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Stock Assessment of Georges Bank Yellowtail Flounder for 2010

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ABSTRACT

The combined Canada/US yellowtail flounder (*Limanda ferruginea*) catch increased from 2008 (1,275 mt) to 2009 (1,778 mt) due mainly to an increase in quota. The 2005 year class did not appear strong in any of the recent surveys and did not dominate the catch, causing the assessment model to estimate the 2005 year class as only average. The 2005 year class had been estimated as one of the largest since the mid 1970s in the previous assessment. This change in perception of the 2005 year class caused the estimated spawning stock biomass to be lower than estimated in the last assessment. The recent trend in estimated spawning stock biomass is increasing, with 2009 estimates around 14,000 mt, but still well below the US rebuilding target of 43,200 mt. The 2005 and 2006 year classes were estimated to be about average at 23.9 million and 22.2 million, respectively, the 2007 year class is well below average, and the 2008 year class is estimated to be the lowest in the time series at 6.1 million. Fishing mortality rates for fully recruited ages 4+ were estimated to be 0.15 in both 2008 and 2009, below the F_{ref} of 0.25. Assuming a 2010 catch equal to the 1,956 mt quota, a combined Canada/US yield of about 3,400 mt in 2011 results from the deterministic application of F_{ref} = 0.25. The current US rebuilding strategy cannot be achieved even with a fishing mortality rate of zero. Examination of a range of alternative rebuilding strategies resulted in median catches in 2011 ranging from 600 mt to 2,700 mt.

These results are based on a single model formulation, denoted Split Series, as opposed to the previous assessment which provided the results from two model formulations. The previous assessment treated the unusual large tows for the 2008 and 2009 DFO survey as either the same values in the assessment (i.e. “Including”) or removed from tuning (i.e. ”Excluding”), as a way to bracket the uncertainty associated with these surveys. This assessment down-weights the DFO 2008 and 2009 surveys, as recommended by the TRAC last year to produce results approximately half way between the two previous formulations.

Despite splitting the survey time series to eliminate the retrospective pattern, this assessment now shows a moderate retrospective pattern in SSB due to the change in perception of the 2005 year class. Alternative projections which adjust the starting population abundance to account for the retrospective pattern lead to lower catch advice than the standard projections. For example, fishing at F_{ref} = 0.25 has a median 2011 catch of approximately 2,100-2,300 mt depending on the method used to adjust for the retrospective pattern. Additionally, projections which utilize only recent recruitment levels have lower rebuilding probabilities and lower expected catch in medium term projections, although the 2011 catch advice is essentially unaffected.

RÉSUMÉ

Les captures combinées de limande à queue jaune (Limanda ferruginea) du Canada et des États Unis ont augmenté de 2008 (1 275 tm) à 2009 (1 778 tm), cela en raison surtout d'une hausse du quota. La classe d'âge de 2005 n'a pas semblée forte dans les relevés récents et elle n'était pas dominante dans les captures; de ce fait, elle est jugée seulement moyenne dans le modèle d'évaluation, alors qu'elle avait été considérée comme une des plus fortes classes d'âge depuis le milieu des années 1970 dans l'évaluation précédente. En raison de ce changement dans l'appréciation de la classe d'âge de 2005, l'estimation de la biomasse du stock de reproducteurs est inférieure à celle de l'évaluation précédente. La tendance récente de la biomasse estimée du stock de reproducteurs est en hausse, l'estimation pour 2009 se situant alentour de 14 000 tm, mais restant encore bien inférieure à l'objectif de rétablissement fixé par les États-Unis, qui est de 43 200 tm. On a estimé que les classes d'âge de 2005 et de 2006 se situaient à peu près dans la moyenne, avec un effectif de 23,9 millions et de 22,2 millions, respectivement; la classe d'âge de 2007 est, quant à elle, bien inférieure à la moyenne, tandis que celle de 2008 est considérée comme étant la plus basse de la série chronologique, avec un effectif de 6,1 millions. Le taux de mortalité par pêche parmi les limandes à queue jaune pleinement recrutées des âges 4 + a été estimé à 0,15 en 2008 et également en 2009, ce qui est inférieur à Fréf. (0,25). Dans l'hypothèse où les captures de 2010 seraient égales au quota de 1 956 tm, l'application déterministe de $F_{réf.}$ = 0,25 aboutirait à un rendement combiné de la pêche canadienne et américaine d'environ 3 400 tm en 2011. L'actuelle stratégie de rétablissement adoptée par les États-Unis est inatteignable, même avec un taux de mortalité par pêche de zéro. D'autres stratégies de rétablissement ont été examinées; elles se traduiraient par des captures médianes allant de 600 tm à 2 700 tm en 2011.

