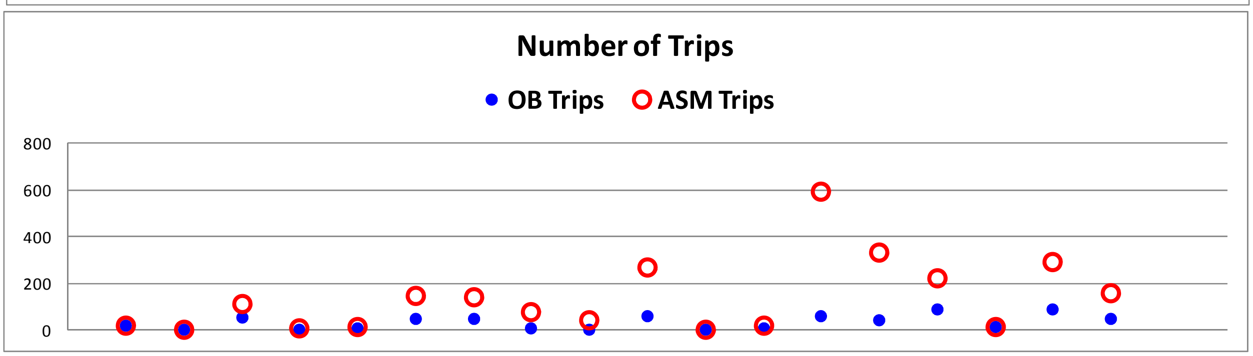
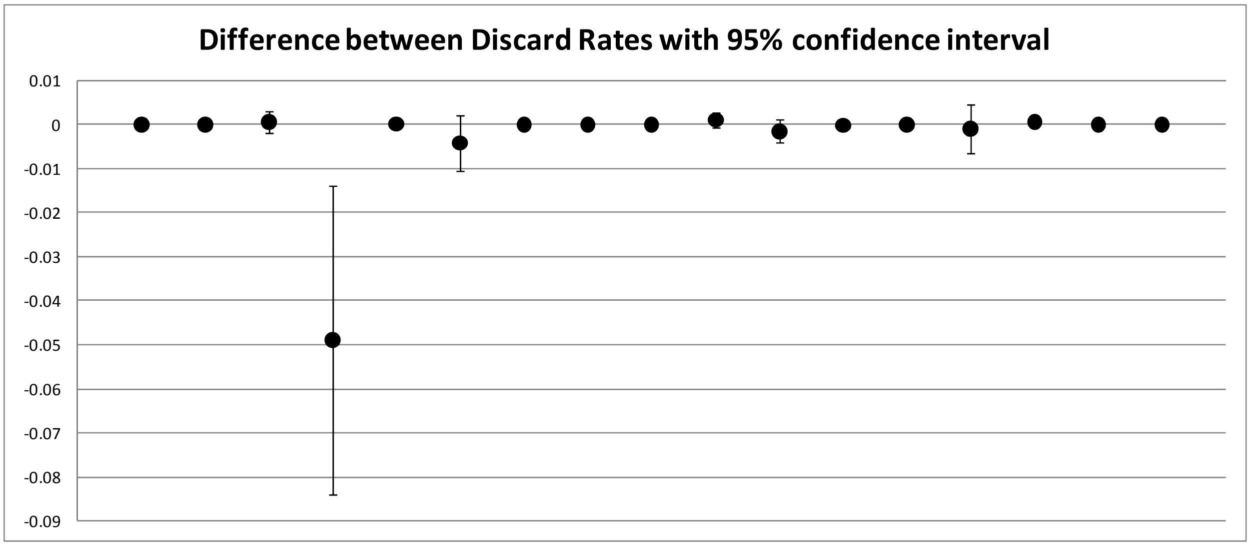


Figure 24. Difference between ASM and Observer discard rate, with 95% confidential interval, for **northern silver hake** for NEFOP data collection from May through December 2010. Seventeen gear/mesh and quarter combinations were evaluated; samples sizes are given by ASM and OB data set.

15 of 17 cells overlapped zero



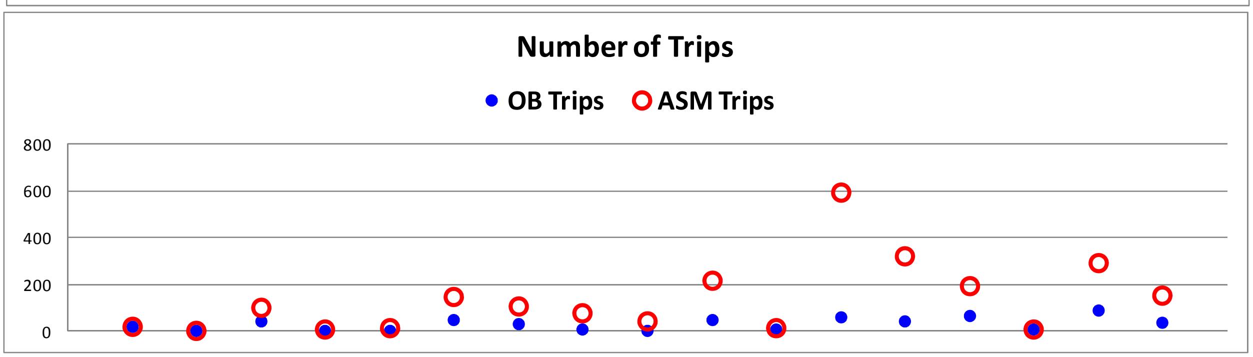


Figure 25. Difference between ASM and Observer discard rate, with 95% confidential interval, for **southern silver hake** for NEFOP data collection from May through December 2010. Ten gear/mesh and quarter combinations were evaluated; samples sizes are given by ASM and OB data set.

9 of 10 cells overlapped zero

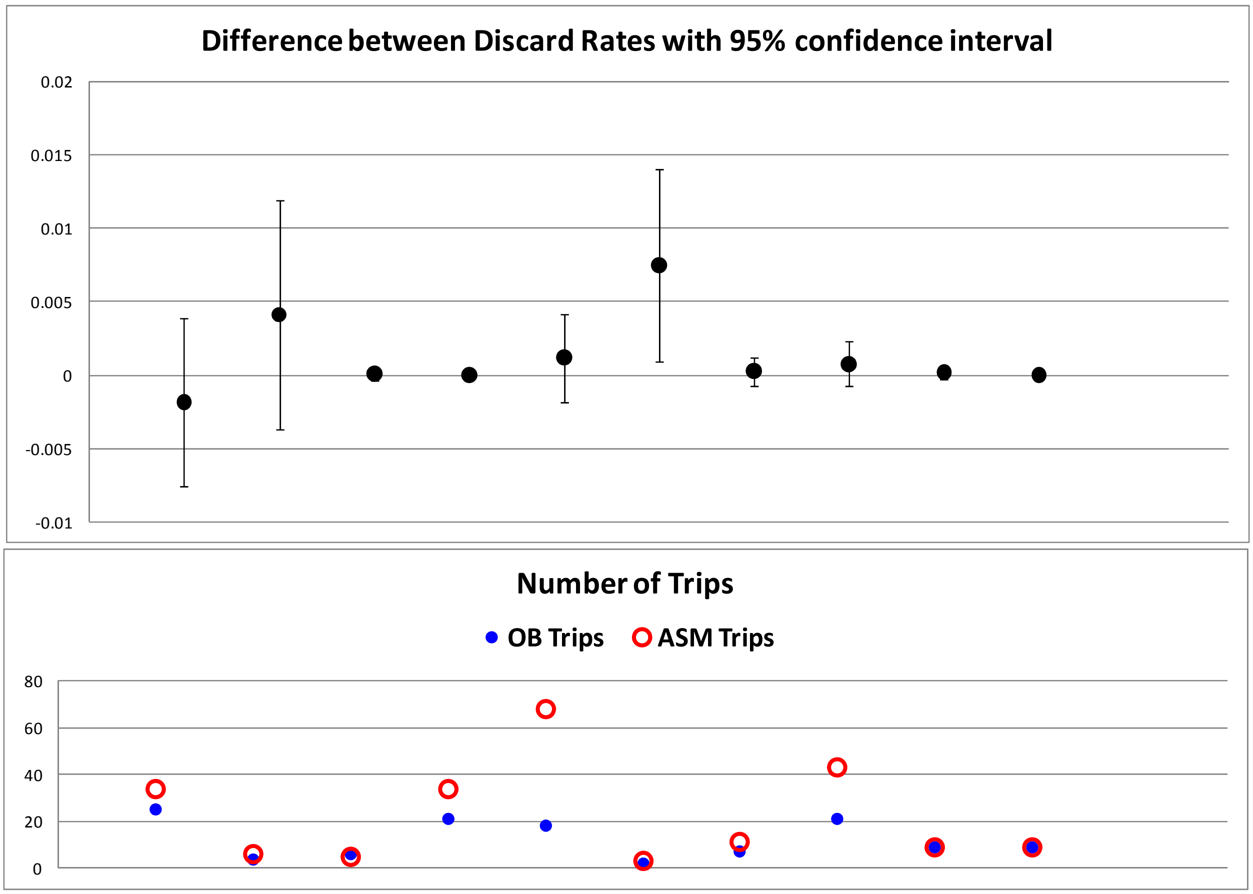


Figure 26. Difference between ASM and Observer discard rate, with 95% confidential interval, for **white hake** for NEFOP data collection from May through December 2010. Eighteen gear/mesh and quarter combinations were evaluated; samples sizes are given by ASM and OB data set.

15 of 18 cells overlapped zero

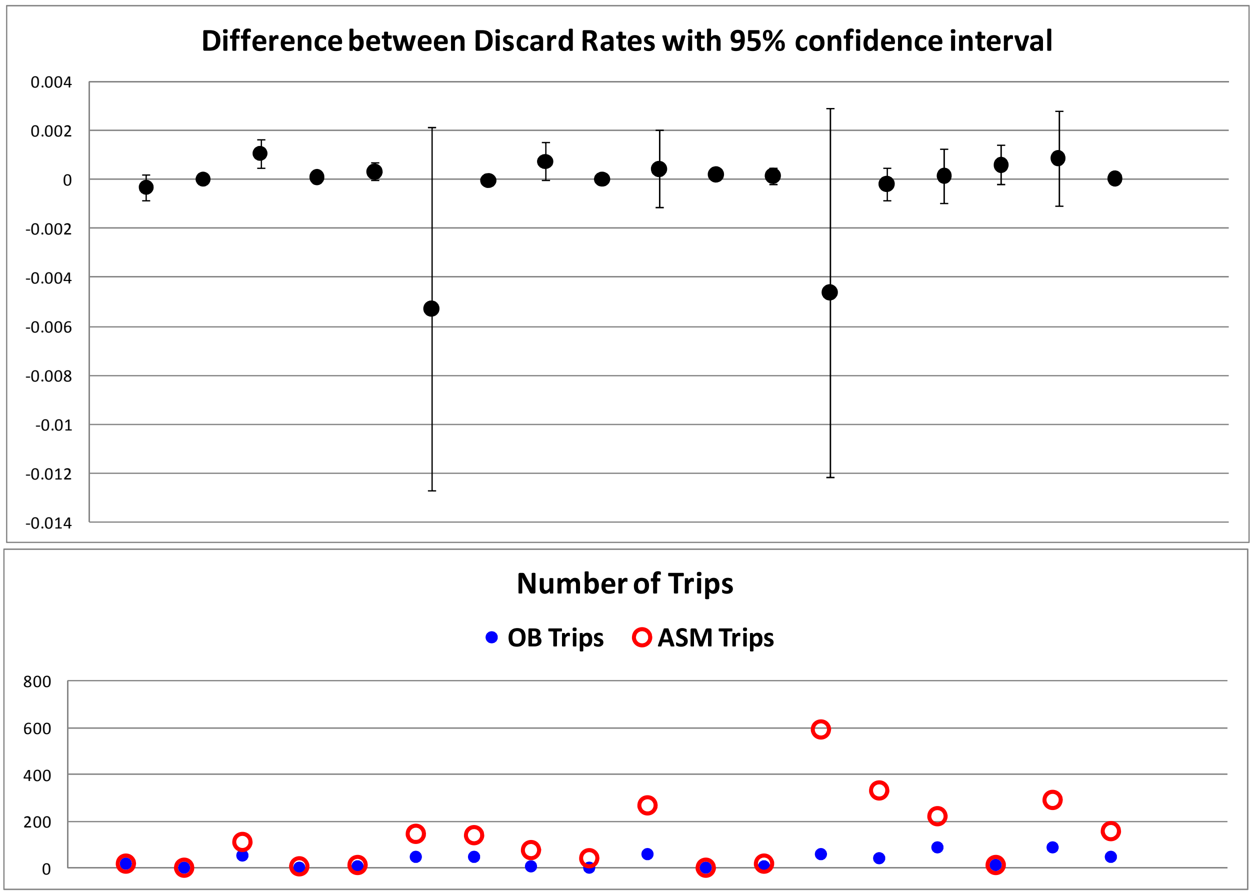
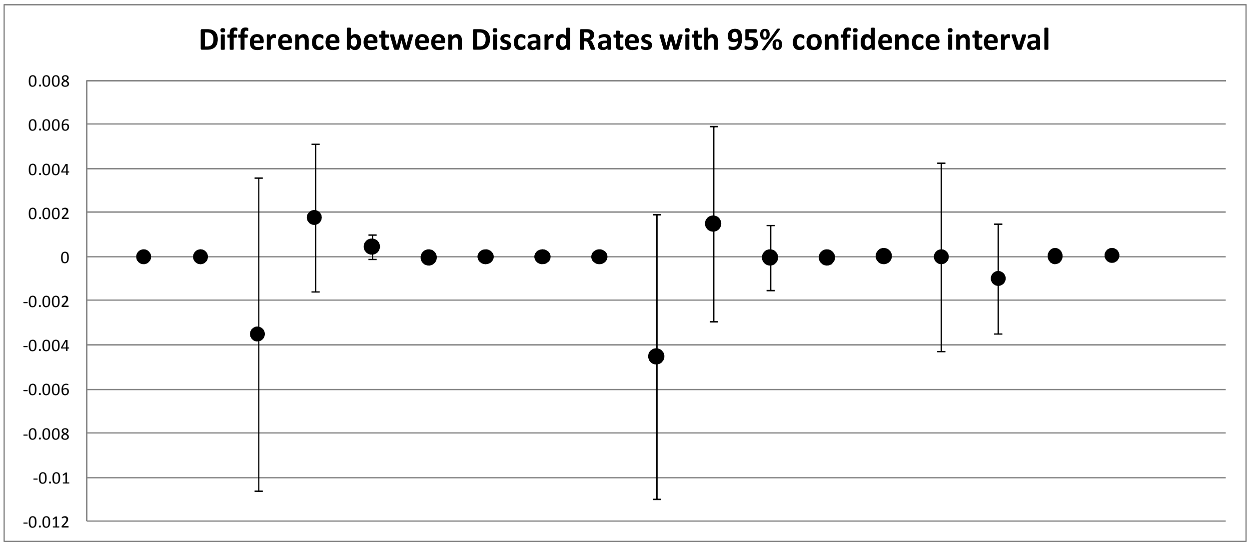


Figure 27. Difference between ASM and Observer discard rate, with 95% confidential interval, for **northern windowpane flounder** for NEFOP data collection from May through December 2010. Eighteen gear/mesh and quarter combinations were evaluated; samples sizes are given by ASM and OB data set.

all 18 cells overlapped zero



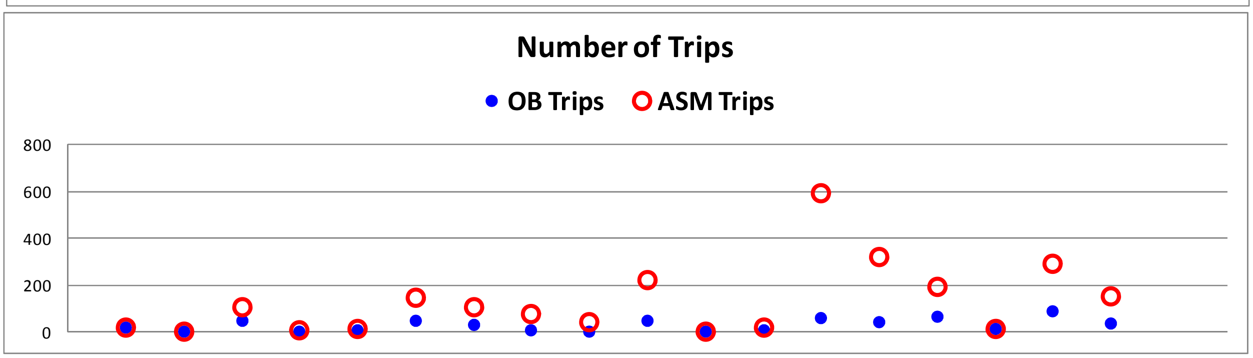
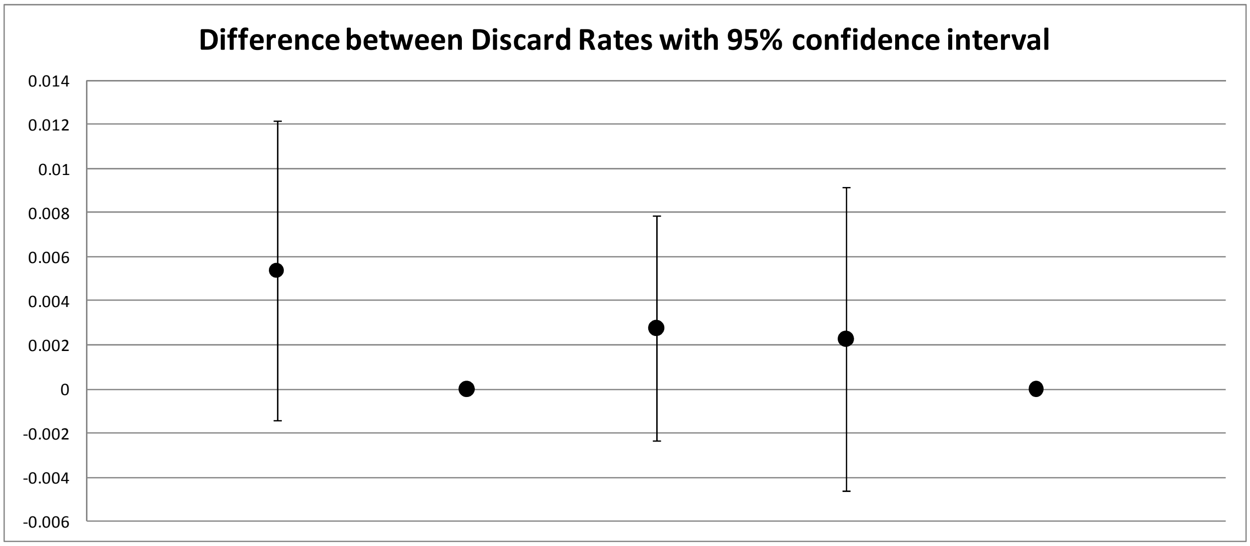


Figure 28. Difference between ASM and Observer discard rate, with 95% confidential interval, for **southern windowpane flounder** for NEFOP data collection from May through December 2010. Five gear/mesh and quarter combinations were evaluated; samples sizes are given by ASM and OB data set.

All 5cells overlapped zero



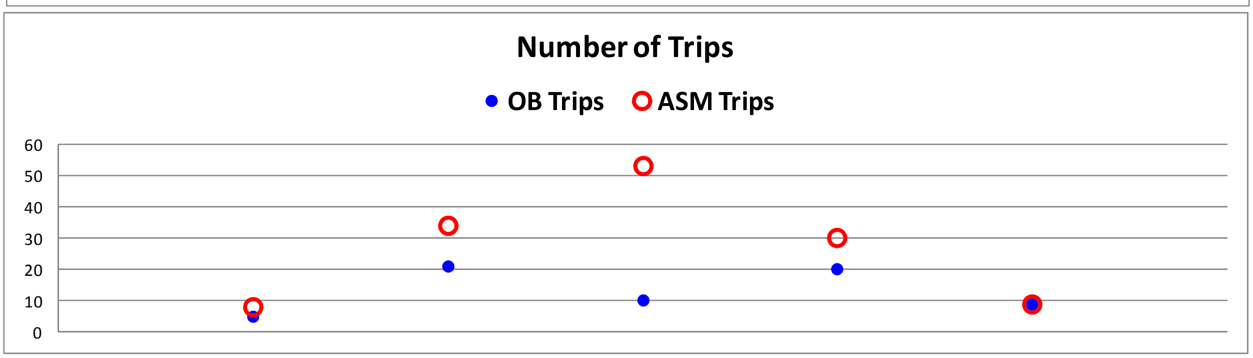


Figure 29. Difference between ASM and Observer discard rate, with 95% confidential interval, for **witch flounder** for NEFOP data collection from May through December 2010. Eighteen gear/mesh and quarter combinations were evaluated; samples sizes are given by ASM and OB data set.

16 of 18 cells overlapped zero

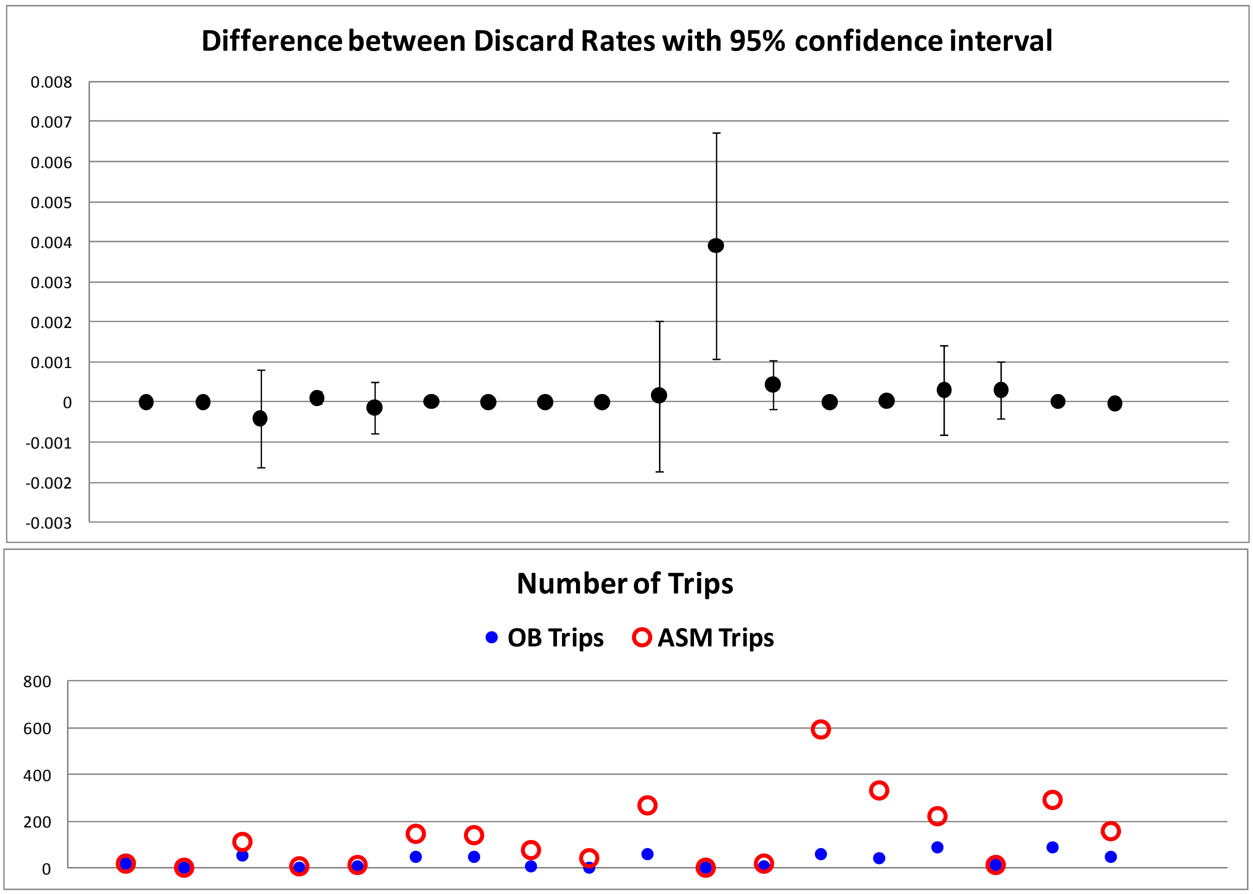


Figure 30. Difference between ASM and Observer discard rate, with 95% confidential interval, for **Atlantic wolffish** for NEFOP data collection from May through December 2010. Eighteen gear/mesh and quarter combinations were evaluated; samples sizes are given by ASM and OB data set.

all 18 cells overlapped zero

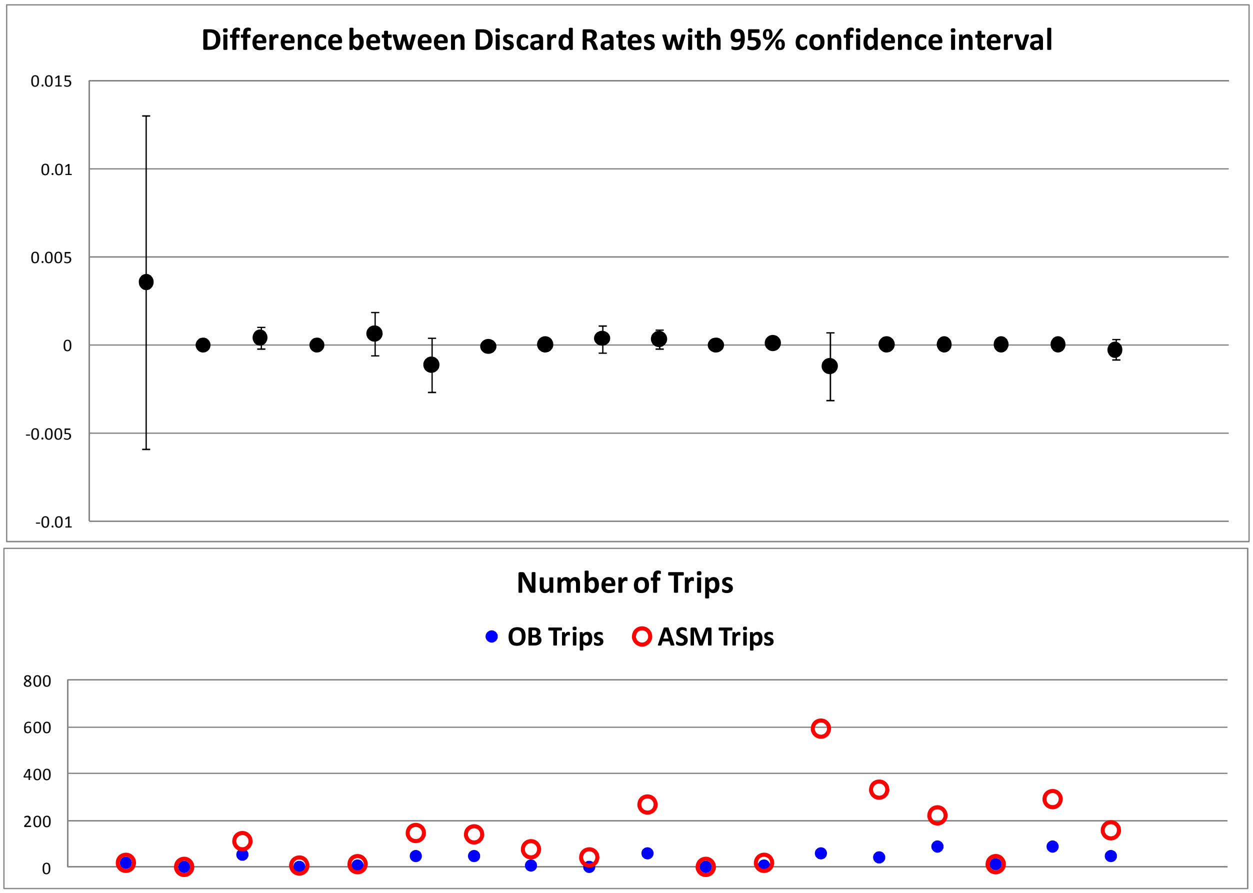
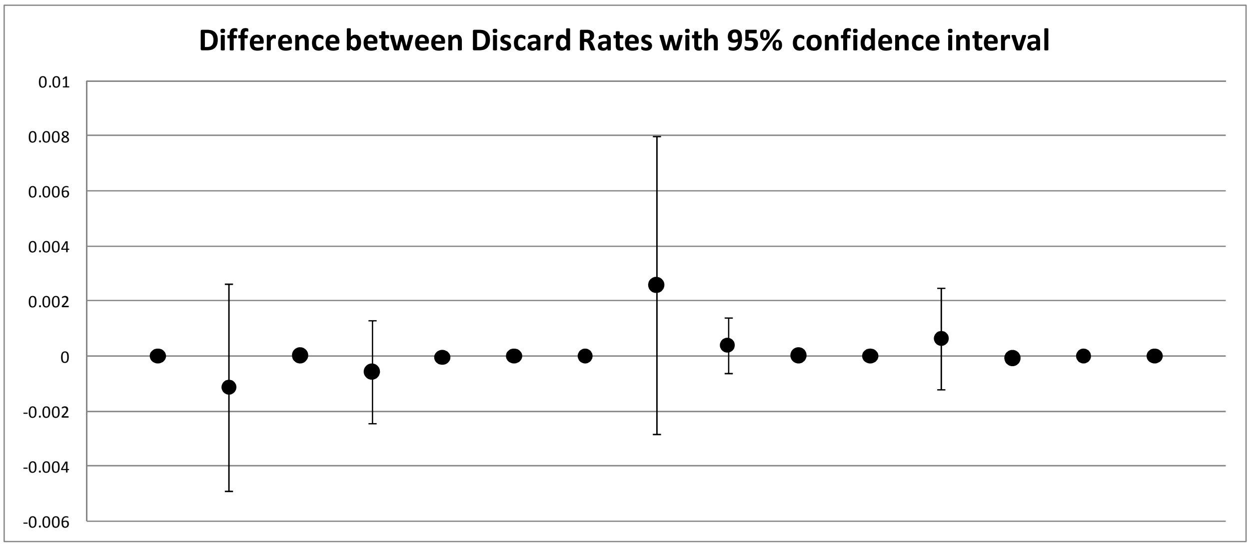


Figure 31. Difference between ASM and Observer discard rate, with 95% confidential interval, for **Gulf of Maine yellowtail flounder** for NEFOP data collection from May through December 2010. Fifteen gear/mesh and quarter combinations were evaluated; samples sizes are given by ASM and OB data set.

All 15 cells overlapped zero



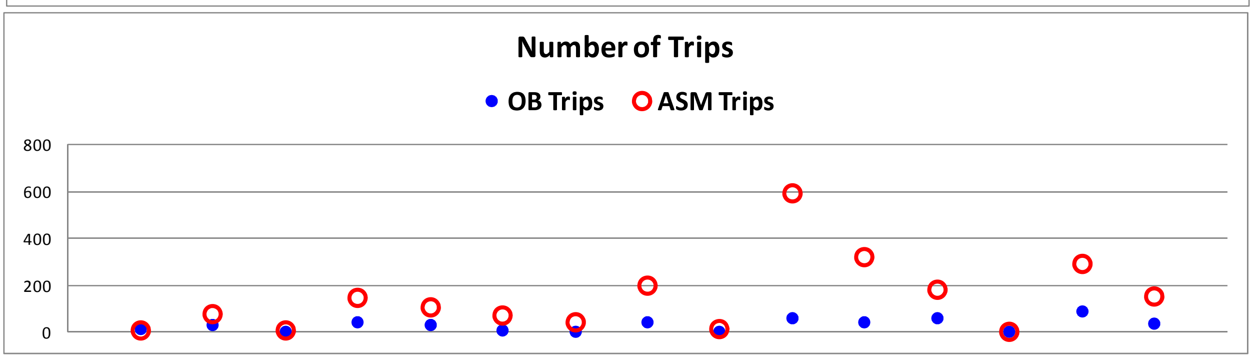


Figure 32. Difference between ASM and Observer discard rate, with 95% confidential interval, for **Georges Bank yellowtail flounder** for NEFOP data collection from May through December 2010. Nine gear/mesh and quarter combinations were evaluated; samples sizes are given by ASM and OB data set.

7 of 9 cells overlapped zero

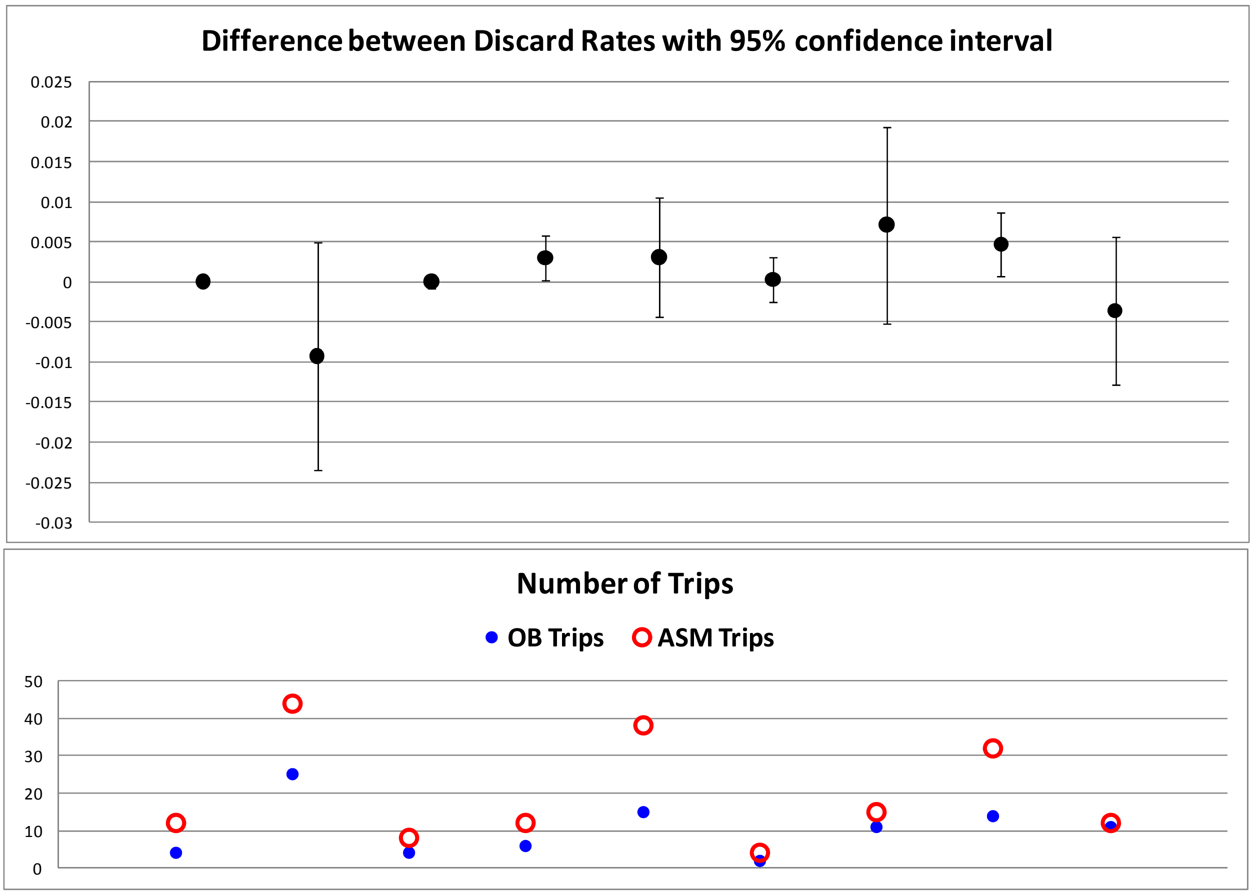
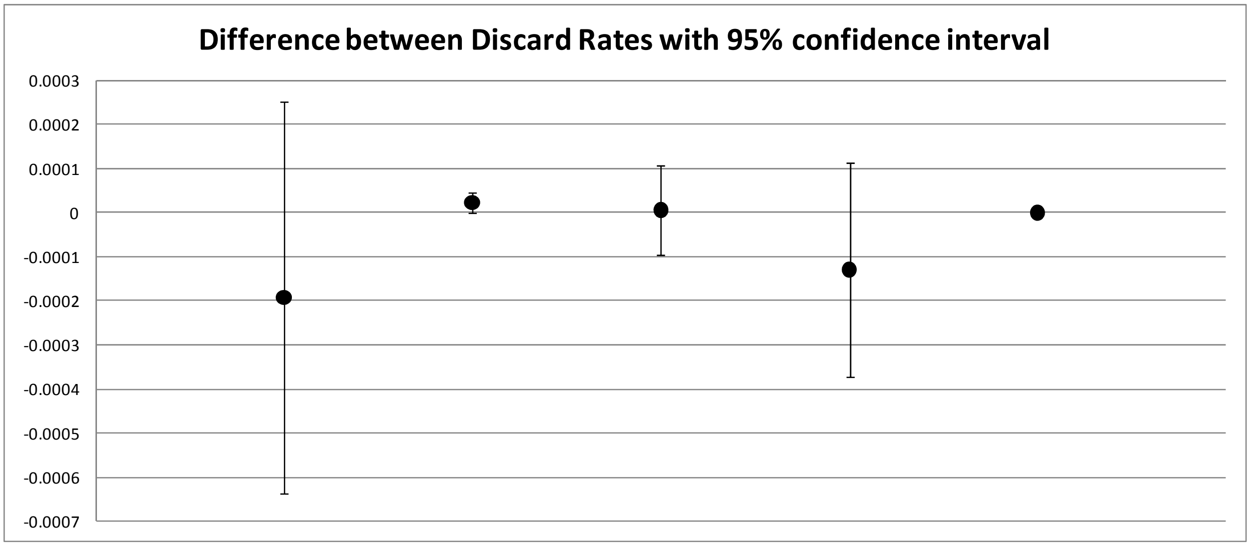
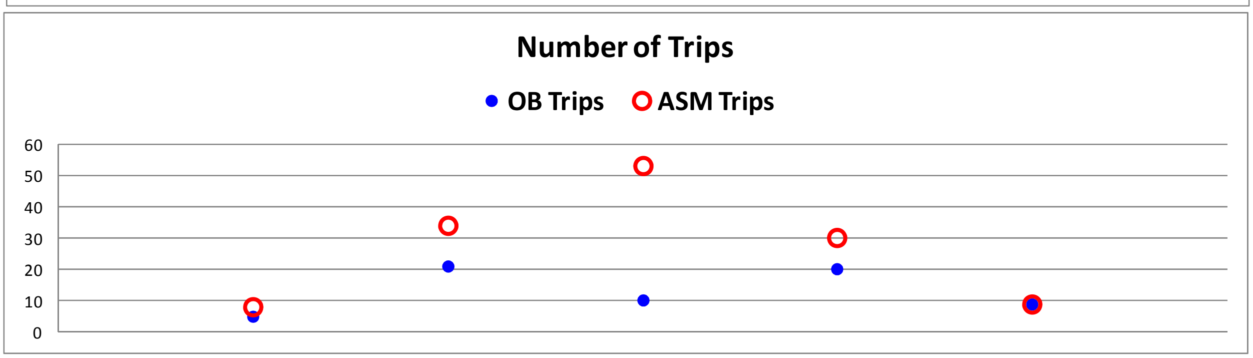


Figure 33. Difference between ASM and Observer discard rate, with 95% confidential interval, for **Southern New England yellowtail flounder** for NEFOP data collection from May through December 2010. Five gear/mesh and quarter combinations were evaluated; samples sizes are given by ASM and OB data set.

4 of 5 cells overlapped zero





SDWG Background WP#12
May 2011
Fish Repro Potential

Reproductive potential of female winter flounder, *Pseudopleuronectes americanus*:
Comparison of fecundity and skipped spawning among three stocks

A working paper presented at SARC 52

April 2011

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1.0 Introduction

Data on the reproductive potential of a species are useful for estimating egg production and improving stock-recruitment relationships; however, these data are limited for many species in the northwest Atlantic (reviewed in Tomkiewicz et al. 2003). Some studies have estimated potential annual fecundity in winter flounder, *Pseudopleuronectes americanus* (Saila 1961; Topp 1967; Kennedy and Steele 1971; NUSCO 1987; Buckley et al. 1991), but these investigations differed widely in methodologies, geographic locales, and years. Spawning frequency, another important measure of reproductive potential, has been found to be non-annual for some mature individuals in several species of marine fish (skipped spawning). Skipped spawning has been identified in winter flounder in several parts of its range (Burton and Idler 1984; Burton 1994; Wuenschel et al. 2009; McBride et al. 2010). The pathway for this interruption to the reproductive cycle can vary among species (reviewed in Rideout et al. 2005). Skipped spawning in winter flounder has been characterized as the 'resting' type where a clutch of oocytes is not developed in that year (Burton 1994; Rideout et al. 2005). Although some data on the reproduction of winter flounder exists; there remains a need for data on many reproductive traits over the geographic range of this species as well as for providing time series for these parameters. This working paper addresses this reproductive data need and establishes a method for long-term monitoring of mature winter flounder annual spawning rates and potential fecundity.

Autodiametric curves are a recent advancement for estimating fecundity from the relationship between oocyte diameter and oocyte density (number per gram) within the ovary(Kurita & Kjesbu 2008; Witthames et al. 2009). As oocyte diameter increases the packing density decreases in a curvilinear relationship. This curve can then be used to rapidly estimate oocyte density from oocyte diameters, and potential annual fecundity (PAF) is estimated as the product of oocyte density and gonad weight. These curves have been applied successfully to a number of species with determinate fecundity but not winter flounder (reviewed in Kurita & Kjesbu 2008; Witthames et al. 2009). In species with determinate fecundity, the total fecundity just prior to spawning is equivalent to the PAF for the year (Murua and Saborido-Rey 2003). The autodiametric method provides a rapid and easily standardized methodology for the estimation of fecundity, enabling fecundity estimation across a broad geographic scale and over multiple years. Time-series of fecundity estimates can be used to identify the importance of environmental (e.g. temperature) and biological (e.g. feeding) factors on the annual reproductive potential of fishes (Rideout and Morgan 2010). The autodiameteric method should be applicable to winter flounder, as this species exhibits group synchronous oocyte development and determinate fecundity (Murua and Saborido-Rey 2003).

The objective of this study was to evaluate the reproductive potential of winter flounder and some of the factors that influence it. This included examination of differences in reproductive potential among the three stocks of winter flounder in US waters: Gulf of Maine (GOM), Georges Bank (GB), and Mid-Atlantic-Southern New England (SNE). Reproductive potential was evaluated by estimating both potential annual fecundity and skip spawning rates.

2.0 Methods

2.1 Fish collection and processing

Data presented here are from an ongoing project (December 2009-present). Winter flounder were obtained on a monthly basis, and samples from December 2009 through February 2011 are included in this analysis. Fish were collected primarily by commercial fishing vessels in the Cooperative Research Study Fleet program. Some supplemental samples were acquired from field studies conducted by the

NEFSC Cooperative Research Program, Massachusetts Department of Fish and Game, Division of Marine Fisheries trawl survey, and the University of Rhode Island Jefferies trawl survey. Fish were requested from the last few tows of the last day of a fishing trip and were placed on ice to ensure the quality of the reproductive tissue. Approximately 30 fish were requested over the range of sizes captured on the last few tows, and therefore do not represent a random sample of the population or commercial catch. Fish were worked up immediately upon arrival at the lab. Fish length and mass, gonad mass, age samples, and other biological data were collected in the lab. A one cubic centimeter piece of tissue was excised from the middle of one of the ovarian lobes and fixed in 10% buffered formalin, and otoliths were removed for subsequent age determination by the NEFSC Fishery Biology Program (Penttila and Dery 1988).

2.2 Fecundity sample & image processing

Mature developing females with vitellogenic (yolked) oocytes were selected for fecundity analysis. The histology was evaluated to exclude females with signs of spawning activity, high levels of natural or post-mortem atresia or cell damage. Subsamples were taken from the fixed ovarian tissue avoiding the tunica tissue (gonad wall), patted dry, and weighed to the nearest 0.0001g. A sample of ~300-400 oocytes was targeted to balance the image quality with processing time. The subsamples were manually manipulated to separate the individual oocytes, which were then transferred to three small dishes to avoid crowding. Images were taken of each dish with a Leica MZ6 scope and DFC295 camera. ImageJ software (v. 1.44n, National Institute of Health) and the ObjectJ (v. 1.01i, University of Amsterdam) plugin were used for image processing. Treatment of images was made consistent between samples by use of a macro, modified from one developed for mackerel (provided by Dr. Anders Thorsen, Institute of Marine Research, Bergen, Norway). This macro automatically measured oocyte diameters, and subsequent inspection of the image allowed removal or remeasurement of erroneous values. Any damaged or warped oocytes were not utilized for diameter measurements, but these were still included in the total oocyte count used to determine the final number of oocytes per gram of ovarian tissue (# oocytes/g) in each subsample. All subsamples and images were evaluated on a qualitative scale (1-3), which were classified based on the clarity of images, amount of warped and damaged oocytes, and quantity of connective tissue clinging to oocytes. Poor samples (3) were excluded from analysis (n = 91), and additional subsamples were processed for those fish. The replicate weighed subsamples from individual fish were pooled for the analyses below.

2.3 Auto-diametric curves and statistical fitting

The resulting relationship between oocyte density (# oocytes/g) and oocyte diameter was described with both a power and exponential function, as regression models have varied among species in previous studies (Thorsen and Kjesbu 2001; Kennedy et al. 2007; Witthames et al. 2009). Regressions were fit by least squares regression using “R” (v. 2.12.1, R Foundation for Statistical Computing), and the most appropriate model was selected by comparison of Akaike’s Information Criterion (AIC). The model with the lowest AIC value was considered the most appropriate (Anderson 2008). The effect of stock as a factor in the autodiameteric relationship was tested on the natural log transformed data, with stock as a main effect as well as with an interaction term included.

2.4 Potential annual fecundity (PAF) estimation

The wet weight of the gonads includes the tunica, so an adjustment factor needed to be determined to not attribute tunica mass to that of oocytes. For a subsample of developing winter flounder (n = 71), a whole gonad was weighed and then stripped of all oocytes, and the remaining tunica tissue was weighed.

The mean percentage of the gonad mass that was tunica was 5.26 % (0.17 s.e.). The following relationship was used to calculate PAF for all fish:

$PAF = NG \cdot (GM \cdot 0.9474)$,

where NG is the number of vitellogenic oocytes per gram and GM the total gonad mass. Least-squares linear regressions were compared among stocks for natural log transformed PAF and gonad-free fish mass data, and transformed PAF data was also compared to the non-transformed age data. The regression models were compared using AICc values, as this measure is less influenced by low sample sizes (Anderson 2008). A base model with PAF results for all fish was compared to a model including stock as a main effect and a third model including an interaction term. The final accepted model was the one with lowest AICc value. As age and fish mass are related, regression analysis was also conducted between fish age and log-transformed gonad-free fish mass.

2.4 Histology processing & staging scheme

Fresh ovary tissue was fixed in 10% buffered formalin, cut to < 1 cm thickness, loaded in cassettes, and stored in 70% ethyl alcohol. These were then sent to an outside firm, Mass Histology Inc. Samples were dehydrated in a series of increasing ethyl alcohol concentrations before embedding in wax, and thin sections (5 µm) of embedded tissue were stained with Schiffs-Mallory trichrome (SMT) and mounted on microscope slides.

Histology slides were analyzed with a digital microscope (Nikon Coolscope II). Our protocol included recording the most advanced oocyte stage (MAOS), the presence and stage of postovulatory follicles (POF's) and atresia, presence of cysts, and tunica and stroma thickness. The MAOS was defined as primary growth (all oocyte stages prior to late cortical alveolar), early cortical alveolar, late cortical alveolar, early vitellogenic, late vitellogenic, germinal vesicle migration, nucleus breakdown one (hydrated oocyte inside the follicle), and nucleus breakdown two (hydrated oocyte outside the follicle).

2.5 Definition of criteria for skip spawning

Development of oocytes from primary growth to hydration takes approximately 1 year. As females reached the end of the spawning season in late spring and early summer and begin to prepare for the following season a cohort of oocytes enter into the cortical alveolar stage. For a majority of females, a cohort of oocytes advanced into vitellogenesis in the fall and winter, taking the next step towards spawning. Mature winter flounder can skip spawning, which is evident when a clutch of vitellogenic oocytes does not develop (Burton 1994; Rideout et al. 2005). A 'skipper' looks mature (thick tunica) but resting through the spawning period. Microscopically, the oocytes in these mature females remained in the primary growth or early cortical alveolar stage, and these fish also did not exhibit signs of spawning (POF's).

The months used to estimate skipped spawning were stock-specific, as the peak spawning period varies. These stock-specific periods were determined for each winter flounder stock based on two histological variables: MAOS and the occurrence of POFs. These patterns were also compared to monthly patterns in GSI. Skipped spawning should be best evaluated after the majority of the population had begun the physiological buildup for spawning (a substantial increase in GSI and the most advanced oocytes being vitellogenic). However, after the peak in spawning for each stock (determined based on the occurrence of numerous spent fish with low GSI's and lots of POF's) it became difficult to identify skipped spawners from those that spawned early. Based on these criteria skipped spawning was evaluated from the beginning of December until the end of April in SNE and GB stock areas, and from the beginning of January through the end of May in the GOM stock.

3.0 Results and Discussion

3.1 Autodiametric curves

A total of 236 fish that met the sample quality criteria were used to develop the oocyte diameter vs. oocyte density relationship (Appendix Figure 1). Examination of the histology for individuals with mean oocyte diameters < 500 μm, indicated more frequent occurrence of a low-level of atresia than for individuals with higher mean diameters. This may indicate down-regulation of fecundity; therefore subsequent analysis was constricted to only those fish with a mean oocyte diameter > 500 μm. Both the power and exponential functions fit the autodiametric data well, but lower AIC values indicated the power function was the more appropriate model for this species (Table 1) and was utilized in all subsequent analyses. Individual variation among fish appeared to be more important than stock for the autodiametric curves (Figure 1). As the individual variation was high and the truncated data set exhibited a less-curved nature, examination of the effect of stock on the autodiametric relationship was tested on the linear regressions of natural log-transformed data. The model with the lowest AIC value was the base model without stock as a factor (Table 2). Therefore, one autodiametric curve for all three populations can be used to estimate fecundity of winter flounder (n = 165),
$NG = 5.756 \cdot 10^{10} \cdot (OD)^{-2.442}$,
where NG is the number of oocytes per gram and the OD the mean oocyte diameter (μm). Overall the autodiametric method was found to be applicable to this species, and the resulting curve will facilitate future estimation of fecundity. This will include tracking interannual changes, as a time series of fecundity might help explain some of the variability in fecundity observed here (by exploration of the influence of environmental or physiological factors).

3.2 Potential annual fecundity

Estimates of potential annual fecundity for winter flounder were found to exhibit a strong relationship with increasing fish mass (Figure 2), as has been shown in other fishes (Lowerre-Barbieri 2009; Rideout and Morgan 2010). Some of the variation in PAF estimates was explained by stock, which as a main effect was found to improve regression models of fish mass and PAF (Table 3). The inclusion of an interaction term did not lower the AICc value so was not considered an improvement in the model. The SNE stock was found to have the highest production of eggs relative to fish mass and the GOM stock had the lowest (Figure 2). The GB stock had the heaviest fish of the three stocks, so produced the greatest total number of eggs per individual. Although, analysis of PAF was conducted on gonad-free fish mass; final stock specific regressions for PAF in relation to fish mass were determined for both gonad-free and total fish mass (Table 4).

Observed ranges of fish mass were not consistent among stock areas, particularly GB (Figure 2); so comparisons of the fish mass to PAF relationship were also made across masses common to the stock areas (Appendix Table 1). Overlapping mass ranges were compared between GOM and SNE, SNE and GB, and all three stock areas. Although, the sample sizes were quite low in some cases, the same results were found for all comparisons in that the main effect of stock always had the lowest AICc values with a substantial improvement over the base model of PAF and gonad-free fish mass. Inclusion of the interaction term consistently had a lower value than the base model, but not from the model with the main effect alone.

All the statistical comparisons of PAF estimates indicated distinct differences among the three stock areas, with SNE exhibiting the greatest number of eggs produced relative to body mass. Fish mass was found to have a strong relationship with egg numbers, evidenced by the highest fecundities in the GB stock that has faster growth and attains greater sizes than the other stocks. Fecundity results in the present study are within the range but higher than most estimates previously reported for this species (Table 5). There is considerable variation, however, among studies even within the same region. Comparison of specific values among studies is confounded by many factors, including temporal and geographic variation and differences in methodology. In the current study, the utilization of one method, as well as being within the one time period, enables comparison across a broad geographic region. This includes the first estimates of fecundity for Georges Bank.

Fish size and age are closely related, and differences among stocks were also clearly evident in comparisons of fish mass (gonad-free) at age (Figure 3a). Georges Bank consistently had heavier fish at age than the SNE stock, and especially relative to the GOM stock. Potential annual fecundity at age exhibited a similar pattern of gradually increasing with age in all three stock areas (Figure 3b). The differences in PAF at age among the stock areas reflected the differences in size at age, with GB having the highest values and GOM the lowest. However, the differences in PAF at age estimates between GB and SNE fish were not as strong as the differences were in size at age. Regression models of PAF with age again showed an improvement with the inclusion of stock as a main effect, though only slightly over the model with the interaction term (Table 3b). Results of the age analysis were consistent with those for fish size. When adjusted for fish size, SNE winter flounder produced the greatest number of eggs and GOM fish produced the fewest. The differences in size at age of the GB fish resulted in greater egg production by the older (larger) individuals of that population, and the smaller size of the GOM fish resulted in lower egg production at age for that population.

Results here support the idea that female size is the most important factor for egg production, which is consistent with work on many species (Lowerre-Barbieri 2009). These fecundity results emphasize the importance of larger fish to the population, even when their numbers may be a much less significant portion of the total population. These results, however, are just for total egg numbers and do not include egg quality or size, which can also vary with female size and have consequences for the size and survival of larvae (Buckley et al. 1991; Tomkiewicz et al. 2003; Lowerre-Barbieri 2009; Rideout and Morgan 2010).

3.3 Skipped spawning

The processing and examination of gonad histology slides for female winter flounder from the 2010 spawning season has been completed. A total of 332 mature females were examined in all three stock areas during the five month periods analyzed. Sample sizes for the GOM and SNE stocks were similar, with fewer fish collected from the GB stock (Table 6). Only two individuals were identified as skipped spawners for the 2010 spawning season, both of which came from the Gulf of Maine. This was 1.3 % of the sampled adult female winter flounder from the GOM stock (Table 6). The prevalence of skipped spawning for the US winter flounder stocks in 2010 was below that of winter flounder sampled in Newfoundland, 19.1% (9 of 47 mature females examined; Burton and Idler 1984), but closer to that reported for winter flounder in New Jersey, 4.8 % (3 of 63 mature females; Wuenschel et al. 2009). Burton and Idler (1984) also identified skipped spawning in 18 of 63 (28.6 %) mature males. A latitudinal gradient in the frequency of non-annual spawning may be exist. This was suggested in preliminary results of a histological examination of winter flounder from the US Mid-Atlantic bight up to the Scotian Shelf (McBride et al. 2010), which ranged from zero to greater than 30%.

Skipping rates can vary substantially among years as a suite of environmental and physiological factors could impact spawning participation (Rideout et al. 2005). Although, the overall incidence of skipped spawning observed in this study was low, captive studies suggest that feeding during a critical period after spawning influenced whether individuals were non-reproductive the following season (Burton 1994). This suggests that interannual variation in the environment could have a substantial role in the frequency of occurrence of skipped spawning, and in years of high incidence (~10-20%) this could significantly decrease the realized spawning biomass of the population. Inclusion of skipped spawning rates in population models may improve estimates of spawning stock biomass and their relationship to recruitment. Egg production models incorporating stock-specific differences in fecundity and female size could also provide insight into year to year variation in the stock recruitment relationship.

4.0 Conclusions

This work provides reproductive parameters for potential annual fecundity (2010-2011) and skipped spawning (2010) for the three US stocks of winter flounder. This study developed autodiametric curves for winter flounder, which enables rapid estimation of fecundity in the future by utilizing just the mean oocyte diameter for an individual fish to determine oocyte density. This will facilitate our ability to track longterm changes in this reproductive parameter, as well as investigate the effects of factors influencing egg production in the wild, such as temperature, fish condition, and food availability. Monthly sampling enabled identification of, and resulting analysis during, the optimal months for evaluating reproductive parameters for each particular stock.

The overall reproductive potential for individuals in the Gulf of Maine stock of winter flounder were the lowest of the three US stocks, as both fecundity and skipped spawning suggest lower reproductive output for fish in this population. This is consistent with the growth rate for this stock, which is slower than the other two (O'Brien et al. 1993). Preliminary results suggest geographic differences in fecundity on a smaller scale than stock may exist, especially for the Gulf of Maine, and future work is under way to examine this possibility further. The two southern stocks appear to have lower rates of skipped spawning, as well as higher egg production per fish than GOM, both in relation to fish mass and age. SNE fish have the greatest individual egg production in relation to body mass, but the larger mass attained by Georges Bank flounder results in a higher reproductive capacity for the large individuals in this stock. These results indicate that the reproductive potential of the stocks could differ and may provide indicators of the resiliency of the different populations to fishing pressure.

5.0 Acknowledgements

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7.0 Tables

Table 1. Coefficients and statistics for the power and exponential models as fit with least squares regression of oocyte density (# / g ovarian tissue) and mean oocyte diameter (Mean OD) are tabulated along with residual sums of squares (RSS) and the Akaike's Information Criterion (AIC). Analysis conducted with all winter flounder stocks combined and only on females with mean oocyte diameters > 500 μm.

Oocyte Density =	d.f.	a	b	RSS	AIC	ΔAIC
$a \cdot (\text{Mean OD})^b$	163	$5.756 \cdot 10^{10}$	-2.442	$1.359 \cdot 10^8$	2721.804	
$a \cdot e^{(\text{Mean OD} \cdot b)}$	163	$1.222 \cdot 10^5$	$-4.255 \cdot 10^{-3}$	$1.379 \cdot 10^8$	2724.208	2.404

Table 2. Comparison of autodiametric relationships between stocks were conducted only on fecundity samples with oocyte diameters > 500 μm. Data were natural log transformed, and models of the linear regression of the oocyte density and mean oocyte diameters were compared using AICc values and weights (Wt). The first model was without stock as a factor (base model), the second with stock as a main effect, and the third with the interaction term.

	K	AICc	ΔAICc	AICc Wt.
1 Base Model	3	-346.18		0.50
2 Main effect of stock	5	-345.75	0.42	0.40
3 Model w/Interaction Term	7	-342.97	3.21	0.10

Table 3. Natural log transformed potential annual fecundity (PAF) data was regressed with log-transformed gonad-free fish mass (a) and non-transformed fish age (b), and the model was tested with and without stock as a factor. Base model is without stock, the second model is with stock as a main effect, and the third is the model with the interaction term included. The forms of the model were compared using AICc values and weights (Wt).

a	K	AICc	ΔAICc	AICc Wt.
1 Base Model	3	6.42	22.26	0.00
2 Main effect of stock	5	-15.84		0.67
3 Model w/Interaction Term	7	-14.40	1.44	0.33

b	K	AICc	ΔAICc	AICc Wt.
1 Base Model	3	266.15	163.22	0.00
2 Main effect of stock	5	102.52		0.78
3 Model w/Interaction Term	7	105.52	2.59	0.22

Table 4. Final regression coefficients for the relationship between fish mass and potential annual fecundity (PAF) for each stock area, LN(PAF) = b · LN(Mass) + a, where mass is either gonad-free or total fish mass.

Gonad-Free	a	b	n
GOM	7.726	0.959	45
GB	6.626	1.150	47
SNE	6.860	1.138	72

Total Mass	a	b	n
GOM	7.213	1.016	45
GB	6.974	1.069	47
SNE	6.520	1.152	72

Table 5. Predicted PAF estimates are based on regressions from previous studies and stock specific regressions from the current study based on whole fish mass. The 500g and 1000g estimates were not determined for the GB and GOM stock areas, respectively; since in the current study fish those sizes were not encountered from those regions. The 1000g size was not estimated for the two more northern studies as this size would not be typically encountered in those regions.

	Location	Total Fish Mass (g) 500	800	1000
Current Study	GOM	747,676	1,205,057	
	GB		1,353,164	1,717,619
	SNE	870,343	1,495,392	1,933,555
Saila (1961)	Narragansett Bay	554,134	946,065	1,219,586
Topp (1967)	Cape Cod Bay	884,163	1,459,162	
Kennedy & Steele (1971)	Newfoundland	545,673	977,468	
NUSCO (1987)	Long Island Sound	650,271	1,295,795	1,797,637
Buckley et al. (1991)	Narragansett Bay	624,720	1,043,820	1,323,220

Table 6. Total number of mature female winter flounder examined by histology in each stock area in winter 2009-2010, and the number of mature non-spawning participant females (skipped spawners) within each stock area. Skipped spawning identification period was defined for Southern New England (SNE) and Georges Bank (GB) stock areas to be from December through the end of April, and January until the end of May for the Gulf of Maine (GOM) stock.

Stock	Mature Females	Skipped Spawners	% Skipped
GOM	151	2	1.32
GB	35	0	0.00
SNE	146	0	0.00

8.0 Figures

Figure 1. Relationship between oocyte density (number per gram) and mean oocyte diameter (autodiametric curves) for the three stocks of winter flounder. Individuals with mean diameters < 500 µm were excluded from analysis. Curves represent least-squares fit regressions for the power function.

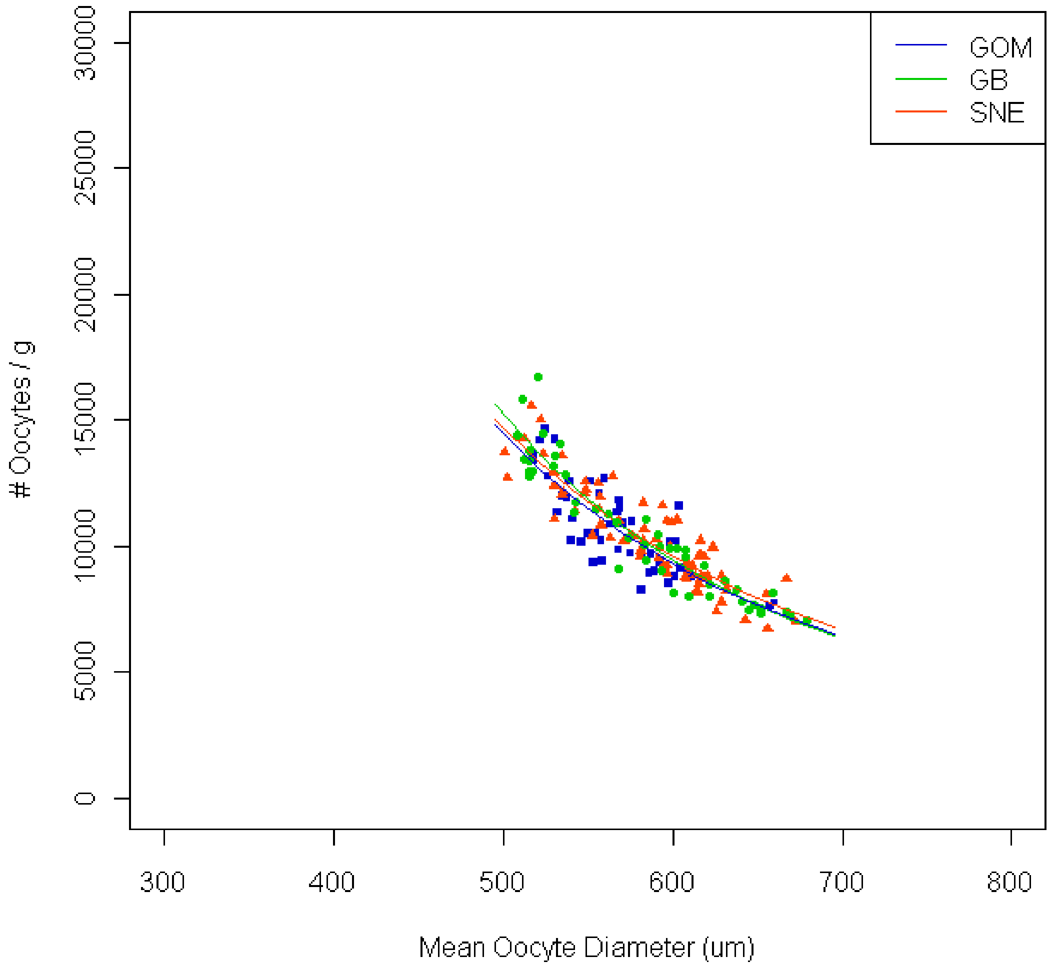


Figure 2. Comparison of gonad-free fish mass and potential annual fecundity plotted on a log-log scale for each stock of winter flounder. Lines are least-squares fit of the linear regressions of each stock over the size range sampled.

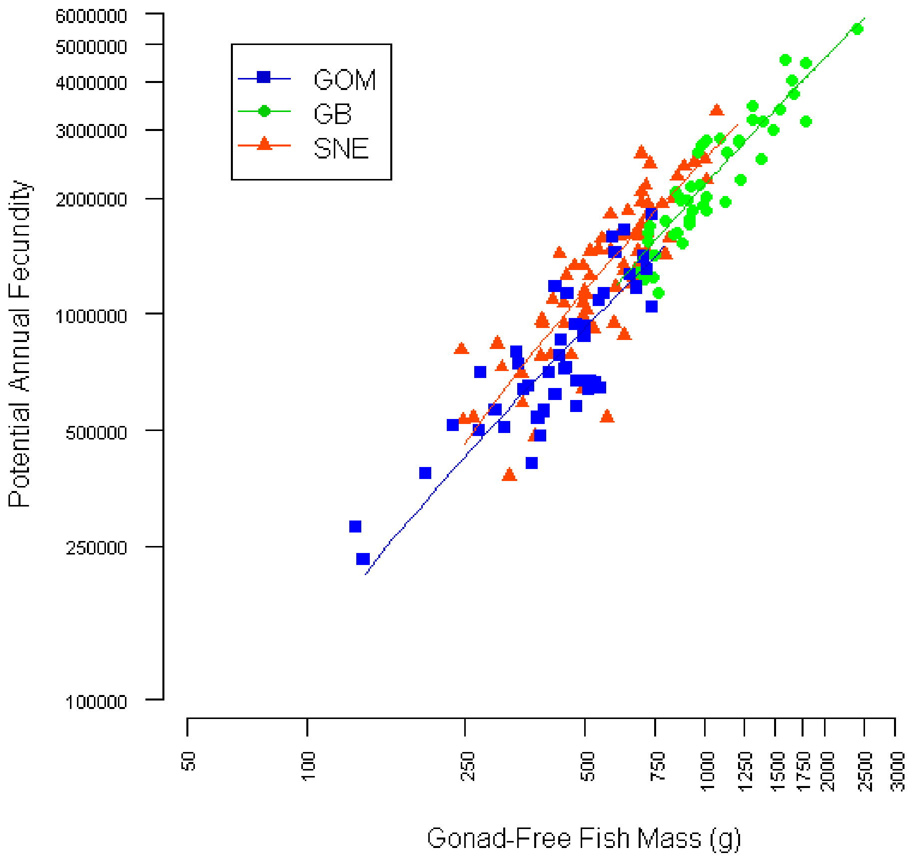
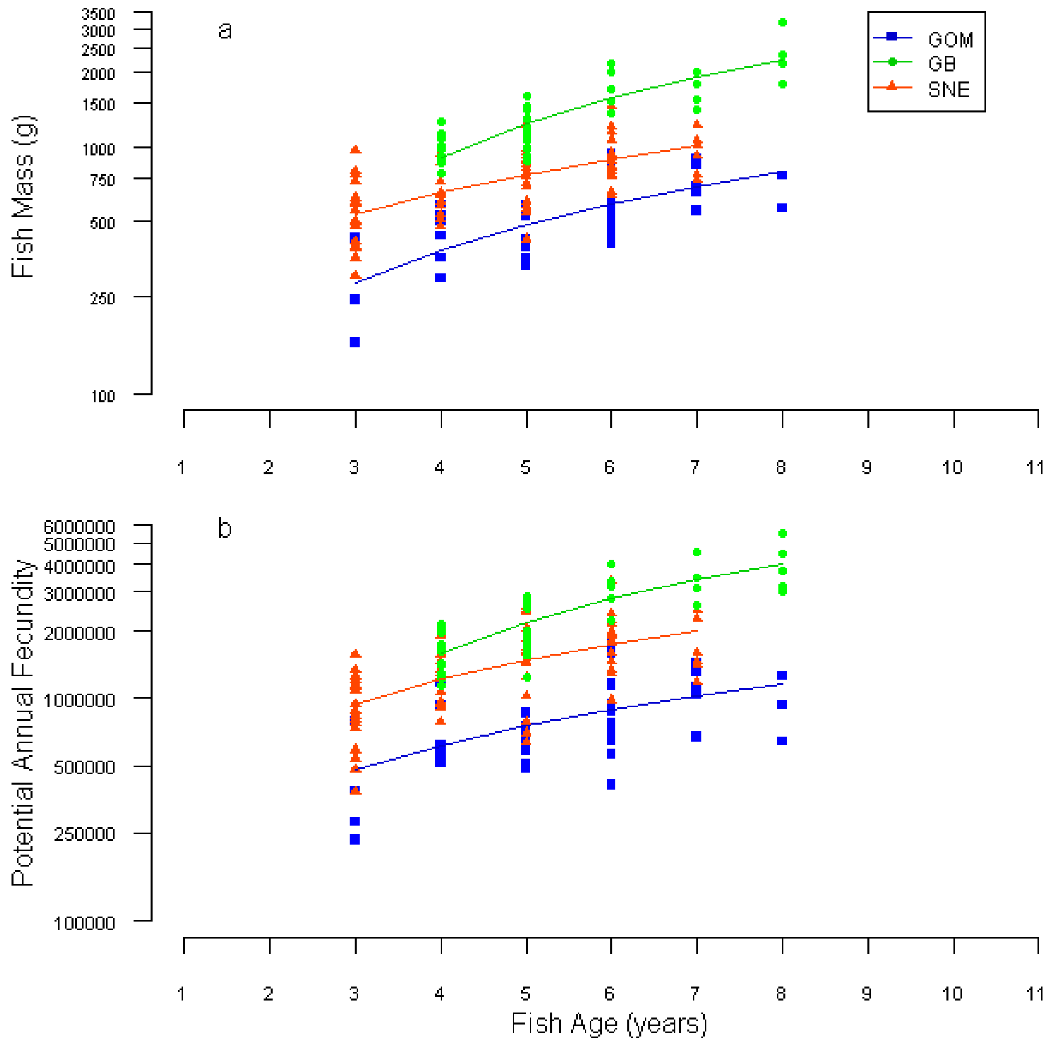
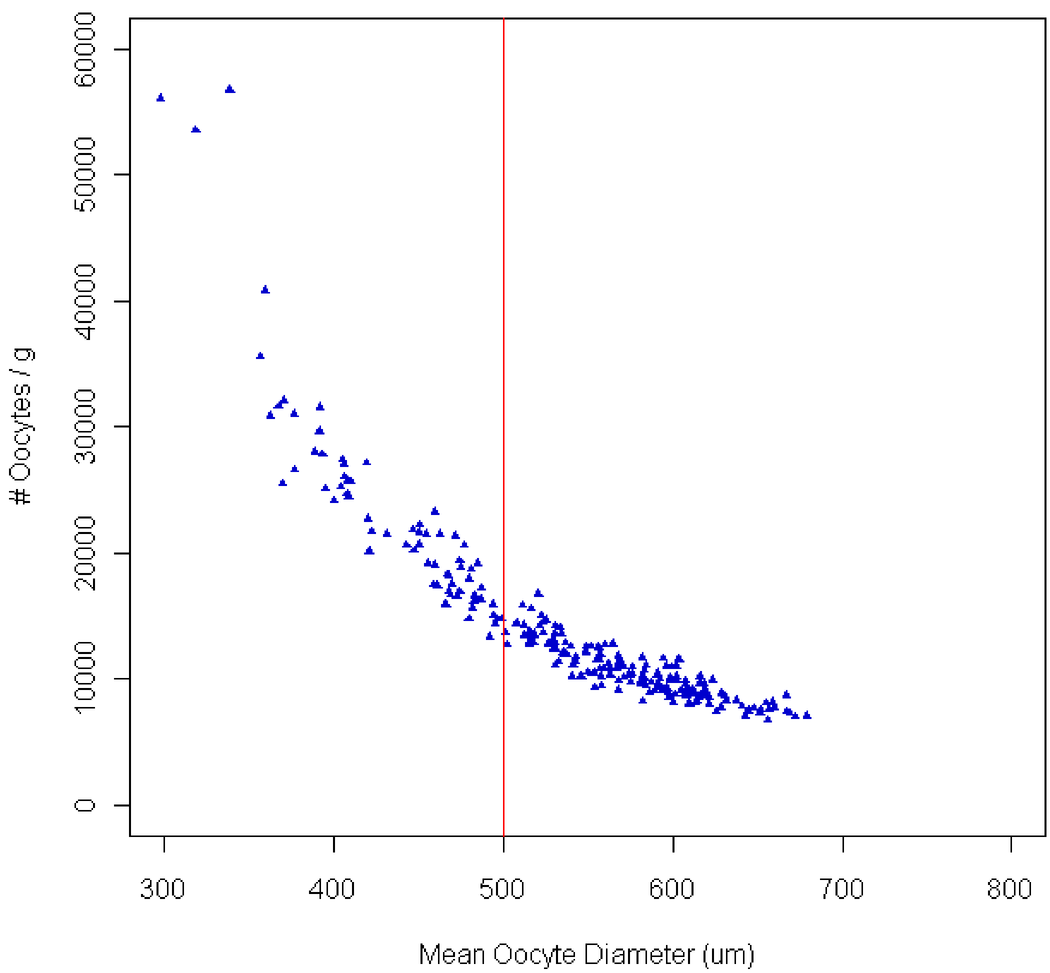


Figure 3. Winter flounder mass (on a log scale) plotted in relation to age by stock (a). Potential annual fecundity plotted on a log scale against fish age for each winter flounder stock (b). Lines are least-squares fit of the linear regressions of each stock over the size range sampled.



Appendix

Appendix Figure 1. Relationship between oocyte density (number per gram) and mean oocyte diameter for all winter flounder sampled for fecundity and meeting sample quality criteria. Verticle line at 500 µm indicates oocyte diameter cutoff employed for analysis; as histology slides indicated greater occurrence of atresia below that size.



Appendix Table 1. Natural log transformed potential annual fecundity (PAF) data was regressed with log-transformed gonad-free fish mass, and the model was tested with and without stock as a factor for each grouping below. Base model is without stock, the second model is with stock as a main effect, and the third is the model with the interaction term included. The forms of the model were compared using AICc values and weights (Wt). Potential annual fecundity comparisons among stocks were restricted to fish sizes overlapping in value between the stocks. Two stock comparisons were made for winter flounder from SNE < 740g (n = 62) with GOM flounder > 230g (n = 42, a), as well as SNE flounder > 675g (n = 23) and GB flounder < 1070g (n = 29, b). The comparison of regressions between all three stocks was constricted to flounder in GOM > 675g (n = 5), GB < 740g (n = 7), and SNE between 675-740g (n = 13, c).

a	K	AICc	ΔAICc	AICc Wt.
1 Base Model	3	37.19	16.42	0.00
2 Main effect of stock	4	20.77		0.68
3 Model w/Interaction Term	5	22.31	1.54	0.32

b	K	AICc	ΔAICc	AICc Wt.
1 Base Model	3	-19.32	13.85	0.00
2 Main effect of stock	4	-33.17		0.60
3 Model w/Interaction Term	5	-32.33	0.84	0.40

c	K	AICc	ΔAICc	AICc Wt.
1 Base Model	3	3.63	8.10	0.02
2 Main effect of stock	5	-4.47		0.95
3 Model w/Interaction Term	7	2.56	7.03	0.03

ToR 5. Examine the effects of incorporating environmental factors in models of population dynamics (e.g., spring water temperatures in an environmentally-explicit stock recruitment function).

Development of environmentally-explicit stock-recruitment models for three stocks of winter flounder (*Pseudopleuronectes americanus*) along the northeast coast of the United States

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Introduction

Winter flounder spawn in winter and early spring in estuaries along the mid-Atlantic, southern New England and Gulf of Maine, as well as in continental shelf waters on Georges Bank (Able and Fahay 2010). There is also recent evidence of more coastal spawning in both Southern New England (Wuenschel et al. 2009) and the Gulf of Maine (Fairchild et al. 2010). In southern New England, Manderson (2008) found that overall recruitment was linked to spring temperatures, presumably by acting on larvae, settlement stage, and/or early juveniles. Further, Manderson (2008) found that young-of-the-abundance among 19 coastal nurseries became more synchorized in the early 1990's and argued that increased frequency of warm springs was creating coherence in early life stage dynamics among local populations.

The specific mechanism linking temperature to recruitment was not defined by Manderson (2008), but temperature is an important parameter in many ecological processes affecting winter flounder. In a mesocosm study, Keller and Klein-MacPhee (2000) found that winter flounder egg survival, percent hatch, time to hatch, and initial size were significantly greater in cool mesocosms. Further, mortality rates were lower in cool mesocosms and related to the abundance of active predators. In the laboratory, Taylor and Collie (2003) found that consumption rates of sand shrimp were lower at lower temperatures implying lower predation pressure at colder temperatures. In the field, Stoner et al. (2001) found that settlement stage winter flounder prefer colder waters and that the importance of temperature in defining juvenile habitat decreases through ontogeny. Thus, temperature has multiple effects on the early life history of winter flounder and colder temperatures in general lead to higher survival and recruitment.

The relationship between winter flounder recruitment and temperature identified by Manderson (2008) did not include the effect of population size. The relationship between stock size and subsequent recruitment is generally poor in marine fishes (Rothschild 1986) but can have explanatory power. To examine the combined effect of environment and spawning stock biomass on recruitment, the goal here was to develop environmentally-explicit stock recruitment relationships that include temperature and related environmental variables for the three stocks of winter flounder. As a basic framework, the approach of Hare et al. (2010) was followed. The resulting models could be used in short-term forecasts based on fishing and temperature scenarios (fixed patterns of temperature variability over several years) and long-term forecasts based on fishing and temperature projections from general circulation models.

Materials and Methods

<u>Data</u>

To develop environmentally-explicit stock recruitment relationships, three specific types of data are required: spawning stock biomass, recruitment, and environmental data.

<u>Spawning stock biomass and recruitment data</u> – Results from the preferred assessment models were used in the analysis. For the Southern New England stock, recruitment (lagged by 1 year) and spawning stock biomass pairs used from the CAT10 ASAP model. For the Gulf of Maine stock, data from the MULTI ASAP model were used. For the Georges Bank stock, data from the preferred VPA model were used (Table 1).

<u>Environmental Data - Temperature</u> – Two general types of temperature data were used: air temperatures and coastal water temperatures. Data sources are provided in Table 2.

Air temperature data from the NCEP/NCAR Reanalysis (Kalnay et al. 1996) were used. This product combines observations and an atmospheric model to produce an even grid of atmospheric variables, in our case monthly mean surface air temperature. The spatial resolution is 2.5^{o} latitude by 2.5^{o} longitude. Air temperatures are closely related to estuarine water temperatures owing to efficient heat exchange in the shallow systems (Roelofs and Bumpus 1953, Hettler and Chester 1982, Hare and Able 2007). Data from representative grid points were averaged for each of three regions: Southern New England, Georges Bank, and Southern New England (see Figure 1). The monthly/regional averages were further averaged into annual estimates for three, two monthly periods (January-February, March-April, May-June).

Coastal water temperature data from Woods Hole, Massachusetts and Boothbay Harbor, Maine were used (see Nixon et al. 2004 and Lazzari 1997 respectively). Monthly means were calculated from mostly daily data. These monthly means were then averaged into annual estimates for the three, two monthly periods (January-February, March-April, May-June). The Woods Hole data were evaluated relative to the Southern New England and Georges Bank stock; the Boothbay Harbor data were evaluated relative to the Gulf of Maine stock.

Temperature data were analyzed as annual averages for three, two month periods (January-February, March-April, May-June). These two monthly periods capture temperature variability from the late winter, through spring and into early summer. The spring period was identified as important by Manderson (2008). The broader seasonal range was chosen because of potential differences in the timing of winter flounder spawning and development among the three stocks (Able and Fahay 2010) and the uncertainty as to the stage where recruitment is determined.

Environmental Data - Large-scale forcing variables – In addition to temperature, four large-scale forcing indices were included in the analyses (see Table 2). The North Atlantic Oscillation (NAO) is the dominant mode of winter climate variability in the North Atlantic region and has been related to numerous physical and biological variables across the North Atlantic (Ottersen et al. 2001, Visbeck et al. 2003). Brodziak and O'Brien (2005) identified a significant effect of NAO on recruit-spawner anomalies of winter flounder in the Gulf of Maine. The mechanism is unspecified, but NAO is related to estuarine water temperatures in the region (Hare and Able 2007). The winter NAO index is used here (Hurrell and Deser 2010). The Atlantic Multidecadal Oscillation (AMO) is a natural mode of climate variability and represents a detrended multi-decadal pattern of sea surface temperatures across the North Atlantic with a period of 60-80 years (Kerr 2005). Nye et al. (2009) found the AMO was strongly related to distribution shifts of fishes in the northeast U.S. shelf ecosystem. Finally, the Gulf Stream index is a measure of the northern extent of the Gulf Stream south of the northeast U.S. shelf ecosystem. The Gulf Stream position is related to the larger basin-wide circulation, which in turn is related to NAO and AMO. Work by Nye et al (in review) shows the Gulf Stream index has explanatory power for the distribution of silver hake in the system, possibly through the large-scale linkages between the Gulf Stream, Labrador Current and hydrographic conditions on the northeast U.S. shelf. Two Gulf Stream indices are used here (Joyce and Zhang 2010, Taylor and Stephens 1998). The two indices differ in their calculation, with the Joyce and Zhang (2010) index more associated with the Gulf Stream south of the northeast U.S. shelf and the Taylor and Stephens (1998) index more associated with the Gulf Stream across the North Atlantic.

For all four large-scale forcing indices, annual values were obtained. Numerous studies have found lagged effects of the NAO on the northeast U.S. shelf ecosystem (Greene et al. 2003, Hare and Kane in press). In particular, a two year lag has been related to the remote forcing of the NAO on the northeast U.S. shelf through the Labrador Current system. In addition, a zero year lag has been related to direct atmospheric forcing on the northeast U.S. shelf. Zero, one, and two year lags of were included for NAO and zero year lags were used for the other three large-scale forcing variables.

Preliminary Analysis of Environmental Data

To understand the relations between the host of 21 environmental variables, a simple correlation matrix was calculated. Significant correlations were considered in the context of previous research in the region. Significance was based on standard p-values; no corrections for multiple comparisons were made. The purpose was exploratory with an aim of understanding the relation between variables before incorporating them into stock recruitment functions.

Environmentally-Explicit Stock-Recruit Models

Initially, Ricker, Beverton-Holt, and Cushing stock recruitment models were used with and without the different environmental terms. The model forms followed Levi et al. (2003), who built upon the ideas of Neill et al. (1994) and Iles and Beverton (1998). The fits of the three standard models were all very similar for the Southern New England and Gulf of Maine stocks. Owing to the general acceptance of the Beverton-Holt model for use in stock-recruitment relationships and the overall similarity in the fits of the three models, here only the analyses using the Beverton-Holt model are presented (see Table 3 for model forms).

Environmental variables were assigned *a priori* for consideration with specific stocks (e.g., air temperatures over the Gulf of Maine were examined for the Gulf of Maine stock only, see Table 2). This was done to limit the number of environmentally-explicit stock recruitment relationships considered for each stock (see Table 2).

The standard stock-recruitment relationships were calculated first using the lsqcurvefit function in MatLab using the trust-region-reflective algorithm. A series of environmentally-explicit models also were fit using the same methods (Table 3). The resulting models were compared using AICc and AICc weights, which represent the relative weight of evidence in favor of a model. The best environmentally-explicit model also was compared to the standard stock recruitment model using an evidence of weights procedure (Burnham and Anderson 1998). In this way the value of the environmentally-explicit stock recruitment functions relative to standard stock recruitment functions was judged.

Model fitting included bounded parameters (or priors) to force realistic model forms. Without bounded parameters the b term in the Beverton-Holt model (see Table 3) was estimated to be negative for the Georges Bank stock, which results in an unrealistic function. To deal with this issue, starting values for the nonlinear estimation were derived from the linearized standard Beverton-Holt function and bounds of ± two orders of magnitude were imposed. The fit of the models for the Georges Bank and Southern New England data were much less sensitive to the bounds.

Results

<u>Preliminary Analysis of Environmental Data</u>

Numerous relationships between environmental variables were evident based on the correlation analysis. The complete correlation matrix is presented in Table 4 and representative time series are shown in Figure 2.

The two Gulf Stream indices were related (r=0.54) but different enough to retain both in the analyses. Both Gulf Stream indices were related to the NAO with a 2 year lag (NAO leading). This relationship has been described before (Taylor and Stephens 1998).

The Atlantic Multidecadal Oscillation exhibited relatively little relationship with other variables. There was a negative relationship with the 2 year lagged NAO. The only strong positive correlation was found with Boothbay Harbor water temperatures. Both series exhibit a strong increasing trend over the time period considered (Figure 2).

The North Atlantic Oscillation was related to the two Gulf Stream indices as already noted. NAO was not related to winter temperatures which may result from non-stationarity in the NAO-winter temperature relationship (Joyce 2002).

Woods Hole temperature is closely related to regional air temperatures. This link is not surprising based on previous studies. Woods Hole temperature is also related to a lesser extent Boothbay Harbor temperatures. There is evidence of seasonal correlation in Woods Hole temperature, with values in January and February correlated to values in March and April, which in turn are correlated to values in May and June. However, the seasonal correlation is diminished after two months; temperatures in January and February are less related to temperatures in May and June.

Boothbay Harbor temperature is strongly related to the AMO particularly in early summer. The lower magnitude of correlation with air temperatures compared to Woods Hole temperature is interesting and an explanation is lacking. It is possible that greater depths of coastal Maine increase the influence of oceanic factors and decreases the influence of atmospheric factors. The seasonal correlation described for Woods Hole temperatures in evident for Boothbay Harbor temperatures, but to a lesser degree.

The three air temperature series were all closely related indicating coherent air temperatures over the entire region. These analyses agree with the more comprehensive results of Joyce (2002). Correlations among regions over the same time (Jan-Feb) were higher than correlations within region between times (Gulf of Maine Jan-Feb compared to Gulf of Maine Mar-Apr). Seasonal correlation (Jan-Feb to Mar-Apr) were lower in the air temperature series compared to the water temperatures series as expected from the greater specific heat capacity of water.

The analyses suggest that the environmental forcing experienced by the three stocks differs in several important elements. The Southern New England stock experiences coastal water temperatures that are strongly linked to local air temperatures. The Georges Bank stock experiences water temperatures that are affected by both local air temperatures and more importantly, large-scale advective supply of relative cold, fresh water associated with the Labrador Current. Finally, the temperatures experienced by the Gulf of Maine stock remain uncertain. If the Boothbay Harbor data is representative, then temperature is related to large-scale processes (AMO) and not local processes (air temperature). On the other hand, air temperature may be important, if early stage winter flounder are using shallower habitats.

<u>Standard Stock-Recruitment Models</u>

Spawning stock biomass is comparable between the Southern New England and Georges Bank stock but recruitment is approximately four times greater for the Southern New England stock at higher stock sizes (Figure 3). The stock recruitment functions for the Georges Bank and Gulf of Maine stock are similar, with near constant recruitment over a relatively broad range of spawning stock biomasses. Recruitment on Georges Bank is estimated to be higher than the Gulf of Maine at a given spawning stock biomass.

The residuals of the stock-recruitment relationships for the three stocks appear to exhibit synchrony through time (Figure 4). Early in the time series, residuals between the stocks appear unrelated, but all residuals were positive in the mid-1990’s and all were negative in the early 2000’s. A formal analysis was conducted using serial correlation: calculating the correlation coefficient between two variables using a moving window. A similar analysis was used by Joyce (2002) to show that the relationship between NAO and east coast air temperatures has changed over the last 80 years and by Hare and Kane (in press) to show that the correlation between NAO and *Calanus finmarchicus* abundance has changed over the last twenty years. The serial correlation analysis demonstrated that early in the time series the residuals of the stock-recruitment functions were negatively or not correlated between the stocks (Figure 5). Then, during the early 1990's, the residuals became positively correlated. The trend is most evident for the Southern New England and Gulf of Maine stocks and less so for these two stocks compared to the Georges Bank stock.

The timing in the synchrony between the Southern New England and Gulf of Maine stocks is similar to the timing in synchrony among local populations within the Southern New England stock (Manderson 2008). This synchrony suggests that some large-scale forcing is responsible for creating variance in the stock recruitment relationships of winter flounder across the northeast U.S. shelf ecosystem. The synchrony is greater between the Southern New England and Gulf of Maine stocks suggesting that the large-scale forcing has greater coherence along the coastal areas of the northeast compared to the offshore waters of Georges Bank.

Environmentally-Explicit Stock Recruitment Models

The best fit environmentally-explicit stock recruitment relationship for the Southern New England stock predicted higher recruitment at lower winter air temperatures (Table 5, Figure 6). The variable in the best model was Southern New England air temperature in January and February. This model had an evidence ratio of 151 compared to the standard model and explained an additional 14% of the variance (Table 6). Several other environmental variables were included in the top ten models (AMO, GS-J, and WH-JF), but three of the four top models included winter air temperatures over Southern New England. The best environmentally-model provided a similar function to the standard model at mean environmental conditions, but importantly the predicted asymptotic recruitment was lower with the environmental model (Figure 6).

Including an environmental term did not improve the stock recruitment relationship for the Georges Bank stock (Table 6). The standard model was the best fit model and predicted near constant recruitment over the range of observations (Figure 7). The evidence ratio of the best environmental model was 0.7 compared to the standard model (Table 6). Environmental variables in the top 10 models included air temperatures, water temperatures and the Gulf Stream index, but these variables added no strength to the stock recruitment relationship (Table 5). Importantly, the model fit, whether standard or environmental, was dependent on the priors imposed for the b term (Table 3), which is related to but not identical to the steepness term (see Myers et al. 1999).

For the Gulf of Maine stock, the best model included winter air temperature over the Gulf of Maine (Table 5); at higher temperatures, there was a decrease in recruitment (Figure 8). Air temperatures through the spring and Boothbay Harbor winter temperatures were also included in the top 10 models. The best fit environmentally-explicit model has an evidence ratio of 2 compared to the best fit standard stock recruitment model and explained an additional 14% variance (Table 6).

The environmentally-explicit models support the hypothesis that increased temperatures during spawning and the early life history result in decreased recruitment in the Southern New England and Gulf of Maine stocks. This pattern was most evident for the Southern New England stock. Winter temperature is correlated with spring temperature (Table 3) providing a potential bridge between this study and that of Manderson (2007). For the Gulf of Maine stock, increased winter air temperatures are related to lower recruitment, but the strength of this environmental forcing is less than for Southern New England. This result makes sense in the context of the distribution of winter flounder; the southern stock is most affected by warmer temperatures. There was no evidence for a temperature effect on the Georges Bank stock; the environmentally-explicit models did not provide a better fit compared to the standard stock recruitment model. Overall, recruitment in the coastal stocks of winter flounder were linked to winter temperatures, while recruitment in the Georges Bank stock was largely independent of the environmental variables examined here.

Using the same serial correlation approach to examine trends in winter air temperature shows an increase in correlation among the three regions starting in the late-1980's early-1990's (Figure 9). The correlation coefficients of Southern New England and Gulf of Maine air temperatures are correlated with the similar coefficients for recruitment (Figure 9, see Figure 5) This result suggests that as regional air temperatures have become more coherent, winter flounder recruitment in the coastal stocks also has become more coherent.

Summary of Stock Recruitment Models for Reference Point Calculation

To consider these environmentally explicit models stock recruitment models in the context of reference points, it is necessary to summarize model parameters. For the Georges Bank stock, there was no demonstrated benefit of the environmentally-explicit model over the standard model, so reference points should be calculated from the standard model. For the Southern New England stock, an important issue in the standard stock recruitment model is the perceived need to bound the model parameters in both the prior stock assessment (NEFSC 2008) and in the current assessment. Specifically, the standard model estimates a high asymptotic recruitment (Table 7). Bounding asymptotic recruitment to the mean observed in a series of high recruitment years results in a very different model. At the mean environmental conditions, the unbounded environmentally-explicit model has a lower asymptotic recruitment (Table 7) and one benefit of this model is the lack of need for bounded parameters. For the Gulf of Maine stock, the standard model is almost identical to the environmentally-explicit model under mean conditions (Figure 8).

Another potential benefit for the environmentally explicit models is to forecast recruitment under different environmental conditions. Over the assessment record, there has been no change in winter air temperature (Figure 10). Further, the ability to forecast winter air temperatures in the 1-5 year range is limited at best. There is some skill in statistical seasonal forecasts with several months lead time (Cohen et al. 2010) and developing forecast skill on the decadal scale is a major topic of research in the climate modeling community (Smith et al. 2007, Keenlyside et al. 2008), but interannual forecasts with demonstrated skill are few. Thus, the environmental models developed here can be used with a mean environment to calculate reference points (Table 7 and 8). Additionally, scenarios could be evaluated calculating reference points under an assumption of warm winters and an assumption of cool winters to better inform management in the short-term.

Discussion

The results of the analyses support Manderson (2008) earlier finding. Recruitment in coastal stocks of winter flounder is related to temperature during the spawning season. Importantly, recruitment is also dependent on spawning stock biomass and the environmentally-explicit stock-recruitment models capture the combined effect of environment and stock size. The temperature effect is strongest in the Southern New England stock, where the species is at the southern extent of its range. The signal is less pronounced in the Gulf of Maine, but recruitment is still linked to winter temperatures. The effect of environment on recruitment of Georges Bank winter flounder is less clear. There is a lot of variability in the stock-recruitment relationship and none of this variability is explained with the environmental terms considered here. Whether other environmental factors play a role in Georges Bank winter flounder recruitment is an important question requiring future research.

The closer link to air temperatures for the Southern New England stock is explained by the argument that water temperatures in estuarine winter flounder spawning, larval, and juvenile habitats are more closely related to air temperature than to coastal water temperatures. Prior studies have found a close link between air temperature and estuarine water temperature (Hare and Able 2007). Future studies should explicitly treat the spatial dynamics of winter flounder in more detail (see Manderson 2008); such an approach could better examine the effect of environmental forcing on local populations.

One use of the environmentally-explicit models is to develop short-term and long-term forecasting models. Based on the above analyses, there is no trend in winter temperature over the past 30 years and thus short-term forecasts can be developed using the environmentally-explicit models assuming winter temperatures to be at their mean state. It may also be useful to develop short-term forecasts under warm temperatures and short temperatures to provide managers with a tangible understanding of the effect of temperature on the stocks. The environmentally-explicit models could also be used to develop longer-term forecasts following the approach of Hare et al. (2010). These forecasts would provide an assessment of the sustainability of the winter flounder fishery on the 30-100 time scale.

Table 1. Spawning stock biomass and recruitment pairs for the three stocks used in this study. Values are derived from the preferred model for all three stocks.

	GOM Stock		GB Stock		SNE Stock	
Year	SSB	R (lag -1)	SSB	R (lag -1)	SSB	R (lag -1)
1982	12,506	11,871	17,380	8,338	19,392	64,782
1983	8,609	9,055	16,473	17,881	20,108	43,197
1984	6,552	10,758	10,532	16,791	18,093	37,470
1985	4,747	9,182	6,256	21,914	15,948	43,484
1986	3,995	7,312	7,817	15,543	11,500	35,777
1987	3,717	6,885	8,082	26,317	9,087	34,914
1988	2,884	6,009	6,681	14,913	7,500	34,040
1989	2,521	5,967	5,299	9,881	6,205	20,447
1990	1,759	6,214	6,895	13,239	5,413	15,437
1991	1,490	7,263	6,791	6,424	5,479	17,117
1992	1,545	8,194	5,587	5,205	5,762	24,841
1993	1,487	8,007	4,843	7,314	4,977	18,385
1994	1,664	7,577	3,781	22,836	3,941	24,687
1995	1,797	8,735	3,424	16,323	3,990	20,118
1996	2,285	8,527	4,724	16,273	5,732	28,272
1997	3,030	8,100	6,901	18,754	6,481	22,122
1998	3,323	8,079	7,421	18,351	7,510	15,453
1999	3,648	5,864	9,761	14,432	7,753	12,809
2000	3,826	5,561	13,790	8,975	8,213	15,110
2001	4,040	6,196	10,722	7,279	8,941	7,454
2002	4,139	7,580	10,200	6,063	8,124	7,507
2003	4,198	10,686	9,490	5,520	6,045	15,790
2004	3,895	10,637	5,510	5,555	5,555	14,182
2005	4,338	10,007	5,305	10,493	4,911	8,259
2006	4,904	10,211	5,943	15,577	4,505	7,541
2007	5,623	8,928	6,229	18,849	5,194	13,494
2008	5,632	6,235	6,457	4,032	6,221	8,749
2009	5,817	4,673	7,917	22,530	5,850	8,711

Table 2. Environmental variables used in this study and their source.