Comparativement à l'évaluation précédente, qui comprenait deux formules de modèle, les résultats présentés ici sont fondés sur une seule formule de modèle, dite de la « série fractionnée ». Dans l'évaluation précédente, on avait traité les gros traits inhabituels des relevés du MPO de 2008 et de 2009 de deux façons, soit en les intégrant à l'évaluation en leu donnant la même pondération que ceux des autres relevés (option d'inclusion) soit en les écartant de l'ajustement du modèle (option d'exclusion), pour refléter l'incertitude associée à ces relevés. Dans la présente évaluation, on attribue une moindre pondération aux relevés du MPO de 2008 et 2009, ainsi que l'a recommandé l'an dernier le CERT, pour obtenir des résultats se situant à mi-chemin environ de ceux des deux formules précédentes.

Malgré le fractionnement opéré dans la série chronologique des relevés pour éliminer la tendance rétrospective, la présente évaluation reflète maintenant une tendance rétrospective modérée dans la BSR, due au changement dans l'appréciation de l'effectif de la classe d'âge de 2005. D'autres projections dans lesquelles la valeur de départ de l'abondance de la population est corrigée en fonction de la tendance rétrospective aboutissent à des captures recommandées inférieures à celles des projections standards. Ainsi, pour une pêche à $F_{réf.}$ = 0,25, les captures médianes se situent à 2 100 tm 2 300 tm environ, selon la méthode qui a été utilisée pour tenir compte de la tendance rétrospective. De plus, les projections fondées uniquement sur le recrutement récent aboutissent à de plus faibles probabilités de rétablissement et à de moindres captures à moyen terme, quoique pour l'essentiel cela n'ait pas d'effet sur la recommandation concernant les captures de 2011.

INTRODUCTION

The Georges Bank yellowtail flounder *(Limanda ferruginea)* stock is a transboundary resource in US and Canadian jurisdictions. This paper updates the last stock assessment of yellowtail flounder on Georges Bank, completed by the US and Canada (Legault et al. 2009) addressing technical recommendations from the 2005 benchmark review (TRAC 2005). A primary objective of the benchmark review was to address the retrospective pattern that had been apparent from assessments conducted during the previous several years. During the benchmark assessment meeting, several analytical models were reviewed, all of which indicated poor correspondence between the catch at age and survey abundance at age that could not be reconciled. Various possible reasons for the retrospective pattern were identified including an increase in natural mortality, large amounts of unreported catch, and changes in survey catchability since 1995. The consensus view from the benchmark meeting was that management advice should be formulated on the basis of results from several approaches:

- Analysis of data from survey and fishery (trends in relative fishing mortality, F, and total mortality, Z)
- 'Base Case' VPA model formulation from 2004 assessment
- Two new VPA model formulations with minor & major changes to Base Case.

The analytical methods used in the current assessment were based on revised model formulations adopted during the 2005 TRAC benchmark review using updated information from both countries on catches and survey indices of abundance. During the 2009 TRAC meeting, it was decided that neither the 'Base Case' or 'Minor Change' VPA formulation would be considered any longer because neither had been used for management advice in a number of years (O'Brien and Worcester 2009). The 'Major Change' VPA formulation was modified from the benchmark and the modified formulation will be referred to as the 'Split Series' model in this document, since it is now the default model.

Last year, two 'Major Change' VPA formulations were used to provide catch advice: "Including" used the full time series of all surveys while "Excluding" did not include the Canadian 2008 or 2009 survey information due to the influence of single large tows. Both formulations indicated that fishing mortality in 2008 was below the target rate F_{ref} = 0.25 and that biomass was increasing rapidly due to a strong 2005 year class. Projections indicated that catching the TAC of 2,100 mt in 2009 would result in a fishing mortality rate below F_{ref} (F_{2009} = 0.09 Including, 0.12 Excluding). US rebuilding projections were also conducted which required F in years 2010 through 2014 to be 0.085 (Including) or 0.02 (Excluding). Due to an inability to agree on a consensus catch quota, the two countries each set their quota independently. The US set a 2010 fishing year (May 1 – April 30) quota of 1,200 mt and Canada set a 2010 calendar year quota of 756 mt, for a total combined US/Canada catch of 1,956 mt.