Variable	Abbreviation		Stocks	Source
Southern New England Air Temperature	aSNE	three 2 monthly periods	SNE	http://www.esrl.noaa.gov/psd/data/gridded/data.ncep.reanalysis.html
Georges Bank Air Temperature	aGB	three 2 monthly periods	GB	http://www.esrl.noaa.gov/psd/data/gridded/data.ncep.reanalysis.html
Gulf of Maine Air Temperature	aGOM	three 2 monthly periods	GOM	http://www.esrl.noaa.gov/psd/data/gridded/data.ncep.reanalysis.html
Woods Hole Coastal Water Temperature	WH	three 2 monthly periods	GB, SNE	http://www.nefsc.noaa.gov/epd/ocean/MainPage/ioos.html
Boothbay Harbor Coastal Water Temperature	BH	three 2 monthly periods	GOM	http://www.nefsc.noaa.gov/epd/ocean/MainPage/ioos.html
Atlantic Multidecadal Oscillation	AMO	0 year lag	GB, GOM, SNE	http://www.cdc.noaa.gov/Correlation/amon.us.long.data
North Atlantic Oscillation (DJFM)	NAO	0, 1, and 2 year lags	GB, GOM, SNE	http://www.cgd.ucar.edu/cas/jhurrell/Data/naodjfmindex.asc
Gulf Stream Index – Joyce and Zhang (2010)	GS-J	0 year lag	GB, GOM, SNE	Terry Joyce (pers. comm.)
Gulf Stream Index – Taylor and Stephens (1998)	GS-PLY	0 year lag	GB, GOM, SNE	http://www.pml-gulfstream.org.uk/Web2009.pdf

Table 3. List of standard and environmentally-explicit stock recruitment models used in the study. Formulation follows Levi et al. (2003).

Model Name	Model Formulation	Model
Beverton-Holt	$R = S/(b + aS)$	Standard / No Environment
Beverton-Holt	$R = Se^{cE}/(b + aS)$	Environmental Model 1 Controlling Effects (alters the rate of change of numbers of young fish in time)
Beverton Holt	$R = S/(b + ae^{cE}S)$	Environmental Model 2 Limiting Effects (alters the carrying capacity of the habitat for recruits)
Beverton Holt	$R = S/(be^{cE} + aS)$	Environmental Model 3 Masking Effects (determines the metabolic work needed for the maintenance of the individual.)

Table 4. Correlation matrix for the 21 environmental variables considered in this study. Significance denoted by color: p<0.05 yellow; p<0.01 orange; p<0.001 red.

Environmental Variables	GS-J-0	GS-PML-0	AMO-0	NAO-0	NAO-1	NAO-2	WH-JF	WH-MA	WH-MJ	BH-JF	BH-MA	BH-MJ	aSNE-JF	aSNE-MA	aSNE-MJ	aGB-JF	aGB-MA	aGB-MJ	aGOM-JF	aGOM-MA	aGOM-MJ
GS-J-0	1.00	0.54	-0.07	-0.02	0.33	0.46	0.20	0.21	0.15	0.32	0.26	0.19	0.19	0.05	0.02	0.38	0.29	0.20	0.12	-0.14	0.11
GS-PML-0	0.54	1.00	-0.23	0.31	0.40	0.53	0.22	0.24	0.28	0.32	0.05	0.06	0.19	0.10	0.09	0.35	0.21	0.33	0.15	-0.09	0.13
AMO-0	-0.07	-0.23	1.00	-0.22	-0.29	-0.49	0.25	-0.01	-0.34	0.27	0.47	0.69	0.26	0.17	0.12	0.13	-0.20	-0.40	0.24	-0.05	0.19
NAO-0	-0.02	0.31	-0.22	1.00	0.14	-0.09	0.26	0.25	0.24	-0.13	-0.42	-0.27	0.18	0.07	0.02	0.17	0.17	0.22	0.10	0.09	0.12
NAO-1	0.33	0.40	-0.29	0.14	1.00	0.17	-0.14	-0.06	0.28	-0.09	-0.20	-0.02	0.04	-0.07	0.12	0.10	0.19	0.32	-0.01	0.02	0.12
NAO-2	0.46	0.53	-0.49	-0.09	0.17	1.00	0.07	0.10	0.06	0.30	0.10	-0.21	-0.02	0.02	-0.08	0.07	0.08	0.08	-0.08	-0.14	-0.19
WH-JF	0.20	0.22	0.25	0.26	-0.14	0.07	1.00	0.63	0.28	0.54	0.33	0.20	0.81	0.36	0.26	0.74	0.16	0.10	0.73	0.21	0.28
WH-MA	0.21	0.24	-0.01	0.25	-0.06	0.10	0.63	1.00	0.47	0.17	0.24	-0.07	0.65	0.73	0.34	0.68	0.60	0.34	0.67	0.63	0.23
WH-MJ	0.15	0.28	-0.34	0.24	0.28	0.06	0.28	0.47	1.00	-0.06	-0.29	-0.11	0.26	0.14	0.71	0.25	0.33	0.67	0.27	0.29	0.62
BH-JF	0.32	0.32	0.27	-0.13	-0.09	0.30	0.54	0.17	-0.06	1.00	0.72	0.50	0.50	0.05	0.04	0.47	-0.12	-0.10	0.42	-0.15	0.10
BH-MA	0.26	0.05	0.47	-0.42	-0.20	0.10	0.33	0.24	-0.29	0.72	1.00	0.70	0.41	0.36	0.00	0.42	0.08	-0.30	0.38	0.11	-0.07
BH-MJ	0.19	0.06	0.69	-0.27	-0.02	-0.21	0.20	-0.07	-0.11	0.50	0.70	1.00	0.22	0.08	0.23	0.22	-0.10	-0.18	0.21	-0.12	0.24
aSNE-JF	0.19	0.19	0.26	0.18	0.04	-0.02	0.81	0.65	0.26	0.50	0.41	0.22	1.00	0.39	0.13	0.87	0.13	0.09	0.93	0.25	0.22
aSNE-MA	0.05	0.10	0.17	0.07	-0.07	0.02	0.36	0.73	0.14	0.05	0.36	0.08	0.39	1.00	0.29	0.39	0.59	0.13	0.39	0.77	-0.01
aSNE-MJ	0.02	0.09	0.12	0.02	0.12	-0.08	0.26	0.34	0.71	0.04	0.00	0.23	0.13	0.29	1.00	0.16	0.38	0.37	0.16	0.38	0.67
aGB-JF	0.38	0.35	0.13	0.17	0.10	0.07	0.74	0.68	0.25	0.47	0.42	0.22	0.87	0.39	0.16	1.00	0.38	0.24	0.91	0.27	0.24
aGB-MA	0.29	0.21	-0.20	0.17	0.19	0.08	0.16	0.60	0.33	-0.12	0.08	-0.10	0.13	0.59	0.38	0.38	1.00	0.51	0.12	0.74	0.15
aGB-MJ	0.20	0.33	-0.40	0.22	0.32	0.08	0.10	0.34	0.67	-0.10	-0.30	-0.18	0.09	0.13	0.37	0.24	0.51	1.00	0.11	0.35	0.63
aGOM-JF	0.12	0.15	0.24	0.10	-0.01	-0.08	0.73	0.67	0.27	0.42	0.38	0.21	0.93	0.39	0.16	0.91	0.12	0.11	1.00	0.25	0.24
aGOM-MA	-0.14	-0.09	-0.05	0.09	0.02	-0.14	0.21	0.63	0.29	-0.15	0.11	-0.12	0.25	0.77	0.38	0.27	0.74	0.35	0.25	1.00	0.11
aGOM-MJ	0.11	0.13	0.19	0.12	0.12	-0.19	0.28	0.23	0.62	0.10	-0.07	0.24	0.22	-0.01	0.67	0.24	0.15	0.63	0.24	0.11	1.00

Table 5. Akaike Information Criteria statistics for the top ten ranked models for each stock.

Stock	Model Rank	Model	Variable	AICc	delta	weight	cumulative weight
Southern New England	1	BH env M2	aSNE-JF	505.12	0.00	0.214	0.214
	2	BH env M2	GS-J-0	505.62	0.50	0.166	0.380
	3	BH env M1	aSNE-JF	505.79	0.66	0.153	0.533
	4	BH env M3	aSNE-JF	506.15	1.03	0.128	0.661
	5	BH env M2	AMO-0	507.47	2.35	0.066	0.727
	6	BH env M3	AMO-0	508.00	2.88	0.051	0.778
	7	BH env M1	AMO-0	508.05	2.93	0.049	0.827
	8	BH env M1	GS-J-0	509.17	4.05	0.028	0.855
	9	BH env M3	GS-J-0	509.21	4.09	0.028	0.883
	10	BH env M1	WH-JF	509.47	4.35	0.024	0.907
Georges Bank	1	BH std M	none	496.04	0.00	0.082	0.082
	2	BH env M3	aGB-JF	496.76	0.72	0.057	0.139
	3	BH env M1	aGB-MJ	496.95	0.91	0.052	0.191
	4	BH env M2	aGB-MJ	496.96	0.92	0.052	0.243
	5	BH env M3	GS-PML-0	497.29	1.25	0.044	0.287
	6	BH env M2	GS-J-0	497.55	1.51	0.039	0.326
	7	BH env M1	GS-J-0	497.56	1.51	0.039	0.365
	8	BH env M2	WH-MJ	498.04	2.00	0.030	0.395
	9	BH env M1	WH-MJ	498.06	2.02	0.030	0.425
	10	BH env M2	NAO-0	498.15	2.11	0.029	0.454
Gulf of Maine	1	BH env M2	aGOM-JF	423.39	0.00	0.108	0.108
	2	BH env M1	aGOM-JF	423.50	0.10	0.103	0.211
	3	BH env M2	aGOM-MJ	424.72	1.33	0.056	0.267
	4	BH env M2	BH-JF	424.83	1.44	0.053	0.320
	5	BH env M1	aGOM-MJ	424.84	1.45	0.052	0.372
	6	BH env M1	BH-JF	424.86	1.47	0.052	0.424
	7	BH std M	none	424.97	1.58	0.049	0.473
	8	BH env M2	aGOM-MA	425.04	1.64	0.048	0.521
	9	BH env M1	aGOM-MA	425.13	1.74	0.045	0.566
	10	BH env M3	BH-JF	425.63	2.24	0.035	0.601

Table 6. Model weights, explained variance and evidence ratios for best environmentally-explicit models compared to best standard model.

Stock	Model	Variable	W	r^2	Evidence Ratio
Southern New England	BH env M2	aSNE-JF	0.214	0.74	105.8
	BH std M	None	0.002	0.60	
Georges Bank	BH env M3	aGB-JF	0.057	0.07	0.7
	BH std M	None	0.082	0.00	
Gulf of Maine	BH env M2	aGOM-JF	0.108	0.21	2.2
	BH std M	None	0.003	0.07	

Table 7. Results of Beverton-Holt stock recruitment model fits for the Southern New England stock. Model parameters are provided following Table 2 and asymptotic recruitment is calculated as $\frac{1}{a}$. The lognormal deviate ($\frac{\sum(\ln(R)-\ln(\hat{R}))^2}{n-1}$), mean environmental term, and standard deviation of the environmental term for the environmentally-explicit model are also provided.

	No prior – standard model	No prior – environmental model aSNE-JF	Prior a=50,409,200 standard model	Prior a=50,409,200 environmental model
b	0.3482	0.2777	0.1879	0.2842
a	2.4433e-6	2.2278e-5	1.9836e-5	1.9840e-5
c	NA	0.6203	NA	0.6129
ae^{cT}	NA	8.2171e-6	NA	7.4048e-6
Asym Rec	409,280,000	121,700,000	50,414,000	135,050,000
lognormal deviate	0.2464	0.1963		
$\bar{E}$		-1.6079		
σ_E		1.6654		

Table 8. Results of Beverton-Holt stock recruitment model fits for the Gulf of Maine stock. Model parameters are provided following Table 2 and asymptotic recruitment is calculated as $\frac{1}{a}$. The lognormal deviate ($\frac{\sum(\ln(R)-\ln(\hat{R}))^2}{n-1}$), mean environmental term, and standard deviation of the environmental term are also provided.

	No prior – standard model	No prior – environmental model
b	0.0509	0.0533
a	1.0893e-4	1.5225e-4
c	Na	0.0599
ae^{cT}	Na	1.0857e-4
Asym Rec	9,179,800	9,211,000
lognormal deviate	0.0540	0.0487
$\bar{E}$		-5.6454
σ_E		1.6562

Figure 1. Map showing locations of temperature data used in this study. Air temperatures were derived from the NCEP Reanalysis. Grid denoted as thin gray lines and grid points used in air temperature calculations marked by circles (red – Southern New England, green – Georges Bank, blue – Gulf of Maine, cyan – regional). Coastal water temperatures were obtained for Woods Hole, Massachusetts (WH - red triangle) and Boothbay Harbor, Maine (BH - blue triangle). Data sources are provided in Table 2.

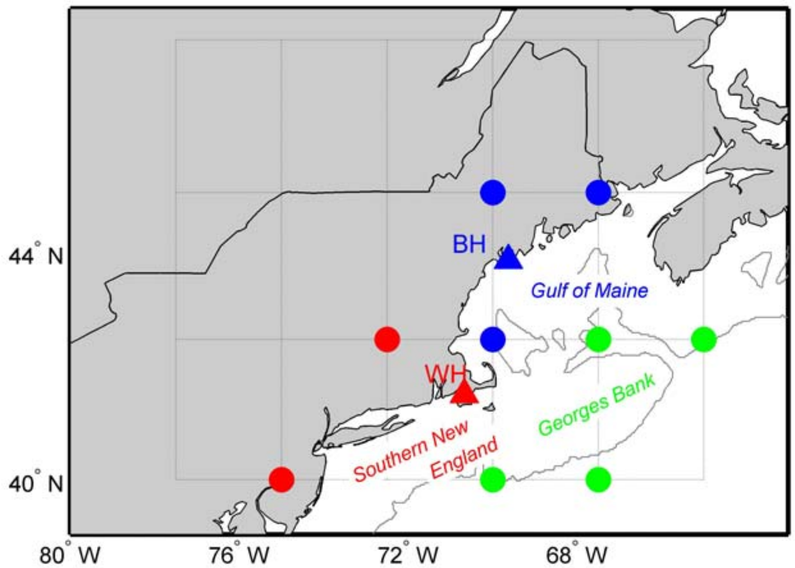


Figure 2. Representative time series for environmental variables considered here. Abbreviations for the variable names are provided in Table 2. Air and water temperatures are presented relative to their mean value. The large-scale environmental variables are presented as anomalies.

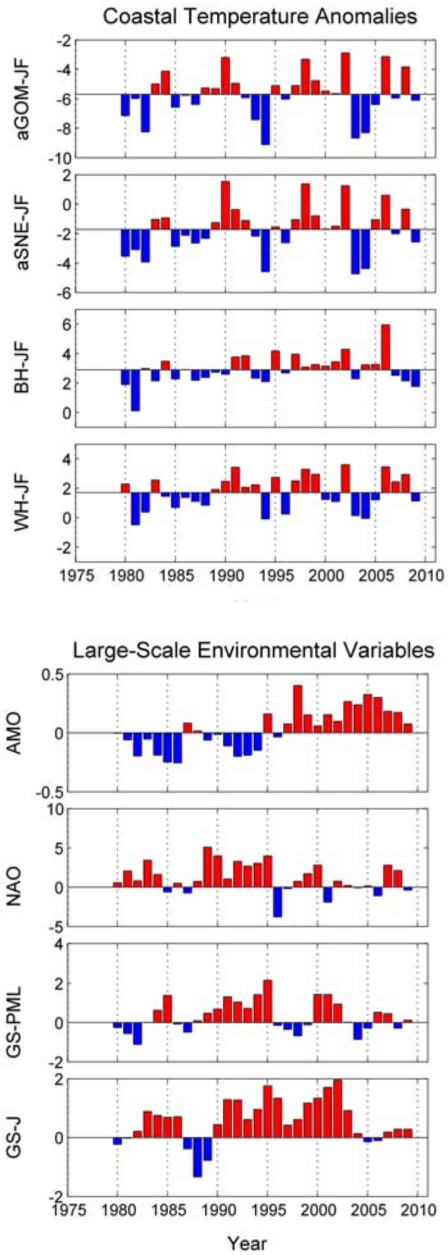


Figure 3. Comparison of stock-recruitment data and Beverton-Holt models for the three stocks of winter flounder.

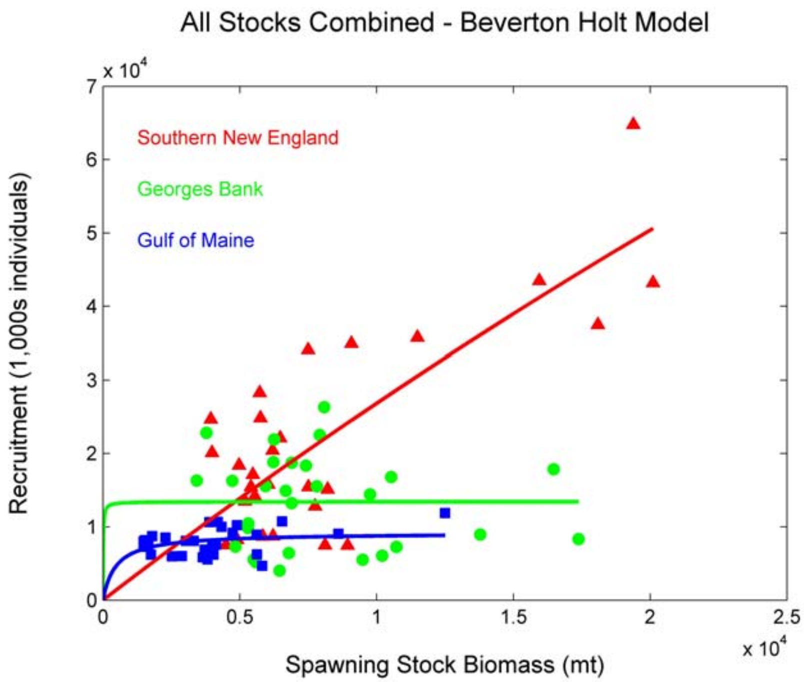


Figure 4. Comparison of the residuals of the stock-recruitment relationships for the three winter flounder stocks based on the standard Beverton-Holt model.

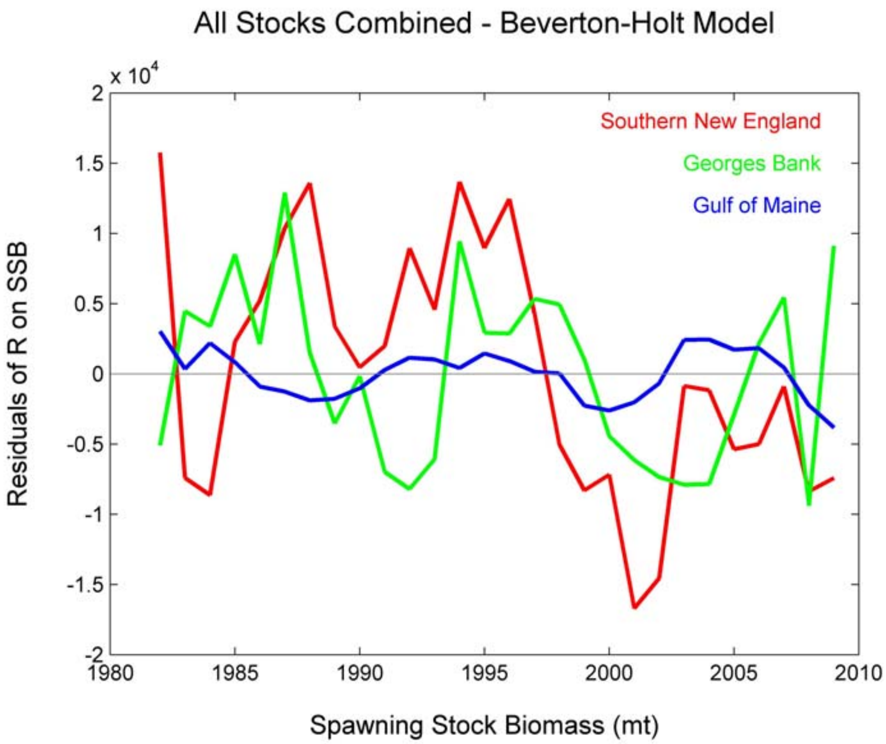


Figure 5. Serial correlation of the residuals of the stock recruitment relationship making the three pairwise comparisons: SNE vs. GB, SNE vs. GOM, and GB vs. GOM. Window for serial correlations set at 10 years.

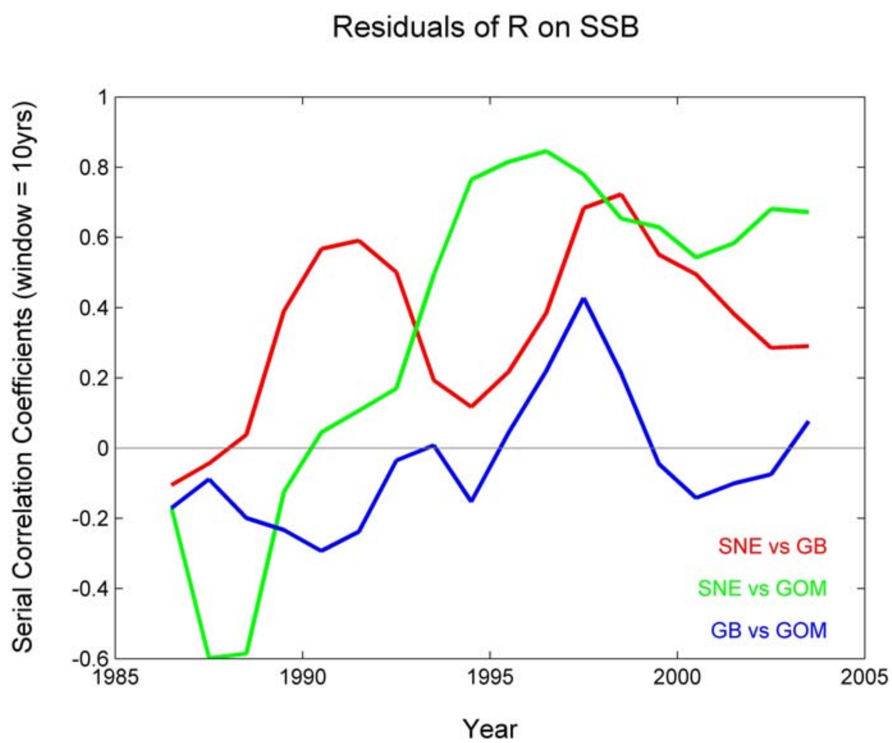


Figure 6. Environmentally-explicit stock recruitment relationships for the Southern New England stock of winter flounder. The best overall environmental model is shown as is the standard model (gray). Symbols are color coded to the value of the environmental variable and model predictions for mean environment and ± 1 standard deviation of the environmental variable are shown. The specific model and environmental variable are noted in the upper left hand corner (see Table 1 and 2 for abbreviations).

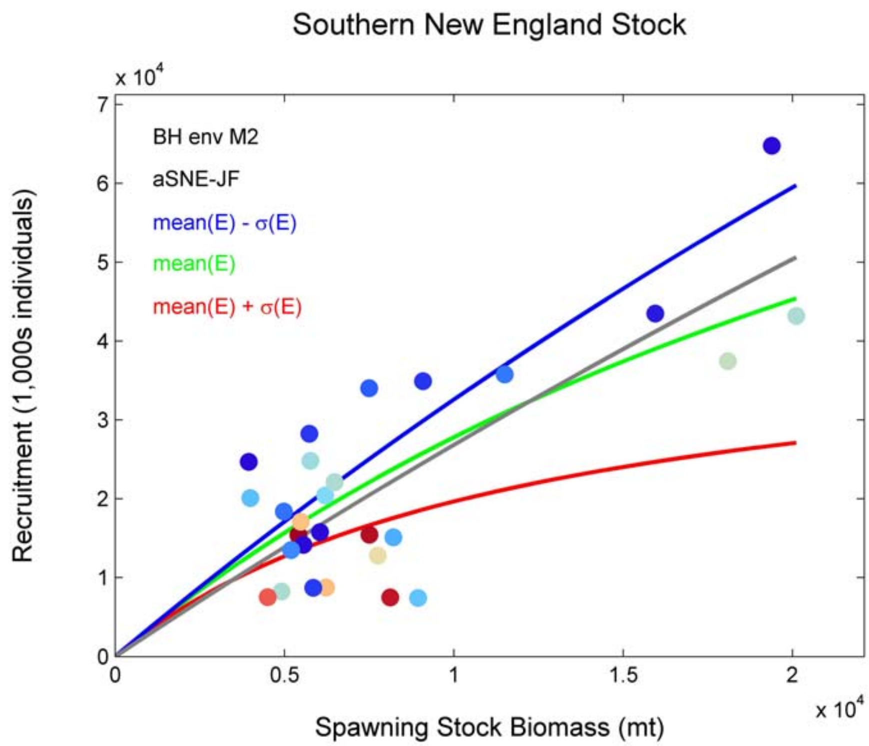


Figure 7. Environmentally-explicit stock recruitment relationships for the Georges Bank stock of winter flounder. The best overall environmental model is shown as is the standard model (gray). Symbols are color coded to the value of the environmental variable and model predictions for mean environment and ± 1 standard deviation of the environmental variable are shown. The specific model and environmental variable are noted in the upper left hand corner (see Table 1 and 2 for abbreviations).

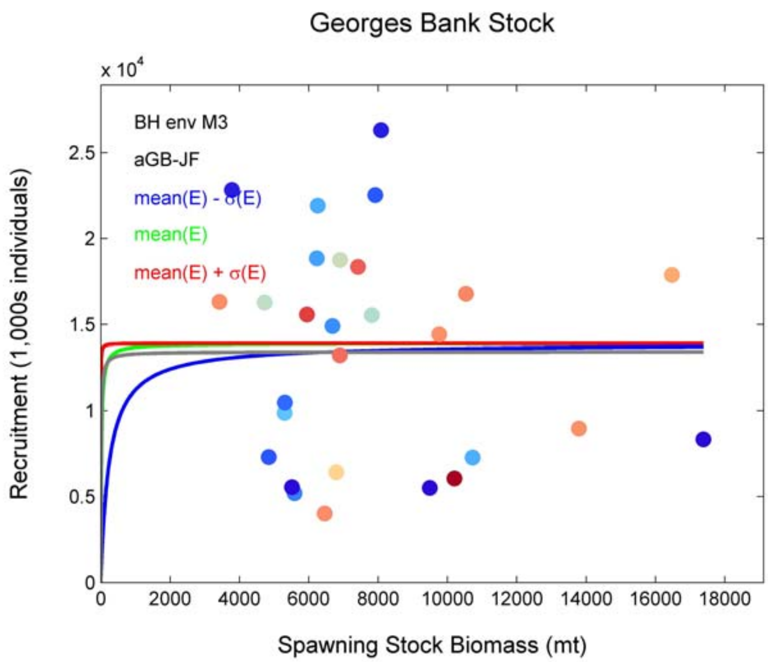


Figure 8. Environmentally-explicit stock recruitment relationships for the Gulf of Maine stock of winter flounder. The best overall environmental model is shown as is the standard model (gray). Symbols are color coded to the value of the environmental variable and model predictions for mean environment and ± 1 standard deviation of the environmental variable are shown. The specific model and environmental variable are noted in the upper left hand corner (see Table 1 and 2 for abbreviations).

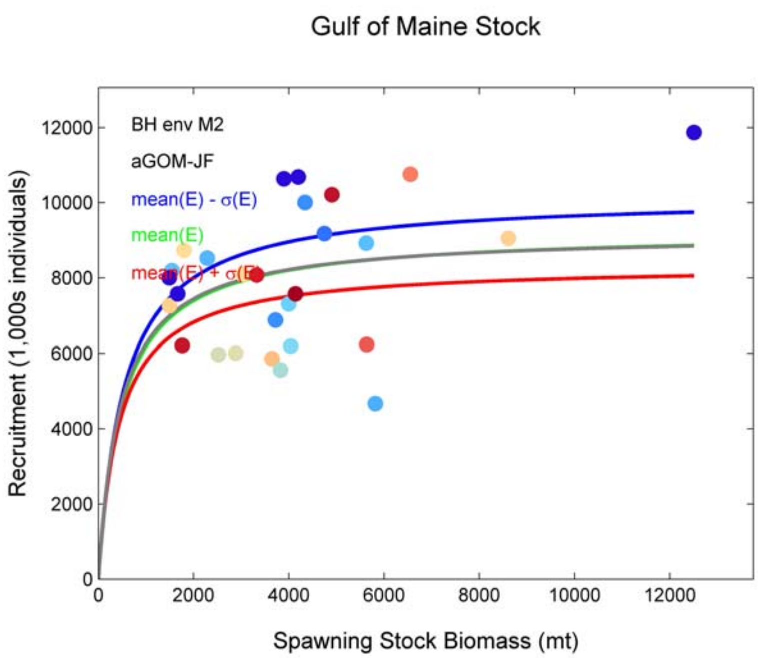
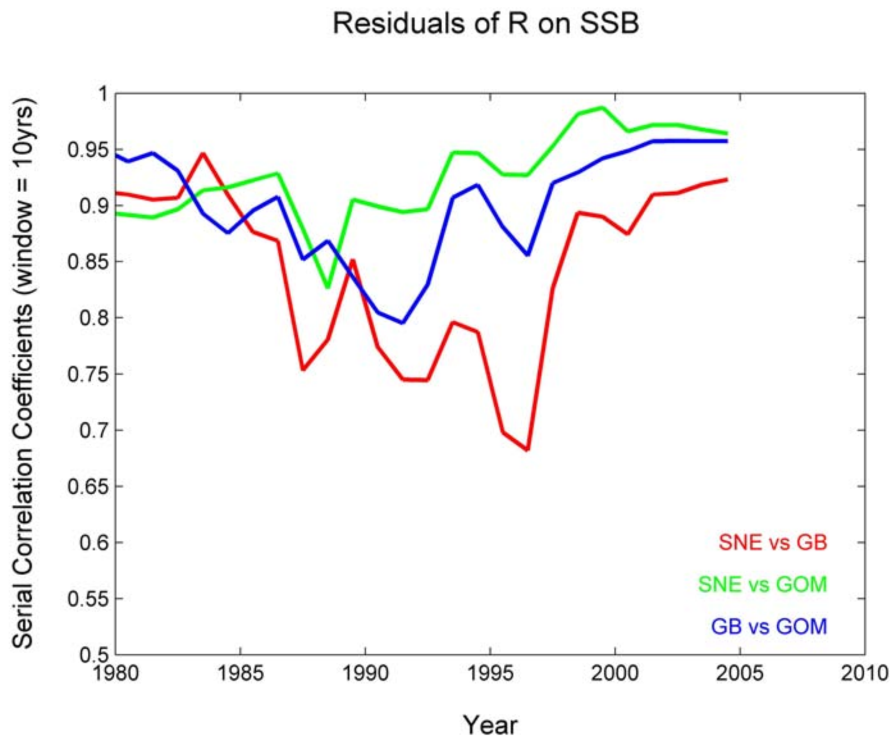


Figure 9. Serial correlation of winter air temperatures across the region making the three pairwise comparisons: SNE vs. GB, SNE vs. GOM, and GB vs. GOM.



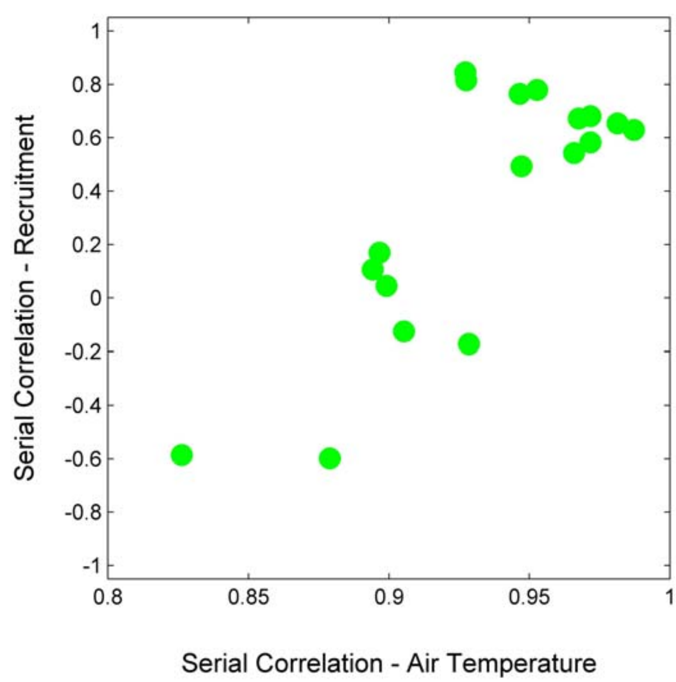
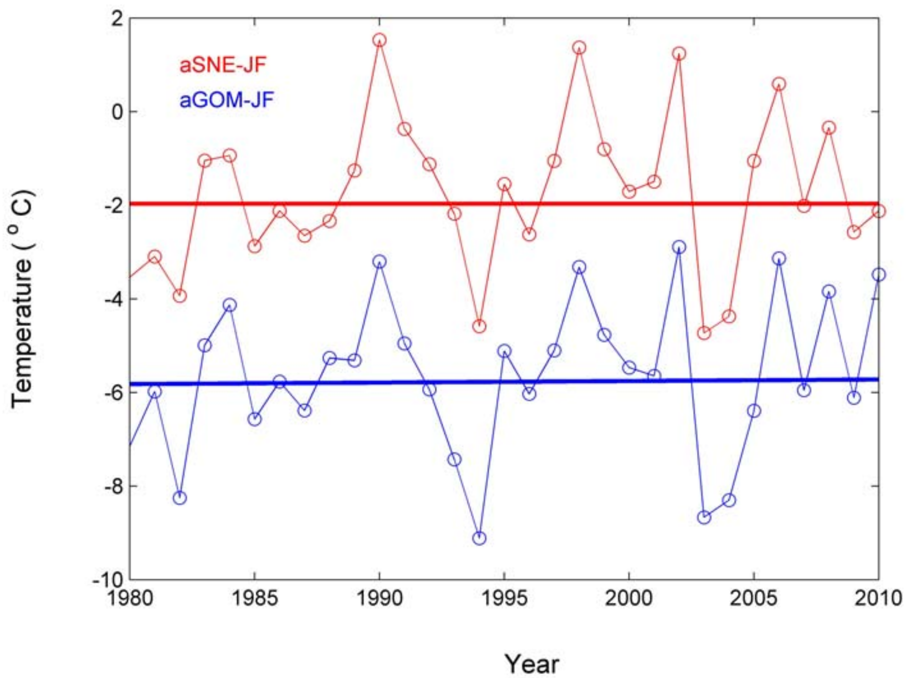


Figure 10. Time series of winter air temperature over Southern New England and the Gulf of Maine for the period of the assessment. The lines represent the linear regression; the slopes of both were not significantly different than zero.



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SDWG Background WP#14
May 2011
TOR4-Uncertainty Landings

A Working Paper in support of SARC 52 Winter Flounder TOR 4 "Perform a sensitivity analysis which examines the impact of allocation of catch to stock areas on model performance (in TOR 5)."

Measures of Uncertainty in the Trip-based Allocated Landings

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Brief Summary

- Prior to 1994, Dealer landings had area fished determined by the port agent based on interviews conducted with the vessel captains; not all trips were interviewed. For non-interviewed trips, port agent would use knowledge gained through prior interviews of the vessel and the fleet to assign statistical area
- Dealer allocated landings (1994 onward) have area fished determined by a multi-tier trip-based allocation method (Wigley et al 2008) that utilizes Vessel Trip Report data
- For allocated landings, a meta data element (Alevel) indicate whether a trip matched at one of the four tiers, Alevel A (direct 1:1 trip match between Dealer and VTR data), Alevel B (vessel match between Dealer and VTR data); Alevel C (fleet match between Dealer and VTR data) or Alevel D (broad fleet match between Dealer and VTR data)
- Alevel A is equivalent to a port agent's interview prior to 1994 (intv = 1)
- Trips that matched at Alevel B, C or D have an area assigned on a probabilistic basis using VTR data.
- The probability associated with each trip can be used to approximate the uncertainty associated with landings at Alevel = B, C or D.
- Calculated the variance and coefficient of variation of an allocated trip (and associated landings) using the multinomial distribution:

  Eq. 1 $V(T) = pq = p * (1-p)$

  Eq. 2 $CV(T) = sqrt(pq)$

  Eq. 3 $CV(L) \sim CV(T)$

  Eq. 4 $V(L) = (CV(T) * L)^2$

  Eq 5. $Var\_mt = prob * (1-prob) * mt^2$

  Where p is the probability (*prob*) of the trip (stored in the Dealer AA data)

  T is the given allocated trip at Alevel =B, C, or D

  L are the landings associated with an allocated trip at Alevel = B, C or D.

- Winter flounder stock landings are summarized by Alevel and year (Figures 1 – 3)
  - High percentage of winter flounder stock landings match at Alevel = A
  - generally ranges between 60% and 68%
  - Level A percentages are greater than interview percentages for SNE and GOM winter flounder stocks
- Winter flounder stock landings and 95% confidence intervals are summarized by year (Table 1).
  - No measure of uncertainty for landings prior to 1994

- Explore the magnitude of under-reporting of statistical areas on Vessel Trip Reports (VTR) using three years of matched trips from Northeast Fisheries Observer Program (OB) and VTR data for 2007, 2008 and 2009. OB and VTR trips were matched using the M Palmer's mid-point match method (Palmer and Wigley 2007). A "diagnostic ratio" (observed kept weight of all species divided by the VTR kept weight of all species) was used to create a subset of matched trips and applied to Dealer trips with Alevel = A. Percentage of trips under-reporting statistical areas in the subset of trips ranged between 7% and 13% (Table 2).
    - Further exploration of the 'matched set' is needed
    - Utilizing data leveraging between VMS and VTR is the best way to improve VTR reporting compliance

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Table 1. Winter flounder stock landings (mt) with 95% confidence intervals, and percentage of uncertain landings associated with the trip-bases allocation (Alevel = B, C, & D).

Year	GOM	95 CI	%	GB	95 CI	%	SNE	95 CI	%	Area 000	UNID stock	
1982	2798.7			2958.6			8420.1				0.2	
1983	2099.1			3893.8			7963.7					
1984	1706.0			3926.6			7635.2					
1985	1583.4			2151.0			6005.4				23.2	Grand Banks
1986	1216.0			1761.3			4639.4				7.1	Grand Banks
1987	1159.9			2636.6			4482.7					
1988	1250.6			2803.9			3932.1				0.0	
1989	1252.9			1880.1			3846.9					
1990	1117.0			1898.0			3963.5					
1991	1008.3			1814.3			4782.8					
1992	824.6			1821.5			3815.5					
1993	611.5			1659.6			3010.4				2.3	
1994	528.5	4.6	0.9%	929.1	16.3	1.8%	2113.7	18.3	0.9%	30.5	1.2	stat area 460s
1995	699.9	11.3	1.6%	728.3	16.0	2.2%	2582.9	18.1	0.7%	18.1		
1996	602.2	11.5	1.9%	1366.3	24.0	1.8%	2767.7	29.3	1.1%	23.9		
1997	566.3	16.4	2.9%	1219.0	24.4	2.0%	3515.5	47.8	1.4%	42.6		
1998	640.7	7.8	1.2%	1308.0	32.1	2.5%	3134.8	42.1	1.3%	5.4		
1999	348.5	4.7	1.3%	937.5	21.5	2.3%	3342.8	32.5	1.0%	8.3	0.1	
2000	533.1	5.6	1.0%	1603.1	31.0	1.9%	3692.8	28.1	0.8%	13.7		
2001	691.0	11.3	1.6%	1667.4	32.6	2.0%	4509.0	32.4	0.7%	63.0		
2002	658.2	14.3	2.2%	2079.7	34.0	1.6%	3033.2	33.2	1.1%	106.4		
2003	716.0	4.9	0.7%	2828.2	38.9	1.4%	2301.8	25.8	1.1%	46.0		
2004	573.0	6.2	1.1%	2647.2	39.8	1.5%	1593.3	39.0	2.4%	106.0		
2005	282.5	4.4	1.5%	1882.0	24.0	1.3%	1168.0	26.8	2.3%	334.5		
2006	180.7	2.4	1.3%	814.1	13.0	1.6%	1632.0	14.5	0.9%	119.4		
2007	209.8	1.8	0.9%	785.9	15.0	1.9%	1525.5	17.4	1.1%	155.1		
2008	242.4	2.9	1.2%	944.5	14.7	1.6%	1043.0	12.9	1.2%	117.2		
2009	261.3	1.7	0.7%	1656.4	30.8	1.9%	242.1	10.9	4.5%	52.6	2.2	stat area 468
2010	129.4	1.6	1.3%	1249.6	32.4	2.6%	157.8	13.9	8.8%	28.5		
avearge			1.4%			1.9%			1.8%			

Table 2. Number and percentage of matched trips for 2007, 2008 and 2009 for trips where the count of observed statistical areas equaled the count of statistical areas reported in the VTR (SA Count Equal) and where the counts of statistical areas were not equal (SA Count Not Equal), for single and multiple statistical areas reported on the observed trip. (SA = statistical area; Multi = multiple).

	2007		2008		2009	
Stat Area Level	**Trips**	**%**	**Trips**	**%**	**Trips**	**%**
Matched Trips Alevel = A	929		874		1062	
SA Count Equal, Single SA	670	72.1%	587	67.2%	755	71.1%
SA Count Equal, Multi SA	28	3.0%	35	4.0%	28	2.6%
SA Count Not Equal, Multi SA	**231**	**24.9%**	**252**	**28.8%**	**279**	**26.3%**
Matched Trips Alevel = A and landed Winter Flounder	305		340		327	
SA Count Equal, Single SA	208	68.2%	230	67.6%	243	74.3%
SA Count Equal, Multi SA	13	4.3%	7	2.1%	12	3.7%
SA Count Not Equal, Multi SA	**84**	**27.5%**	**103**	**30.3%**	**72**	**22.0%**
Stock Level						
Multi SA	97	31.8%	110	32.4%	84	25.7%
Stock Count Equal	66	21.6%	66	19.4%	62	19.0%
Stock Count Not Equal	**31**	**10.2%**	**44**	**12.9%**	**22**	**6.7%**

Figure 1. Percentage of Gulf of Maine winter flounder landings, by Alevel and year.

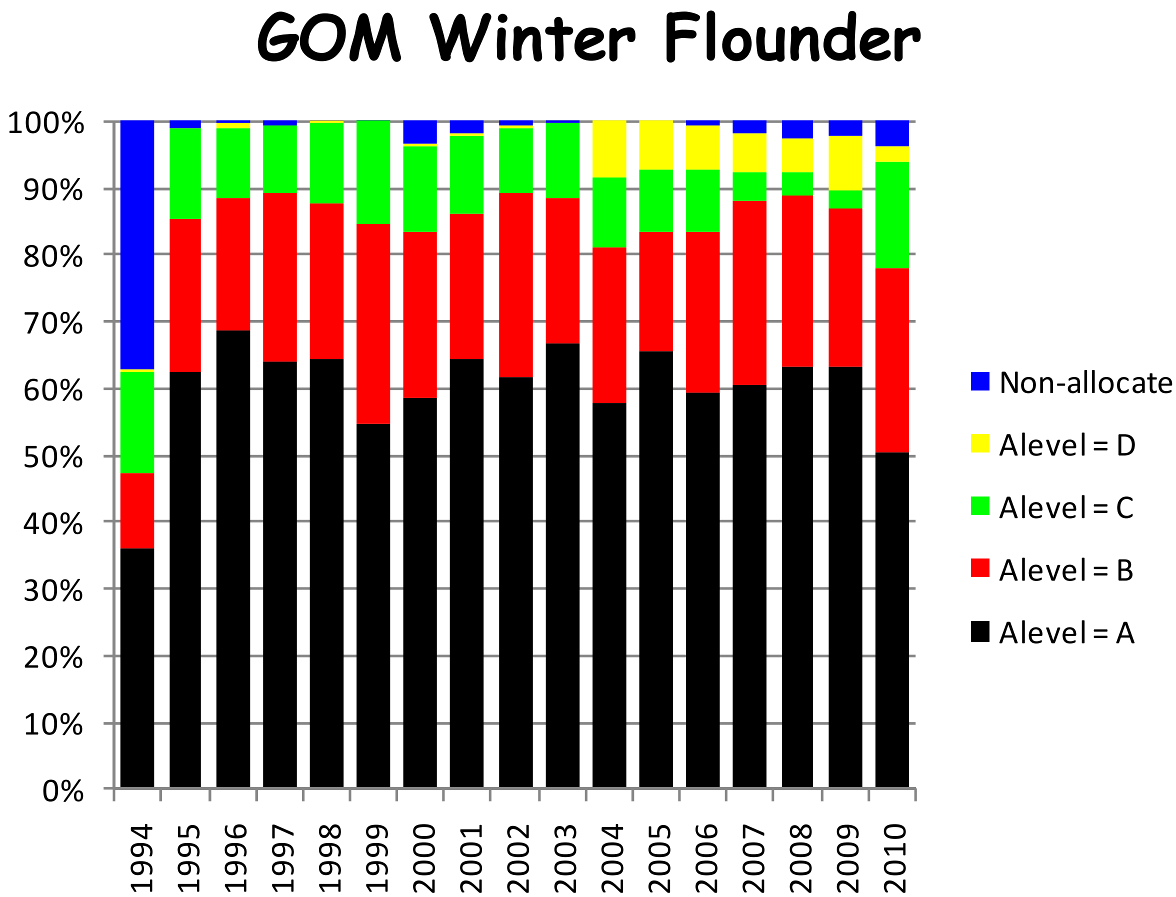


Figure 2. Percentage of Georges Bank winter flounder landings, by Alevel and year.

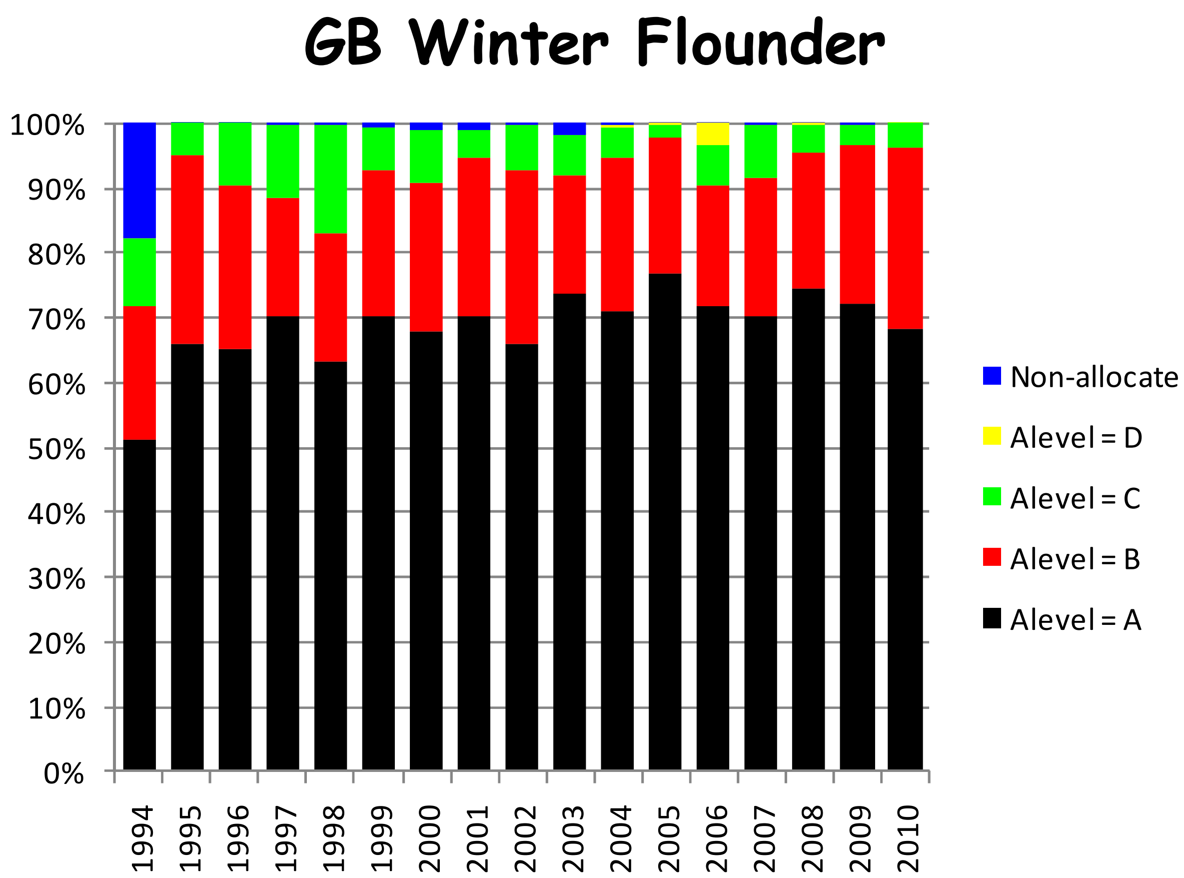


Figure 3. Percentage of Georges Bank winter flounder landings, by Alevel and year.

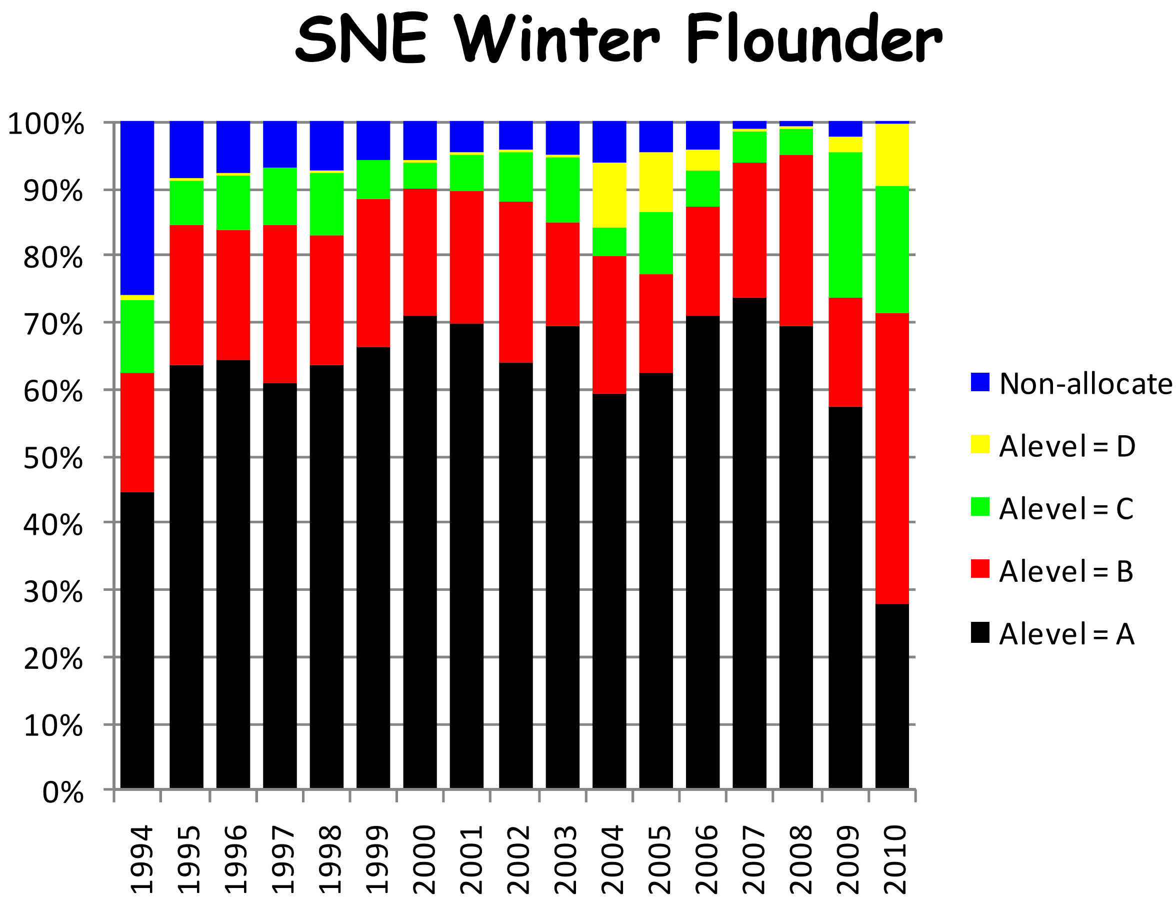


Figure 4. Winter flounder stock landings (mt) with 95% confidence intervals associated with the trip-bases allocation (Alevel = B, C, & D).

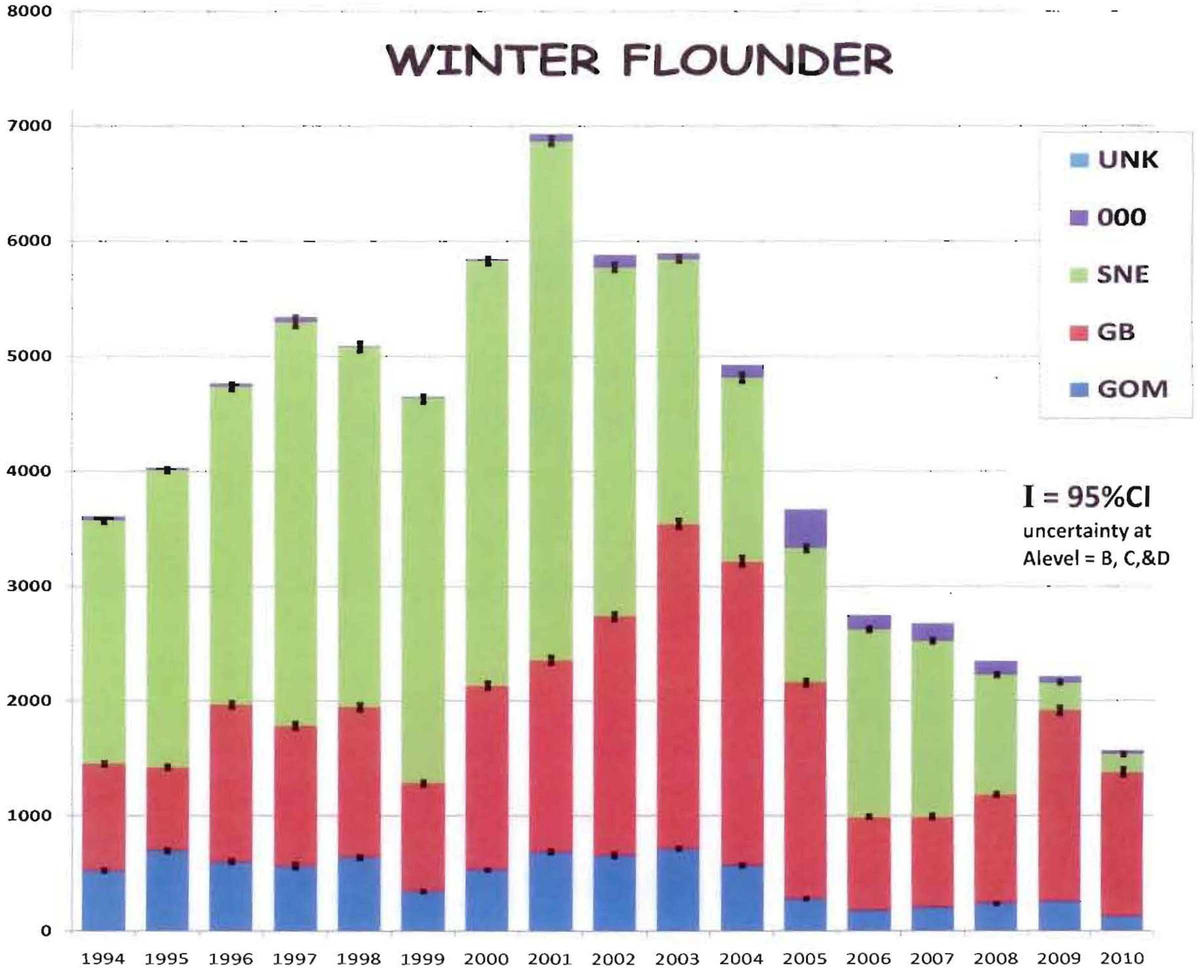
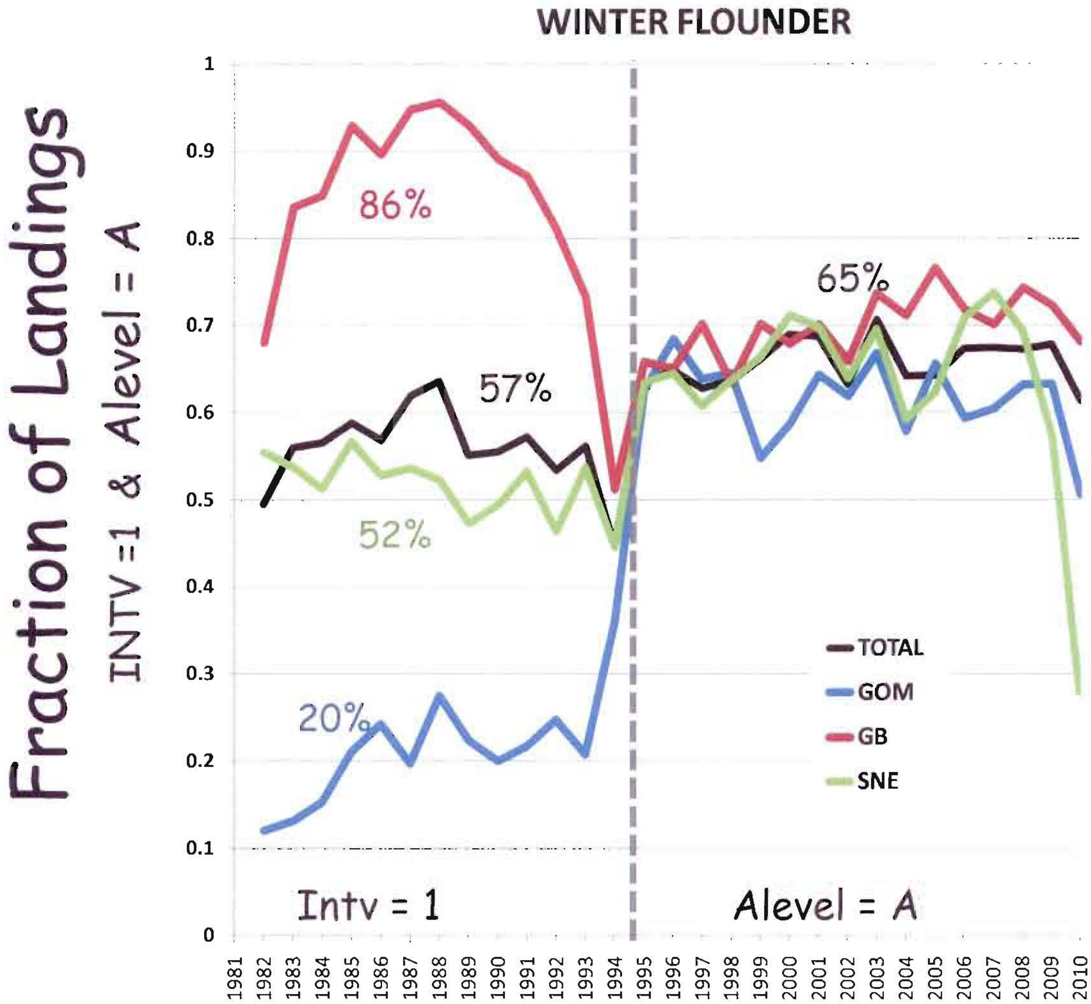


Figure 5. Fraction of winter flounder stock landings associated with Alevel = A of the trip-based allocation (1994 onward) and port agents' interviews (intv = 1; prior to 1993). Time series average percentage of stock landings are given.



SARC 52 Southern Demersal Working Group (SDWG)
Working Paper: Re-analysis of Howe and Coates (1975)
April 29 2011
Anthony Wood
**************DRAFT: DO NOT DISTRIBUTE OR CITE**************

Winter flounder natural mortality derived from data in Howe and Coates (1975) using instantaneous rates tagging models.

Introduction

Tag based estimates of natural mortality for winter flounder (*Pseudopleuronectes americanus*) off New England are limited to a few studies carried out decades ago (Dickie and McCraken 1955, Poole 1966, Howe and Coates 1975). These studies implemented ratio based formulas of tag releases and recoveries to estimate natural mortality without modeling. The methodology and model development of tag-recovery analysis has advanced since these early studies were conducted (Brownie et al. 1985, Lebrenton et al. 1992, Hoenig et al. 1998). The purpose of this analysis was to apply a more advanced tagging model to data from Howe and Coates (1975) to estimate natural mortality. The tagging model fit to the data was the instantaneous rates formulation of Brownie et al. (1985) recovery model s (Hoenig et al. 1998).

Methods

A subset of tag-recovery data from Howe and Coates (1975) detailing 5 release cohorts (Table 1) were analyzed with 4 different parameterizations of the Hoenig et al. (1998) instantaneous rates tagging model. All models assumed a constant natural mortality across time and cohorts as well as constant fishing mortality throughout each year. It was also assumed that tags were not lost or missed, and that tagging did not influence survival, recovery rate, or mixture within the overall population.

Brownie et al. (1985) models use survival (*S*) and recovery rate (*f*) parameters to model tag returns. The instantaneous rates tagging model specifies the survival (*S*) and recovery rate (*f*) parameters in terms of fishing (*F*) and natural (*M*) mortality (Hoenig et al. 1998). Survival becomes:

$$S = e^{-(F+M)}$$

And recovery rate is:

$$f = \lambda \phi u$$

Where λ is the reporting rate (assumed 1.0 for all models) and ϕ is tag loss (assumed no tag loss in all models). Exploitation rate (*u*) is also specified in terms of *F* and *M*:

$$u = \frac{F}{F+M}\left(1 - e^{-(F+M)}\right)$$

Matrices of expected values for each model structure were developed (Table 2). Recoveries were modeled as multinomial random variables and parameters were estimated via maximum likelihood estimation. Akaike's information criterion (AIC) was used to rank and select the model with the best fit:

$$\text{AIC} = -2\ln(L) + 2K$$

Where *L* is the model likelihood and K is the number of parameters.

An over-dispersion estimate was derived for the general model (year and cohort parameterization) by dividing the model deviance by the degrees of freedom. To account for over-dispersion ($\hat{c}$) and for differences in effective sample size (*N*), a quasi likelihood adjusted AIC was used to adjust fit of the top selected models (Burnham and Anderson, 2002):

$$\text{QAIC}_c = \frac{-2\ln(L)}{\hat{c}} + 2K + \frac{2K(K+1)}{N-K-1}$$

To quantify the differences in support between models an index using normalized Akaike weights (*w*) was also calculated for each model (*i*) (Buckland et al., 1997):

$$w_i = \frac{e^{\frac{-\Delta QAIC_i}{2}}}{\sum e^{\frac{-\Delta QAIC_i}{2}}}$$

Results and Conclusion

The general model fit the data well (c = 1.55) and returned the lowest AIC value with the majority of support (0.98) among models (Table 3). Residuals for all models did not show any remarkable patterns (Figure 1). For the general model the terminal year Fs for each cohort had to be fixed to achieve convergence and realistic estimates for all *F*s. The values were fixed to the estimates derived from the cohort dependent parameterization. The need to fix these parameters suggests there was not enough information in the data to estimate an *F* for each cohort/year combination.

Estimates of M were similar across models, ranging from 0.30 to 0.35 (Table 3). The model with cohort dependent parameters, which converged without the need to fix parameters, returned an M of 0.30 and Fs equal to 0.17, 0.21, 0.36, 0.24, and 0.32 for cohorts 1 through 5, respectively.

It should be emphasized that these models assumed full reporting and no tag loss. Any violation of either assumption would lead to higher estimates for M. The estimated values of M should be viewed as a minimum. This short analysis of historical tagging data confirms that *M* for winter flounder is likely higher than 0.2 and an increase in *M* should be considered for assessment purposes.

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Table 1. Winter flounder tag-recovery data from Howe and Coates (1975).

Release	Releases	Recaptures				
Cohort	1964	1964	1965	1966	1967	1968
1. Tarpaulin Cove, Menemsha	500	72	43	28	7	5
2. Hedge Fence Shoal	500	92	45	32	11	2
3. Tuckernuck Shoal	498	132	63	44	13	7
4. Great Point, Nantucket	456	102	38	18	15	13
5. Rodgers Shoal	500	102	64	47	47	12

Table 2. Expected recoveries from four different model structures fit to winter flounder tagging data from Howe and Coates (1975). Parameters are specified in terms of survival (S) and recovery rate (f) for clarity.

Cohort	Year 1964	1965	1966	1967	1968
		1. Constant rate model (parameters: F, and M)			
1	N_1f	N_2Sf	N_3SSf	N_4SSSf	N_5SSSSf
2	N_6f	N_7Sf	N_8SSf	N_9SSSf	$N_{10}SSSSf$
3	$N_{11}f$	$N_{12}Sf$	$N_{13}SSf$	$N_{14}SSSf$	$N_{15}SSSSf$
4	$N_{16}f$	$N_{17}Sf$	$N_{18}SSf$	$N_{19}SSSf$	$N_{20}SSSSf$
5	$N_{21}f$	$N_{22}Sf$	$N_{23}SSf$	$N_{24}SSSf$	$N_{25}SSSSf$
		2. Cohort dependent (parameters: F_c for c = 1, 2, 3, 4, 5, and M)			
1	N_1f_1	$N_2S_1f_1$	$N_3S_1S_1f_1$	$N_4S_1S_1S_1f_1$	$N_5S_1S_1S_1S_1f_1$
2	N_6f_2	$N_7S_2f_2$	$N_8S_2S_2f_2$	$N_9S_2S_2S_2f_2$	$N_{10}S_2S_2S_2S_2f_2$
3	$N_{11}f_3$	$N_{12}S_3f_3$	$N_{13}S_3S_3f_3$	$N_{14}S_3S_3S_3f_3$	$N_{15}S_3S_3S_3S_3f_3$
4	$N_{16}f_4$	$N_{17}S_4f_4$	$N_{18}S_4S_4f_4$	$N_{19}S_4S_4S_4f_4$	$N_{20}S_4S_4S_4S_4f_4$
5	$N_{21}f_5$	$N_{22}S_5f_5$	$N_{23}S_5S_5f_5$	$N_{24}S_5S_5S_5f_5$	$N_{25}S_5S_5S_5S_5f_5$
		3. Year dependent (parameters: F_t for t = 1, 2, 3, 4, 5, and M)			
1	N_1f_1	$N_2S_1f_2$	$N_3S_1S_2f_3$	$N_4S_1S_2S_3f_4$	$N_5S_1S_2S_3S_4f_5$
2	N_6f_1	$N_7S_1f_2$	$N_8S_1S_2f_3$	$N_9S_1S_2S_3f_4$	$N_{10}S_1S_2S_3S_4f_5$
3	$N_{11}f_1$	$N_{12}S_1f_2$	$N_{13}S_1S_2f_3$	$N_{14}S_1S_2S_3f_4$	$N_{15}S_1S_2S_3S_4f_5$
4	$N_{16}f_1$	$N_{17}S_1f_2$	$N_{18}S_1S_2f_3$	$N_{19}S_1S_2S_3f_4$	$N_{20}S_1S_2S_3S_4f_5$
5	$N_{21}f_1$	$N_{22}S_1f_2$	$N_{23}S_1S_2f_3$	$N_{24}S_1S_2S_3f_4$	$N_{25}S_1S_2S_3S_4f_5$
		4. Cohort and year dependent (parameters: F_{ct} for t = 1, 2, 3, 4, 5, c = 1, 2, 3, 4, 5 and M)			
1	N_1f_1	$N_2S_1f_2$	$N_3S_1S_2f_3$	$N_4S_1S_2S_3f_4$	$N_5S_1S_2S_3S_4f_5$
2	N_6f_6	$N_7S_6f_7$	$N_8S_6S_7f_8$	$N_9S_6S_7S_8f_9$	$N_{10}S_6S_7S_8S_9f_{10}$
3	$N_{11}f_{11}$	$N_{12}S_{11}f_{12}$	$N_{13}S_{11}S_{12}f_{13}$	$N_{14}S_{11}S_{12}S_{13}f_{14}$	$N_{15}S_{11}S_{12}S_{13}S_{14}f_{15}$
4	$N_{16}f_{16}$	$N_{17}S_{16}f_{17}$	$N_{18}S_{16}S_{17}f_{18}$	$N_{19}S_{16}S_{17}S_{18}f_{19}$	$N_{20}S_{16}S_{17}S_{18}S_{19}f_{20}$
5	$N_{21}f_{21}$	$N_{22}S_{21}f_{22}$	$N_{23}S_{21}S_{22}f_{23}$	$N_{24}S_{21}S_{22}S_{23}f_{24}$	$N_{25}S_{21}S_{22}S_{23}S_{24}f_{25}$

Table 3. Model diagnostics and ranks from four instantaneous rates model fit to winter flounder tag-recovery data from Howe and Coates (1975). Adjustments were made based on a c-hat for the general model of 1.55.

Model	QAIC	Delta QAIC	QAIC weight	# of Parameters	QDeviance	M estimate
M(.) *F*(Cohort * t)	3930.48	0	0.98	21	21.73	0.31
M(.) *F*(Cohort)	3938.35	7.88	0.02	6	90.28	0.30
M(.) *F*(.)	3969.68	39.21	0	2	155.49	0.32
M(.) *F*(t)	3973.99	43.52	0	6	145.96	0.35

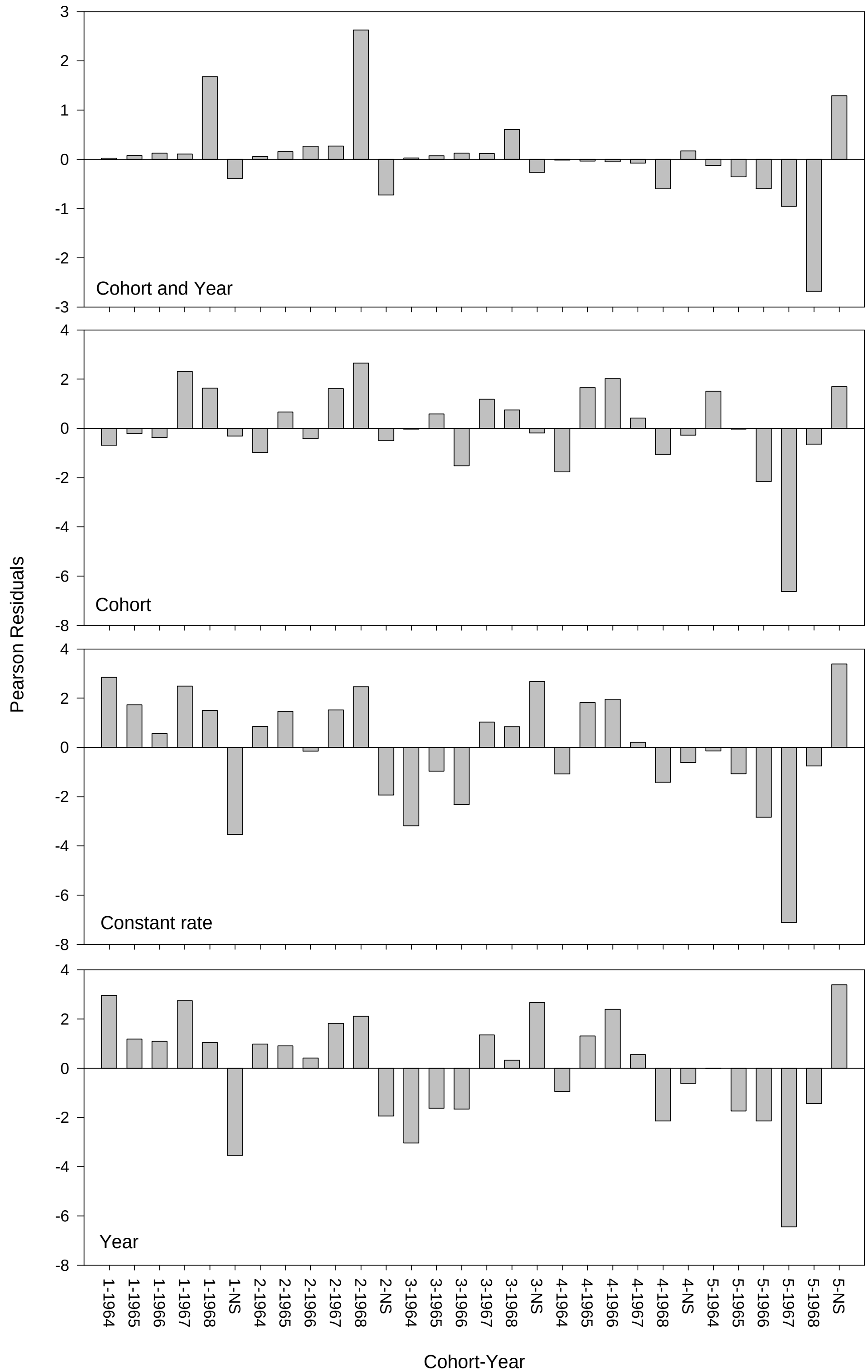

Figure 1. Pearson residuals from four instantaneous rates models fit to winter flounder data from Howe and Coates (1975). NS residuals are from probabilities relating to tags in a cohort that were never seen.

SDWG Background WP_D_16
May 2011
BRPs Vulnerability

D. SDWG52 Consensus Statement on

Biological Reference Points (Term of Reference 6) and

Vulnerability (Term of Reference 8b)

for Winter Flounder Stocks

Term of Reference 6. *State the existing stock status definitions for "overfished" and "overfishing". Then update or redefine biological reference points (BRPs; point estimates or proxies for BMSY, BTHRESHOLD, and FMSY) and provide estimates of their uncertainty. If analytic model-based estimates are unavailable, consider recommending alternative measurable proxies for BRPs. Comment on the scientific adequacy of existing BRPs and the "new" (i.e., updated, redefined, or alternative) BRPs.*

In addition to the stock-specific results, the SDWG developed a consensus response to TOR6, taking into consideration the assessment results for all three stocks. The fishing mortality and biomass Biological Reference Points (BRPs) discussed below are from the Final models accepted for the stocks. As defined in the Magnuson Act, 'overfishing' means "a rate or level of fishing mortality that jeopardizes the capacity of a fishery to produce the maximum sustainable yield on a continuing basis" (i.e., FMSY). The guidelines allow for the projected catch associated with the overfishing limit (OFL) to be based on FSMY proxies. Many proxies are used to define overfishing in situations when FMSY is not well determined. The SDWG interpreted these guidelines to mean that best practice is to use a FMSY estimate instead of a proxy when FSMY can be reliably estimated. The SDWG estimated FSMY for the winter flounder stocks as well as proxies in the form of F40%. The SDWG developed consensus on some aspects of the FMSY estimates (relative magnitude across stocks), but also had some disagreement about the reliability of FMSY estimates (related to the perceived reliability of the respective assessments). The SDWG could not come to consensus on the preferred reference points for the three winter flounder stocks. Updated estimates of F40% were provided as the existing overfishing definitions and as alternatives to FMSY and SSBMSY estimates. Estimates of F40% and SSB40% were provided as potential overfishing definitions based on the precedence offered by GARM3 (NEFSC 2008), instead of other potential Percent Maximum Spawning Potential (%MSP) alternatives.

Appropriateness of FMSY Estimates

The SDWG estimates of FMSY utilize data and prior information in a statistical framework. Estimation of the steepness parameters (*h*) in the stock-recruitment relationships used the available stock-recruitment estimates and a prior distribution of *h* from other Pleuronectid flatfishes (Myers et al. 1999), as was used in previous assessments of SNE/MA winter flounder (NEFSC 2002).

Steepness was estimated to be:

- 0.84 for Gulf of Maine winter flounder
- 0.85 for Georges Bank winter flounder
- 0.64 for SNE/MA winter flounder

The SDWG estimates of *h* for winter flounder stocks are realistic. They are compatible with both the estimates of *h* for Pleuronectids that were used as priors, and with the distribution of all of the estimates in Myers et al. (1999). Uncertainty in FMSY is estimable based on stock-recruitment relationships, but not all sources of uncertainty are included in the SDWG evaluation (e.g., uncertainty in assumed natural mortality, precision and accuracy of stock-recruit estimates are not considered).

Concerns about the reliability of the estimates FMSY

There are aspects of using a prior for steepness for these stocks that are problematic. If no prior is applied, two of the three resulting stock-recruit relationships are not theoretically feasible (e.g., the linear increase in SNE/MA recruitment as a function of spawning stock size; the constant recruitment even at low spawning stock size for GBK winter flounder). There are several concerns with the prior on *h* from Myers et al. (1999) meta-analysis for Pleurinectid flatfishes. The prior is not well understood, because the original data was not available at the SDWG. Many of the stocks used to form the prior have M < 0.2. The appropriateness of this prior for the U.S. winter flounder stocks, with assumed M = 0.3, is therefore unknown. The number of Pleuronectid stocks in the Myers et al. (1999) study is limited (n=14), and there were no winter flounder stocks included. Derivation of the precision estimate of *h* (0.09; NEFSC 2002) is not clearly documented. The assumed normal error structure for the prior may not be appropriate for a parameter bounded by 0.2 and 1. Myers et al. (1999) stated that "the family-level estimates (shown in boldface) should be used with caution." FMSY estimates depend on both mean and precision of steepness, but the SDWG did not have information on how well the Myers et al. (1999) values were estimated.

The precision of steepness (*h*) estimates show a moderate range of possible values and an associated moderate range in the estimates of FMSY (see text table below):

Estimates of steepness (h), FMSY and %MSP with 80% confidence intervals and CVs.

Stock	h	CV	10%	90%	FMSY	CV	10%	90%	%MSP	10%	90%
GOM	0.84	0.08	0.75	0.92	0.565	0.19	0.43	0.77	28	34	21
GBK	0.85	0.08	0.75	0.94	0.500	0.22	0.39	0.69	29	35	22
SNE/MA	0.64	0.08	0.57	0.76	0.310	0.07	0.27	0.43	42	46	32

The implied maximum lifetime reproductive rate [4*h*/(1-*h*)] is quite variable among the stock (*h*=0.64 implies *ahat*=7.1 while *h*=0.85 implies *ahat*=22.7), where *ahat* represents the number of spawners produced by each spawner over its lifetime at very low spawner abundance (i.e., assuming absolutely no density dependence). With similar growth, maturity and natural mortality rates, it is not clear why the implied reproductive rates are so different.

The %MSP associated with the range of FMSY estimates suggests that F40% is compatible with FMSY for SNE/MA winter flounder, but those ranges suggest that F40% is not compatible with FMSY for the GOM and GBK stocks. The %MSP associated with FMSY estimates range from 28% to 42%, but it is again unclear why the %MSP values are up to 50% different for stocks with similar biology and fishery characteristic, when only the stock-recruitment steepness differs.

The SDWG had several concerns about the use of F40% as an overfishing definition. F%MSP ignores any information from stock and recruitment estimates, and therefore may be inconsistent with FMSY estimates that use such information. The performance of F40% for achieving MSY has not been evaluated specifically for winter flounder stocks. The SDWG recognized the logical difference between "data-based" inferences involved in estimates of FMSY vs. “hypothesis-based” expectations of inter-stock similarities based on analogy to justify F40%.

In summary, from a comparative approach to MSY reference points, F40% is similar for all three stocks. The estimate of FMSY for GOM winter flounder is similar to that for the GBK stock but 60% higher than that for the SNE/MA stock. This range in FMSY among the three stocks is due to the differing patterns in the estimated stock-recruitment data (see text table below). The SNE/MA stock has a low steepness estimate that is driven by estimates of strong recruitment and high spawning stock size from the 1980s. Unlike the situation for SNE/MA winter flounder, for GOM and GBK winter flounder there is no pattern in the stock-recruitment estimates that supports inferences of lower steepness. The influences of environmental conditions that limit recruitment success (e.g., warmer temperatures and subsequent larval predation effects) are possible explanations of the lower steepness of the SNE/MA stock (and subsequently lower FMSY). The SDWG noted that these explanations assume no local and complete adaptation to environmental conditions among the stocks.

Stock	F_{MSY}	h	SSB_{MSY}	SSB_0	SSB_0/SSB_{MSY}	MSY	F_{40}	SSB_{40}	MSY_{40}
GOM	0.565	0.84	2,167	8,887	4.10	1,152	0.340	3,287	1,080
GBK	0.500	0.85	8,260	31,478	3.81	4,200	0.320	11,300	3,200
SNE/MA	0.310	0.64	33,820	92,657	2.74	9,763	0.327	29,045	8,903

Implications of Reference Point Decisions

Despite the uncertainty in reference point estimation for SNE/MA Atlantic winter flounder, the determination of stock status and rebuilding conclusions are robust. All candidate reference points lead to a conclusion that the stock cannot rebuild to SSBMSY by 2014, even at F = 0.

Major uncertainty persists in the GOM winter flounder stock assessment, and estimates of current biomass are much greater than all candidate estimates of BSMY or BMSY proxies. However, the relatively low estimates of F and conclusion that overfishing is not occurring are consistent with recent regulations and restrictions on catch. The estimate of SSBMSY corresponding to h = 0.84 for GOM winter flounder is close to the lower end of the range of past SSB estimates, in contrast to the situation for GBK winter flounder, where it is close to the middle of this range. The minimum observed GOM SSB was 1,487 mt, and the 80% confidence interval of SSBMSY is 1,640 to 2,700 mt. Although the 80% confidence intervals for h for each of these two stocks are similar, this feature of the GOM estimates renders them less reliable than those for the GBK stock. While there were disagreements within the SDWG on the BRPs to use as the overfishing definition, the SDWG reached consensus that the current model and associated reference points for GOM winter flounder were acceptable and the best that could be determined at this time.

Term of Reference 8b. "*Take into consideration uncertainties in the assessment and the species biology to describe this stock's vulnerability (see "Appendix to the SAW TORs") to becoming or remaining overfished, and how this could affect the choice of ABC.*"

Appendix to the SAW Terms of Reference: "*Vulnerability. A stock's vulnerability is a combination of its productivity, which depends upon its life history characteristics, and its susceptibility to the fishery. Productivity refers to the capacity of the stock to produce MSY and to recover if the population is depleted, and susceptibility is the potential for the stock to be impacted by the fishery, which includes direct captures, as well as indirect impacts to the fishery (e.g., loss of habitat quality).*"

The Working Group accounted for vulnerability, productivity and susceptibility using conventional MSY reference points, and evaluated uncertainty using model estimates of precision and qualification of other uncertainties. Age-based analytical stock assessment models and associated MSY reference point evaluations provide a relatively comprehensive and synthetic evaluation of vulnerability that is consistent with stock status determination and projection. Vulnerability and susceptibility were accounted for in both aspects of status determination (estimation of F and FMSY) and projections as the magnitude of fishing mortality and recent fishery selectivity at age. All components of productivity (reproduction, individual growth, and survival) were also explicitly accounted for in stock status determination and projections. Reproduction was monitored as age-1 recruitment, and projected as a function of SSB (the product of abundance, weight and maturity at age). Individual growth was monitored as empirical size at age, and projected as recent mean size at age. Survival was accounted for based on model estimates of fishing mortality and selectivity as well as assumed natural mortality, which was informed by tagging analysis.

Uncertainties that were not accounted for by assessment and reference point models were evaluated using model diagnostics. Standard model diagnostics (e.g., residual analyses, retrospective analyses) were used for model validation. Retrospective inconsistencies that were outside the bounds of model precision estimates were addressed through selection of alternative models.

Vulnerabilities that were not accounted for by assessment and reference point models were evaluated using exploratory modeling, habitat observations and testing the influence of environmental factors on recruitment dynamics. All three winter flounder stocks are harvested in mixed-stock fisheries, but bycatch and discards are monitored and managed through Annual Catch Limits with Accountability Measures for exceeding those limits.

Additional considerations of vulnerability and productivity are the implications of shifts in distribution, recruitment dynamics and increased natural mortality. Nye et al. (2009) found an annual increase in mean depth (0.8 m per year) of the winter flounder distribution over the NEFSC survey time series from 1968-2007, which may have productivity and vulnerability implications. Apparent decreases in estuarine spawning or shifts toward coastal spawning (e.g., DeCelles and Cadrin 2010) may also have implications for vulnerability (e.g., less availability to recreational fisheries) and productivity (less larval retention). Consumption of winter flounder by other fishes, birds and mammals may be increasing as these predator populations increase.

A considerable source of additional vulnerability is the continued weak recruitment and low reproductive rate (e.g., recruits per spawners) of Southern New England/Mid Atlantic (SNE/MA) winter flounder. If weak recruitment and low reproductive rate continues, productivity and rebuilding of SNE/MA winter flounder will be less than projected. Stock-recruit modeling suggests that warm temperatures are having a negative effect on recruitment of SNE/MA winter flounder.

The GOM assessment indicates that the stock is well above BMSY and experiencing very low fishing mortality. However, the GOM assessment is the most uncertain of the three (from a “feasibility” perspective, if not from a “statistical precision” perspective). Therefore, it may be vulnerable to overfishing if managed at a catch level close to the nominally projected catch in the near term.

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Initial Applications of Statistical Catch-at-Age Assessment Methodology to the Southern New England/Mid-Atlantic Winter Flounder Resource

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Abstract

SCAA is applied to the SNE winter flounder resource, for which past VPA assessments have been plagued by retrospective patterns. It is shown that these patterns can be removed by the combination of allowance for autocorrelation in the residuals of survey series fits to underlying abundance trends, and an increase in natural mortality over time commencing sometime during the 1990s.

Introduction

This paper presents the results of some initial applications of Statistical Catch-at-Age methodology to data for the Southern New England/Mid-Atlantic winter flounder resource. This exercise has focused on attempts to remove the retrospective pattern evident in past assessments, which has been reduced though not eliminated by the approach of allowing an estimable change in survey catchability *q* between 1993 and 1994 (Terceiro, 2008).

Data and Methodology

The catch and survey based data (including catch-at-age information) and some biological data are listed in Tables in Appendix A. They are as kindly provided by Mark Terceiro on 17 March. The aim of the paper is primarily methodological, and the work was carried out before subsequent updates to these data became available. The key run will be repeated with these updated data and the results presented in a subsequent document.

The details of the SCAA assessment methodology are provided in Appendix B.

Various approaches were attempted to remove the retrospective pattern which occurs in this assessment as for earlier VPAs (Terceiro, 2008). These included adding auto-correlation to the recruitment time series, which proved unsuccessful. The most successful approach was found to be the combination of allowing estimable auto-correlation in the residuals about the fits to each survey index and an increase in natural mortality over recent years, where best results were found to be provided by having this increase occur smoothly from M=0.3 prior to 1995 to 0.6 by 2005 and thereafter (the higher value was estimated in the model fit, subject to an upper bound of 0.6).

Results are illustrated in terms of three Base Cases, with the following characteristics:

	Base Case 1 (BC1)	Base Case 2 (BC2)	Base Case 3 (New Base Case, NBC)
Survey indices	split in 1993/1994, different q's estimated for the two periods but same selectivity	Not split	Not split
First order autocorrelation in the surveys	No	Estimated for each survey index	Estimated for each survey index
Natural mortality	0.2 throughout	0.2 throughout	0.3 pre-1995, linear increase from 0.3 in 1995 to 0.6* in 2005, 0.6* thereafter
Commercial selectivity	two periods: 1981-1993, 1994-2010	two periods: 1981-1993, 1994-2010	two periods: 1981-1993, 1994-2010
Starts in	1981	1981	1981

* Estimate hit upper bound

A series of variants of the NBC are also considered.

Results and Discussion

Results for the three Base Cases are given in Table 1. Retrospective patterns for spawning biomass and recruitment trajectories are compared in Fig. 1 for each of the three Base Cases. A full set of results are shown for the New Base Case in Figs 2-6, which show the estimated spawning biomass trend, the stock-recruitment relationship and residuals, the selectivity-at-age vectors, and the model fits to data for the survey indices of abundance and the various sources of proportions-at-age information. Fig. 7 plots the biomass loss to the increase in *M* in the NBC.

Tables 2 and 3 give results for variants to the NBC, with retrospective patterns plotted in Fig. 8 and the spawning biomass trajectories for variant 8 (starting in 1964) plotted in Fig. 9.

Results shown in Table 1 (Mohn's ρ) and in Fig. 1 show that the NBC approach of allowing for autocorrelation in the residuals for the survey indices, and for natural mortality to increase after 1995, effectively removes the retrospective pattern in this assessment.

The reason the autocorrelation (which of itself does little to remove this pattern) is required is evident from inspection of Fig. 5. Fig. 5a shows that with the surveys split in 1993/1994, the NEFSC fall survey fits the survey trend reasonably. However if the split is removed (Fig. 5b) the fit appears very poor, with clear systematic trends in residuals (Fig. 5b). If autocorrelation is taken into account though, the associated residuals no longer show these systematic trends, both in Fig. 5b and for the NBC in Fig. 5c. Hypothesising such auto-correlation is not unreasonable, as the environmental effects responsible for the fluctuations in survey *q* over time could well have some persistence and hence show positive autocorrelation. CAA residuals for the NBC (Fig. 6) appear acceptable.

Table 1 also shows that for the NBC, the variability in recruitment is more consistent over time (similar values of σ_R_out for earlier and later periods unlike for BC1 or BC2.

Table 2 compares results for different input values for natural mortality *M* and its changes over time. In log likelihood terms, the only (slight) improvement compared to the NBC is through commencing the increase in *M* in 1990 rather than 1995. Results in Table 3 show that replacing estimation of a separate autocorrelation parameter for each survey by a single estimable parameter is marginally preferable in AIC terms, but makes little difference to key results. Retrospective patterns are all minimal for these further scenarios (see Mohn's ρ values in Tables 2 and 3, and Fig. 8).

Fig. 2 compares the NBC estimate of the spawning biomass trajectory with that from the previous GARM assessment as provided by VPA. The trends are very similar, with the differences in scale attributable primarily for the higher (initial) M value of 0.3 for the NBC compared to 0.2 for that VPA.

Fig. 7 reports the additional loss of flounder to natural mortality arising from the increase in M over time for the NBC. Note that the assessment results would be essentially unchanged if this reflected catches not taken into account rather than additional natural predation.

Fig. 9 reports results of starting the assessment in 1964 rather than 1981. This requires assumptions to develop the total catch made over that period, which are detailed in Appendix A. Because no catch-at-age data are available for that period, there is no basis to estimate recruitment residuals, so a constant recruitment level is assumed. These results suggest that the peak in spawning biomass in about 1980 initiated as a result of reduction of catches in the 1970's, and was reversed by an increase in those catches in the 1980s, rather than reflecting a period of enhanced reproduction during favourable environmental conditions.

In summary, the adjustment of the assessment to include autocorrelation in the residuals of survey indices as measures of abundance, together with an increase in M over time initiating sometime during the 1990s, can resolve the retrospective pattern observed in past assessments of this resource. Ready biological justification is available for the introduction of the first of these features, but it is more difficult to suggest mechanisms to explain the second.

Further Work Planned

The New Base Case reported here will be updated given updated data.

Reference

Terceiro M. 2008. J. Southern New England/Mid-Atlantic winter flounder. Appendix to the Report of the 3rd Groundfish Assessment Review Meeting (GARM III): Assessment of 19 Northeast Groundfish Stocks through 2007, Northeast Fisheries Science Center, Woods Hole, Massachusetts, August 4-8, 2008 http://www.nefsc.noaa.gov/publications/crd/crd0816/pdfs/garm3j.pdf

Table 1: Results for the three Base Cases. Biomass units are '000t. The two recruitment values refer to the averages over two recruitment periods, i.e. 1989-2010 and 1981-1988 respectively. MSY and related quantities have been computed under each of these recruitment levels, assuming the natural mortality *M* that applies in the most recent year if *M* is taken to have changed over time. Further details regarding some of the quantities shown can be found in Appendix B, section B.3.2.

	Base Case 1						Base Case 2				New Base Case			
'-lnL:overall	-763.2						-798.7				-864.1			
'-lnL:Survey	-27.5						-37.2				-49.8			
'-lnL:CAA	-90.3						-92.8				-91.7			
'-lnL:CAAsurv	-640.9						-662.0				-701.7			
'-lnL:RecRes	-5.7						-7.9				-21.9			
'-lnL:SelSmoothing	1.1						1.1				0.9			
Mohn's rho: SSB	0.48						0.49				-0.03			
Mohn's rho: rec.	1.28						1.11				0.16			
Phi	0.59						0.85				0.83			
Bsp(1981)	20.8						19.5				20.8			
Bsp(2010)	5.0						6.4				4.1			
Bsp(2010)/Bsp(1981)	0.24						0.33				0.20			
M	0.20						0.20				0.3-0.6			
Recruitment	11.2	37.5					11.9	39.3			25.7	52.8		
Bsp(MSY)	4.6	15.5					5.2	17.1			2.0	4.1		
MSY	3.2	10.8					3.4	11.4			2.4	5.0		
σ_{comCAA}	0.10						0.10				0.10			
		first period			second period									
Survey	q x10^6	σ_{surv}	σ_{CAA}	q x10^6	σ_{surv}	σ_{CAA}	q x10^6	σ_{surv}	σ_{CAA}	ρ	q x10^6	σ_{surv}	σ_{CAA}	ρ
NEFSCspr	182.1	0.31	0.12	280.6	0.32	0.10	255.1	0.35	0.11	0.37	285.2	0.31	0.10	0.06
NEFSCfall	549.7	0.56	0.18	1790.5	0.54	0.13	1086.4	0.50	0.15	0.78	936.6	0.47	0.15	0.67
NEFSCwinter	364.7	0.41	0.20		-		358.9	0.34	0.20	0.48	233.5	0.30	0.19	0.21
MADFM	1.40	0.47	0.18	2.48	0.37	0.15	2.74	0.41	0.16	0.56	3.31	0.41	0.15	0.51
RIDFW	0.49	0.63	0.14	0.64	0.42	0.16	0.57	0.54	0.15	0.29	0.57	0.51	0.16	0.20
CTDEP	2.47	0.60	0.15	2.10	0.54	0.15	2.79	0.50	0.13	0.57	3.13	0.51	0.12	0.68
NY	0.23	0.73	0.08	0.23	0.90	0.25	0.21	0.86	0.19	0.03	0.11	0.92	0.20	0.28
NJDFW Ocean	3.23	0.46	0.16		-		4.22	0.44	0.16	0.02	4.13	0.42	0.16	-0.03
NJDFW River	0.32	0.22	0.18		-		0.42	0.23	0.18	0.23	0.39	0.27	0.18	0.58
MADFM YOY	0.01	0.51	-	0.02	0.61	-	0.01	0.48	-	0.66	0.01	0.44	-	0.50
CTDEP YOY	0.38	0.70	-	0.62	0.60	-	0.53	0.66	-	0.29	0.24	0.65	-	0.26
RIDFW YOY	0.96	0.59	-	1.08	1.09	-	1.00	0.74	-	0.62	0.48	0.71	-	0.52
NY YOY	0.36	1.61	-	0.25	1.26	-	0.28	1.30	-	0.44	0.14	1.33	-	0.60
DEDFW YOY	0.01	1.30	-	0.01	0.88	-	0.01	1.01	-	-0.24	0.00	1.00	-	-0.23
URIGSO	0.70	0.36	0.16	0.98	0.60	0.15	0.82	0.53	0.15	0.34	0.53	0.51	0.13	0.31
σ_R_out (81-88, 89-10)	0.28	0.46					0.27	0.43			0.27	0.26		

Table 2: Results for variants on the New Base Case relating to different specifications for *M* and its changes over time.