Yellowtail flounder range from southern Labrador to Chesapeake Bay and are typically caught at depths between 30 and 70 m. Recently, fishermen have reported catching yellowtail flounder in deeper waters than they are traditionally found. An examination of catch by depth did not support a statistically significant change in the distribution of yellowtail flounder at depth over time (see TRAC Working Paper 17 Hyun et al. 2010). A major concentration occurs on Georges Bank from the northeast peak to the Great South Channel. Yellowtail flounder have previously been described as relatively sedentary, although a growing body of evidence counters this classification with off bottom movements (Walsh and Morgan 2004; Cadrin and Westwood 2004), limited seasonal movements (Royce et al. 1959; Lux 1963; Stone and Nelson 2003), and transboundary movements both east and west across the Hague Line (Stone and Nelson 2003; Cadrin 2005). On Georges Bank, spawning occurs during late spring and summer, peaking in May. Eggs are deposited on or near the bottom and after fertilization float to the surface where they drift during development. Larvae are pelagic for a month or more, then become demersal and settle to benthic habitats. Based on the distribution of both ichthyoplankton and mature adults, spawning occurs on both sides of the Hague Line. Growth is sexually dimorphic, with females growing at a faster rate than males (Lux and Nichy 1969; Moseley 1986; Cadrin 2003). Yellowtail flounder mature earlier than most flatfish with approximately 50% of age two females mature and nearly all age 3 females mature.

MANAGEMENT

Historical and new information pertaining to the current management unit for the Georges Bank yellowtail flounder stock was reviewed during the 2005 benchmark assessment. Tagging data, larval distribution, vital population parameters (i.e. growth, survival, recruitment, reproduction, abundance), and geographic patterns of landings and survey data indicate that Georges Bank yellowtail flounder comprise a relatively discrete stock, separate from those on the western Scotian Shelf, off Cape Cod and southern New England (Royce et al. 1959; Lux 1963; Neilson et al. 1986; Begg et al. 1999; Cadrin 2003; Stone and Nelson 2003). Based on information from a comprehensive review by Cadrin (2003) and recent results from cooperative science/industry tagging programs conducted by the US and Canada, there does not appear to be any justification for redefining the geographic boundaries of the Georges Bank yellowtail flounder stock management unit.

The management unit currently recognized by the US and Canada for the transboundary Georges Bank stock includes the entire bank east of the Great South Channel to the Northeast Peak, encompassing U.S. statistical reporting areas 522, 525, 551, 552, 561 and 562 (Fig. 1a) and Canadian fisheries statistical areas 5Zj, 5Zm, 5Zn and 5Zh (Fig. 1b). Both the US and Canada employ the same management unit.

In 1985, the World Court determined US and Canadian jurisdictions for Georges Bank fishery resources. At that time, there was no Canadian fishery for yellowtail. When a Canadian fishery developed in the early 1990s, US and Canada were exchanging information but doing separate assessments. In the late 1990s, joint assessments were developed, and in 2001 a sharing agreement was formed (TMGC 2002). Since the establishment of the US and Canada sharing agreement in 2001, advice for the Georges Bank yellowtail flounder relied primarily on a bilateral management system provided by the Transboundary Management Guidance Committee (TMGC). The agreement includes total allowable catch for each country based on a formulaic calculation using both historical catch and current spatial stock distribution. The quota sharing agreement between the two countries requires that catches from all sources be counted against the national allocations, regardless of whether the catch was landed or discarded. Although there is coordination between the US and Canadian fishery management, objectives between the two countries remain inconsistent, with US law requiring stock biomass rebuilding targets that are not part of Canadian management.