	New Base Case				Variant 1: M_{start}=0.2				Variant 2: M_{start}=0.4				Variant 3: *M* changes over 1995-2000				Variant 4: *M* changes over 1995-2010				Variant 5: *M* changes over 1990-2005				Variant 6: *M* changes over 2000-2010			
'-lnL:overall	-864.1				-863.6				-860.2				-856.9				-859.3				-867.4				-860.5			
'-lnL:Survey	-49.8				-48.9				-52.1				-49.7				-51.5				-52.5				-47.2			
'-lnL:CAA	-91.7				-91.5				-93.6				-91.8				-94.1				-91.5				-92.8			
'-lnL:CAAsurv	-701.7				-702.2				-694.0				-698.1				-692.9				-703.4				-698.5			
'-lnL:RecRes	-21.9				-22.0				-21.4				-18.3				-21.9				-20.9				-23.2			
'-lnL:SelSmoothing	0.9				1.0				0.9				1.0				1.1				0.9				1.0			
Mohn's rho: SSB	-0.03				-0.03				0.04				0.01				0.05				-0.01				-0.01			
Mohn's rho: rec.	0.16				0.13				0.31				0.27				0.32				0.24				0.15			
Phi	0.83				0.84				0.82				0.83				0.83				0.86				0.83			
Bsp(1981)	20.8				18.6				24.1				21.0				21.3				20.6				21.0			
Bsp(2010)	4.1				3.7				5.3				5.2				4.4				4.8				3.6			
Bsp(2010)/Bsp(1981)	0.20				0.20				0.22				0.25				0.21				0.23				0.17			
M	0.3-0.6				0.2-0.54				0.4-0.6				0.3-0.55				0.3-0.6				0.3-0.6				0.3-0.6			
Recruitment	25.7	52.8			19.0	39.8			32.2	70.9			27.7	52.7			22.7	52.7			29.9	53.0			21.7	52.7		
Bsp(MSY)	2.0	4.1			2.8	5.8			2.6	5.7			2.5	4.7			1.5	3.5			2.6	4.6			1.6	3.8		
MSY	2.4	5.0			1.8	3.8			3.0	6.6			3.0	5.7			2.2	5.2			2.7	4.8			2.1	5.1		
σ_{comCAA}	0.10				0.10				0.10				0.10				0.10				0.10				0.10			
Survey	q x10^6	σ_{surv}	σ_{CAA}	ρ	q x10^6	σ_{surv}	σ_{CAA}	ρ	q x10^6	σ_{surv}	σ_{CAA}	ρ	q x10^6	σ_{surv}	σ_{CAA}	ρ	q x10^6	σ_{surv}	σ_{CAA}	ρ	q x10^6	σ_{surv}	σ_{CAA}	ρ	q x10^6	σ_{surv}	σ_{CAA}	ρ
NEFSCspr	285.2	0.31	0.10	0.06	284.3	0.31	0.10	0.09	260.7	0.30	0.11	0.04	264.9	0.30	0.10	-0.01	250.2	0.31	0.11	0.08	299.7	0.30	0.10	0.03	288.9	0.33	0.10	0.21
NEFSCfall	936.6	0.47	0.15	0.67	1036.6	0.47	0.15	0.69	835.8	0.47	0.15	0.68	892.4	0.47	0.15	0.66	939.6	0.47	0.15	0.70	901.6	0.47	0.15	0.65	985.2	0.47	0.15	0.71
NEFSCwinter	233.5	0.30	0.19	0.21	269.5	0.30	0.19	0.21	211.2	0.30	0.19	0.24	223.7	0.30	0.19	0.23	250.5	0.30	0.19	0.23	217.4	0.31	0.19	0.26	256.6	0.31	0.19	0.29
MADFM	3.31	0.41	0.15	0.51	3.32	0.41	0.15	0.52	2.95	0.40	0.16	0.48	2.98	0.40	0.15	0.46	2.82	0.41	0.16	0.50	3.40	0.39	0.15	0.42	3.38	0.42	0.16	0.56
RIDFW	0.57	0.51	0.16	0.20	0.60	0.51	0.16	0.18	0.50	0.52	0.16	0.21	0.53	0.52	0.16	0.23	0.53	0.51	0.16	0.18	0.56	0.53	0.16	0.25	0.58	0.51	0.16	0.18
CTDEP	3.13	0.51	0.12	0.68	3.07	0.51	0.12	0.67	2.88	0.51	0.13	0.67	2.91	0.51	0.12	0.68	2.68	0.51	0.13	0.66	3.34	0.50	0.12	0.67	3.16	0.51	0.12	0.67
NY	0.11	0.92	0.20	0.28	0.15	0.92	0.21	0.29	0.09	0.90	0.20	0.21	0.11	0.91	0.20	0.26	0.13	0.91	0.20	0.21	0.10	0.89	0.20	0.21	0.13	0.92	0.20	0.28
NJDFW Ocean	4.13	0.42	0.16	-0.03	4.07	0.43	0.16	-0.02	3.85	0.41	0.16	-0.10	3.74	0.45	0.16	0.08	3.59	0.40	0.16	-0.13	4.34	0.42	0.16	-0.06	4.35	0.39	0.16	-0.18
NJDFW River	0.39	0.27	0.18	0.58	0.39	0.27	0.18	0.60	0.37	0.26	0.18	0.53	0.34	0.24	0.18	0.36	0.35	0.26	0.18	0.55	0.41	0.25	0.18	0.48	0.43	0.28	0.18	0.76
MADFM YOY	0.01	0.44	-	0.50	0.01	0.43	-	0.50	0.01	0.44	-	0.52	0.01	0.44	-	0.52	0.01	0.44	-	0.52	0.01	0.44	-	0.51	0.01	0.44	-	0.53
CTDEP YOY	0.24	0.65	-	0.26	0.33	0.65	-	0.28	0.20	0.64	-	0.21	0.23	0.63	-	0.18	0.28	0.64	-	0.24	0.21	0.63	-	0.15	0.29	0.66	-	0.33
RIDFW YOY	0.48	0.71	-	0.52	0.65	0.71	-	0.51	0.39	0.72	-	0.54	0.45	0.74	-	0.57	0.54	0.72	-	0.53	0.42	0.73	-	0.55	0.56	0.69	-	0.47
NY YOY	0.14	1.33	-	0.60	0.18	1.34	-	0.61	0.11	1.32	-	0.57	0.13	1.31	-	0.58	0.15	1.33	-	0.56	0.12	1.30	-	0.57	0.16	1.35	-	0.60
DEDFW YOY	0.00	1.00	-	-0.23	0.00	1.00	-	-0.23	0.00	0.98	-	-0.26	0.00	1.01	-	-0.21	0.00	0.98	-	-0.26	0.00	0.99	-	-0.25	0.00	0.98	-	-0.26
URIGSO	0.53	0.51	0.13	0.31	0.64	0.51	0.13	0.31	0.45	0.50	0.14	0.28	0.50	0.51	0.13	0.33	0.56	0.50	0.14	0.27	0.49	0.51	0.13	0.30	0.58	0.50	0.13	0.29
σ_R_out (81-88, 89-10)	0.27	0.26			0.26	0.26			0.28	0.27			0.27	0.32			0.27	0.26			0.27	0.28			0.27	0.24		

Table 3: Results for two further variants on the New Base Case.

	New Base Case				Variant 7: single ρ for surveys				Variant 8: start in 1960			
'-lnL:overall	-864.1				-851.1				-814.4			
'-lnL:Survey	-49.8				-36.9				-39.0			
'-lnL:CAA	-91.7				-91.8				-66.9			
'-lnL:CAAsurv	-701.7				-701.5				-688.9			
'-lnL:RecRes	-21.9				-21.9				-21.0			
'-lnL:SelSmoothing	0.9				0.9				1.4			
Mohn's rho: SSB	-0.03				-0.02				-0.03			
Mohn's rho: rec.	0.16				0.17				0.04			
Phi	0.83				0.83				0.83			
Bsp(1964)	-				-				9.40			
Bsp(1981)	20.8				20.8				34.5			
Bsp(2010)	4.1				4.1				4.9			
Bsp(2010)/Bsp(1981)	0.20				0.20				0.14			
M	0.3-0.6				0.60	0.60			0.60			
Recruitment	25.7	52.8			25.7	52.8			28.0	60.6		
Bsp(MSY)	2.0	4.1			2.0	4.1			1.8	3.9		
MSY	2.4	5.0			2.4	5.0			2.8	6.0		
σ_{comCAA}	0.10				0.10				0.11			
Survey	q x10^6	σ_{surv}	σ_{CAA}	ρ	q x10^6	σ_{surv}	σ_{CAA}	ρ	q x10^6	σ_{surv}	σ_{CAA}	ρ
NEFSCspr	285.2	0.31	0.10	0.06	279.7	0.32	0.10	0.40	146.0	0.49	0.11	0.37
NEFSCfall	936.6	0.47	0.15	0.67	934.9	0.50	0.15	0.40	803.6	0.49	0.16	0.76
NEFSCwinter	233.5	0.30	0.19	0.21	232.7	0.30	0.19	0.40	208.3	0.30	0.20	0.20
MADFM	3.31	0.41	0.15	0.51	3.22	0.41	0.15	0.40	0.89	0.41	0.15	0.49
RIDFW	0.57	0.51	0.16	0.20	0.56	0.52	0.16	0.40	0.41	0.53	0.16	0.25
CTDEP	3.13	0.51	0.12	0.68	3.03	0.54	0.12	0.40	1.51	0.51	0.12	0.71
NY	0.11	0.92	0.20	0.28	0.11	0.92	0.20	0.40	0.11	0.92	0.20	0.31
NJDFW Ocean	4.13	0.42	0.16	-0.03	3.98	0.46	0.16	0.40	1.53	0.43	0.16	-0.02
NJDFW River	0.39	0.27	0.18	0.58	0.37	0.27	0.18	0.40	0.14	0.27	0.18	0.58
MADFM YOY	0.01	0.44	-	0.50	0.01	0.44	-	0.40	0.01	0.44	-	0.52
CTDEP YOY	0.24	0.65	-	0.26	0.24	0.65	-	0.40	0.22	0.64	-	0.26
RIDFW YOY	0.48	0.71	-	0.52	0.48	0.72	-	0.40	0.45	0.72	-	0.54
NY YOY	0.14	1.33	-	0.60	0.14	1.36	-	0.40	0.13	1.33	-	0.61
DEDFW YOY	0.00	1.00	-	-0.23	0.00	1.18	-	0.40	0.00	1.00	-	-0.21
URIGSO	0.53	0.51	0.13	0.31	0.53	0.51	0.13	0.40	0.49	0.51	0.13	0.33
σ_R_out (81-88, 89-10)	0.27	0.26			0.27	0.26			0.29	0.28		

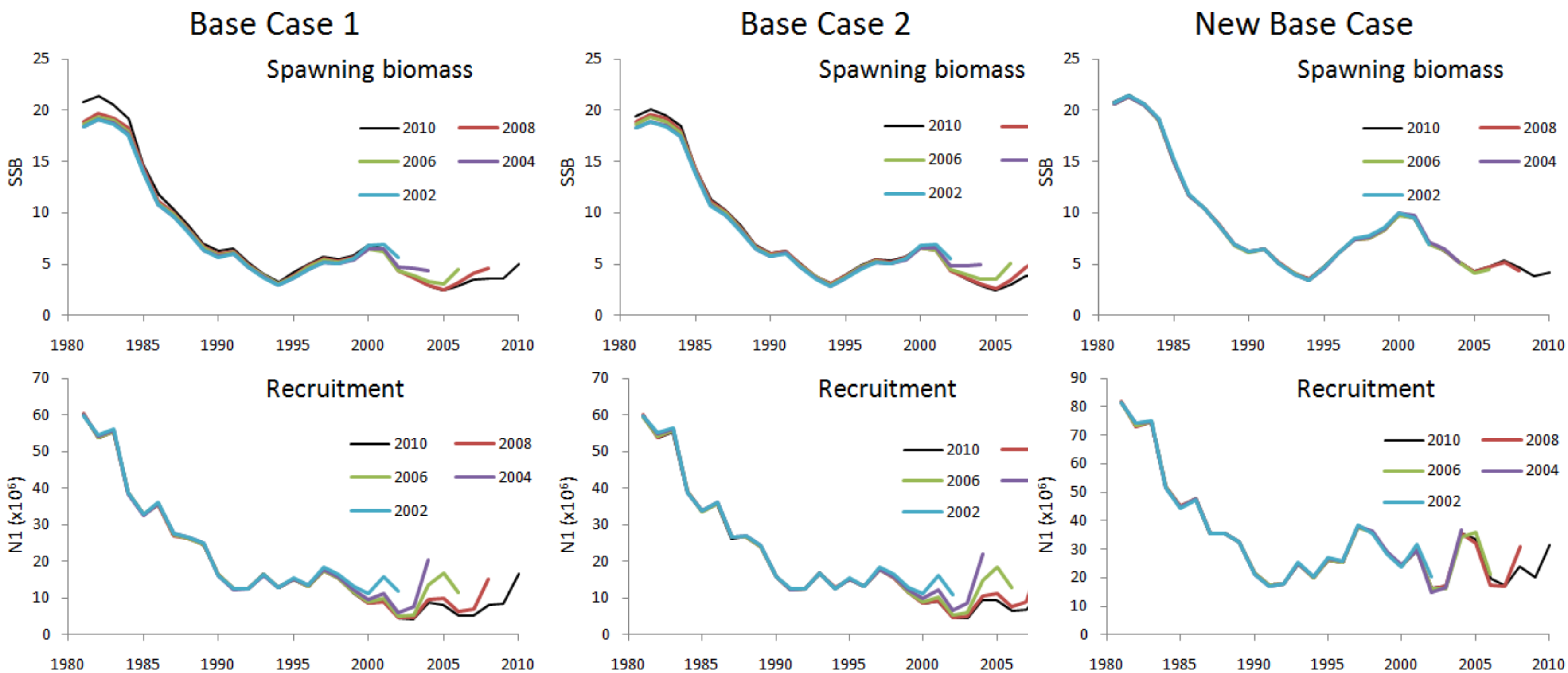

Fig. 1: Retrospective analysis of spawning biomass and recruitment for the three Base Cases.

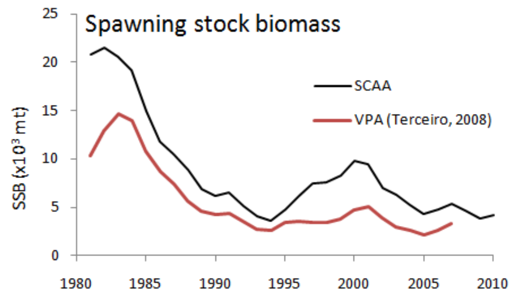

Fig. 2: Spawning stock biomass trajectories for the New Base Case, compared to the GARM3 SPLIT VPA run (Terceiro, 2008).

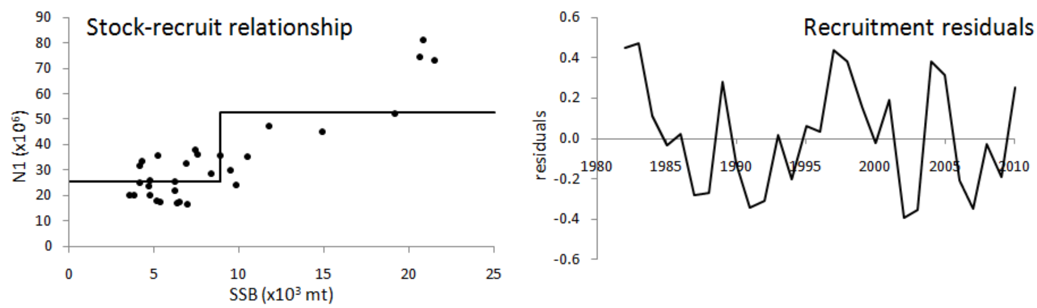

Fig. 3: Stock-recruit relationship and estimated stock-recruit residuals for the New Base Case. The change from high to lower recruitment is taken to occur at the minimum spawning biomass over the pre-1989 period.

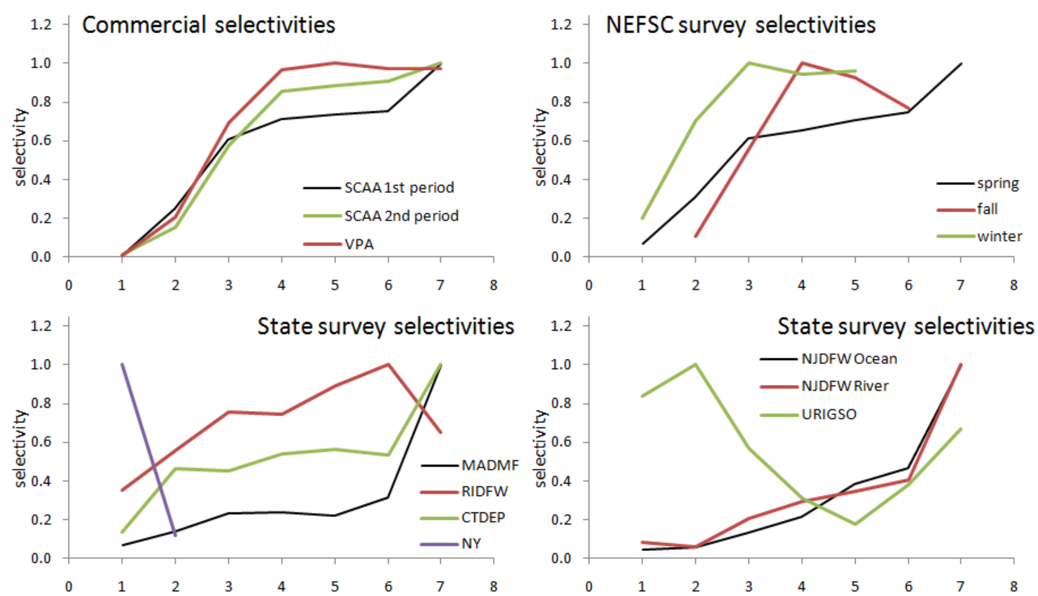

Fig. 4: Commercial and survey selectivities-at-age estimated for the New Base Case.

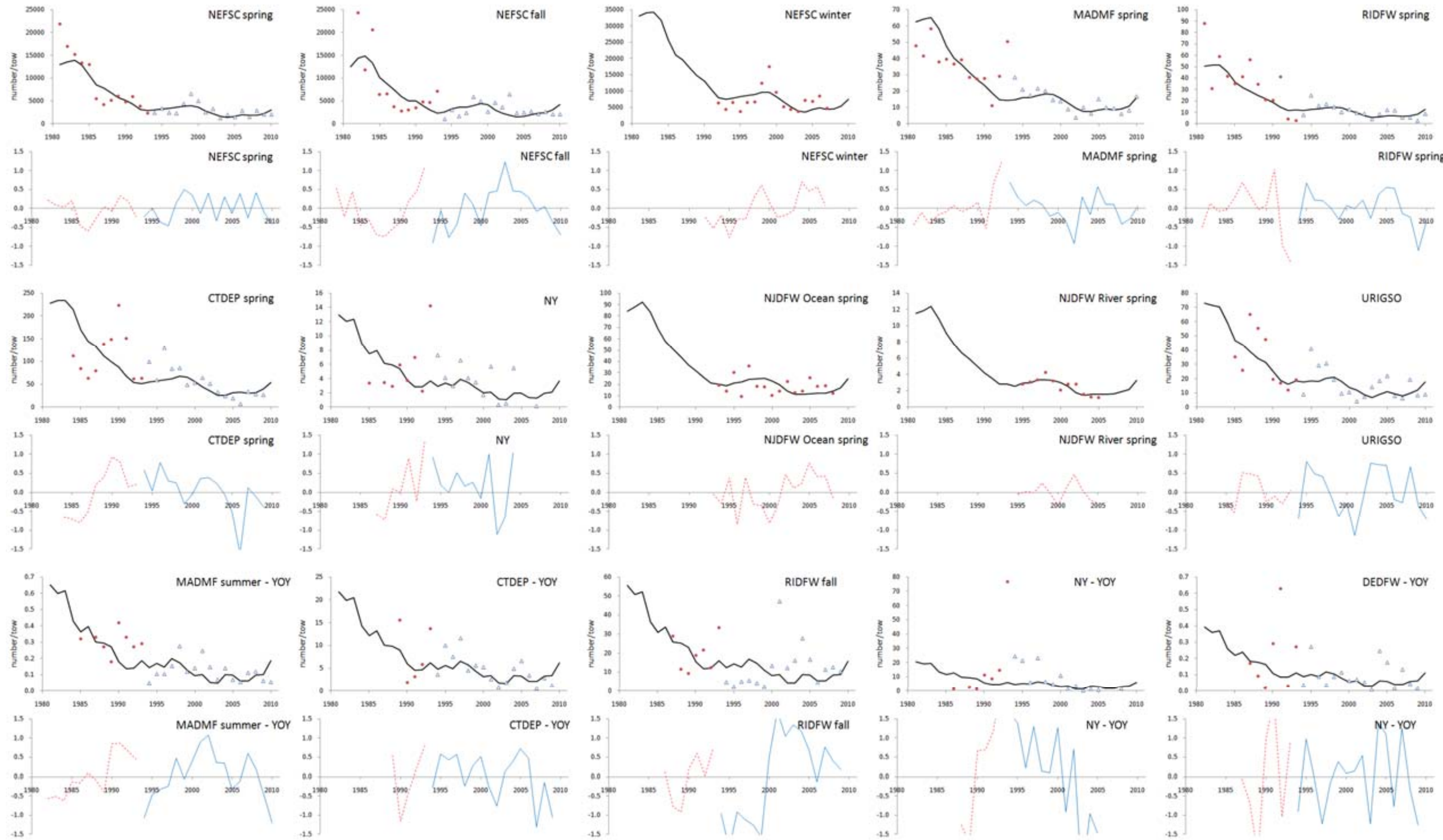

Fig. 5a: Fit of the Base Case 1 to the survey indices of abundance and corresponding survey standardised residuals. The survey data for the second period have been scaled by the ratio of the pre- and post-1993 indices *q*.

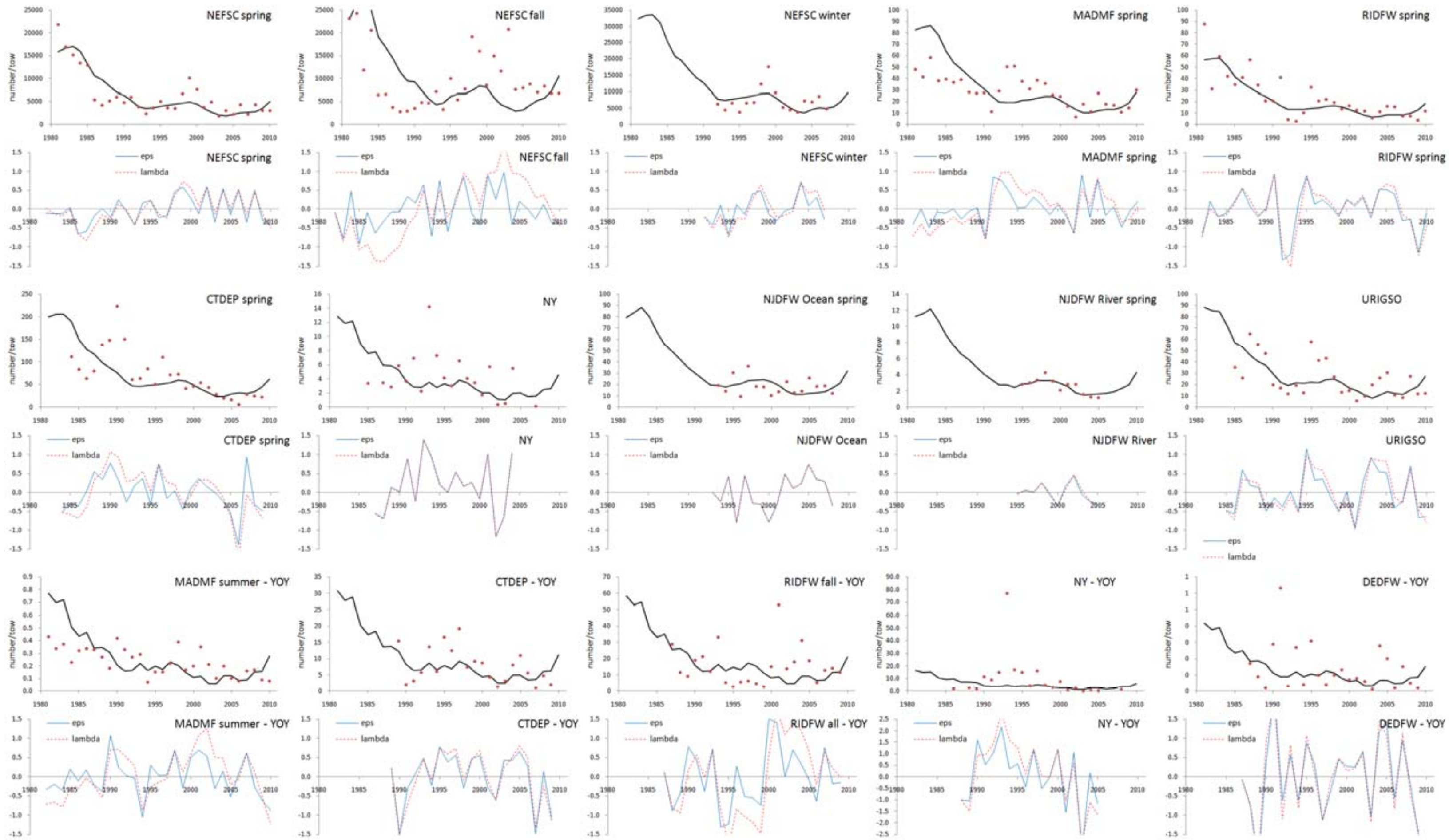

Fig. 5b: Fit of the Base Case 2 to the survey indices of abundance and corresponding survey standardised residuals. Residuals are shown both before ("lambda") and after ("eps") adjustment for serial correlation.

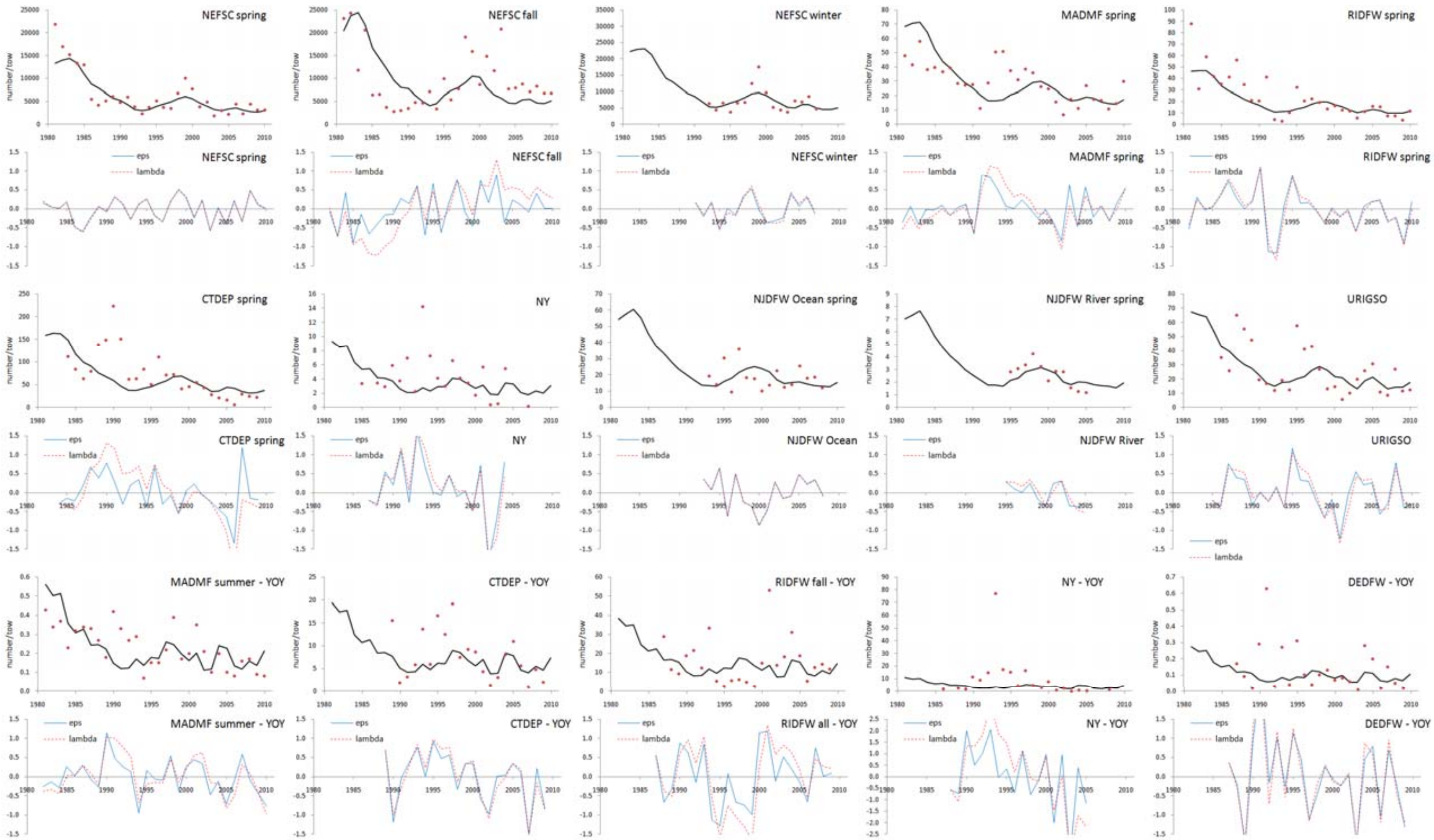

Fig. 5c: Fit of the New Base Case to the survey indices of abundance and corresponding survey standardised residuals. Residuals are shown both before ("lambda") and after ("eps") adjustment for serial correlation.

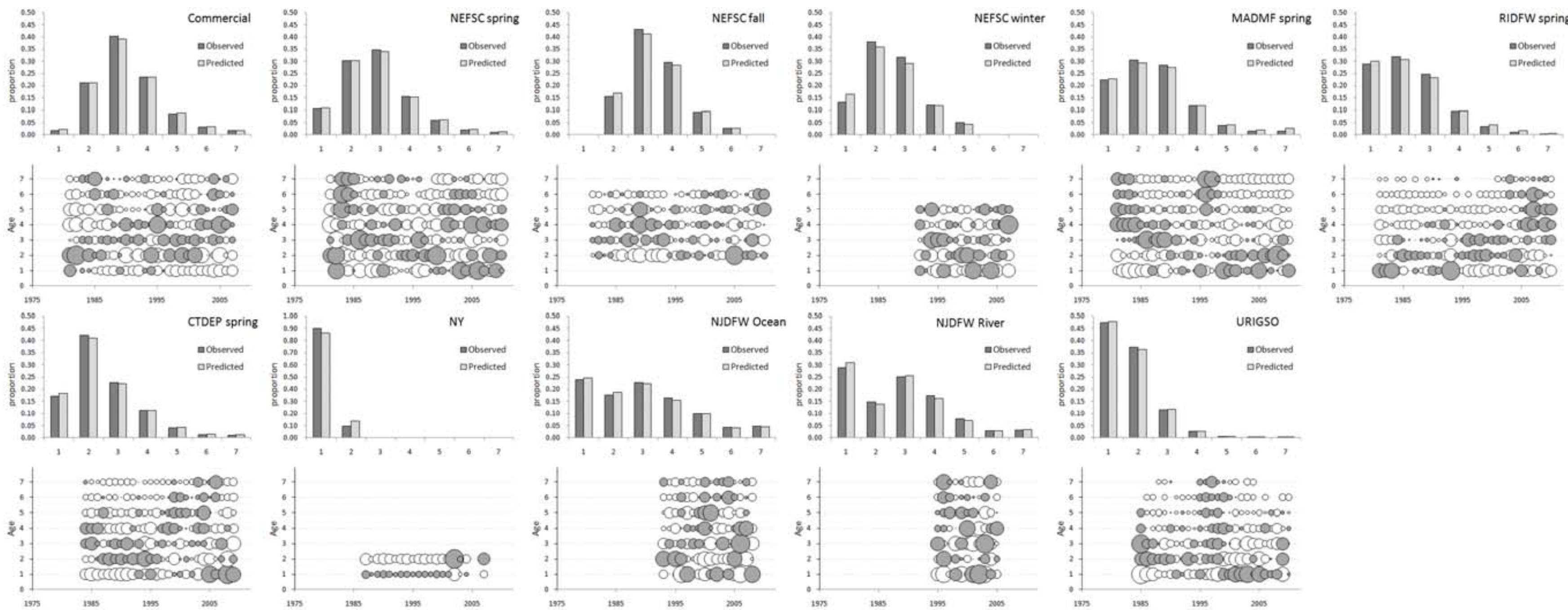

Fig. 6: Fit of the New Base Case to the commercial and survey catch-at-age data. The first and third rows compare the observed and predicted CAA as averaged over all years for which data are available, while the second and fourth rows plot the standardised residuals, with the size (area) of the bubbles being proportional to the magnitude of the corresponding standardised residuals. For positive residuals, the bubbles are grey, whereas for negative residuals, the bubbles are white.

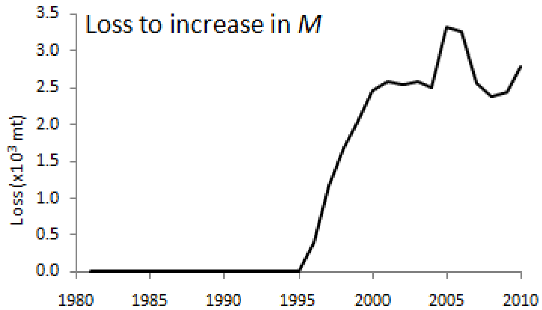

Fig. 7: Additional annual biomass loss from resource due to increase in *M* from 0.3 to 0.6 for the NBC.

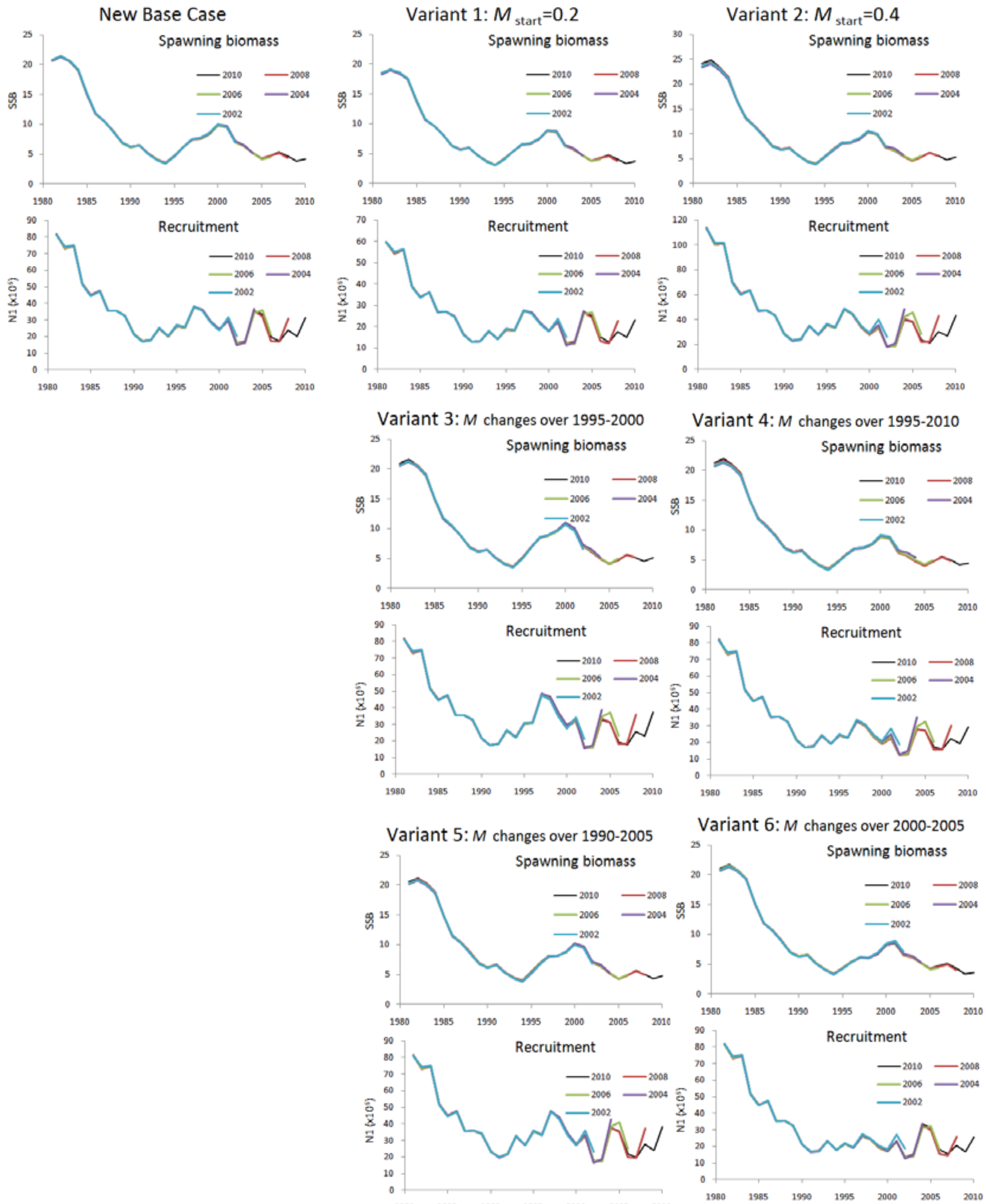

Fig. 8: Retrospective analysis of spawning biomass and recruitment for the New Base Case and some variants.

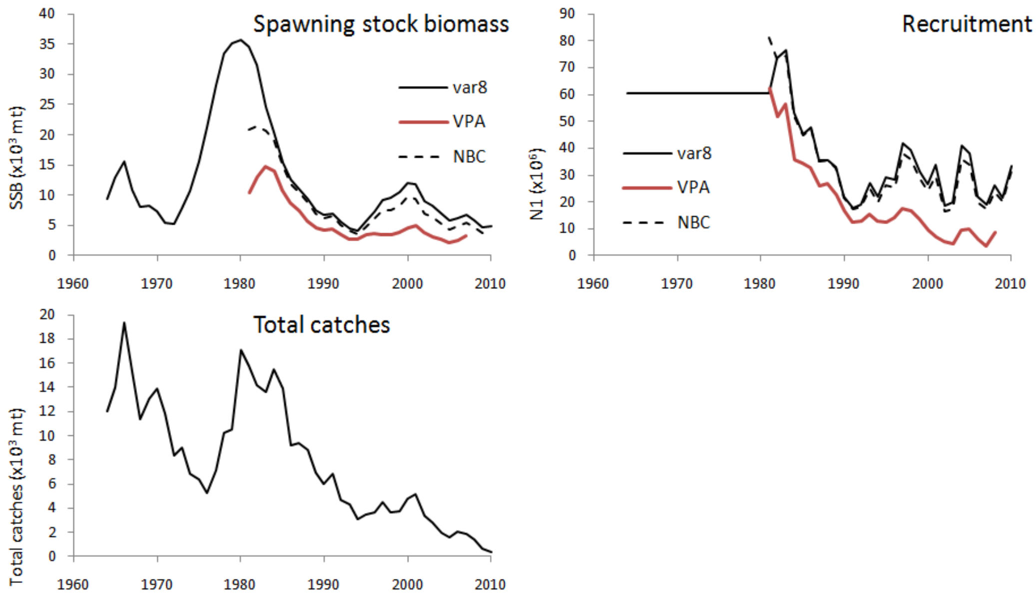

Fig. 9: Spawning stock biomass, recruitment and catch trajectories for the variant 8 of the New Base Case (starting in 1964), compared to the NBC and GARM3 SPLIT VPA run (Terceiro, 2008).

APPENDIX A – Data

Table A1: Total catch (metric tons) for SNE/MA winter flounder (M. Terceiro, pers. commn). Pre-1981, only the commercial landings are available; to compute the total catches, the average 1981-1985 ratio of commercial landings (0.62), commercial discards (0.09), recreational landings (0.28) and recreational discards (0.01) is assumed to apply over the pre-1981 period.

Year	Total catch (mt)	Year	Total catch (mt)	Year	Total catch (mt)
1964	*12053*	1980	*17138*	1996	3702
1965	*13995*	1981	15764	1997	4483
1966	*19315*	1982	14143	1998	3614
1967	*15285*	1983	13582	1999	3745
1968	*11402*	1984	15526	2000	4754
1969	*13074*	1985	13891	2001	5147
1970	*13874*	1986	9217	2002	3412
1971	*11881*	1987	9352	2003	2827
1972	*8370*	1988	8795	2004	1942
1973	*8988*	1989	6915	2005	1563
1974	*6869*	1990	5999	2006	2023
1975	*6422*	1991	6842	2007	1883
1976	*5266*	1992	4729	2008	1432
1977	*7117*	1993	4311	2009	639
1978	*10204*	1994	3092	2010	400
1979	*10552*	1995	3434		

Table A2. Catch at age matrix (000s) for SNE/MA winter flounder (M. Terceiro, pers. commn).

	1	2	3	4	5	6	7+
1981	1380	14183	14401	3608	666	182	111
1982	575	14153	12374	3713	608	212	202
1983	616	7232	13273	6111	1791	695	544
1984	493	11470	13940	4890	1770	873	803
1985	274	7342	12771	6013	2922	1819	1404
1986	216	6327	9101	4218	1053	442	357
1987	74	5265	8988	3084	2690	751	424
1988	85	3946	9401	3963	1206	978	303
1989	468	5275	7208	3541	861	226	214
1990	36	2110	6276	2933	768	196	142
1991	52	3029	7146	3349	860	252	113
1992	25	1507	4460	2582	673	162	53
1993	292	2200	3520	1897	714	188	138
1994	251	2612	2339	1280	337	97	39
1995	88	654	3112	2202	506	83	20
1996	171	1050	3289	2181	556	129	40
1997	88	1841	3488	2252	584	96	39
1998	16	1371	3043	1788	555	185	74
1999	5	2146	4062	1577	375	82	18
2000	43	1336	3436	2473	822	146	72
2001	35	1689	3503	2274	883	231	124
2002	14	478	1897	1830	925	324	115
2003	15	498	1802	1199	501	223	136
2004	36	378	999	858	331	223	167
2005	32	417	765	755	328	134	81
2006	39	758	1598	686	277	133	108
2007	7	334	1492	1033	299	85	32
2008	34	249	724	784	312	162	92
2009	83	195	271	268	211	66	30
2010	83	195	271	268	211	66	30

Table A3a. Total fishery mean weights-at-age (kg) for SNE/MA winter flounder (M. Terceiro, pers. commn).

	1	2	3	4	5	6	7+
1981	0.129	0.274	0.477	0.798	1.063	1.242	1.196
1982	0.092	0.263	0.440	0.697	1.052	1.257	1.840
1983	0.197	0.237	0.354	0.517	0.768	1.047	1.552
1984	0.148	0.261	0.370	0.546	0.695	0.915	1.284
1985	0.111	0.282	0.364	0.482	0.522	0.467	0.613
1986	0.129	0.292	0.398	0.480	0.685	0.879	0.961
1987	0.046	0.287	0.384	0.551	0.475	0.564	0.853
1988	0.039	0.279	0.351	0.508	0.634	0.517	0.827
1989	0.118	0.258	0.378	0.508	0.660	0.716	1.073
1990	0.082	0.295	0.394	0.525	0.672	0.808	0.990
1991	0.093	0.317	0.420	0.534	0.603	0.823	1.168
1992	0.079	0.287	0.427	0.599	0.802	0.945	1.395
1993	0.169	0.334	0.460	0.592	0.689	0.878	1.167
1994	0.162	0.311	0.429	0.550	0.750	0.985	1.281
1995	0.267	0.420	0.470	0.559	0.789	1.089	1.741
1996	0.136	0.380	0.464	0.607	0.824	0.851	1.085
1997	0.245	0.443	0.515	0.644	0.771	0.957	1.477
1998	0.196	0.362	0.465	0.568	0.665	1.090	1.116
1999	0.136	0.359	0.439	0.524	0.684	0.903	1.147
2000	0.106	0.407	0.492	0.622	0.729	0.975	1.079
2001	0.089	0.436	0.519	0.640	0.783	1.051	1.234
2002	0.135	0.372	0.499	0.617	0.747	0.927	1.143
2003	0.167	0.426	0.517	0.672	0.854	1.000	1.135
2004	0.094	0.384	0.549	0.619	0.786	0.945	1.251
2005	0.129	0.342	0.488	0.675	0.834	1.013	1.318
2006	0.118	0.379	0.468	0.652	0.872	1.065	1.289
2007	0.065	0.388	0.473	0.634	0.861	1.097	1.372
2008	0.110	0.355	0.477	0.597	0.754	0.939	1.238
2009	0.126	0.326	0.434	0.594	0.757	1.006	0.941
2010	0.126	0.326	0.434	0.594	0.757	1.006	0.941

Table A3b. Spawning stock biomass mean weights-at-age (kg) for SNE/MA winter flounder (M. Terceiro, pers. commn).

	1	2	3	4	5	6	7+
1981	0.102	0.234	0.420	0.728	1.005	1.179	1.196
1982	0.067	0.207	0.376	0.614	0.959	1.189	1.840
1983	0.179	0.173	0.321	0.490	0.744	1.049	1.552
1984	0.119	0.238	0.319	0.473	0.630	0.863	1.284
1985	0.080	0.228	0.326	0.441	0.530	0.533	0.613
1986	0.099	0.212	0.355	0.438	0.609	0.739	0.961
1987	0.025	0.220	0.351	0.494	0.477	0.602	0.853
1988	0.021	0.153	0.328	0.463	0.605	0.503	0.827
1989	0.087	0.137	0.342	0.449	0.605	0.688	1.073
1990	0.052	0.217	0.342	0.471	0.612	0.755	0.990
1991	0.064	0.202	0.373	0.483	0.576	0.769	1.168
1992	0.049	0.197	0.387	0.532	0.700	0.814	1.395
1993	0.138	0.207	0.393	0.531	0.658	0.852	1.167
1994	0.118	0.254	0.395	0.518	0.693	0.874	1.281
1995	0.237	0.306	0.410	0.512	0.700	0.962	1.741
1996	0.092	0.338	0.449	0.557	0.724	0.830	1.085
1997	0.215	0.299	0.465	0.577	0.712	0.910	1.477
1998	0.160	0.318	0.458	0.550	0.658	0.971	1.116
1999	0.094	0.293	0.412	0.504	0.643	0.815	1.147
2000	0.066	0.283	0.443	0.554	0.653	0.866	1.079
2001	0.055	0.272	0.479	0.586	0.725	0.930	1.234
2002	0.092	0.231	0.477	0.582	0.710	0.876	1.143
2003	0.127	0.290	0.463	0.609	0.766	0.907	1.135
2004	0.061	0.291	0.505	0.583	0.746	0.914	1.251
2005	0.090	0.222	0.451	0.630	0.755	0.931	1.318
2006	0.079	0.265	0.422	0.592	0.801	0.982	1.289
2007	0.037	0.261	0.439	0.573	0.785	1.016	1.372
2008	0.077	0.202	0.445	0.552	0.712	0.912	1.238
2009	0.096	0.227	0.406	0.552	0.699	0.914	0.941
2010	0.096	0.227	0.406	0.552	0.699	0.914	0.941

Table A3c. January-1 mean weights-at-age (kg) for SNE/MA winter flounder (M. Terceiro, pers. commn).

	1	2	3	4	5	6	7+
1981	0.090	0.216	0.395	0.695	0.978	1.149	1.196
1982	0.057	0.184	0.347	0.577	0.916	1.156	1.840
1983	0.171	0.148	0.305	0.477	0.732	1.050	1.552
1984	0.107	0.227	0.296	0.440	0.599	0.838	1.284
1985	0.068	0.204	0.308	0.422	0.534	0.570	0.613
1986	0.087	0.180	0.335	0.418	0.575	0.677	0.961
1987	0.019	0.192	0.335	0.468	0.478	0.622	0.853
1988	0.015	0.113	0.317	0.442	0.591	0.496	0.827
1989	0.075	0.100	0.325	0.422	0.579	0.674	1.073
1990	0.042	0.187	0.319	0.446	0.584	0.730	0.990
1991	0.053	0.161	0.352	0.459	0.563	0.744	1.168
1992	0.038	0.163	0.368	0.502	0.654	0.755	1.395
1993	0.125	0.162	0.363	0.503	0.642	0.839	1.167
1994	0.101	0.229	0.379	0.503	0.666	0.824	1.281
1995	0.224	0.261	0.382	0.490	0.659	0.904	1.741
1996	0.075	0.319	0.442	0.534	0.679	0.819	1.085
1997	0.202	0.246	0.442	0.547	0.684	0.888	1.477
1998	0.145	0.298	0.454	0.541	0.654	0.917	1.116
1999	0.079	0.265	0.399	0.494	0.623	0.775	1.147
2000	0.052	0.235	0.420	0.523	0.618	0.817	1.079
2001	0.044	0.215	0.460	0.561	0.698	0.875	1.234
2002	0.076	0.182	0.466	0.566	0.691	0.852	1.143
2003	0.110	0.240	0.439	0.579	0.726	0.864	1.135
2004	0.049	0.253	0.484	0.566	0.727	0.898	1.251
2005	0.075	0.179	0.433	0.609	0.719	0.892	1.318
2006	0.065	0.221	0.400	0.564	0.767	0.942	1.289
2007	0.028	0.214	0.423	0.545	0.749	0.978	1.372
2008	0.064	0.152	0.430	0.531	0.691	0.899	1.238
2009	0.084	0.189	0.393	0.532	0.672	0.871	0.941
2010	0.084	0.189	0.393	0.532	0.672	0.871	0.941

Table A4: Proportion mature-at-age for SNE/MA winter flounder (M. Terceiro, pers. commn).