THE FISHERIES

Exploitation of the Georges Bank stock began in the mid-1930s by the US trawler fleet. Catch (including discards) increased from 400 mt in 1935 to 9,800 mt in 1949, then decreased in the early 1950s to 2,200 mt in 1956, and increased again in the late 1950s (Fig. 2). The highest annual catches occurred during 1963-1976 (average: 17,500 mt) and included modest catches by distant water fleets (see Other Landings, Table 1). No catches of yellowtail by nations other than US and Canada have occurred since 1975. Catches averaged around 3,500 mt between 1985 and 1994, then dropped to 1,135 mt in 1995 when fishing effort was markedly reduced in order to allow the stock to rebuild. The US fishery in the management area has been constrained by spatial expansion of Closed Area II in 1994 (Fig. 1a) and by extension to year-round closure in December 1994, as well as mesh size and gear regulations and limits on days fished. In 2004, a Yellowtail Special Access Program (SAP) in Closed Area II allowed the US bottom trawl fishery short-term access to the area for the first time since 1995. This SAP did not continue in subsequent years. A directed Canadian fishery began on eastern Georges Bank in 1993. Catches by both nations (including discards) steadily increased (with increasing quotas) from a record low of 1,135 mt in 1995, when the stock was considered to be in a collapsed state, to 7,419 mt in 2001. Since 2004, decreasing quotas and an inability of Canadian fishermen to fill their portion of the quota have resulted in declining catches through 2008 (1,275 mt) with an increase in 2009 to 1,778 mt.

United States

The principle fishing gear used in the US fishery to catch yellowtail flounder is the otter trawl, accounting for more than 98% of the total USA landings in recent years, although sea scallop dredges have accounted for some historical landings. US trawlers that land yellowtail flounder generally target multiple species on the southwest part of the Bank, and on the northern edge along the western and southern boundaries of Closed Area II. Current levels of recreational fishing are negligible.

Landings of yellowtail flounder from Georges Bank by the US fishery during 1994-2009 were derived from the new trip-based allocation described in the GARM III Data meeting (GARM 2007, Palmer 2008, Wigley et al. 2007a). Changes to the data in recent years caused a change in the landings value for 2007 from 1,061 mt to 1,072 mt. This change was incorporated in the catch at age data used in the assessment. US landings have been limited by quotas in recent years. Total US yellowtail landings (excluding discards) for the 2009 fishery were 975 mt, an increase of 30% from 2008 (Table 1; Fig. 2).

US discarded catch for years 1994-2009 was estimated using the Standardized Bycatch Reporting Methodology (SBRM) recommended in the GARM III Data meeting (GARM 2007, Wigley et al. 2007b). Observed ratios of discards of yellowtail flounder to kept of all species for large mesh otter trawl, small mesh otter trawl, and sea scallop dredge were applied to the total landings by these gears by half-year (Table 2). Uncertainty in the discard estimates was estimated based on the SBRM approach detailed in the GARM III Data meeting (GARM 2007, Wigely at al. 2007b). US discards were approximately 18% of the US catch in years 1994-2009 (Table 1; Fig. 2). Total discards of yellowtail in the US increased 93% from 2008 (370 mt) to 2009 (715 mt). This increase was due mainly to an increase in the large mesh discards (Table 2).

The total US catch of Georges Bank yellowtail flounder in 2009, including discards, was 1,689 mt. The US Georges Bank yellowtail flounder quota for fishing year 2009 (1 May 2009 to 30 April 2010) was set at 1,617 mt. Monitoring of the US catches relative to the quota was based on Vessel Monitoring Systems (VMS) and a call-in system for both landings and discards. Preliminary reporting on the Regional Office webpage (http://www.nero.noaa.gov/ro/fso/usc.htm) indicates the US fishery caught 109% of its quota for the 2009 fishing year.

Canada

Canadian fishermen initiated a directed fishery for yellowtail flounder on Georges Bank in 1993. Prior to 1993, Canadian landings were low, typically less than 100 mt (Table 1, Fig. 2). Landings of 2,139 mt of yellowtail occurred in 1994, when the fishery was unrestricted. After a TAC of 400 mt was established, yellowtail landings dropped to 464 mt in 1995. Subsequently, both quotas and landings increased and in 2001 landings reached a peak at 2,913 mt. The majority of Canadian landings of yellowtail flounder were made by otter trawl from vessels less than 20 m (tonnage classes 1-3). The fishery generally occurred from June to December, with most landings in the third quarter. Since 2004, there has been no directed Canadian fishery because fishermen have not been able to find commercial densities of yellowtail flounder. Landings have been less than 100 mt every year since 2004, with a low of 5 mt in 2009. In these years, most of the reported yellowtail landings were from trips directed for other groundfish species (i.e. cod or haddock).

The Canadian offshore sea scallop fishery is the source of Canadian yellowtail flounder discards on Georges Bank. As a result of the 2005 benchmark review, these data are now incorporated into the Canadian fishery catch and catch at age for 1973 onward (TRAC 2005). Discards are not recorded in the Canadian fishery statistics and are therefore estimated from observer deployments using the methodology documented in Van Eeckhaute et al. (2005). Since August 2004, there has been routine observer coverage on vessels in the Canadian scallop fishery on Georges Bank. A total of 5 trips were observed in 2004, 11 in 2005, 11 in 2006, 14 in 2007, 23 in 2008, and 21 in 2009. The seasonal pattern in bycatch rate is taken into account by applying calculations using 3-month moving-average discard rates. Applying this approach to the 2009 data results in a discard estimate of 84 mt, the lowest value in the time series (Table 1, Fig. 2). Canadian discards were approximately 49% of the Canadian catch in years 1994-2009 (Table 1, Fig. 2).

The total Canadian catch of Georges Bank yellowtail flounder in 2009, including discards, was 89 mt, a decrease of 44% from 2008, and well below the 2009 TAC of 483 mt.

Length and Age Composition

The level of US port sampling continued to be strong in 2009, with 12,408 length measurements available from 140 samples, resulting in 1,274 lengths/100 mt of landings (Table 3). This level of sampling resulted in low CVs for the US landings at age, as estimated by a bootstrapping procedure (Table 4). The 140 port samples also provided 2,883 age measurements for use in age-length keys. The Northeast Fisheries Observer Program provided an additional 12,810 length measurements of discarded fish from 207 trips, which were combined with the port samples to characterize the size composition of the US catch.

The US landings are classified by market category (large, small, medium, and unclassified) and this categorization is used to determine the size and age distributions. Both the amount and the proportion of yellowtail landed in the large market category have generally increased since 1995 (from approximately 50% to approximately 75%). Examination of the size distributions of the two market categories continues to show some overlap in the 36-38 cm range, but overall each market group are distinctively separated (Fig. 3).

In 2009, no port samples were collected from the 5 mt of Canadian landings (Table 3). No length measurements were utilized from Canadian at sea observer deployments because sex determinations from these samples were found to be inaccurate.

US discard length frequencies were generated from observer data, expanded to the total weight of discards by gear type and half year. Large mesh trawl discards showed a strong peak near the minimum allowed size, but larger fish were also discarded (Fig. 4). Small mesh discards accounted for only a small portion of the total discards but cover a wide range of lengths because this fishery is prohibited from landing groundfish (Fig. 4). Scallop dredge discards were mainly legal sized fish, as has been typically seen for dredge gear in the past (Fig. 4).

The size composition of yellowtail flounder discards in the Canadian offshore scallop fishery was estimated by half year using length measurements obtained from 21 observed trips in 2009. These were prorated to the total estimated bycatch at size using the corresponding half year length-weight relationship and the estimated half year bycatch (mt) calculated using the methods of Stone and Gavaris (2005).

A comparison of the 2009 size composition of yellowtail catch by country shows the same proportional distribution at length for the landings (Fig. 5). This similarity is because there was no sampling of the Canadian landings and the assumption was made that the US and Canadian landings at length would be the same. US discards were quite similar in both mean size and spread in the distributions relative to Canadian discards (Fig. 6). The relative magnitude of landings and discards by each country resulted in total catch for Canada having a smaller average size than the total catch for the US (Fig. 7).

Although otoliths are used to determine ages for Grand Bank yellowtail (Walsh and Burnett 2001), age determination of Georges Bank yellowtail flounder using otoliths is hampered by the presence of weak, diffuse or split opaque zones and strong checks, which can make interpretation of annuli subjective and difficult (Stone and Perley 2002). Therefore, scales are the preferred structure for aging Georges Bank yellowtail flounder. Percent agreement on scale ages by the US readers continues to be high (>85% for most studies) with no indication of bias.