1	2	3	4	5	6	7+
0.00	0.00	0.53	0.95	1.00	1.00	1.00

Table A5: Survey data in terms of total numbers for SNE/MA winter flounder (M. Terceiro, pers. commn).

	NEFSC spring	NEFSC fall	NEFSC winter	MADMF	RIDFW	CTDEP	NYDEC	NJDFW Ocean	NJDFW Rivers	URIGSO	YOY-MADMF	YOY-CTDEP	YOY-RIDFW	YOY-NYDEC	YOY-DEDFW
Month	4	10	3	5	5	5	5	5	5	5	1	1	1	1	1
Ages	1-7+	2-6+	1-5+	1-7+	1-7+	1-7+	1-2+	1-7+	1-7+	1-7+	1	1	1	1	1
1964	-	22029	-	-	-	-	-	-	-	-	-	-	-	-	-
1965	-	32829	-	-	-	-	-	-	-	-	-	-	-	-	-
1966	-	37305	-	-	-	-	-	-	-	-	-	-	-	-	-
1967	-	23655	-	-	-	-	-	-	-	-	-	-	-	-	-
1968	5919	21871	-	-	-	-	-	-	-	-	-	-	-	-	-
1969	13658	19446	-	-	-	-	-	-	-	-	-	-	-	-	-
1970	6609	16963	-	-	-	-	-	-	-	-	-	-	-	-	-
1971	4928	12387	-	-	-	-	-	-	-	-	-	-	-	-	-
1972	4516	9270	-	-	-	-	-	-	-	-	-	-	-	-	-
1973	15094	18457	-	-	-	-	-	-	-	-	-	-	-	-	-
1974	5907	6461	-	-	-	-	-	-	-	-	-	-	-	-	-
1975	1654	4879	-	-	-	-	-	-	-	-	-	-	-	-	-
1976	3698	5273	-	-	-	-	-	-	-	-	-	-	-	-	-
1977	5047	5705	-	-	-	-	-	-	-	-	-	-	-	-	-
1978	8028	11338	-	-	-	-	-	-	-	-	-	-	-	-	-
1979	3555	8987	-	-	-	-	-	-	-	-	-	-	-	-	-
1980	18284	24152	-	-	-	-	-	-	-	-	-	-	-	-	-
1981	21831	23138	-	47.80	87.98	-	-	-	-	-	0.43	-	-	-	-
1982	16918	24324	-	41.45	30.95	-	-	-	-	-	0.34	-	-	-	-
1983	15151	11859	-	58.13	58.95	-	-	-	-	-	0.37	-	-	-	-
1984	13360	20524	-	38.03	41.64	111.96	-	-	-	-	0.23	-	-	-	-
1985	12973	6462	-	39.50	34.98	83.57	3.35	-	-	35.04	0.32	-	-	-	-
1986	5446	6583	-	36.78	41.02	63.65	-	-	-	25.87	0.34	-	-	1.52	-
1987	4260	3703	-	39.16	56.22	79.93	3.43	-	-	65.05	0.33	-	29.00	-	0.17
1988	5155	2832	-	28.37	34.44	137.59	2.88	-	-	55.21	0.27	-	11.60	2.67	0.09
1989	6026	2977	-	27.40	20.88	148.19	5.89	-	-	47.41	0.18	15.50	9.19	1.47	0.02
1990	4816	3461	-	27.72	20.44	223.09	3.70	-	-	19.62	0.42	1.90	18.92	11.20	0.29
1991	5978	4792	-	11.02	40.97	150.21	6.94	-	-	16.80	0.33	3.10	21.48	8.73	0.63
1992	3824	4720	6303	28.96	4.41	61.38	2.24	-	-	11.89	0.27	5.80	12.19	14.72	0.03
1993	2323	7140	4421	50.41	2.92	63.59	14.24	19.17	-	19.06	0.29	13.70	33.33	76.87	0.27
1994	3679	3340	6580	50.83	10.26	84.45	7.28	14.06	-	12.44	0.07	6.00	5.29	17.10	0.04
1995	5083	9923	3834	37.37	32.19	50.12	4.11	30.41	2.82	57.63	0.15	16.60	2.52	14.93	0.31
1996	3679	5421	6511	30.92	20.68	110.61	2.99	9.40	3.05	41.20	0.15	12.50	5.64	4.10	0.10
1997	3485	7696	6752	38.51	22.27	71.31	6.56	36.02	3.35	43.15	0.22	19.20	6.22	16.25	0.04
1998	6728	19096	12382	35.87	19.22	72.90	4.09	18.20	4.25	26.97	0.39	7.47	4.70	4.42	0.10
1999	10093	15950	17563	25.99	13.46	41.35	3.47	17.79	3.23	13.24	0.17	9.28	2.56	3.11	0.13
2000	7672	8616	9619	24.63	16.32	45.42	1.71	10.10	2.11	14.64	0.20	8.70	14.97	7.52	0.07
2001	3800	14885	5267	15.80	12.49	54.51	5.69	13.83	2.84	5.43	0.35	4.30	53.00	0.90	0.08
2002	4937	11666	4352	6.69	11.56	43.72	0.36	22.58	2.80	9.96	0.21	1.30	13.73	2.31	0.06
2003	1864	20839	3747	17.72	5.56	27.84	0.54	12.52	1.57	19.71	0.10	3.06	18.12	0.07	0.01
2004	3001	7672	7253	11.14	11.16	20.46	5.49	14.21	1.27	25.81	0.20	8.10	31.22	0.86	0.28
2005	2251	7987	6925	27.00	15.74	16.10	-	25.67	1.17	30.75	0.10	10.96	18.72	0.50	0.20
2006	4381	8761	8479	17.62	15.36	5.58	-	18.13	-	10.82	0.08	5.63	5.28	-	0.02
2007	2275	7091	4784	16.69	7.33	28.66	0.15	18.58	-	8.54	0.16	0.93	12.72	-	0.15
2008	4381	8350	-	10.65	7.36	24.12	-	12.01	-	27.03	0.17	4.73	14.17	1.11	0.05
2009	3098	6753	-	14.56	3.67	22.59	-	-	-	11.54	0.09	1.97	11.65	-	0.02
2010	3098	6753	-	29.84	11.56	-	-	-	-	12.31	0.08	-	-	-	-

Table A6: Survey catch-at-age data mean numbers for SNE/MA winter flounder (M. Terceiro, pers. commn).

NEFSC spring

	1	2	3	4	5	6	7+
1981	2396	9681	8253	1138	315	24	24
1982	2808	7745	3776	1791	508	218	73
1983	1404	2348	5179	2977	1960	895	387
1984	581	3292	5228	2057	1113	702	387
1985	992	2929	5228	1743	1234	484	363
1986	242	1186	2759	750	363	121	24
1987	339	1307	1694	678	145	48	48
1988	218	1162	2396	895	387	48	48
1989	339	2299	2178	823	266	48	73
1990	557	1186	2154	678	121	97	24
1991	339	1452	2953	992	121	48	73
1992	339	944	1501	871	121	48	0
1993	339	847	629	290	169	24	24
1994	387	1815	1041	266	97	48	24
1995	532	1815	2106	532	73	0	24
1996	169	1307	1597	411	145	24	24
1997	315	1210	1355	436	145	24	0
1998	799	2929	1743	895	315	48	0
1999	992	4574	3267	871	266	97	24
2000	678	1694	2880	1573	653	169	24
2001	411	629	1138	1065	484	48	24
2002	266	1452	1355	920	557	266	121
2003	290	266	799	242	121	97	48
2004	726	460	702	629	266	121	97
2005	242	1089	266	387	169	73	24
2006	726	1501	1501	387	194	48	24
2007	266	339	871	629	97	24	48
2008	436	1476	1162	992	266	24	24
2009	557	920	799	508	242	48	24
2010	557	920	799	508	242	48	24

NEFSC fall

	2	3	4	5	6+
1981	4260	11182	6632	1041	24
1982	5155	12174	6026	726	242
1983	1839	5349	3243	1138	290
1984	3945	9245	4986	1501	847
1985	411	2517	2832	629	73
1986	387	2856	2396	726	218
1987	557	2178	871	73	24
1988	73	1549	871	290	48
1989	73	726	1549	532	97
1990	678	2009	629	121	24
1991	194	2154	2057	363	24
1992	169	2469	1767	290	24
1993	315	4211	1912	629	73
1994	1041	1259	847	194	0
1995	1089	5397	2614	726	97
1996	1404	2251	1525	218	24
1997	1476	3388	1936	750	145
1998	3582	8665	5325	1331	194
1999	3364	6849	4623	992	121
2000	1041	2299	3534	1307	436
2001	2178	5567	4889	1718	532
2002	1186	4332	3897	1525	726
2003	1259	9705	5688	2759	1428
2004	968	2565	2783	1113	242
2005	4574	1912	678	678	145
2006	1743	4429	1767	508	315
2007	1138	3364	1912	532	145
2008	1452	3969	2493	387	48
2009	1089	1767	1694	1501	702
2010	1089	1767	1694	1501	702

NEFSC winter

	1	2	3	4	5+
1992	1261	1485	1882	1261	414
1993	967	2003	933	311	207
1994	622	2003	3039	432	484
1995	69	1295	2176	294	0
1996	1744	1502	2677	553	35
1997	743	2573	2280	933	225
1998	725	6079	3368	1658	553
1999	1451	10258	3851	1658	345
2000	397	4870	3661	414	276
2001	1796	950	1209	933	380
2002	138	2314	1278	259	363
2003	155	984	1796	432	380
2004	3747	1761	743	622	380
2005	674	4421	622	743	466
2006	0	4145	2988	881	466
2007	35	967	1779	1779	225

MADMF

	1	2	3	4	5	6	7+
1981	8.65	9.07	13.66	9.72	3.81	1.20	1.69
1982	3.06	11.88	12.72	8.80	2.66	1.07	1.26
1983	1.71	15.32	17.85	14.11	4.14	2.34	2.66
1984	1.28	9.59	11.82	10.18	3.35	1.22	0.59
1985	3.13	9.98	16.48	6.35	2.48	0.75	0.33
1986	3.27	7.07	19.36	5.69	0.83	0.13	0.43
1987	9.44	7.74	12.35	6.59	2.21	0.22	0.61
1988	3.61	7.02	14.66	2.45	0.35	0.07	0.21
1989	2.26	6.08	12.30	4.68	1.01	0.29	0.78
1990	4.43	11.73	8.03	2.99	0.40	0.02	0.12
1991	1.65	2.88	4.90	1.18	0.24	0.13	0.04
1992	8.06	7.40	6.73	4.21	1.67	0.60	0.29
1993	16.03	18.75	12.02	2.76	0.65	0.14	0.06
1994	12.15	17.35	14.96	4.72	0.62	0.59	0.44
1995	14.31	11.14	8.10	1.93	0.61	0.80	0.48
1996	4.98	10.12	7.72	2.86	2.00	1.46	1.78
1997	10.43	9.30	10.27	4.26	1.32	1.00	1.93
1998	8.62	13.09	7.21	3.51	1.47	1.22	0.75
1999	9.66	8.00	5.81	1.89	0.21	0.25	0.17
2000	6.41	7.78	6.68	1.74	1.09	0.46	0.47
2001	5.47	4.73	2.39	2.02	0.66	0.20	0.33
2002	0.94	3.00	1.55	0.82	0.29	0.08	0.01
2003	4.12	3.78	6.15	2.25	1.14	0.24	0.04
2004	3.46	3.15	1.97	1.67	0.56	0.21	0.12
2005	14.05	8.42	2.68	1.07	0.59	0.11	0.08
2006	3.19	9.61	2.98	1.12	0.32	0.20	0.20
2007	3.69	5.59	5.32	1.63	0.35	0.09	0.02
2008	3.15	5.14	1.73	0.42	0.13	0.02	0.06
2009	2.60	6.03	4.09	1.06	0.68	0.06	0.04
2010	14.20	6.94	5.57	1.74	0.93	0.40	0.06

Table A6: continued

RIDFW

	1	2	3	4	5	6	7+
1981	45.67	27.88	12.86	1.27	0.23	0.05	0.02
1982	13.42	9.74	5.02	2.31	0.33	0.11	0.02
1983	29.49	9.79	10.98	6.00	2.13	0.56	0.00
1984	6.67	16.79	13.94	2.96	0.83	0.35	0.10
1985	6.01	15.69	10.35	2.24	0.60	0.08	0.01
1986	11.94	15.63	9.59	2.63	1.14	0.09	0.00
1987	15.30	24.59	13.14	2.66	0.41	0.08	0.04
1988	8.93	12.37	9.53	2.92	0.68	0.01	0.00
1989	4.79	8.20	4.95	2.33	0.51	0.07	0.03
1990	6.46	6.36	4.88	2.16	0.48	0.04	0.06
1991	11.21	14.36	12.00	2.78	0.41	0.10	0.11
1992	1.30	0.95	1.17	0.75	0.20	0.04	0.00
1993	2.32	0.35	0.17	0.06	0.02	0.00	0.00
1994	2.84	4.56	1.97	0.63	0.19	0.04	0.03
1995	9.36	11.36	9.87	1.47	0.13	0.00	0.00
1996	3.11	8.36	7.47	1.56	0.15	0.03	0.00
1997	4.90	8.77	6.86	1.48	0.26	0.00	0.00
1998	2.11	9.47	5.90	1.60	0.13	0.01	0.00
1999	1.71	6.52	4.26	0.82	0.09	0.06	0.00
2000	2.88	4.98	5.51	2.19	0.66	0.10	0.00
2001	2.46	3.47	3.67	2.23	0.63	0.02	0.01
2002	1.60	4.76	3.21	1.24	0.54	0.15	0.06
2003	1.72	0.86	1.76	0.50	0.30	0.28	0.14
2004	5.47	3.97	1.03	0.44	0.12	0.09	0.04
2005	8.86	2.41	1.73	1.38	0.79	0.43	0.14
2006	2.07	4.72	5.24	2.24	0.74	0.30	0.05
2007	1.19	1.12	2.03	1.62	0.86	0.43	0.08
2008	3.29	1.00	1.00	1.12	0.67	0.22	0.06
2009	0.37	1.17	0.80	0.70	0.47	0.12	0.04
2010	3.24	2.68	3.13	1.24	1.06	0.18	0.03

CTDEP

	1	2	3	4	5	6	7+
1984	8.21	44.01	31.83	20.96	4.23	1.23	1.49
1985	4.11	28.46	32.88	14.17	2.33	0.82	0.8
1986	6.69	26	15.53	12.26	2.05	0.5	0.62
1987	7.32	44.69	14.56	5.05	6.55	1.28	0.48
1988	14.49	71.87	39.1	8.59	1.83	1.46	0.25
1989	13.56	78.43	41.23	10.85	2.84	0.98	0.3
1990	11.31	131.52	64.97	8.97	4.09	1.96	0.27
1991	8.52	66.99	60.39	9.31	4.05	0.8	0.15
1992	6.8	31.32	12.78	8.97	1.1	0.36	0.05
1993	19.11	19.87	15.46	4.81	3.24	0.8	0.3
1994	9.57	64.14	5.86	3.01	1.14	0.49	0.24
1995	14.35	23.69	9.77	1.36	0.63	0.2	0.12
1996	11.46	59.07	24.17	14.41	0.97	0.28	0.25
1997	12.53	25.53	19.41	9.45	3.76	0.51	0.12
1998	11.22	32.4	12.23	12.67	3.15	0.99	0.24
1999	6.56	12.42	11.27	6.09	3.2	1.14	0.67
2000	7.11	16.66	8.4	7.7	3.42	1.53	0.6
2001	8.45	19.6	10.85	8.06	5.46	1.28	0.81
2002	6.27	19.9	9.56	4.43	1.95	1.02	0.59
2003	2.47	7.83	8.71	4.79	1.95	0.77	1.32
2004	6.34	3.84	3.49	3.88	1.91	0.64	0.36
2005	7.06	6.18	0.84	0.81	0.67	0.21	0.33
2006	1.14	2.6	1.1	0.19	0.14	0.17	0.24
2007	2.98	10.83	10.7	3.1	0.61	0.15	0.29
2008	11.48	3.48	4.19	4.12	0.65	0.12	0.08
2009	7.56	11.21	1.02	1.31	1.21	0.22	0.06

NYDEC

	1	2+
1985	3.05	0.3
1986	-	-
1987	3.31	0.12
1988	2.57	0.31
1989	5.54	0.35
1990	3.44	0.26
1991	6.35	0.59
1992	2.04	0.2
1993	14.12	0.12
1994	6.96	0.32
1995	3.84	0.27
1996	2.84	0.15
1997	6.45	0.11
1998	3.8	0.29
1999	3.25	0.22
2000	1.56	0.15
2001	5.52	0.17
2002	0.17	0.19
2003	0.45	0.09
2004	5.38	0.11
2005	-	-
2006	-	-
2007	0.11	0.04

NJDFW Ocean

	1	2	3	4	5	6	7+
1993	5.1	6.5	2.5	2.4	1.7	0.4	0.57
1994	3.7	4.2	3.9	1.4	0.4	0.3	0.16
1995	8	10.1	8.6	2.4	0.9	0.3	0.11
1996	0.6	2.9	2.6	1.9	0.9	0.3	0.2
1997	16.6	5.4	6.1	6	1.5	0.3	0.12
1998	4.5	3.9	4.8	3.3	1.2	0.4	0.1
1999	2.4	2.2	5.9	3.1	2.9	0.7	0.59
2000	0.7	0.3	2.1	3.3	2	0.9	0.8
2001	3.9	0.6	1.3	2.7	3.8	0.7	0.83
2002	5.81	3.21	4.55	2.22	2.8	2.16	1.83
2003	2.08	1.1	4.79	1.24	1.09	0.87	1.35
2004	6.48	0.72	1.42	2.08	0.56	1.38	1.57
2005	4.97	10.04	2.55	2.76	2.61	1.32	1.42
2006	0.64	2.49	9.43	3.23	0.62	0.75	0.97
2007	3.8	0.67	4.33	6.09	1.51	0.62	1.56
2008	5.57	1.59	0.83	1.75	1.69	0.21	0.37

NJDFW Rivers

	1	2	3	4	5	6	7+
1995	0.6	0.3	1.4	0.4	0.1	0.01	0.01
1996	0.3	0.9	0.7	0.7	0.2	0.1	0.15
1997	1.1	0.4	0.9	0.4	0.4	0.1	0.05
1998	1.9	0.9	0.4	0.7	0.2	0.1	0.05
1999	0.2	0.5	1.4	0.5	0.4	0.1	0.13
2000	0.4	0.2	0.4	0.8	0.2	0.1	0.01
2001	1.4	0.3	0.2	0.4	0.4	0.1	0.04
2002	1.21	0.48	0.49	0.18	0.27	0.13	0.04
2003	0.05	0.22	0.9	0.18	0.03	0.1	0.09
2004	0.67	0.02	0.1	0.29	0.05	0	0.14
2005	0.42	0.24	0.17	0.2	0.09	0.02	0.03

URIGSO

	1	2	3	4	5	6	7+
1985	2.09	18.31	12.15	1.94	0.56	0	0
1986	6.87	13.85	4.23	0.83	0.08	0.02	0
1987	16.69	35.86	10.75	1.54	0.2	0.02	0
1988	22.35	24	7.82	0.95	0.04	0	0.06
1989	19.74	24.18	2.4	0.93	0.12	0.03	0.01
1990	6.22	10.33	2.18	0.75	0.1	0	0.04
1991	7.81	5.84	2.55	0.47	0.07	0.05	0
1992	5.81	4.17	1.35	0.47	0.08	0.01	0
1993	9.03	8.76	0.9	0.3	0.06	0.02	0
1994	4.52	6.22	1.5	0.17	0.02	0.01	0
1995	34.71	13.64	7.26	1.38	0.21	0.26	0.17
1996	14.22	19.68	5.41	1.11	0.43	0.25	0.11
1997	18.06	15.55	6.97	1.56	0.41	0.24	0.36
1998	7.5	13.73	3.9	1.25	0.31	0.21	0.07
1999	7.08	3.07	2.07	0.72	0.09	0.15	0.06
2000	7.47	3.77	2.28	0.82	0.11	0.14	0.05
2001	4.1	0.9	0.27	0.11	0.02	0.03	0.01
2002	5.39	3.18	0.99	0.34	0.06	0.01	0
2003	14.16	4.3	0.82	0.26	0.12	0.03	0.01
2004	18.36	6.47	0.5	0.32	0.09	0.04	0.02
2005	23.59	6.31	0.66	0.16	0.03	0	0
2006	5.2	4.04	1.22	0.34	0.03	0.01	0
2007	4.41	2.88	0.95	0.24	0.06	0	0
2008	18.74	7.41	0.72	0.15	0.01	0	0
2009	3.65	5.92	1.65	0.21	0.11	0.01	0
2010	7.73	3.16	1.1	0.25	0.05	0.02	0

Appendix B - The Age-Structured Production Model

The model used for these assessments is an Age-Structured Production Model (ASPM) (e.g. Hilborn, 1990). Models of this type fall within the more general class of Statistical Catch-at-Age Analyses. The approach used in an ASPM assessment involves constructing an age-structured model of the population dynamics and fitting it to the available abundance indices by maximising the likelihood function. The model equations and the general specifications of the model are described below, followed by details of the contributions to the (penalised) log-likelihood function from the different sources of data available and assumptions concerning the stock-recruitment relationship. Quasi-Newton minimization is used to minimize the total negative log-likelihood function (the package AD Model Builder™, Otter Research, Ltd is used for this purpose).

B.1. Population dynamics

B.1.1 Numbers-at-age

The resource dynamics are modelled by the following set of population dynamics equations:

$$N_{y+1,1} = R_{y+1} \quad \text{(B1)}$$

$$N_{y+1,a+1} = \left(N_{y,a}\, e^{-M_{y,a}/2} - C_{y,a}\right) e^{-M_{y,a}/2} \qquad \text{for } 1 \le a \le m-2 \quad \text{(B2)}$$

$$N_{y+1,m} = \left(N_{y,m-1}\, e^{-M_{y,m-1}/2} - C_{y,m-1}\right) e^{-M_{y,m-1}/2} + \left(N_{y,m}\, e^{-M_{y,m}/2} - C_{y,m}\right) e^{-M_{y,m}/2} \quad \text{(B3)}$$

where

$N_{y,a}$ is the number of fish of age *a* at the start of year *y* (which refers to a calendar year),

R_y is the recruitment (number of 1-year-old fish) at the start of year *y*,

$M_{y,a}$ denotes the natural mortality rate for fish of age *a* in year *y*,

$C_{y,a}$ is the predicted number of fish of age *a* caught in year *y*, and

m is the maximum age considered (taken to be a plus-group).

B.1.2. Recruitment

In line with the approach used at GARM in 2008 (Terciero, 2008), the number of recruits at the start of year *y* is assumed to have two constant levels, depending on the spawning biomass level which corresponds in this case to two particular periods, and allowing for annual fluctuation about the deterministic relationship:

$$R_y = \begin{cases} A^1 e^{(\varsigma_y - (\sigma_R^1)^2/2)} & \text{for } 1981 \le y \le 1988 \\ A^2 e^{(\varsigma_y - (\sigma_R^2)^2/2)} & \text{for } y \ge 1989 \end{cases} \quad \text{(B4)}$$

where

ς_y reflects fluctuation about the expected recruitment for year *y*, which is assumed to be normally distributed with standard deviation $\sigma_R^1 = 0.5$ for the period 1981-1988 and $\sigma_R^2 = 0.3$ for the period 1989-2010; these residuals are treated as estimable parameters in the model fitting process. The value for the earlier period was chosen to be rather uninformative. For the second period, it is rounded to a value slightly above the standard deviations of recruitment residuals shown in a number of these assessments. This value choice is intended to be somewhat informative for the most recent recruitment estimates for which the corresponding cohorts have been sampled relatively few times so that their initial magnitudes are not well estimated by the catch-at-age data alone,

A^1 and A^2 are constants, and

B_y^{sp} is the spawning biomass, computed as:

$$B_y^{sp} = \sum_{a=1}^{m} f_{y,a} w_{y,a}^{strt} N_{y,a} e^{-M_{y,a}\delta} \qquad \text{(B5)}$$

where

$w_{y,a}^{sp}$ is the mass of fish of age *a* during spawning, and

$f_{y,a}$ is the proportion of fish of age *a* that are mature,

δ is the proportion of the natural mortality that occurs before spawning (0.2 here).

B.1.3. Total catch and catches-at-age

The catch by mass in year *y* is given by:

$$C_y = \sum_{a=1}^{m} w_{y,a}^{mid}\, C_{y,a} = \sum_{a=1}^{m} w_{y,a}^{mid}\, N_{y,a}\, e^{-M_{y,a}/2}\, S_{y,a}\, F_y \qquad \text{(B6)}$$

where

$w_{y,a}^{mid}$ denotes the mass of fish of age *a* landed in year *y*,

$C_{y,a}$ is the catch-at-age, i.e. the number of fish of age *a*, caught in year *y*,

$S_{y,a}$ is the commercial selectivity (i.e. combination of availability and vulnerability to fishing gear) at age *a* for year *y*; when $S_{y,a}$ = 1, the age-class *a* is said to be fully selected, and

F_y is the proportion of a fully selected age class that is fished.

The model estimate of the mid-year exploitable ("available") component of biomass is calculated by converting the numbers-at-age into mid-year mass-at-age (using the individual weights of the landed fish) and applying natural and fishing mortality for half the year:

$$B_y^{ex} = \sum_{a=1}^{m} w_{y,a}^{mid} S_{y,a} N_{y,a} e^{-M_{y,a}/2} (1 - S_{y,a} F_y \ / 2) \qquad \text{(B7)}$$

For survey estimates (in numbers):

$$N_y^{surv,i} = \sum_{a=1}^{m} S_a^i N_{y,a} e^{-M_{y,a} \frac{\varpi^1}{12}} \left(1 - S_{y,a} F_y \ \frac{\varpi^1}{12}\right) \qquad \text{(B8)}$$

where

S_a^i is the survey selectivity for age *a* and survey *i*,

ϖ^i is the month in which survey *i* has taken place.

B.1.4. Initial conditions

For the first year (y_0) considered in the model therefore, the stock is assumed to be at a level $B_{y_0}^{sp}$ (estimated in the model fitting procedure), with the starting age structure:

$$N_{y_0,a} = R_{start} N_{start,a} \qquad \text{for } 1 \le a \le m \qquad \text{(B9)}$$

where

$$N_{start,1} = 1 \qquad \text{(B10)}$$

$$N_{start,a} = N_{start,a-1} e^{-M_{y_0,a-1}} (1 - \phi S_{y_0,a-1}) \qquad \text{for } 2 \le a \le m-1 \qquad \text{(B11)}$$

$$N_{start,m} = N_{start,m-1} e^{-M_{y_0,m-1}} (1 - \phi S_{y_0,m-1}) \Big/ (1 - e^{-M_{y_0,m}} (1 - \phi S_{y_0,m})) \qquad \text{(B12)}$$

where ϕ characterises the average fishing proportion over the years immediately preceding *y_0*.

B.2. The (penalised) likelihood function

The model is fit to survey abundance indices, and commercial and survey catch-at-age data to estimate model parameters (which may include residuals about the stock-recruitment function, the fishing selectivities, the annual catches or natural mortality, facilitated through the incorporation of the penalty functions described below). Contributions by each of these to the negative of the (penalised) log-likelihood (- $\ell\text{n}L$) are as follows.

B.2.1. Survey abundance data

The likelihood is calculated assuming that an observed survey index is log-normally distributed about its expected value:

$$I_y^i = \hat{I}_y^i \exp\left(\varepsilon_y^i\right) \quad \text{or} \quad \varepsilon_y^i = \ell\text{n}\left(I_y^i\right) - \ell\text{n}\left(\hat{I}_y^i\right) \qquad \text{(B13)}$$

where

I_y^i is the survey index for year *y* and series *i*,

$\hat{I}_y^i = \hat{q}^i N_y^{surv,i}$ is the corresponding model estimate, where $N_y^{surv,i}$ is the model estimate, given by equation (B8),

$\hat{q}^i$ is the constant of proportionality (catchability) for index *i*, and

ε_y^i from $N\left(0,\left(\sigma_y^i\right)^2\right)$.

For these analyses, selectivities are estimated as detailed in section B.3.1 below.

The contribution of the survey abundance data to the negative of the log-likelihood function (after removal of constants) is then given by:

$$-\ell\text{n}\, L^{survey} = \sum_i \sum_y \left[\ell\text{n}\left(\sigma_y^i\right) + \left(\varepsilon_y^i\right)^2 / 2\left(\sigma_y^i\right)^2\right] \tag{B14}$$

where

σ_y^i is the standard deviation of the residuals for the logarithm of index *i* in year *y*.

Homoscedasticity of residuals is assumed, so that $\sigma_y^i = \sigma^i$ is estimated in the fitting procedure by its maximum likelihood value:

$$\hat{\sigma}^i = \sqrt{1/n_i \sum_y \left(\ell\text{n}(I_y^i) - \ell\text{n}(q^i N_y^{surv,i})\right)^2} \tag{B15}$$

where

n_i is the number of data points for survey index *i*.

The catchability coefficient q^i for survey index *i* is estimated by its maximum likelihood value:

$$\ell n\, \hat{q}^i = 1/n_i \sum_y \left(\ln I_y^i - \ln N_y^{surv,i}\right) \tag{B16}$$

To allow for first order serial correlation between the survey residuals, a serial correlation coefficient ρ^i would be estimated for each survey index:

$$\varepsilon_y^i = \lambda_y^i - \rho\lambda_{y-1}^i \tag{B17}$$

where

$$\lambda_y^i = \ell\text{n}\left(I_y^i\right) - \ell\text{n}\left(\hat{I}_y^i\right)$$

and the summation in equation (B.16) extends over one less year.

B.2.2. Commercial catches-at-age

The contribution of the catch-at-age data to the negative of the log-likelihood function under the assumption of an "adjusted" lognormal error distribution is given by:

$$-\ell n L^{CAA} = \sum_y \sum_a \left[\ell n\left(\sigma_{com} / \sqrt{p_{y,a}}\right) + p_{y,a}\left(\ell n\, p_{y,a} - \ell n\, \hat{p}_{y,a}\right)^2 / 2\left(\sigma_{com}\right)^2 \right] \quad \text{(B18)}$$

where

$p_{y,a} = C_{y,a} / \sum_{a'} C_{y,a'}$ is the observed proportion of fish caught in year *y* that are of age *a*,

$\hat{p}_{y,a} = \hat{C}_{y,a} / \sum_{a'} \hat{C}_{y,a'}$ is the model-predicted proportion of fish caught in year *y* that are of age *a*, where

$$\hat{C}_{y,a} = N_{y,a}\, e^{-M_{y,a}/2}\, S_{y,a}\, F_y \quad \text{(B19)}$$

and

σ_{com} is the standard deviation associated with the catch-at-age data, which is estimated in the fitting procedure by:

$$\hat{\sigma}_{com} = \sqrt{\sum_y \sum_a p_{y,a}\left(\ell n\, p_{y,a} - \ell n\, \hat{p}_{y,a}\right)^2 / \sum_y \sum_a 1} \quad \text{(B20)}$$

B.2.3. Survey catches-at-age

The survey catches-at-age are incorporated into the negative of the log-likelihood in an analogous manner to the commercial catches-at-age, assuming an adjusted log-normal error distribution (equation (B18)) where:

$p_{y,a} = C^{surv}_{y,a} / \sum_{a'} C^{surv}_{y,a'}$ is the observed proportion of fish of age *a* in year *y*, with

$$C^{surv,i}_{y,a} = S^i_a N_{y,a} e^{-M_{y,a}\frac{\varpi^1}{12}} \left(1 - S_{y,a} F_y \frac{\varpi^1}{12}\right) \quad \text{(B21)}$$

$\hat{p}_{y,a}$ is the expected proportion of fish of age *a* in year *y* in the survey.

B.2.4. Stock-recruitment function residuals

The stock-recruitment residuals are assumed to be log-normally distributed. Thus, the contribution of the recruitment residuals to the negative of the (now penalised) log-likelihood function is given by:

$$-\ell n L^{SRpen} = \sum_{y=y1}^{1988} \left[\varepsilon_y^2 \big/ 2\left(\sigma_R^1\right)^2\right] + \sum_{1989}^{y2} \left[\varepsilon_y^2 \big/ 2\left(\sigma_R^2\right)^2\right] \quad \text{(B22)}$$

where

ε_y from $N\left(0, \left(\sigma_R^1\right)^2\right)$ for year *y*1 to 1988, and from $N\left(0, \left(\sigma_R^2\right)^2\right)$ for year 1989 to *y2*.

B.3. Model parameters

B.3.1. Fishing selectivity-at-age:

The commercial and survey fishing selectivities are estimated separately for ages 1-7+. The convention used is to set S_a to 1 for the age with the highest selectivity.

B.3.2.: Other parameters reported in Tables 1-3 and elsewhere

Mohn's ρ

Retrospective evaluations involved four model runs with successively earlier terminal years (2008, 2006, 2004 and 2002), in addition to the run with the full data set (2010). Mohn's ρ for a statistic *S* is calculated as:

$$\rho_S = \sum_{i=1}^{4} \frac{\left(s_{2010-2i} - S_{2010-2i}\right)}{S_{2010-2i}} \Big/ 4 \qquad \text{(B23)}$$

Where S_j is the estimated statistic (here spawning biomass or recruitment) for year *j* from the run with the full data set and s_j is the estimated statistic for year *j* from the model with *j* as the terminal year.

Loss to increased *M*

For each year of the assessment period, a "pseudo" numbers-at-age matrix (N^*) is computed, assuming M=M^1, the natural mortality at the start of the assessment period:

$$N^*_{y+1,a+1} = \left(N_{y,a}\, e^{-M^1/2} - C_{y,a}\right) e^{-M^1/2} \qquad \text{for } 1 \le a \le m-2 \qquad \text{(B24)}$$

$$N^*_{y+1,m} = \left(N_{y,m-1}\, e^{-M^1/2} - C_{y,m-1}\right) e^{-M^1/2} + \left(N_{y,m}\, e^{-M^1/2} - C_{y,m}\right) e^{-M^1/2} \qquad \text{(B25)}$$

The loss to increased *M* is then calculated as:

$$L = \sum_{y=1981}^{2010} \sum_{a=1}^{mm} \left(L^1_{y,a} - L^2_{y,a}\right) \qquad \text{(B26)}$$

where

$$L^1_{y,a} = w^{mid}_{y,a}\left(N_{y,a} - N_{y+1,a+1} + C_{y,a}\right) \qquad \text{(B27)}$$

$$L^2_{y,a} = w^{mid}_{y,a}\left(N_{y,a} - N^*_{y+1,a+1} + C_{y,a}\right) \qquad \text{(B28)}$$

σ_R_out

$$\sigma_R\_\text{out} = \sum_{y=y1}^{y2} \left(\varsigma_y\right)^2 \Big/ \sum_{y=y1}^{y2} 1 \qquad \text{(B29)}$$

This is calculated for two periods: a) *y*1=1981, *y*2=1988 and b) *y*1=1989, *y*2=2010

Calculation of MSY

The equilibrium catch for a fully selected fishing proportion *F* is calculated as:

$$C(F) = \sum_a w_a^{mid} S_a F N_a(F) e^{-(M_a/2)} \tag{B30}$$

where $w_a^{mid} = \sum_{y1=2006}^{2010} w_{y,a}^{mid} \Big/ 5$, $S_a = S_{2010,a}$ and $M_a = M_{2010,a}$

and where numbers-at-age *a* are given by:

$$N_a(F) = \begin{cases} R_1(F) & \text{for } a = 1 \\ N_{a-1}(F) e^{-M_{a-1}} (1 - S_{a-1} F) & \text{for } 1 < a < m \\ \dfrac{N_{m-1}(F) e^{-M_{m-1}} (1 - S_{m-1} F)}{\left(1 - e^{-M_m} (1 - S_m F)\right)} & \text{for } a = m \end{cases} \tag{B31}$$

where

$$R_1(F) = A^1 \text{ or } A^2 \tag{B32}$$

The maximum of $C(F)$ is then found by searching over *F* to give F_{MSY}, with the associated spawning biomass and yield given by

$$B_{\text{MSY}}^{sp} = \sum_a f_a w_a^{strt} N_a(F_{\text{MSY}}) e^{-M_a \delta} \tag{B33}$$

$$MSY = \sum_a w_a^{mid} S_a F_{\text{MSY}} N_a(F_{\text{MSY}}) e^{-(M_a/2)} \tag{B34}$$

where $w_a^{strt} = \sum_{y1=2006}^{2010} w_{y,a}^{strt} \Big/ 5$ and $f_a = \sum_{y1=2006}^{2010} f_{y,a} \Big/ 5$

ADDITIONAL REFERENCE

Hilborn, R. 1990. Estimating the parameters of full age-structured models from catch and abundance data. International North Pacific Fisheries Commission Bulletin, 50: 207-213.

Update of the Southern New England/Mid-Atlantic Winter Flounder Resource New Base Case SCAA using updated data

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Introduction

This paper presents an update of the SCAA "New Base Case" for the Southern New England/Mid-Atlantic winter flounder resource of Rademeyer and Butterworth (2011) using the most recent data available (Terceiro, 2011).

Data and Methodology

The data tables, which have been updated from those used in Rademeyer and Butterworth (2011), are given in Appendix A with the updated data shown in bold. Although the units of NEFSC surveys have changed (given here as stratified mean number per tow instead of mean total number), only the 2010 values are new (i.e. changed).

The methodology is as described in Appendix B of Rademeyer and Butterworth (2011), with the New Base Case specifications.

Results and Discussion

The results for the "New Base Case" and "New Base Case with updated data" are compared in Table 1. Retrospective patterns for spawning biomass and recruitment trajectories are shown in Fig. 1 for the "New Base Case with updated data" and the estimated spawning biomass and recruitment trends are shown in Fig. 2. These show very little change in moving from the original to the new data.

References

Rademeyer R.A. and Butterworth D.S. 2011. Initial applications of statistical catch-at-age methodology to the Southern New England/Mid-Atlantic winter flounder resource. Document to this workshop.

Terceiro M. 2008. J. Southern New England/Mid-Atlantic winter flounder. Appendix to the Report of the 3rd Groundfish Assessment Review Meeting (GARM III): Assessment of 19 Northeast Groundfish Stocks through 2007, Northeast Fisheries Science Center, Woods Hole, Massachusetts, August 4-8, 2008 http://www.nefsc.noaa.gov/publications/crd/crd0816/pdfs/garm3j.pdf

Table 1: Results for the New Base Case as in Rademeyer and Butterworth (2011) and now with the updated data. Biomass units are '000t. The two recruitment values refer to the two recruitment periods, i.e. 1989-2010 and 1981-1988 respectively. MSY and related quantities have been computed for each of these recruitment levels, assuming the natural mortality in recent years.

	New Base Case				New Base Case - Updated data			
'-lnL:overall	-864.1				-848.9			
'-lnL:Survey	-49.8				-42.3			
'-lnL:CAA	-91.7				-95.8			
'-lnL:CAAsurv	-701.7				-690.3			
'-lnL:RecRes	-21.9				-21.7			
'-lnL:SelSmoothing	0.9				1.3			
Mohn's rho: SSB	-0.03				-0.03			
Mohn's rho: rec.	0.16				0.16			
Phi	0.83				0.81			
Bsp(1981)	20.8				21.1			
Bsp(2010)	4.1				4.1			
Bsp(2010)/Bsp(1981)	0.20				0.20			
M	0.3-0.6				0.3-0.6			
Recruitment	25.7	52.8			25.5	52.9		
Bsp(MSY)	2.0	4.1			1.7	3.5		
MSY	2.4	5.0			2.6	5.3		
σ_{comCAA}	0.10				0.10			
Survey	q x10^6	σ_{surv}	σ_{CAA}	ρ	q x10^6	σ_{surv}	σ_{CAA}	ρ
NEFSCspr	285.2	0.31	0.10	0.06	0.10	0.31	0.11	0.03
NEFSCfall	936.6	0.47	0.15	0.67	0.17	0.50	0.13	0.69
NEFSCwinter	233.5	0.30	0.19	0.21	0.14	0.30	0.19	0.18
MADFM	3.31	0.41	0.15	0.51	2.61	0.42	0.15	0.52
RIDFW	0.57	0.51	0.16	0.20	0.52	0.51	0.16	0.19
CTDEP	3.13	0.51	0.12	0.68	2.30	0.50	0.12	0.68
NY	0.11	0.92	0.20	0.28	0.11	0.92	0.20	0.29
NJDFW Ocean	4.13	0.42	0.16	-0.03	2.80	0.43	0.16	-0.03
NJDFW River	0.39	0.27	0.18	0.58	0.28	0.28	0.18	0.67
MADFM YOY	0.01	0.44	-	0.50	0.01	0.44	-	0.45
CTDEP YOY	0.24	0.65	-	0.26	0.21	0.72	-	0.33
RIDFW YOY	0.48	0.71	-	0.52	0.43	0.91	-	0.33
NY YOY	0.14	1.33	-	0.60	0.14	1.33	-	0.60
DEDFW YOY	0.00	1.00	-	-0.23	0.00	1.00	-	-0.18
URIGSO	0.53	0.51	0.13	0.31	0.55	0.44	0.13	0.20
σ_R_out (81-88, 89-10)	0.27	0.26			0.27	0.27		

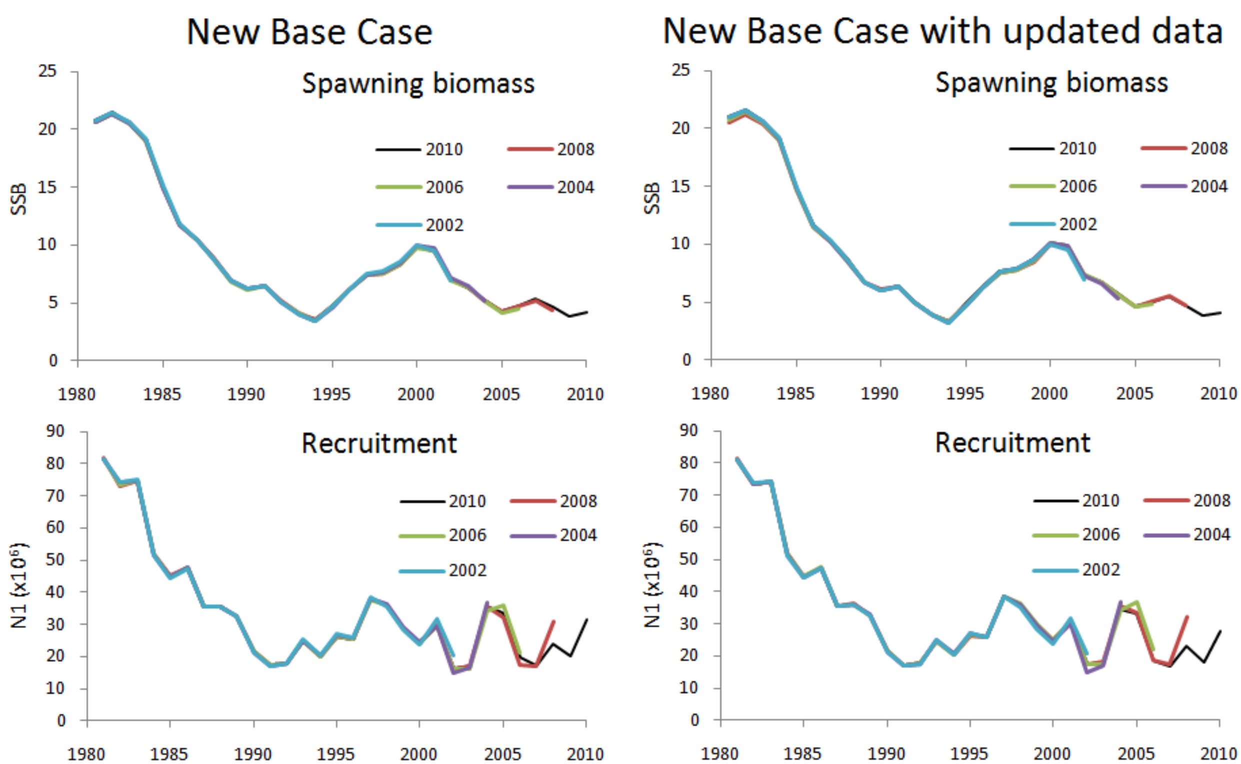

Fig. 1: Retrospective analysis of spawning biomass and recruitment for the two cases.

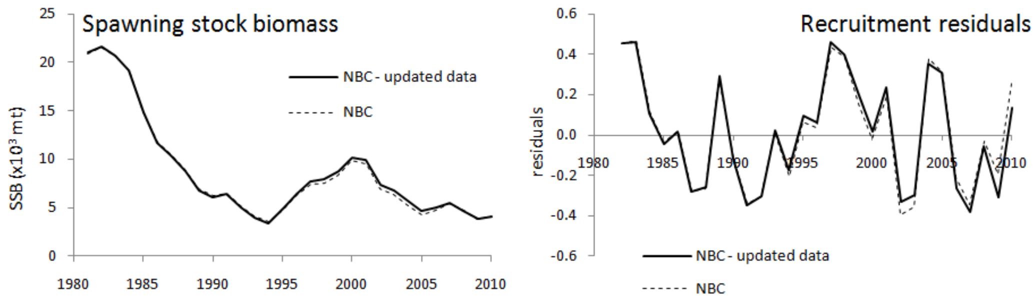

Fig. 2: Spawning stock biomass and recruitment trajectories for the New Base Case and New Base Case with updated data.

APPENDIX A – Data

In the Tables below, the data that are new or have been updated compared to those used in Rademeyer and Butterworth (2011) are shown in bold. The data tables used in Rademeyer and Buttterworth (2011) that have not been updated at all are not repeated here.

Table A1: Total catch (metric tons) for SNE/MA winter flounder (Terceiro, 2011). Pre-1981, only the commercial landings are available; to compute the total catches, the average 1981-1985 ratio of commercial landings (0.62), commercial discards (0.09), recreational landings (0.28) and recreational discards (0.01) is assumed to apply over the pre-1981 period.

Year	Total catch (mt)	Year	Total catch (mt)	Year	Total catch (mt)
1964	*12053*	1980	*17138*	1996	3702
1965	*13995*	1981	15764	1997	4483
1966	*19315*	1982	14143	1998	3614
1967	*15285*	1983	13582	1999	3745
1968	*11402*	1984	15526	2000	4754
1969	*13074*	1985	13891	2001	5147
1970	*13874*	1986	9217	2002	3412
1971	*11881*	1987	9352	2003	2827
1972	*8370*	1988	8795	2004	1942
1973	*8988*	1989	6915	2005	1563
1974	*6869*	1990	5999	2006	2023
1975	*6422*	1991	6842	2007	**1883**
1976	*5266*	1992	4729	2008	**1432**
1977	*7117*	1993	4311	2009	**639**
1978	*10204*	1994	3092	2010	**400**
1979	*10552*	1995	3434		

Table A2. Catch at age matrix (000s) for SNE/MA winter flounder (Terceiro, 2011).