For the US fishery, sample length frequencies were expanded to total landings at size using the ratio of landings to sample weight (predicted from length-weight relationships by season; Lux 1969), and apportioned to age using pooled-sex age length keys in half year groups. Landings were converted by market category and half-year, while discards were converted by gear and half-year. The age length keys for the US landings used only age samples from US port samples. In the past, the age length keys for the US discards used age samples from at sea observers of the discarded catch supplemented with US surveys. Since 2004, the scales collected by the observers have not been aged and so only the US surveys provided ages. This year the resulting survey age distribution appeared unusually strong for a single age class, so the commercial ages were added to the age length key. This had the effect of smoothing the age distribution and was deemed a better approach to forming the US discard at age. The US discards for years 2004-2008 were redone using both US surveys and US commercial ages. Although these years showed only minor changes in age distribution, these changes were incorporated in the catch at age data used for the assessment.

No scale samples were available for the Canadian fishery in 2009. Given the small amount of Canadian landings (5 mt, 0.3% of the total catch), these landings were just apportioned to ages based on the US proportions of landings at age. The 2009 Canadian average weight at age for landed fish was assumed to be the same as the 2009 US average weight at age for landed fish. Canadian discards at age by half year were obtained using half year age length keys based on the following combined ages: Half 1 US commercial fishery + US spring survey + Canadian survey, and Half 2 US commercial fishery + US fall survey.

All discarded yellowtail flounder were assumed to die. This assumption of 100% discard mortality was examined in TRAC Working Paper 16 (Barkley et al. 2010) and found to be not influential in terms of stock status over a range from 0% to 100% discard mortality.

In 2009, ages 3 and 4 (2006 and 2005 year classes, respectively) dominated US landings and discards, with only minor contributions from Canadian catch (Fig. 8). Since the mid 1990s, ages 2-4 have constituted most of the exploited population, with very low catches of age 1 fish due to the implementation of larger mesh in the cod end of commercial trawl gear (Table 5; Fig. 9).

The fishery mean weights at age for each of the combinations of US and Canadian landings and discards were derived using the applicable age length keys, length frequencies, and length-weight relationships. The mean weight at age (kg) for the US and Canadian landings were quite similar and generally were more variable at older ages (5+) during the mid 1980s to the mid 1990s. The overall fishery weight at age were calculated from US and Canadian landings and discards, weighting by the respective catch at age (Table 6; Fig. 10). A trend of increasing weight at age is apparent in both fisheries for all ages since 1995, returning to levels seen in the late 1970s/early 1980s. Recent weight at age (WAA) values are within both the range and one standard deviation of past WAA calculations since 1973.

ABUNDANCE INDICES

Bottom trawl surveys are conducted annually on Georges Bank by Canadian Department of Fisheries and Oceans (DFO) in February (denoted spring) and by the US National Marine Fisheries Service (NMFS) in April (denoted spring) and October (denoted fall). The US NMFS scallop survey is conducted in June and catches a large number of yellowtail flounder, allowing it to be used as an additional tuning index. Both agencies use a stratified random design, though different strata boundaries are defined (Fig. 11). The NMFS spring and fall bottom trawl survey catches (strata 13-21), NMFS scallop survey catches (scallop strata 54, 55, 58-72, 74), and DFO spring bottom trawl survey catches (strata 5Z1-5Z4) were used to estimate relative stock biomass and relative abundance at age for Georges Bank yellowtail. Conversion coefficients, which adjust for survey door, vessel, and net changes in NMFS groundfish surveys (1.22 for old doors, 0.85 for the Delaware II, and 1.76 for the Yankee 41 net; Rago et al. 1994) were applied to the catch of each tow for years 1973-2008.

There continues to be high variability in the survey indices. Specifically, beginning in 2009 the US bottom trawl surveys were conducted with a new vessel, the FRV Henry B. Bigelow, which uses a different net and protocols from the previous survey vessels. Length-based conversion coefficients have been estimated for yellowtail flounder (see TRAC Working Paper 14; Brooks et al. 2010) and applied in this assessment to derive the survey catch at age (Table 7). The 2008 and 2009 Canadian surveys encountered individual tows that were much larger than any seen previously in the time series. The 2009 Canadian survey values at age have been updated from last year due to an incorrect expansion to the total area fished and missing ages in the age length key. The US assessment software has been upgraded to allow the 2009 TRAC recommendation to downweight the 2008 and 2009 Canadian survey values. The Canadian survey biomass index has changed from last assessment due to a miscommunication between US and Canadian scientists regarding the expansion from catch per tow to total biomass. However, these data are not used to calibrate the VPA and so have no impact on catch advice.

Given the lack of evidence for a strong dome in the partial recruitment of yellowtail flounder in the US scallop survey (see Working Paper 9, Legault et al. 2010), the US scallop survey was explored as a means of tuning all ages, instead of just as a recruitment index as has been done in the past. This approach was advanced in the 2009 TRAC meeting, but was not used because the 2008 US scallop survey did not cover the Canadian portion of Georges Bank. The length frequency distributions from the scallop survey were converted to ages by applying age length keys from the US spring and fall surveys combined. Comparison of the trends over time from the scallop and three bottom trawl surveys indicate they are tracking similar trends (Fig. 12a). Concern was expressed during the TRAC meeting that the scallop survey ages are smeared by using a combined spring and fall age-length key. Suggestions were made to either include the survey as an age 2+ index, although age 2 would not be fully selected, or to use age length keys from commercial data instead. The TRAC agreed the scallop survey should be used for older ages in future assessments, but recommended the older ages not be included in the current assessment due to uncertainty in how variable the trends in older ages will be due to the approach used to age the length distributions.

Trends in yellowtail flounder biomass indices from the four surveys track each other quite well over the past two decades, with the exception of the DFO survey in 2008 and 2009 which were influenced by single large tows (Fig. 12b). The minimum swept area biomass estimated from the DFO survey increased from 1995 to 2001, declined through 2004, fluctuated through 2007, and then increased dramatically in 2008 and 2009 due single large tows in each year, as seen by the indices declining by about an order of magnitude when the single tows are excluded (Table 8a; Fig. 12b). The 2010 DFO biomass is close to the average of the time series when 2008 and 2009 are not included. The NMFS spring series was high in the mid 1970s, low in the late 1980s through mid 1990s, high from 1999 through 2003, sharply decreased in 2004, and has shown a recent increasing trend from 2004 through 2010 (Table 8b; Fig. 12b). The NMFS fall survey, which is the longest running time series, was high in the mid 1960s through mid 1970s, low in the mid 1980s through mid 1990s, increased through 2001, declined through 2005, and has remained at levels comparable to the late 1960s for the past three years, 2007-2009 (Table 8c; Fig. 12). The scallop survey stratified mean catch per tow shows a strong increase from low levels in the mid 1990s to a peak in 1998 followed by a decline through 2005, and has fluctuated since (Table 8d; Fig. 12b). Both the NMFS spring and fall survey indices show high inter-annual variability during the periods of high abundance (i.e. the 1960s and 1970s) which may reflect the patchy distribution of yellowtail on Georges Bank and the low sampling density of NMFS surveys.

The distribution of catches (weight/tow) for the most recent year is compared with the previous ten year average for the three groundfish surveys in Figs. 13a-13b. Note the 2009 and 2010 NEFSC survey biomass values were adjusted from Bigelow to Albatross IV equivalents by dividing Bigelow catch in weight by 2.244 (spring) or 2.402 (fall), in contrast to the length specific conversion coefficients used to generate the age specific indices of abundance used for tuning the VPA (Table 7). This conversion of Bigelow survey biomass values is still under review and may change in the future. Since 1996, most of the DFO survey biomass and abundance of yellowtail flounder has occurred in strata 5Z2 and 5Z4 (Fig. 14a). However, in 2008 and 2009 almost the entire Canadian survey catch occurred in just one or two tows in stratum 5Z1, making interpretation of trends over time difficult. The 2010 DFO survey had a high proportion of the total catch in Stratum 5Z1 as well. The NEFSC bottom trawl surveys have been dominated by stratum 16 since the mid 1990s (Figs. 14b-14c). The apparent large differences in spatial distribution among surveys in the most recent year were discussed at length during the TRAC meeting. The use of different scales for US and Canada plots made direct comparison more difficult, but there are still apparently large changes in spatial distribution that can occur rapidly for this stock.

Age-structured indices of abundance for NMFS spring and fall surveys were derived using survey-specific age-length keys. In the past, age-length keys from NMFS spring surveys have been substituted to derive age composition for same-year DFO spring surveys, as no ages were available from the DFO surveys because of difficulties associated with age interpretation from otoliths (Stone and Perley 2002). To avoid having to use substituted age data, NMFS personnel have been ageing scales collected on DFO surveys since 2004 and continued to do so this year. From the 2010 DFO survey, 197 male and 170 female fish were aged and used to produce separate-sex age-length keys, subsequently used to generate the 2010 DFO age-specific indices of abundance.