	1	2	3	4	5	6	7+
1981	1380	14183	14401	3608	666	182	111
1982	575	14153	12374	3713	608	212	202
1983	616	7232	13273	6111	1791	695	544
1984	493	11470	13940	4890	1770	873	803
1985	274	7342	12771	6013	2922	1819	1404
1986	216	6327	9101	4218	1053	442	357
1987	74	5265	8988	3084	2690	751	424
1988	85	3946	9401	3963	1206	978	303
1989	468	5275	7208	3541	861	226	214
1990	36	2110	6276	2933	768	196	142
1991	52	3029	7146	3349	860	252	113
1992	25	1507	4460	2582	673	162	53
1993	292	2200	3520	1897	714	188	138
1994	251	2612	2339	1280	337	97	39
1995	88	654	3112	2202	506	83	20
1996	171	1050	3289	2181	556	129	40
1997	88	1841	3488	2252	584	96	39
1998	16	1371	3043	1788	555	185	74
1999	5	2146	4062	1577	375	82	18
2000	43	1336	3436	2473	822	146	72
2001	35	1689	3503	2274	883	231	124
2002	14	478	1897	1830	925	324	115
2003	15	498	1802	1199	501	223	136
2004	36	378	999	858	331	223	167
2005	32	417	765	755	328	134	81
2006	39	758	1598	686	277	133	108
2007	**7**	**335**	**1460**	**1010**	**290**	**84**	**42**
2008	**34**	**243**	**699**	**725**	**278**	**126**	**66**
2009	**83**	**195**	**271**	**268**	**211**	**66**	**30**
2010	**67**	**87**	**150**	**159**	**87**	**52**	**35**

Table A3. Total fishery mean weights-at-age (kg) for SNE/MA winter flounder (M. Terceiro, pers. commn).

	1	2	3	4	5	6	7+
1981	0.129	0.274	0.477	0.798	1.063	1.242	1.196
1982	0.092	0.263	0.440	0.697	1.052	1.257	1.840
1983	0.197	0.237	0.354	0.517	0.768	1.047	1.552
1984	0.148	0.261	0.370	0.546	0.695	0.915	1.284
1985	0.111	0.282	0.364	0.482	0.522	0.467	0.613
1986	0.129	0.292	0.398	0.480	0.685	0.879	0.961
1987	0.046	0.287	0.384	0.551	0.475	0.564	0.853
1988	0.039	0.279	0.351	0.508	0.634	0.517	0.827
1989	0.118	0.258	0.378	0.508	0.660	0.716	1.073
1990	0.082	0.295	0.394	0.525	0.672	0.808	0.990
1991	0.093	0.317	0.420	0.534	0.603	0.823	1.168
1992	0.079	0.287	0.427	0.599	0.802	0.945	1.395
1993	0.169	0.334	0.460	0.592	0.689	0.878	1.167
1994	0.162	0.311	0.429	0.550	0.750	0.985	1.281
1995	0.267	0.420	0.470	0.559	0.789	1.089	1.741
1996	0.136	0.380	0.464	0.607	0.824	0.851	1.085
1997	0.245	0.443	0.515	0.644	0.771	0.957	1.477
1998	0.196	0.362	0.465	0.568	0.665	1.090	1.116
1999	0.136	0.359	0.439	0.524	0.684	0.903	1.147
2000	0.106	0.407	0.492	0.622	0.729	0.975	1.079
2001	0.089	0.436	0.519	0.640	0.783	1.051	1.234
2002	0.135	0.372	0.499	0.617	0.747	0.927	1.143
2003	0.167	0.426	0.517	0.672	0.854	1.000	1.135
2004	0.094	0.384	0.549	0.619	0.786	0.945	1.251
2005	0.129	0.342	0.488	0.675	0.834	1.013	1.318
2006	0.118	0.379	0.468	0.652	0.872	1.065	1.289
2007	0.065	0.388	0.473	0.634	0.861	1.097	1.372
2008	0.110	0.355	0.477	0.597	0.754	0.939	1.238
2009	0.126	0.326	0.434	0.594	0.757	1.006	0.941
2010	**0.127**	**0.329**	**0.505**	**0.615**	**0.766**	**0.899**	**1.075**

Table A4: Survey data in terms of total numbers for SNE/MA winter flounder (Terceiro, 2011). The NEFSC survey units have changed (now given as stratified mean number per tow instead of mean total number), but only the 2010 data points are new.

	NEFSC spring	NEFSC fall	NEFSC winter	MADMF	RIDFW	CTDEP	NYDEC	NJDFW Ocean	NJDFW Rivers	URIGSO	YOY-MADMF	YOY-CTDEP	YOY-RIDFW	YOY-NYDEC	YOY-DEDFW
Month	4	10	3	5	5	5	5	5	5	5	1	1	1	1	1
Ages	1-7+	2-6+	1-5+	1-7+	1-7+	1-7+	1-2+	1-7+	1-7+	1-7+	1	1	1	1	1
1981	9.02	10.21	-	47.80	87.98	-	-	-	-	0.43	-	-	-	-	-
1982	6.99	4.93	-	41.46	30.95	-	-	-	-	0.34	-	-	-	-	-
1983	6.26	8.76	-	58.14	58.95	-	-	-	-	0.37	-	-	-	-	-
1984	5.52	2.68	-	38.02	41.64	111.96	-	-	-	0.23	-	-	-	-	-
1985	5.36	2.73	-	39.49	34.98	83.57	3.35	-	-	0.32	-	-	1.52	-	35.04
1986	2.27	1.54	-	36.78	41.02	63.65	-	-	-	0.34	-	29.00	-	-	25.87
1987	1.76	1.17	-	39.16	56.22	79.93	3.43	-	-	0.33	-	11.60	2.67	0.17	65.05
1988	2.13	1.25	-	28.36	34.44	137.59	2.88	-	-	0.27	-	9.19	1.47	0.09	55.21
1989	2.49	1.44	-	27.38	20.88	148.19	5.89	-	-	0.18	15.46	18.92	11.20	0.02	**36.44**
1990	1.99	1.98	-	27.72	20.44	223.09	3.70	-	-	0.42	1.90	21.48	8.73	0.29	**20.12**
1991	2.47	1.95	-	11.02	40.97	150.21	6.94	-	-	0.33	2.85	12.19	14.72	0.63	16.80
1992	1.58	2.96	3.68	28.96	4.41	61.38	2.24	-	-	0.27	5.23	33.33	76.87	0.03	11.89
1993	0.96	1.38	2.59	50.40	2.92	63.59	14.24	19.17	-	0.29	11.90	5.29	17.10	0.27	19.06
1994	1.51	4.13	3.80	50.84	10.26	84.45	7.28	14.06	-	0.07	5.61	2.52	14.93	0.04	12.44
1995	2.10	2.25	2.22	37.37	32.19	50.12	4.11	30.41	2.82	0.15	14.23	5.64	4.10	0.31	57.63
1996	1.52	3.19	3.78	30.92	20.68	110.61	2.99	9.40	3.05	0.15	10.10	6.22	16.25	0.10	41.20
1997	1.44	7.89	3.91	38.51	22.27	71.31	6.56	36.02	3.35	0.22	19.22	4.70	4.42	0.04	43.05
1998	2.77	6.60	7.17	35.88	19.22	72.90	4.09	18.20	4.25	0.39	7.47	2.56	3.11	0.10	26.97
1999	4.17	3.60	10.33	25.98	13.46	41.35	3.47	17.79	3.23	0.17	9.24	14.97	7.52	0.13	13.24
2000	3.17	6.17	5.57	24.64	16.32	45.42	1.71	10.10	2.11	0.20	8.70	53.00	0.90	0.07	14.64
2001	1.57	4.88	3.10	15.79	12.49	54.51	5.69	13.83	2.84	0.35	4.33	13.73	2.31	0.08	**16.70**
2002	2.04	8.86	2.90	6.70	11.56	43.72	0.36	22.58	2.80	0.21	1.34	18.12	0.07	0.06	9.96
2003	0.77	3.21	2.20	17.73	5.56	27.84	0.54	12.52	1.57	0.10	3.06	31.22	0.86	0.01	19.71
2004	1.24	3.36	4.34	11.14	11.16	20.46	5.49	14.21	1.27	0.20	8.07	18.72	0.50	0.28	25.81
2005	0.93	3.71	4.05	27.02	15.74	16.10	-	25.67	**0.99**	0.10	10.96	5.28	-	0.20	30.75
2006	1.81	2.95	5.08	17.63	15.36	5.58	-	18.13	-	0.08	5.63	12.72	-	0.02	10.82
2007	0.94	3.48	2.79	16.68	7.33	28.66	0.15	18.58	-	0.16	0.93	14.17	1.11	0.15	8.54
2008	1.81	2.86	-	10.63	7.36	24.12	-	12.01	-	0.17	4.73	11.65	-	0.05	27.03
2009	0.99	1.78	-	14.58	3.67	22.64	-	**13.98**	-	0.09	1.97	10.77	-	0.02	11.54
2010	**0.97**	**2.65**	-	29.84	11.56	**20.88**	-	**7.99**	-	0.08	**0.78**	**1.52**	-	**0.04**	12.31

Table A6: Survey catch-at-age data mean numbers for SNE/MA winter flounder (Terceiro, 2011). The NEFSC survey units have changed (now given as stratified mean number per tow instead of mean total number), but only the 2010 data points are new.

NEFSC spring

	1	2	3	4	5	6	7+
1981	0.99	4.00	3.41	0.47	0.13	0.01	0.01
1982	1.16	3.20	1.56	0.74	0.21	0.09	0.03
1983	0.58	0.97	2.14	1.23	0.81	0.37	0.16
1984	0.22	1.36	2.18	0.85	0.46	0.29	0.16
1985	0.41	1.21	2.16	0.72	0.51	0.20	0.15
1986	0.10	0.49	1.16	0.31	0.15	0.05	0.01
1987	0.14	0.54	0.70	0.28	0.06	0.02	0.02
1988	0.09	0.48	0.99	0.37	0.16	0.02	0.02
1989	0.14	0.95	0.90	0.34	0.11	0.02	0.03
1990	0.23	0.49	0.89	0.28	0.05	0.04	0.01
1991	0.14	0.60	1.22	0.41	0.05	0.02	0.03
1992	0.14	0.39	0.62	0.36	0.05	0.02	0.00
1993	0.14	0.35	0.26	0.12	0.07	0.01	0.01
1994	0.16	0.74	0.43	0.11	0.04	0.02	0.01
1995	0.22	0.75	0.87	0.22	0.03	0.00	0.01
1996	0.07	0.54	0.66	0.17	0.06	0.01	0.01
1997	0.13	0.50	0.56	0.18	0.06	0.01	0.00
1998	0.33	1.21	0.72	0.37	0.13	0.01	0.00
1999	0.41	1.89	1.35	0.36	0.11	0.04	0.01
2000	0.28	0.70	1.19	0.65	0.27	0.07	0.01
2001	0.17	0.26	0.47	0.44	0.20	0.02	0.01
2002	0.11	0.60	0.56	0.38	0.23	0.11	0.05
2003	0.12	0.11	0.33	0.10	0.05	0.04	0.02
2004	0.30	0.19	0.29	0.26	0.11	0.05	0.04
2005	0.10	0.45	0.11	0.16	0.07	0.03	0.01
2006	0.30	0.62	0.62	0.16	0.08	0.02	0.01
2007	0.11	0.14	0.36	0.26	0.04	0.01	0.02
2008	0.18	0.61	0.48	0.41	0.11	0.01	0.01
2009	0.06	0.22	0.30	0.16	0.18	0.05	0.02
2010	**0.21**	**0.24**	**0.30**	**0.14**	**0.07**	**0.01**	**0.00**

NEFSC fall

	2-	3	4	5	6+
1981	7.16	2.49	0.30	0.10	0.12
1982	2.97	1.34	0.47	0.12	0.02
1983	5.45	2.06	0.62	0.35	0.28
1984	1.21	1.17	0.26	0.03	0.01
1985	1.34	0.99	0.30	0.09	0.01
1986	1.13	0.36	0.03	0.01	0.01
1987	0.67	0.36	0.12	0.02	0.00
1988	0.33	0.64	0.22	0.04	0.02
1989	1.11	0.26	0.05	0.01	0.01
1990	0.97	0.85	0.15	0.01	0.00
1991	1.09	0.73	0.12	0.01	0.00
1992	1.87	0.79	0.26	0.03	0.01
1993	0.95	0.35	0.08	0.00	0.00
1994	2.68	1.08	0.30	0.04	0.03
1995	1.51	0.63	0.09	0.01	0.01
1996	2.01	0.80	0.31	0.06	0.01
1997	5.06	2.20	0.55	0.08	0.00
1998	4.22	1.91	0.41	0.05	0.01
1999	1.38	1.46	0.54	0.18	0.04
2000	3.20	2.02	0.71	0.22	0.02
2001	2.28	1.61	0.63	0.30	0.06
2002	4.53	2.35	1.14	0.59	0.20
2003	1.46	1.15	0.46	0.10	0.04
2004	2.68	0.28	0.28	0.06	0.06
2005	2.55	0.73	0.21	0.13	0.09
2006	1.86	0.79	0.22	0.06	0.02
2007	2.24	1.03	0.16	0.02	0.03
2008	1.18	0.70	0.62	0.29	0.07
2009	1.29	0.23	0.15	0.09	0.02
2010	**1.51**	**0.66**	**0.23**	**0.19**	**0.06**

NEFSC winter

	1	2	3	4	5+
1992	0.73	0.86	1.09	0.73	0.28
1993	0.56	1.16	0.54	0.18	0.15
1994	0.36	1.16	1.76	0.25	0.28
1995	0.04	0.75	1.26	0.17	0.00
1996	1.01	0.87	1.55	0.32	0.02
1997	0.43	1.49	1.32	0.54	0.13
1998	0.42	3.52	1.95	0.96	0.32
1999	0.84	5.94	2.23	0.96	0.36
2000	0.23	2.82	2.12	0.24	0.16
2001	1.04	0.55	0.70	0.54	0.27
2002	0.08	1.34	0.74	0.15	0.59
2003	0.09	0.57	1.04	0.25	0.25
2004	2.17	1.02	0.43	0.36	0.36
2005	0.39	2.56	0.36	0.43	0.31
2006	0.00	2.40	1.73	0.51	0.44
2007	0.02	0.56	1.03	1.03	0.15

CTDEP

	1	2	3	4	5	6	7+
1984	8.21	44.01	31.83	20.96	4.23	1.23	1.49
1985	4.11	28.46	32.88	14.17	2.33	0.82	0.8
1986	6.69	26	15.53	12.26	2.05	0.5	0.62
1987	7.32	44.69	14.56	5.05	6.55	1.28	0.48
1988	14.49	71.87	39.1	8.59	1.83	1.46	0.25
1989	13.56	78.43	41.23	10.85	2.84	0.98	0.3
1990	11.31	131.52	64.97	8.97	4.09	1.96	0.27
1991	8.52	66.99	60.39	9.31	4.05	0.8	0.15
1992	6.8	31.32	12.78	8.97	1.1	0.36	0.05
1993	19.11	19.87	15.46	4.81	3.24	0.8	0.3
1994	9.57	64.14	5.86	3.01	1.14	0.49	0.24
1995	14.35	23.69	9.77	1.36	0.63	0.2	0.12
1996	11.46	59.07	24.17	14.41	0.97	0.28	0.25
1997	12.53	25.53	19.41	9.45	3.76	0.51	0.12
1998	11.22	32.4	12.23	12.67	3.15	0.99	0.24
1999	6.56	12.42	11.27	6.09	3.2	1.14	0.67
2000	7.11	16.66	8.4	7.7	3.42	1.53	0.6
2001	8.45	19.6	10.85	8.06	5.46	1.28	0.81
2002	6.27	19.9	9.56	4.43	1.95	1.02	0.59
2003	2.47	7.83	8.71	4.79	1.95	0.77	1.32
2004	6.34	3.84	3.49	3.88	1.91	0.64	0.36
2005	7.06	6.18	0.84	0.81	0.67	0.21	0.33
2006	1.14	2.6	1.1	0.19	0.14	0.17	0.24
2007	2.98	10.83	10.7	3.1	0.61	0.15	0.29
2008	11.48	3.48	4.19	4.12	0.65	0.12	0.08
2009	7.56	11.21	1.02	1.31	1.21	0.22	0.06
2010	**6.64**	**8.45**	**3.94**	**0.71**	**0.57**	**0.44**	**0.13**

NJDFW Ocean

	1	2	3	4	5	6	7+
1993	5.1	6.5	2.5	2.4	1.7	0.4	0.57
1994	3.7	4.2	3.9	1.4	0.4	0.3	0.16
1995	8	10.1	8.6	2.4	0.9	0.3	0.11
1996	0.6	2.9	2.6	1.9	0.9	0.3	0.2
1997	16.6	5.4	6.1	6	1.5	0.3	0.12
1998	4.5	3.9	4.8	3.3	1.2	0.4	0.1
1999	2.4	2.2	5.9	3.1	2.9	0.7	0.59
2000	0.7	0.3	2.1	3.3	2	0.9	0.8
2001	3.9	0.6	1.3	2.7	3.8	0.7	0.83
2002	5.81	3.21	4.55	2.22	2.8	2.16	1.83
2003	2.08	1.1	4.79	1.24	1.09	0.87	1.35
2004	6.48	0.72	1.42	2.08	0.56	1.38	1.57
2005	4.97	10.04	2.55	2.76	2.61	1.32	1.42
2006	0.64	2.49	9.43	3.23	0.62	0.75	0.97
2007	3.8	0.67	4.33	6.09	1.51	0.62	1.56
2008	5.57	1.59	0.83	1.75	1.69	0.21	0.37
2009	**2.84**	**4.35**	**3.54**	**1.34**	**1.48**	**0.33**	**0.1**
2010	**0.75**	**1.59**	**2.63**	**1.5**	**0.94**	**0.37**	**0.21**

Initial Applications of Statistical Catch-at-Age Assessment Methodology to the Gulf of Maine Winter Flounder Resource

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Abstract

Application of SCAA to the Gulf of Maine flounder resource, though initial at this stage, suggests that with some downweighting of catch-at-age data in the likelihood, the serious retrospective problem of previous VPA assessments of this resource disappear. There are indications from the model fits considered that survey selectivity is domed (assuming commercial selectivity to be asymptotically flat at higher ages) and/or natural mortality is higher than the conventionally assumed 0.2.

Introduction

This paper presents the results of some initial applications of Statistical Catch-at-Age methodology to data for the Gulf of Maine winter flounder resource.

Data and Methodology

The catch and survey based data (including catch-at-age information) and some biological data are listed in Tables in Appendix A, from Nitschke (2011).

The details of the SCAA assessment methodology are provided in Appendix B. The Beverton-Holt stock-recruitment steepness h is fixed at 0.9 for the analyses that follow. The contribution of all catch-at-age data to the negative log-likelihood is down-weighted by a multiplicative factor w^{CAA}.

Results and Discussion

Case 1: Base Case with w^{CAA}=0.1, M=0.2 and commercial selectivity-at-age flat for ages 5 and above. (Figs 1-5)
Particular reasons for this choice were to not have all selectivities domed, and especially the fact that unlike the GARM3 VPA assessment (Nitschke, 2008) there is virtually no retrospective pattern (Fig. 5). Note (Fig. 1) that the spawning biomass estimates are much greater than for that GARM3 VPA. The survey selectivities are domed (Fig. 3) and fit the CAA data well, but forcing the commercial selectivity to be flat leads to systematic overestimation of the commercial plus-group numbers by the model (Fig. 4).

Case 2: Split the commercial selectivity vector estimation between 1997 and 1998
This split makes very little difference to the results; hence no plts are shown.

Case 3: Force selectivity at age for the NEFSC surveys to be flat from age 5 and above (Fig. 6)
This leads to an appreciable deterioration to the for to the data: -lnL increases by 13. The primary reason for this deterioration is evident from the CAA residual plots in Fig. 6, which show a poor fit to the plus group proportions at age for the two NEFSC surveys.

Case 4: Fix natural mortality $M = 0.4$ (Fig. 7)
This leads to a 6 point improvement in the log-likelihood for the fit, with reduced residuals for the plus group for the commercial CAA data.

Case 5: Estimate a (constant) M bounded above by 0.6 (Fig. 8)
The estimated M hits the upper constraint of 0.6. There is a further improvement in the negative log-likelihood of 3 points, with the residuals for the plus group for the commercial CAA data reduced to near zero. Spawning biomass is however estimated to be lower in circumstances of an increased estimate for the pre-exploitation level.

Case 6: Force selectivities-at-age for all surveys to be flat above age 5 (Fig. 9)
This leads to further appreciable increases in –lnL, and further deterioration in the fits to the plus group proportions in the CAA for all data sets.

Case 7: Different weightings ($w^{survCAA}$) for the survey CAA data in the likelihood (Figs 10-12), where the reference alternative value for $w^{survCAA}$ is 0.3 (results in Table 1 are shown for this choice) in place of the 0.1 for the Base Case, but results for additional choices for $w^{survCAA}$ are shown in Fig. 11.
Results are qualitatively different for $w^{survCAA} = 0.3$, with substantial deterioration in the fits to trends in the survey abundance series (Fig. 10) and a bad retrospective pattern (Fig. 12). Fig 11 shows how as $w^{survCAA}$ is increased the fit moves closer to the VPA solution, but with a large jump between $w^{survCAA}$ values of 0.27 and 0.28 which is suggestive of a multi-modal likelihood and some conflict between the survey trend and CAA data.

Case 8: Allowance for doming in the commercial as well as the survey selectivity vectors (Fig. 13)
Unsurprisingly the negative log-likelihood improves, and the commercial plus group proportions for the CAA data are better fitted. The estimated magnitude of the spawning biomass increases markedly.

Concluding remarks

This does not pretend to be a comprehensive analysis, but some important points nevertheless seem reasonably established:

- Survey selectivity must be domed (though to a lesser extent as M might be set higher than 0.2).
- There is some conflict between the CAA data and the trends in the survey estimates, but if the former are given lower weight, their fit to the data does not appear visually to deteriorate substantially.
- Downweighting of the CAA data leads to higher estimated abundance, but also to the disappearance of the retrospective pattern that marks the VPA results.

References

Nitschke P. 2008. I. Gulf of Maine winter flounder. Appendix to the Report of the 3rd Groundfish Assessment Review Meeting (GARM III): Assessment of 19 Northeast Groundfish Stocks through 2007, Northeast Fisheries Science Center, Woods Hole, Massachusetts, August 4-8, 2008 http://www.nefsc.noaa.gov/publications/crd/crd0816/pdfs/garm3i.pdf

Nitschke P. 2011. Working paper (Nitschke, pers. comm)

Table 1: Results of SCAA for the Gulf of Maine winter flounder – see main text and Appendix B for specifications and definitions of some of the symbols used. Biomass units are '000t. Values input rather than estimated are shown in bold.

	1) Base Case (BC)	2) Case 2: as BC but two commercial selectivity periods	3) Case 3: as BC but NEFSC surveys selectivity flat from age 5	4) Case 4: as BC but M=0.4 throughout	5) Case 5: as BC but M estimated	6) Case 6: as BC but flat selectivity from age 5 for all surveys	7) Case 7: as Case 6 but weight of survey CAA likelihood is 0.3 instead of 0.1	8) as BC but commercial selectivity domed
'-lnL:overall	-123.2	-123.5	-110.1	-129.1	-132.3	-101.3	-156.9	-133.5
'-lnL:Survey	-72.4	-72.4	-71.6	-72.4	-72.7	-79.5	1.8	-72.8
'-lnL:CAA	8.0	7.4	7.2	2.3	-0.1	7.8	-1.6	-1.9
'-lnL:CAAsurv	-42.7	-42.8	-29.0	-42.4	-42.9	-14.4	-142.5	-42.6
'-lnL:RecRes	-17.2	-17.2	-17.4	-17.1	-17.0	-15.8	-14.9	-17.1
'-lnL:SelSmoothing	1.0	1.5	0.7	0.6	0.4	0.5	0.3	0.9
h	**0.90**	**0.90**	**0.90**	**0.90**	**0.90**	**0.90**	**0.90**	**0.90**
M	**0.20**	**0.20**	**0.20**	**0.40**	**0.60**	**0.20**	**0.20**	**0.20**
Theta	0.50	0.54	0.35	0.79	0.25	0.25	0.41	0.62
Phi	0.12	0.11	0.19	0.08	0.34	0.30	0.30	0.15
ρ_{SR}	-	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Ksp	37.97	37.90	38.98	20.35	55.94	41.00	23.09	53.06
B^{sp}_{2010}	15.88	15.98	15.78	11.39	10.33	16.46	4.73	23.53
B^{sp}_{2010}/K^{sp}	0.42	0.42	0.40	0.56	0.18	0.40	0.20	0.44
$B^{sp}_{2010}/B^{sp}_{1982}$	0.83	0.79	1.15	0.71	0.73	1.64	0.50	0.72
$MSYL^{sp}$	0.17	0.17	0.17	0.15	0.15	0.17	0.17	0.14
B^{sp}_{MSY}	6.33	6.43	6.56	3.10	8.42	6.93	3.94	7.18
MSY	1.89	1.97	1.98	2.59	7.24	2.09	1.21	2.37
σ_{comCAA}	0.21	0.21	0.21	0.17	0.15	0.21	0.14	0.14

	1) Base Case (BC)			2) Case 2			3) Case 3			4) Case 4			5) Case 5			6) Case 6			7) Case 7			8) as BC but commercial selectivity domed		
Survey	q x10[6]	σ_{surv}	σ_{CAA}	q x10[6]	σ_{surv}	σ_{CAA}	q x10[6]	σ_{surv}	σ_{CAA}	q x10[6]	σ_{surv}	σ_{CAA}	q x10[6]	σ_{surv}	σ_{CAA}	q x10[6]	σ_{surv}	σ_{CAA}	q x10[6]	σ_{surv}	σ_{CAA}	q x10[6]	σ_{surv}	σ_{CAA}
NEFSCspring	0.31	0.55	0.15	0.31	0.54	0.15	0.29	0.57	0.21	0.20	0.55	0.16	0.18	0.54	0.16	0.27	0.58	0.22	0.71	0.63	0.16	0.22	0.55	0.15
NEFSCfall	0.45	0.46	0.16	0.46	0.46	0.16	0.42	0.47	0.23	0.30	0.46	0.16	0.24	0.47	0.16	0.40	0.46	0.24	0.94	0.72	0.15	0.31	0.46	0.16
MADspring	4.08	0.25	0.14	4.07	0.25	0.14	4.04	0.25	0.14	1.98	0.25	0.13	1.29	0.25	0.13	3.62	0.28	0.20	7.59	0.55	0.12	2.83	0.26	0.14
MADfall	4.32	0.17	0.12	4.33	0.17	0.12	4.26	0.17	0.13	2.26	0.17	0.13	1.31	0.17	0.13	3.89	0.12	0.19	8.30	0.58	0.12	3.01	0.17	0.13
σ_{R_out}	0.27			0.27			0.24			0.29			0.30			0.29			0.33			0.29		

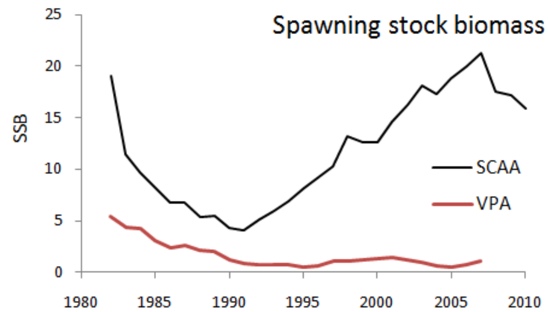

Fig. 1: Spawning stock biomass trajectories for the Base Case, compared to the GARM3 VPA (Nitschke, 2008).

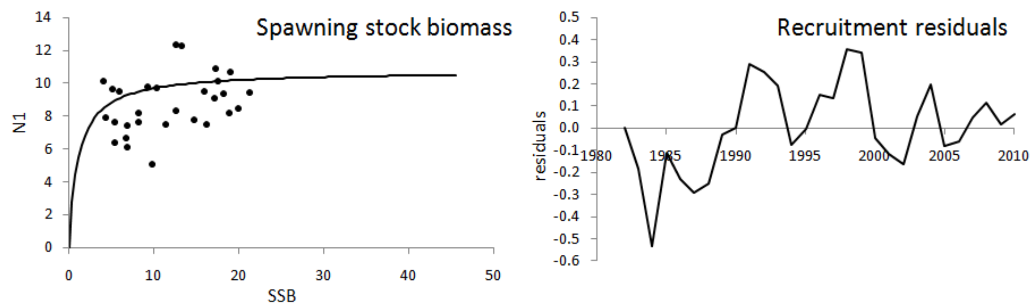

Fig. 2: Stock-recruit relationship and estimated stock-recruit residuals for the Base Case.

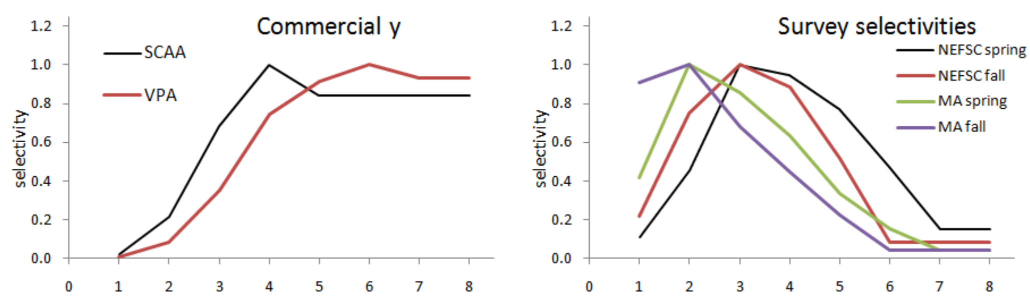

Fig. 3: Commercial and survey selectivities-at-age estimated for the Base Case.

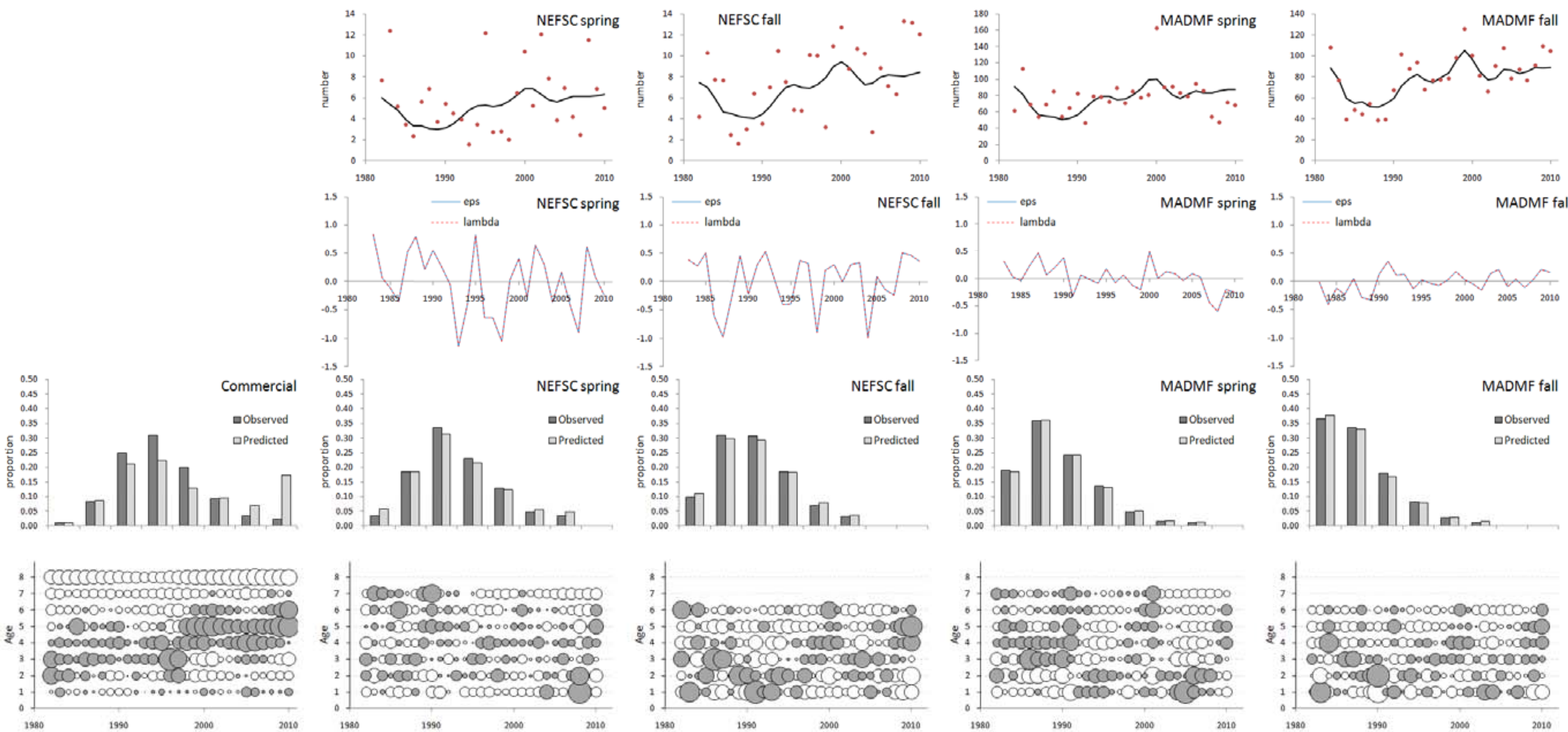

Fig. 4: The first two rows give the fit of the Base Case to the survey indices of abundance and corresponding survey standardised residuals. The third and fourth row plot the fit of the Base Case to the commercial and survey catch-at-age data. The third row compares the observed and predicted CAA as averaged over all years for which data are available, while the fourth row plots the standardised residuals, with the size (area) of the bubbles being proportional to the magnitude of the corresponding standardised residuals. For positive residuals, the bubbles are grey, whereas for negative residuals, the bubbles are white.

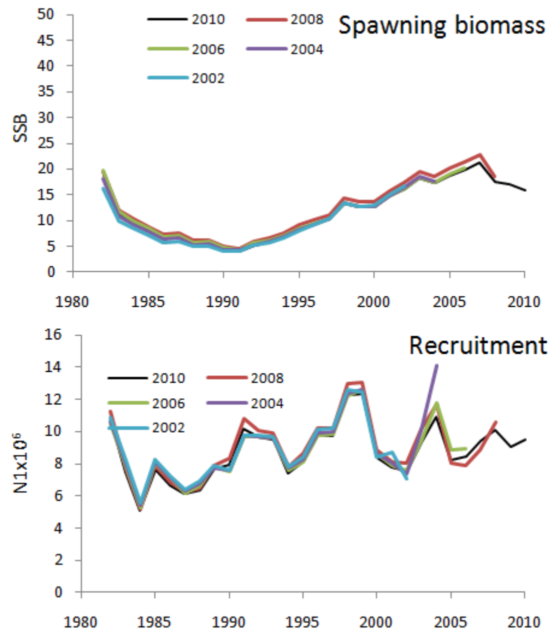

Fig. 5: Retrospective analysis of spawning biomass and recruitment for the Base Case.

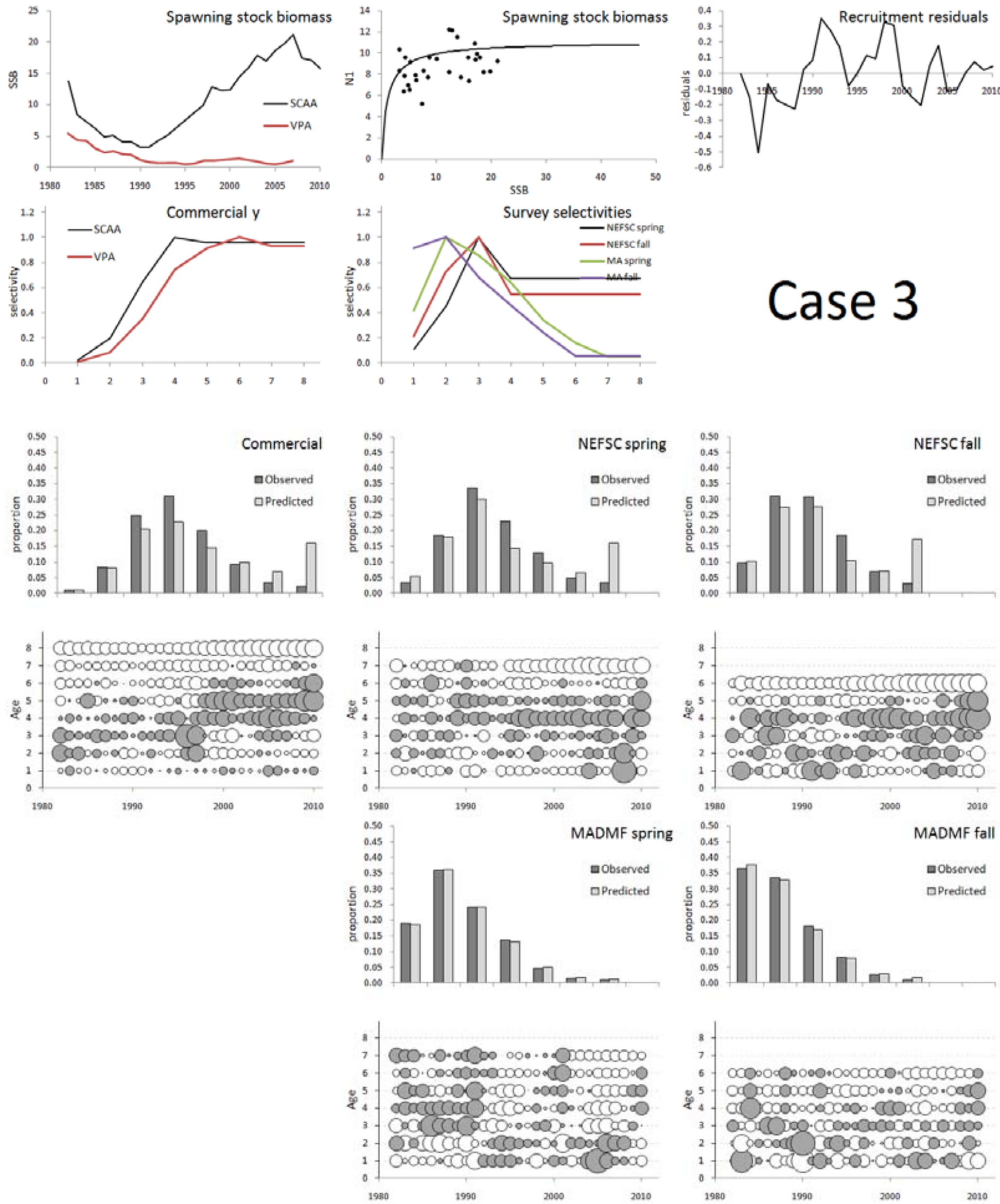

Fig. 6: Spawning stock biomass trajectories, stock-recruit relationship, recruitment residuals and selectivities for Case 3 (NEFSC survey selectivity flat). The fits to the commercial and survey CAA are also shown.

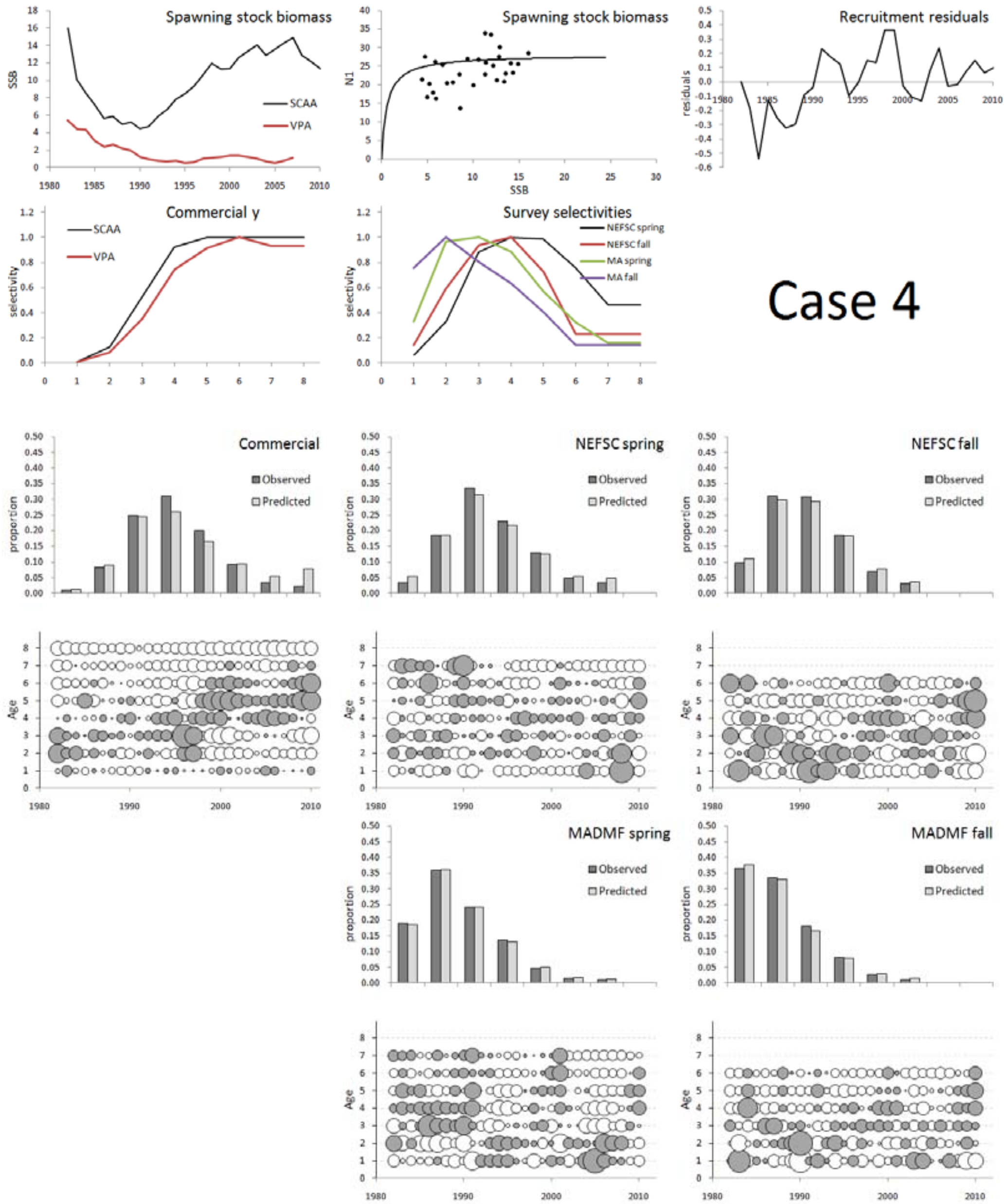

Fig. 7: Spawning stock biomass trajectories, stock-recruit relationship, recruitment residuals and selectivities for Case 4 (M = 0.4). The fits to the commercial and survey CAA are also shown.

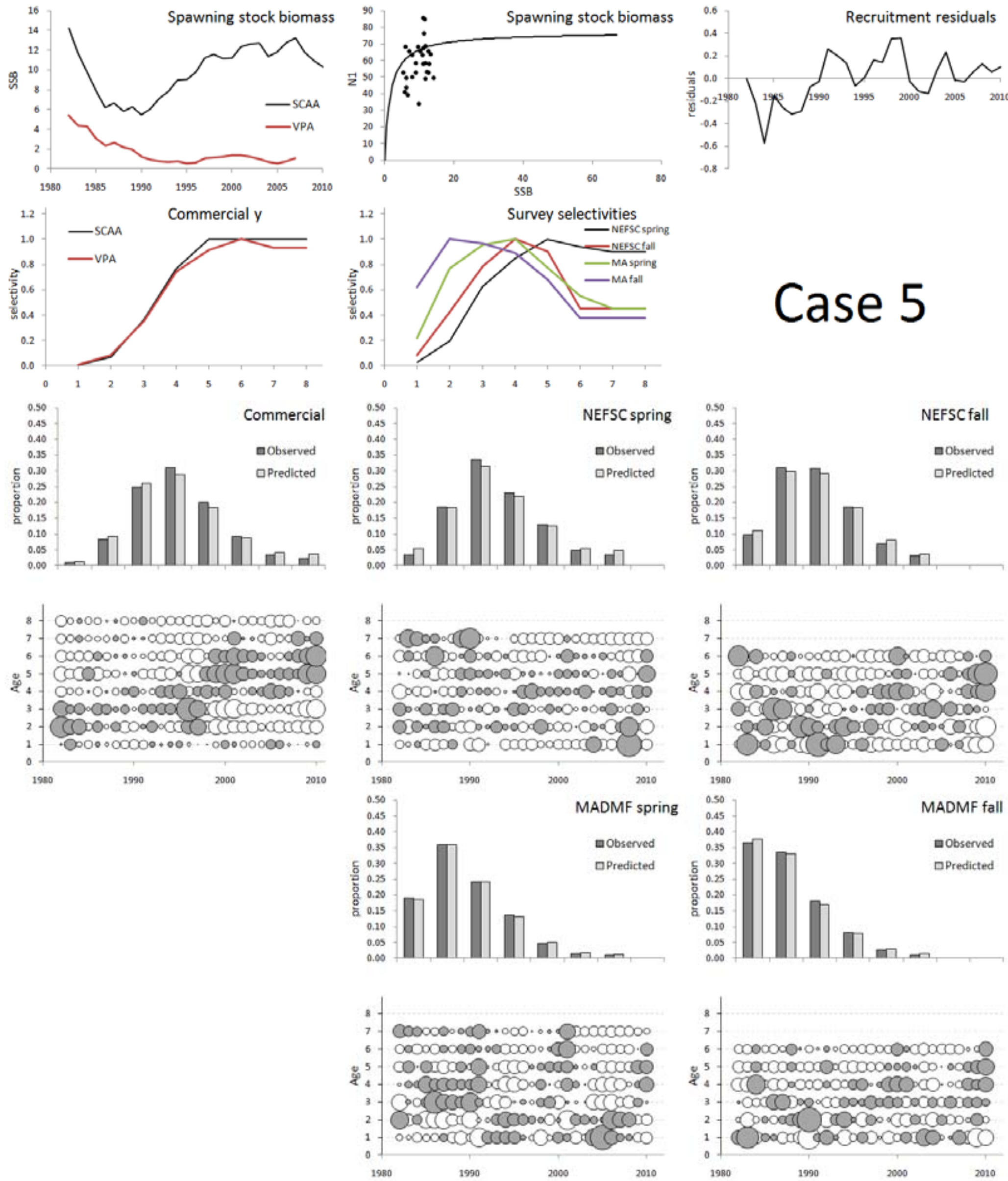

Fig. 8: Spawning stock biomass trajectories, stock-recruit relationship, recruitment residuals and selectivities for Case 5 (*M* estimated at 0.6). The fits to the commercial and survey CAA are also shown.

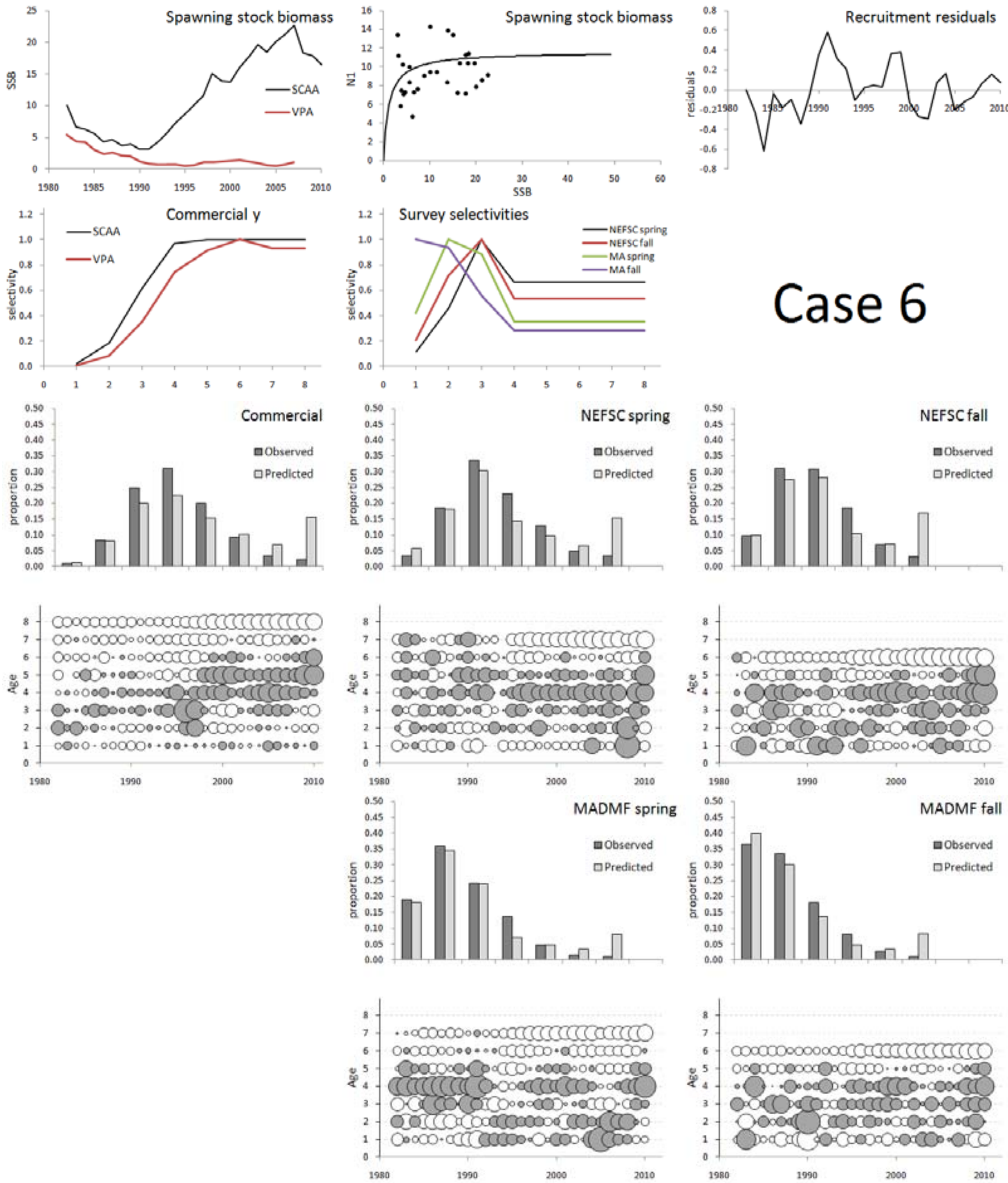

Fig. 9: Spawning stock biomass trajectories, stock-recruit relationship, recruitment residuals and selectivities for Case 6 (flat selectivities for all surveys). The fits to the commercial and survey CAA are also shown.

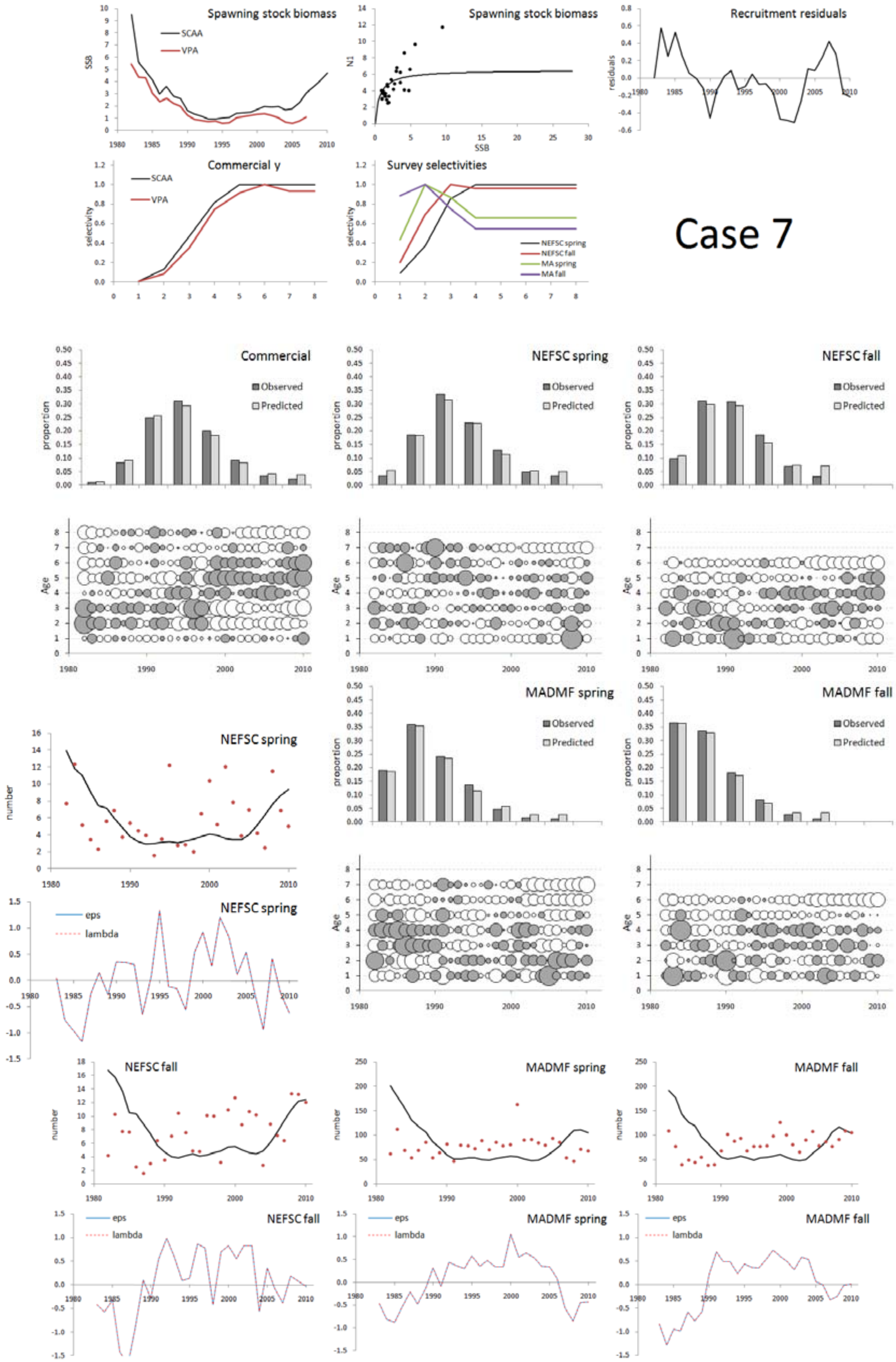

Fig. 10: Spawning stock biomass trajectories, stock-recruit relationship, recruitment residuals and selectivities for Case 7 (survey CAA data upweighted in the likelihood). The fits to the commercial and survey CAA and to the survey indices are also shown.

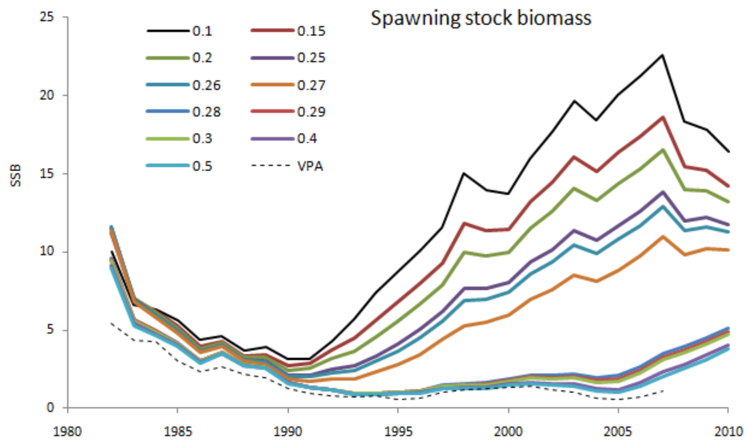

Fig. 11: Spawning stock biomass trajectories for Case 7 with different weightings (w^{CAA}) for the survey CAA data in the likelihood. The VPA results are also shown (Nitschke, 2008).

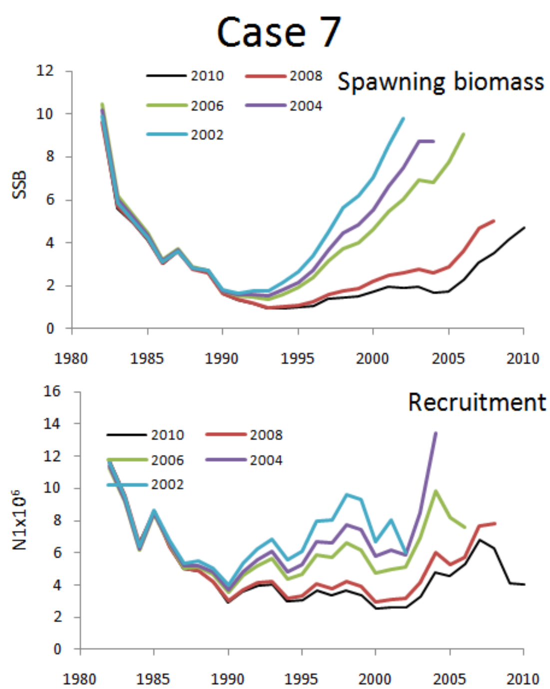

Fig. 12: Retrospective analysis of spawning biomass and recruitment for Case 7.

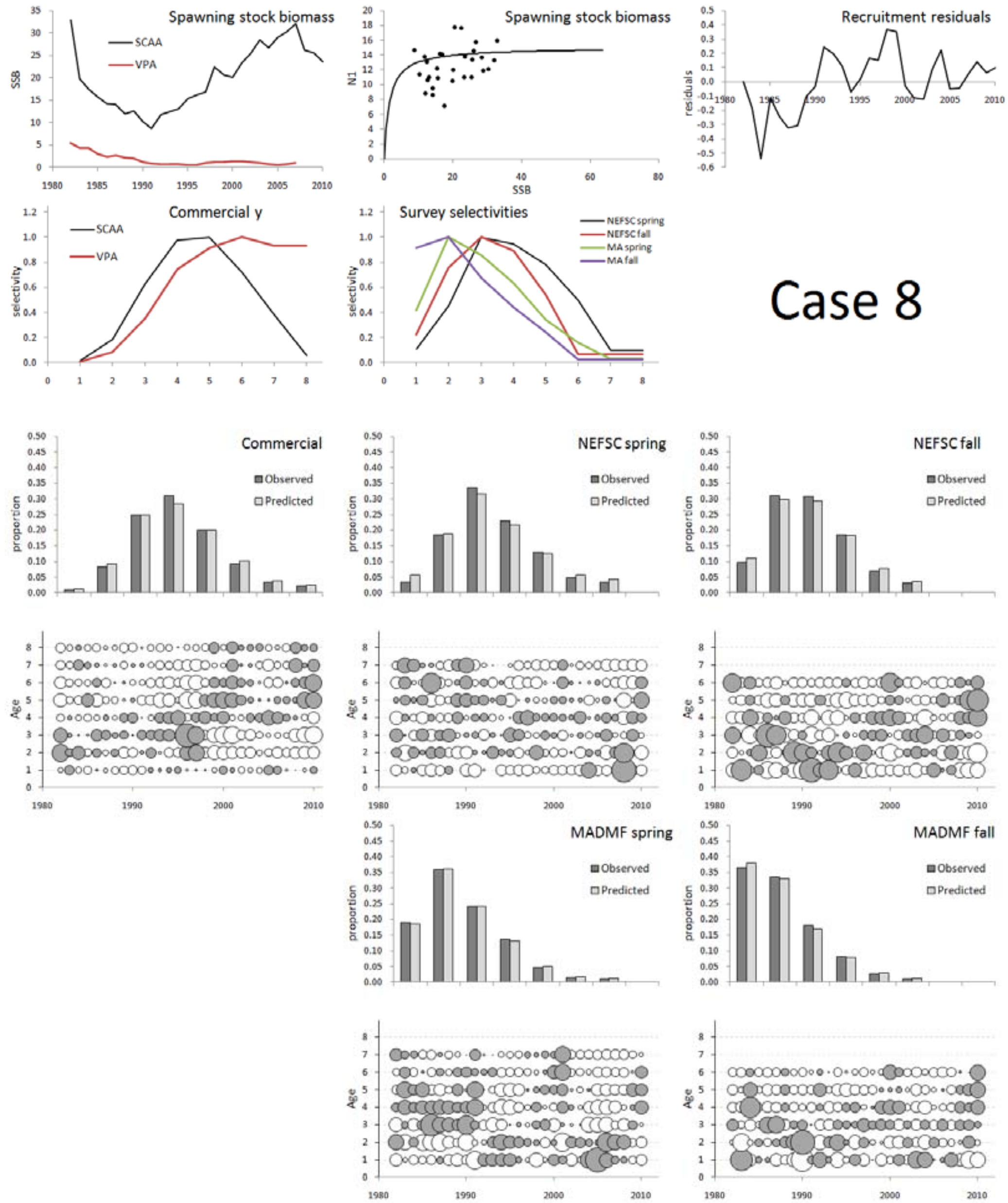

Fig. 13: Spawning stock biomass trajectories, stock-recruit relationship, recruitment residuals and selectivities for Case 8 (commercial selectivity domed). The fits to the commercial and survey CAA are also shown.

APPENDIX A – Data

Table A1: Total catch (metric tons) for Gulf of Maine winter flounder (Nitschke, 2011).

Year	Total catch (mt)	Year	Total catch (mt)
1982	6178	1997	660
1983	3035	1998	689
1984	2883	1999	399
1985	3327	2000	587
1986	1692	2001	756
1987	2713	2002	740
1988	1927	2003	801
1989	2315	2004	687
1990	1511	2005	387
1991	1136	2006	247
1992	947	2007	297
1993	778	2008	405
1994	640	2009	367
1995	776	2010	195
1996	674		

Table A2. Catch at age matrix (000s) for Gulf of Maine winter flounder (Nitschke, 2011).

	1	2	3	4	5	6	7	8+
1982	112	2883	5267	3487	1402	617	276	104
1983	135	915	1955	1838	857	362	158	133
1984	23	916	2077	1901	856	348	312	225
1985	31	288	1598	2122	1925	398	218	136
1986	49	505	928	851	373	353	102	62
1987	53	486	2004	1224	794	311	138	136
1988	23	471	1188	1177	361	248	123	89
1989	24	238	1353	1478	777	213	51	38
1990	9	263	836	1008	504	172	49	29
1991	18	304	864	610	234	119	57	41
1992	44	390	734	585	207	72	28	18
1993	28	197	758	669	149	69	9	3
1994	18	81	503	623	152	44	16	7
1995	27	70	335	765	392	122	18	18
1996	16	217	733	350	79	13	7	11
1997	19	286	592	449	117	22	8	12
1998	20	64	264	474	333	115	41	12
1999	7	13	79	240	227	103	29	28
2000	17	29	89	394	380	142	34	15
2001	13	21	84	384	432	242	101	56
2002	4	31	167	383	408	187	65	34
2003	9	41	168	390	419	247	78	46
2004	10	89	202	345	250	195	64	47
2005	15	54	165	259	139	55	17	16
2006	7	14	104	160	89	27	14	12
2007	5	23	93	193	135	57	16	9
2008	8	21	75	181	205	116	66	40
2009	6	22	54	146	219	144	41	26
2010	6	10	20	70	120	84	40	16

Table A3a. Total fishery mean weights-at-age (kg) for Gulf of Maine winter flounder (Nitschke, 2011).

	1	2	3	4	5	6	7	8+
1982	0.084	0.224	0.375	0.487	0.595	0.802	0.943	2.037
1983	0.123	0.257	0.358	0.502	0.644	0.795	0.946	1.164
1984	0.082	0.264	0.306	0.401	0.543	0.708	0.855	1.115
1985	0.043	0.174	0.312	0.447	0.584	0.809	0.927	1.122
1986	0.050	0.309	0.410	0.510	0.664	0.813	1.005	1.221
1987	0.035	0.259	0.392	0.527	0.690	0.858	1.070	1.284
1988	0.038	0.396	0.426	0.487	0.648	0.754	1.022	1.204
1989	0.040	0.229	0.427	0.582	0.629	1.004	1.175	1.397
1990	0.034	0.301	0.421	0.538	0.625	0.763	0.979	1.226
1991	0.038	0.277	0.451	0.583	0.599	0.695	0.744	0.929
1992	0.027	0.227	0.406	0.533	0.638	0.788	1.051	1.465
1993	0.028	0.238	0.367	0.439	0.645	0.667	1.115	1.453
1994	0.028	0.090	0.369	0.470	0.610	0.747	1.068	1.229
1995	0.038	0.105	0.341	0.421	0.535	0.635	0.833	1.563
1996	0.028	0.321	0.454	0.541	0.643	0.722	0.767	1.321
1997	0.038	0.240	0.421	0.512	0.628	0.889	0.784	0.921
1998	0.029	0.202	0.392	0.472	0.615	0.755	0.910	1.557
1999	0.039	0.114	0.377	0.487	0.542	0.665	0.838	1.219
2000	0.041	0.146	0.353	0.473	0.581	0.698	0.817	1.03
2001	0.034	0.115	0.319	0.448	0.538	0.693	0.852	1.194
2002	0.050	0.182	0.415	0.496	0.593	0.705	0.882	1.285
2003	0.035	0.156	0.366	0.482	0.560	0.704	0.889	1.436
2004	0.035	0.207	0.352	0.494	0.628	0.763	0.923	1.269
2005	0.042	0.172	0.380	0.505	0.669	0.895	1.038	1.346
2006	0.048	0.138	0.404	0.535	0.715	0.811	1.032	1.365
2007	0.043	0.200	0.386	0.487	0.639	0.815	0.964	1.476
2008	0.046	0.153	0.375	0.474	0.549	0.671	0.784	1.097
2009	0.043	0.155	0.329	0.449	0.565	0.678	0.692	1.115
2010	0.031	0.065	0.314	0.427	0.507	0.604	0.717	0.947

Table A3b. Spawning stock biomass mean weights-at-age (kg) for Gulf of Maine winter flounder (Nitschke, 2011).

	1	2	3	4	5	6	7	8+
1982	0.048	0.177	0.324	0.424	0.515	0.738	0.870	2.037
1983	0.084	0.147	0.283	0.434	0.560	0.688	0.871	1.164
1984	0.056	0.180	0.280	0.379	0.522	0.675	0.825	1.115
1985	0.016	0.119	0.287	0.370	0.484	0.663	0.810	1.122
1986	0.022	0.115	0.267	0.399	0.545	0.689	0.902	1.221
1987	0.010	0.114	0.348	0.465	0.593	0.755	0.933	1.284
1988	0.016	0.118	0.332	0.437	0.584	0.721	0.936	1.204
1989	0.015	0.093	0.411	0.498	0.554	0.807	0.941	1.397
1990	0.012	0.110	0.311	0.479	0.603	0.693	0.991	1.226
1991	0.016	0.097	0.368	0.495	0.568	0.659	0.753	0.929
1992	0.009	0.093	0.335	0.490	0.610	0.687	0.855	1.465
1993	0.016	0.080	0.289	0.422	0.586	0.652	0.937	1.453
1994	0.015	0.050	0.296	0.415	0.518	0.694	0.844	1.229
1995	0.013	0.054	0.175	0.394	0.501	0.622	0.789	1.563
1996	0.010	0.110	0.218	0.430	0.520	0.622	0.698	1.321
1997	0.017	0.082	0.368	0.482	0.583	0.756	0.752	0.921
1998	0.015	0.088	0.307	0.446	0.561	0.689	0.899	1.557
1999	0.020	0.058	0.276	0.437	0.506	0.640	0.795	1.219
2000	0.025	0.076	0.201	0.422	0.532	0.615	0.737	1.03
2001	0.015	0.069	0.216	0.398	0.505	0.635	0.771	1.194
2002	0.028	0.079	0.219	0.398	0.515	0.616	0.782	1.285
2003	0.014	0.088	0.258	0.447	0.527	0.646	0.792	1.436
2004	0.016	0.085	0.234	0.425	0.550	0.654	0.806	1.269
2005	0.023	0.078	0.281	0.422	0.575	0.750	0.890	1.346
2006	0.024	0.076	0.264	0.451	0.601	0.737	0.961	1.365
2007	0.023	0.098	0.231	0.444	0.585	0.763	0.884	1.476
2008	0.025	0.081	0.274	0.428	0.517	0.655	0.799	1.097
2009	0.035	0.084	0.224	0.410	0.518	0.610	0.681	1.115
2010	0.018	0.053	0.223	0.369	0.477	0.588	0.700	0.969

Table A3c. January-1 mean weights-at-age (kg) for Gulf of Maine winter flounder (Nitschke, 2011).

	1	2	3	4	5	6	7	8+
1982	0.048	0.177	0.324	0.424	0.515	0.738	0.870	2.037
1983	0.084	0.147	0.283	0.434	0.560	0.688	0.871	1.164
1984	0.056	0.180	0.280	0.379	0.522	0.675	0.825	1.115
1985	0.016	0.119	0.287	0.370	0.484	0.663	0.810	1.122
1986	0.022	0.115	0.267	0.399	0.545	0.689	0.902	1.221
1987	0.010	0.114	0.348	0.465	0.593	0.755	0.933	1.284
1988	0.016	0.118	0.332	0.437	0.584	0.721	0.936	1.204
1989	0.015	0.093	0.411	0.498	0.554	0.807	0.941	1.397
1990	0.012	0.110	0.311	0.479	0.603	0.693	0.991	1.226
1991	0.016	0.097	0.368	0.495	0.568	0.659	0.753	0.929
1992	0.009	0.093	0.335	0.490	0.610	0.687	0.855	1.465
1993	0.016	0.080	0.289	0.422	0.586	0.652	0.937	1.453
1994	0.015	0.050	0.296	0.415	0.518	0.694	0.844	1.229
1995	0.013	0.054	0.175	0.394	0.501	0.622	0.789	1.563
1996	0.010	0.110	0.218	0.430	0.520	0.622	0.698	1.321
1997	0.017	0.082	0.368	0.482	0.583	0.756	0.752	0.921
1998	0.015	0.088	0.307	0.446	0.561	0.689	0.899	1.557
1999	0.020	0.058	0.276	0.437	0.506	0.640	0.795	1.219
2000	0.025	0.076	0.201	0.422	0.532	0.615	0.737	1.03
2001	0.015	0.069	0.216	0.398	0.505	0.635	0.771	1.194
2002	0.028	0.079	0.219	0.398	0.515	0.616	0.782	1.285
2003	0.014	0.088	0.258	0.447	0.527	0.646	0.792	1.436
2004	0.016	0.085	0.234	0.425	0.550	0.654	0.806	1.269
2005	0.023	0.078	0.281	0.422	0.575	0.750	0.890	1.346
2006	0.024	0.076	0.264	0.451	0.601	0.737	0.961	1.365
2007	0.023	0.098	0.231	0.444	0.585	0.763	0.884	1.476
2008	0.025	0.081	0.274	0.428	0.517	0.655	0.799	1.097
2009	0.035	0.084	0.224	0.410	0.518	0.610	0.681	1.115
2010	0.018	0.053	0.223	0.369	0.477	0.588	0.700	0.969

Table A4: Proportion mature-at-age for Gulf of Maine winter flounder (Nitschke, 2011).

1	2	3	4	5	6	7	8+
0.00	0.04	0.35	0.88	0.99	1.00	1.00	1.00

Table A5: Survey data for Gulf of Maine winter flounder (Nitschke, 2011).

	NEFSC spring	NEFSC fall	MADMF spring	MADMF fall
Month	4	10	5	5
Ages	1-8+	1-8+	1-8+	1-8+
1982	7.67	4.201	61.61	108.20
1983	12.367	10.304	112.49	76.66
1984	5.155	7.732	68.95	39.54
1985	3.469	7.638	54.21	48.68
1986	2.342	2.502	68.98	44.65
1987	5.609	1.605	85.18	54.43
1988	6.897	3	54.04	38.42
1989	3.717	6.402	64.70	39.25
1990	5.415	3.527	82.13	67.66
1991	4.517	7.035	46.63	101.72
1992	3.932	10.447	79.00	87.58
1993	1.556	7.559	78.02	93.53
1994	3.481	4.87	72.58	67.79
1995	12.185	4.765	89.36	76.74
1996	2.736	10.099	70.49	77.01
1997	2.806	10.008	85.40	78.40
1998	2.001	3.218	77.77	98.45
1999	6.51	10.921	80.78	125.74
2000	10.383	12.705	162.19	99.95
2001	5.242	8.786	89.74	81.07
2002	12.066	10.691	91.08	65.81
2003	7.839	10.182	83.69	90.48
2004	3.879	2.763	79.12	107.59
2005	6.92	8.807	94.04	78.59
2006	4.173	7.117	85.55	86.99
2007	2.5	6.378	53.58	76.67
2008	11.543	13.319	46.86	90.92
2009	6.846	13.176	71.32	109.00
2010	5.023	12.046	68.24	104.67

Table A6a: NEFSC spring survey catch-at-age data for Gulf of Maine winter flounder (Nitschke, 2011).

	1	2	3	4	5	6	7	8+
1982	92.06	1075.75	1900.83	474.97	570.39	62.23	0.00	116.13
1983	229.12	401.15	2462.32	1546.13	918.71	560.03	654.61	149.20
1984	117.19	640.90	901.25	554.72	315.92	92.45	154.91	107.51
1985	3.36	289.22	823.35	330.86	329.13	49.86	86.58	28.77
1986	17.96	433.05	217.59	308.31	54.06	202.14	59.71	18.13
1987	81.71	891.46	1480.03	368.52	187.09	32.68	66.93	30.61
1988	332.32	610.85	1895.85	706.61	190.39	82.21	29.61	12.03
1989	0.00	260.85	636.15	586.17	366.68	64.58	96.26	69.40
1990	12.82	448.05	1042.22	522.76	487.56	235.44	4.20	277.58
1991	34.70	619.24	985.48	540.22	285.31	54.34	8.62	0.00
1992	153.40	577.22	533.12	529.81	270.53	96.15	34.81	5.71
1993	0.00	250.89	345.92	148.98	98.55	9.51	17.18	0.00
1994	13.49	403.22	645.77	470.88	310.94	103.70	0.00	0.00
1995	161.96	1226.23	3090.63	1658.95	493.72	49.30	138.51	0.00
1996	39.12	180.65	538.43	509.44	240.20	14.83	8.28	0.00
1997	28.93	284.63	413.07	499.20	249.38	59.71	18.08	17.18
1998	58.31	328.96	335.67	269.41	118.20	5.32	0.00	3.97
1999	172.59	654.05	1276.04	940.03	398.47	183.79	18.13	0.00
2000	85.68	859.33	2136.77	1399.95	900.91	330.30	65.87	32.12
2001	39.40	289.84	787.19	833.64	462.88	333.04	121.50	66.15
2002	89.04	914.29	1670.48	1999.27	1280.52	513.98	188.71	96.54
2003	65.42	356.38	1203.79	1294.40	895.20	430.20	77.06	64.47
2004	299.30	466.35	494.33	414.36	186.42	209.70	100.51	0.00
2005	64.08	866.55	1278.73	789.99	438.54	288.94	102.41	43.15
2006	35.37	126.48	1065.67	664.02	332.99	85.01	25.86	0.00
2007	70.18	287.04	349.44	418.44	217.81	38.73	17.52	0.00
2008	1524.69	2335.33	1503.76	654.45	358.68	73.93	9.29	0.00
2009	33.63	618.24	1489.88	1100.43	474.02	69.00	41.86	4.20
2010	20.32	158.60	819.32	752.16	685.34	316.42	39.51	19.59

Table A6b: NEFSC fall survey catch-at-age data for Gulf of Maine winter flounder (Nitschke, 2011).

	1	2	3	4	5	6	7	8+
1982	166.83	636.37	971.76	230.63	117.64	46.56	153.90	27.09
1983	1198.31	2012.87	1743.29	564.01	151.83	59.60	36.66	0.00
1984	250.50	1310.80	935.83	1216.16	332.60	124.30	61.90	95.31
1985	728.04	1533.42	1075.86	641.74	182.78	52.33	60.50	0.00
1986	16.85	403.67	645.88	272.60	30.61	11.42	0.00	18.92
1987	43.43	255.37	474.91	106.11	10.63	0.00	0.00	7.84
1988	237.79	572.96	338.53	394.66	85.91	30.89	18.13	0.00
1989	259.11	2015.33	792.01	419.62	52.66	37.72	0.00	6.27
1990	53.22	1039.03	610.79	221.90	30.61	12.03	6.04	0.00
1991	1452.33	1585.02	607.55	215.52	17.01	26.19	16.68	0.00
1992	1073.90	2072.97	1341.52	913.06	424.66	8.28	12.09	0.00
1993	927.61	1765.90	1015.75	385.09	130.45	5.65	0.00	0.00
1994	208.97	1288.30	846.18	354.03	22.05	5.65	0.00	0.00
1995	200.97	865.54	869.63	563.11	81.60	86.02	0.00	0.00
1996	987.88	1328.70	1440.52	1472.48	334.78	80.81	0.00	0.00
1997	231.19	2418.72	1787.72	823.63	320.68	18.80	0.00	0.00
1998	124.41	498.25	630.83	436.13	77.96	33.24	0.00	0.00
1999	453.37	1552.06	2040.57	1595.32	381.06	81.32	8.00	0.00
2000	349.16	1134.00	2238.63	1980.58	780.70	535.30	91.73	0.00
2001	200.58	927.38	1451.49	1564.59	539.55	203.93	23.73	5.93
2002	374.90	1535.49	1921.20	1317.96	698.88	109.52	11.70	13.32
2003	310.55	1779.16	1912.69	1004.00	562.33	111.15	18.24	0.00
2004	162.91	510.73	596.58	107.28	93.68	16.68	36.82	21.71
2005	699.89	1714.19	1313.43	751.88	327.61	54.51	30.67	36.49
2006	361.92	589.64	1718.72	758.82	490.53	22.22	41.25	0.00
2007	434.28	1174.69	760.78	774.43	315.69	109.30	0.00	0.00
2008	257.83	1391.66	2267.90	1873.80	1145.37	485.99	0.00	31.56
2009	80.31	1558.66	2246.74	1757.39	1320.20	382.96	20.99	6.16
2010	21.77	576.66	1908.49	2241.48	1448.19	307.47	190.11	46.84

Table A6c: Massachusetts spring survey catch-at-age data for Gulf of Maine winter flounder (Nitschke, 2011).

	1	2	3	4	5	6	7	8+
1982	1658.16	6361.20	1836.79	1947.30	419.94	111.03	354.05	14.45
1983	3175.87	6278.94	6590.91	4132.55	1984.33	537.40	211.29	270.09
1984	1309.41	5596.43	3427.98	2620.57	907.69	55.09	216.20	82.31
1985	2136.45	1672.36	3405.67	2706.69	1008.58	146.04	49.75	23.13
1986	2295.95	3780.69	5293.35	2403.82	349.06	43.77	16.58	39.63
1987	3593.98	3635.32	7003.94	2556.53	169.83	334.75	85.54	182.30
1988	1650.94	3169.97	3910.95	2118.61	170.88	56.20	13.38	45.67
1989	2065.50	4331.80	3825.33	2021.71	823.53	166.82	28.18	75.85
1990	3265.41	4208.90	6244.24	2282.77	471.16	312.09	108.94	38.78
1991	984.48	3502.56	2550.99	1649.27	683.00	110.68	53.05	103.32
1992	4447.96	6709.79	2828.85	1562.76	476.95	173.95	39.07	48.72
1993	4039.88	7104.62	2796.09	1358.03	435.10	264.34	49.42	38.14
1994	3310.73	7781.04	3075.77	1000.02	169.00	26.08	36.60	21.32
1995	4474.23	7433.04	4751.29	1288.26	294.75	117.69	32.78	32.10
1996	3212.26	5900.09	3246.03	1531.28	419.30	165.27	42.62	17.48
1997	3199.00	7320.28	3758.75	1838.01	1030.33	220.03	134.86	105.44
1998	2106.16	5871.00	4368.13	2399.67	833.70	248.73	169.48	37.69
1999	3181.83	5455.98	4427.92	2024.19	1045.28	268.24	134.22	116.41
2000	5997.82	13694.80	6182.92	3527.20	2279.87	1248.05	381.06	128.22
2001	3038.06	2156.92	5664.30	4172.67	1605.77	1067.98	528.95	268.38
2002	1891.06	6962.83	4197.19	3884.95	1482.33	263.39	94.94	2.54
2003	3172.08	6338.79	3738.01	2264.07	1262.44	353.59	108.26	18.25
2004	5569.03	6461.18	1671.73	1208.82	911.14	381.53	70.33	37.83
2005	7223.85	8227.77	2691.42	870.50	305.58	57.54	7.07	5.98
2006	4302.98	8758.47	2948.09	1189.54	331.10	70.95	26.99	10.00
2007	2302.69	4893.18	2081.50	1254.46	398.77	94.72	13.44	8.78
2008	2072.08	4453.26	1452.02	1133.50	417.03	93.32	27.65	13.15
2009	2115.48	4797.99	3989.67	1995.28	1290.75	364.95	103.95	45.75
2010	1832.75	3890.83	3509.46	2881.02	1191.91	539.98	194.14	28.37

Table A6d: Massachusetts fall survey catch-at-age data for Gulf of Maine winter flounder (Nitschke, 2011).

	1	2	3	4	5	6	7	8+
1982	9419.66	7334.77	4407.41	810.44	147.11	46.47	20.97	20.49
1983	8909.33	3589.56	2474.79	572.97	229.08	14.04	1.57	13.73
1984	1715.39	2715.77	1434.21	1640.61	449.45	121.07	53.19	8.84
1985	4897.43	2810.59	1411.26	638.41	160.34	38.18	18.47	8.58
1986	3738.84	3230.42	1830.09	319.49	43.50	0.00	0.00	21.28
1987	3325.39	4315.82	3177.09	249.97	9.26	15.26	23.15	24.37
1988	2789.74	3194.71	935.84	672.78	185.46	99.42	34.14	0.00
1989	2794.61	3609.79	1286.50	292.09	65.44	22.56	10.62	10.62
1990	1801.47	9234.03	2325.97	532.45	48.99	0.00	0.00	7.15
1991	10419.18	6327.18	2900.09	604.12	8.99	70.76	26.93	0.00
1992	9367.51	4532.62	1891.98	1295.20	675.75	67.61	21.44	57.21
1993	7523.20	7769.60	2747.19	747.78	331.78	65.28	21.44	21.46
1994	2918.62	6752.77	3179.56	1042.23	47.30	0.00	5.38	5.46
1995	5419.59	4880.19	3341.76	1844.44	133.38	76.55	10.93	34.33
1996	7524.31	3352.89	2575.63	1884.97	265.84	92.20	4.78	4.78
1997	4814.83	6418.38	3467.90	1051.98	317.18	14.93	0.00	0.00
1998	8603.17	5826.52	3839.39	1490.50	272.57	155.48	15.22	20.72
1999	7886.42	8744.32	4914.05	3132.82	783.29	126.35	15.71	26.70
2000	5374.73	5949.39	4929.16	2799.49	787.06	559.15	132.26	0.00
2001	6126.97	3548.97	2918.46	2868.44	787.16	327.31	37.26	22.14
2002	3776.65	4675.99	2613.62	1531.07	686.63	93.81	16.02	15.98
2003	10176.70	4439.24	2015.05	979.79	458.87	61.36	25.65	0.00
2004	11968.46	4887.41	3668.01	544.31	411.16	145.38	127.40	16.35
2005	5186.41	7090.88	2258.30	1090.90	435.57	40.02	31.92	38.62
2006	6248.84	4626.76	4821.72	1472.35	616.90	11.46	39.26	9.48
2007	7590.02	4281.27	1958.21	1358.60	422.81	107.75	14.14	2.76
2008	5706.92	5761.15	3592.51	2148.16	1096.47	307.90	0.00	35.38
2009	4210.96	9523.65	4708.05	2278.75	1288.61	365.94	16.37	34.91
2010	4923.51	6220.98	4294.42	3028.39	1596.86	618.12	341.24	66.76

Appendix B - The Age-Structured Production Model

The model used for these assessments is an Age-Structured Production Model (ASPM) (e.g. Hilborn, 1990). Models of this type fall within the more general class of Statistical Catch-at-Age Analyses. The approach used in an ASPM assessment involves constructing an age-structured model of the population dynamics and fitting it to the available abundance indices by maximising the likelihood function. The model equations and the general specifications of the model are described below, followed by details of the contributions to the (penalised) log-likelihood function from the different sources of data available and assumptions concerning the stock-recruitment relationship. Quasi-Newton minimization is used to minimize the total negative log-likelihood function (the package AD Model Builder™, Otter Research, Ltd is used for this purpose).

B.1. Population dynamics

B.1.1 Numbers-at-age

The resource dynamics are modelled by the following set of population dynamics equations:

$$N_{y+1,1} = R_{y+1} \tag{B1}$$

$$N_{y+1,a+1} = \left(N_{y,a}\, e^{-M_{y,a}/2} - C_{y,a}\right) e^{-M_{y,a}/2} \qquad \text{for } 1 \le a \le m-2 \tag{B2}$$

$$N_{y+1,m} = \left(N_{y,m-1}\, e^{-M_{y,m-1}/2} - C_{y,m-1}\right) e^{-M_{y,m-1}/2} + \left(N_{y,m}\, e^{-M_{y,m}/2} - C_{y,m}\right) e^{-M_{y,m}/2} \tag{B3}$$

where

$N_{y,a}$ is the number of fish of age *a* at the start of year *y* (which refers to a calendar year),

R_y is the recruitment (number of 1-year-old fish) at the start of year *y*,

$M_{y,a}$ denotes the natural mortality rate for fish of age *a* in year *y*,

$C_{y,a}$ is the predicted number of fish of age *a* caught in year *y*, and

m is the maximum age considered (age 8 here) (taken to be a plus-group).

B.1.2. Recruitment

The number of recruits at the start of year *y* is assumed to follow a Beverton-Holt stock-recruit curve, and allowing for annual fluctuation about the deterministic relationship:

$$R_y = \frac{\alpha B_y^{sp}}{\beta + B_y^{sp}} e^{(\varsigma_y - (\sigma_R^1)^2/2)} \tag{B4}$$

where

α and β are spawning biomass-recruitment relationship parameters,

ς_y reflects fluctuation about the expected recruitment for year *y*, which is assumed to be normally distributed with standard deviation $\sigma_R = 0.5$

B_y^{sp} is the spawning biomass, computed as:

$$B_y^{sp} = \sum_{a=1}^{m} f_{y,a} w_{y,a}^{strt} N_{y,a} e^{-M_{y,a}\delta} \tag{B5}$$

where

$w_{y,a}^{sp}$ is the mass of fish of age *a* during spawning, and

$f_{y,a}$ is the proportion of fish of age *a* that are mature,

δ is the proportion of the natural mortality that occurs before spawning (0.25 here).

B.1.3. Total catch and catches-at-age

The catch by mass in year *y* is given by:

$$C_y = \sum_{a=1}^{m} w_{y,a}^{mid}\ C_{y,a} = \sum_{a=1}^{m} w_{y,a}^{mid}\ N_{y,a}\ e^{-M_{y,a}/2}\ S_{y,a}\ F_y \tag{B6}$$

where

$w_{y,a}^{mid}$ denotes the mass of fish of age *a* landed in year *y*,

$C_{y,a}$ is the catch-at-age, i.e. the number of fish of age *a*, caught in year *y*,

$S_{y,a}$ is the commercial selectivity (i.e. combination of availability and vulnerability to fishing gear) at age *a* for year *y*; when $S_{y,a}$ = 1, the age-class *a* is said to be fully selected, and

F_y is the proportion of a fully selected age class that is fished.

The model estimate of the mid-year exploitable ("available") component of biomass is calculated by converting the numbers-at-age into mid-year mass-at-age (using the individual weights of the landed fish) and applying natural and fishing mortality for half the year:

$$B_y^{ex} = \sum_{a=1}^{m} w_{y,a}^{mid} S_{y,a} N_{y,a} e^{-M_{y,a}/2} (1 - S_{y,a} F_y\ /2) \tag{B7}$$

For survey estimates (in numbers):

$$N_y^{surv,i} = \sum_{a=1}^{m} S_a^i N_{y,a} e^{-M_{y,a}\frac{\varpi^1}{12}} \left(1 - S_{y,a} F_y\ \frac{\varpi^1}{12}\right) \tag{B8}$$

where

S_a^i is the survey selectivity for age *a* and survey *i*,

ϖ^i is the month in which survey *i* has taken place.

B.1.4. Initial conditions

For the first year (y_0) considered in the model therefore, the stock is assumed to be at a level $B_{y_0}^{sp}$ (estimated in the model fitting procedure), with the starting age structure:

$$N_{y_0,a} = R_{start} N_{start,a} \qquad \text{for } 1 \le a \le m \qquad \text{(B9)}$$

where

$$N_{start,1} = 1 \qquad \text{(B10)}$$

$$N_{start,a} = N_{start,a-1} e^{-M_{y_0,a-1}} (1 - \phi S_{y_0,a-1}) \qquad \text{for } 2 \le a \le m-1 \qquad \text{(B11)}$$

$$N_{start,m} = N_{start,m-1} e^{-M_{y_0,m-1}} (1 - \phi S_{y_0,m-1}) \Big/ (1 - e^{-M_{y_0,m}} (1 - \phi S_{y_0,m})) \qquad \text{(B12)}$$

where ϕ characterises the average fishing proportion over the years immediately preceding y_0.

B.2. The (penalised) likelihood function

The model is fit to survey abundance indices, and commercial and survey catch-at-age data to estimate model parameters (which may include residuals about the stock-recruitment function, the fishing selectivities, the annual catches or natural mortality, facilitated through the incorporation of the penalty functions described below). Contributions by each of these to the negative of the (penalised) log-likelihood (- $\ell\text{n}L$) are as follows.

B.2.1. Survey abundance data

The likelihood is calculated assuming that an observed survey index is log-normally distributed about its expected value:

$$I_y^i = \hat{I}_y^i \exp\left(\varepsilon_y^i\right) \quad \text{or} \quad \varepsilon_y^i = \ell\text{n}\left(I_y^i\right) - \ell\text{n}\left(\hat{I}_y^i\right) \qquad \text{(B13)}$$

where

I_y^i is the survey index for year *y* and series *i*,

$\hat{I}_y^i = \hat{q}^i N_y^{surv,i}$ is the corresponding model estimate, where $N_y^{surv,i}$ is the model estimate, given by equation (B8),

$\hat{q}^i$ is the constant of proportionality (catchability) for index *i*, and

ε_y^i from $N\left(0, \left(\sigma_y^i\right)^2\right)$.

For these analyses, selectivities are estimated as detailed in section B.3.1 below.

The contribution of the survey abundance data to the negative of the log-likelihood function (after removal of constants) is then given by:

$$-\ell\text{n}\, L^{survey} = \sum_i \sum_y \left[\ell\text{n}\left(\sigma_y^i\right) + \left(\varepsilon_y^i\right)^2 / 2\left(\sigma_y^i\right)^2\right] \quad \text{(B14)}$$

where

σ_y^i is the standard deviation of the residuals for the logarithm of index *i* in year *y*.

Homoscedasticity of residuals is assumed, so that $\sigma_y^i = \sigma^i$ is estimated in the fitting procedure by its maximum likelihood value:

$$\hat{\sigma}^i = \sqrt{1/n_i \sum_y \left(\ell\text{n}(I_y^i) - \ell\text{n}(q^i N_y^{surv,i})\right)^2} \quad \text{(B15)}$$

where

n_i is the number of data points for survey index *i*.

The catchability coefficient q^i for survey index *i* is estimated by its maximum likelihood value:

$$\ell n\, \hat{q}^i = 1/n_i \sum_y \left(\ln I_y^i - \ln N_y^{surv,i}\right) \quad \text{(B16)}$$

To allow for first order serial correlation between the survey residuals, a serial correlation coefficient ρ^i would be estimated for each survey index:

$$\varepsilon_y^i = \lambda_y^i - \rho \lambda_{y-1}^i \quad \text{(B17)}$$

where

$$\lambda_y^i = \ell\text{n}\left(I_y^i\right) - \ell\text{n}\left(\hat{I}_y^i\right)$$

and the summation in equation (B.16) extends over one less year.

B.2.2. Commercial catches-at-age

The contribution of the catch-at-age data to the negative of the log-likelihood function under the assumption of an "adjusted" lognormal error distribution is given by:

$$-\ell\text{n}\, L^{CAA} = w^{CAA} \sum_y \sum_a \left[\ell n\left(\sigma_{com} / \sqrt{p_{y,a}}\right) + p_{y,a}\left(\ell n\, p_{y,a} - \ell n\, \hat{p}_{y,a}\right)^2 / 2\left(\sigma_{com}\right)^2\right]$$

(B18)

where

w^{comCAA} is a multiplicative factor to downweight the commercial CAA likelihood,

$p_{y,a} = C_{y,a} / \sum_{a'} C_{y,a'}$ is the observed proportion of fish caught in year *y* that are of age *a*,

$\hat{p}_{y,a} = \hat{C}_{y,a} / \sum_{a'} \hat{C}_{y,a'}$ is the model-predicted proportion of fish caught in year *y* that are of age *a*, where

$$\hat{C}_{y,a} = N_{y,a}\, e^{-M_{y,a}/2}\, S_{y,a}\, F_y \tag{B19}$$

and

σ_{com} is the standard deviation associated with the catch-at-age data, which is estimated in the fitting procedure by:

$$\hat{\sigma}_{com} = \sqrt{\sum_y \sum_a p_{y,a} \left(\ell n\, p_{y,a} - \ell n\, \hat{p}_{y,a}\right)^2 / \sum_y \sum_a 1} \tag{B20}$$

B.2.3. Survey catches-at-age

The survey catches-at-age are incorporated into the negative of the log-likelihood in an analogous manner to the commercial catches-at-age (thus they are also weighted by a factor $w^{survCAA}$), assuming an adjusted log-normal error distribution (equation (B18)) where:

$p_{y,a} = C^{surv}_{y,a} / \sum_{a'} C^{surv}_{y,a'}$ is the observed proportion of fish of age *a* in year *y*, with

$$C^{surv,i}_{y,a} = S^i_a N_{y,a} e^{-M_{y,a}\frac{\varpi^1}{12}} \left(1 - S_{y,a} F_y \frac{\varpi^1}{12}\right) \tag{B21}$$

$\hat{p}_{y,a}$ is the expected proportion of fish of age *a* in year *y* in the survey.

B.2.4. Stock-recruitment function residuals

The stock-recruitment residuals are assumed to be log-normally distributed. Thus, the contribution of the recruitment residuals to the negative of the (now penalised) log-likelihood function is given by:

$$-\ell n L^{SRpen} = \sum_{y=y1}^{1988} \left[\varepsilon_y^2 / 2\left(\sigma_R^1\right)^2\right] + \sum_{1989}^{y2} \left[\varepsilon_y^2 / 2\left(\sigma_R^2\right)^2\right] \tag{B22}$$

where

ε_y from $N\left(0, \left(\sigma_R\right)^2\right)$

B.3. Model parameters

B.3.1. Fishing selectivity-at-age:

The commercial selectivity is estimated separately for ages 1 to 4 and is assumed to be flat for ages 5 and above (except for case 8) for which selectivity is also estimated separately for ages 5 and above. The survey fishing selectivities are estimated separately for ages 1 to a_{plus} (the plus group age) and flat thereafter. a_{plus}=7 for the spring surveys and 6 for the fall surveys.

B.3.2.: Other parameters reported in Table 1 and elsewhere

σ_R_out

$$\sigma_R\_\text{out} = \sum_{y=y1}^{y2} (\varsigma_y)^2 \Big/ \sum_{y=y1}^{y2} 1 \qquad \text{(B23)}$$

where $y1$=1982 and $y2$=2010.

Calculation of MSY

The equilibrium catch for a fully selected fishing proportion F is calculated as:

$$C(F) = \sum_a w_a^{mid} S_a F N_a(F) e^{-(M_a/2)} \qquad \text{(B24)}$$

where $w_a^{mid} = \sum_{y1=2006}^{2010} w_{y,a}^{mid} \Big/ 5$, $S_a = S_{2010,a}$ and $M_a = M_{2010,a}$

and where numbers-at-age a are given by:

$$N_a(F) = \begin{cases} R_1(F) & \text{for } a = 1 \\ N_{a-1}(F) e^{-M_{a-1}} (1 - S_{a-1}F) & \text{for } 1 < a < m \\ \dfrac{N_{m-1}(F) e^{-M_{m-1}} (1 - S_{m-1}F)}{(1 - e^{-M_m}(1 - S_m F))} & \text{for } a = m \end{cases} \qquad \text{(B25)}$$

where

$$R_1(F) = \frac{\alpha B^{sp}(F)}{\beta + B^{sp}(F)} \qquad \text{(B26)}$$

The maximum of $C(F)$ is then found by searching over F to give F_{MSY}, with the associated spawning biomass and yield given by

$$B_{\text{MSY}}^{sp} = \sum_a f_a w_a^{strt} N_a(F_{\text{MSY}}) e^{-M_a \delta} \qquad \text{(B27)}$$

$$MSY = \sum_a w_a^{mid} S_a F_{\text{MSY}} N_a(F_{\text{MSY}}) e^{-(M_a/2)} \qquad \text{(B28)}$$

where $w_a^{strt} = \sum_{y1=2006}^{2010} w_{y,a}^{strt} \Big/ 5$ and $f_a = \sum_{y1=2006}^{2010} f_{y,a} \Big/ 5$

ADDITIONAL REFERENCE

Hilborn, R. 1990. Estimating the parameters of full age-structured models from catch and abundance data. International North Pacific Fisheries Commission Bulletin, 50: 207-213.