Even though all four surveys initially indicated a strong 2005 year class, none of the surveys currently indicate the 2005 year class is particularly strong (Table 8; Figs. 15a-15f). Even though each index is noisy, the age specific trends track relatively well among the four surveys (Table 8; Fig. 16).

Trends in relative fishing mortality and total mortality from the surveys were examined as part of the consensus benchmark formulations agreed to at the second benchmark assessment meeting in April 2005. Relative fishing mortality (fishery catch biomass/survey biomass, scaled to the mean for 1987-2009) was quite variable but followed a similar trend for all four surveys, with a sharp decline to low levels since 1995 (Fig. 17). In contrast, estimates of total mortality rates from the surveys for ages 2, 3 and 4-6, although noisy, are without trend and indicate no overall reduction in mortality since 1995 (Fig. 18). This disagreement between the relative F and survey Z trends lies at the heart of the retrospective pattern in this assessment. If fishing mortality has really decreased substantially since 1995, as indicated by the relative F pattern, why do we not see many old fish (ages 6+) in the surveys or catch? This disagreement in the basic data causes the challenges for this assessment.

ESTIMATION OF STOCK PARAMETERS

Results from assessment analyses conducted in recent years have displayed: a) retrospective patterns; b) residual patterns that are indicative of a discontinuity starting in 1995; and c) fishing mortality rates that are not consistent with the decline in abundance along cohorts evident in the survey data. Essentially, the catch at age data and assumed natural mortality rate cannot be reconciled with the high survey abundance indices at ages 2 and 3 and low survey abundance at ages 4 and older.

The empirical evidence suggests that significant modifications to the population and fishery dynamics assumptions are required to reconcile the fishery and the survey observations. Models that adopt such modifications imply major consequences on underlying processes or fishery monitoring procedures. The magnitude of implied changes to natural mortality rate, survey catchability relationships, or unreported catch is so great that the acceptability of models that incorporate these effects is suspect. However, these models may provide better catch advice for management of this resource than ignoring the changes in underlying processes (ICES 2008).

In view of these reservations, adoption of a benchmark formulation that incorporated these modifications to assumptions, as the sole basis for management advice was not advocated (TRAC 2005). Therefore the TRAC recommended that management advice be formulated after considering the results from three VPA approaches: Base Case, Minor Change, and Major Change. The Minor Change VPA was never used in any subsequent assessment (Stone and Legault 2005, Legault et al. 2006, Legault et al. 2007, Legault et al. 2008) and it was agreed during the 2009 TRAC that it would not be continued in the future (Legault et al. 2009). The Base Case VPA was continued for a number of years after the benchmark, but has not been accepted for use in providing management advice for the past few years (Legault et al. 2006, Legault et al. 2007, Legault et al. 2008, Legault et al. 2009). At the 2009 TRAC meeting, it was agreed that the Base Case model would no longer be considered in future assessments due to its strong retrospective pattern and inability to match trends observed in the surveys. To reduce confusion, the (modified) Major Change VPA is referred to as the Split Series VPA in this assessment, and is the default approach for providing management advice.

The VPAs are calibrated using the adaptive framework, ADAPT (Gavaris 1988) to calibrate the sequential population analysis with the research survey abundance trend results, specifically the NOAA Fisheries Toolbox VPA v3.0.3. The model formulation employed assumed error in the catch at age was negligible. Errors in the abundance indices were assumed independent and identically distributed after taking natural logarithms of the values. The exception to this assumption is the DFO survey values for 2008 and 2009 were downweighted (residuals multiplied by 0.5) to reflect the higher uncertainty associated with these observations relative to all other survey observations. Zero observations for abundance indices were treated as missing data, because the logarithm of zero is undefined. The annual natural mortality rate, M, was assumed constant and equal to 0.2 for all ages. The fishing mortality rates for age groups 4, 5 and 6+ were assumed equal. These model assumptions and methods were the same as those applied in the last assessment (Legault et al. 2009). Both point estimates and bootstrap statistics of the estimated parameters were derived using only the US software for this assessment.

The Major Change VPA recommended during the benchmark assessment expanded the ages from 6+ to 12, assumed a constant small number of fish (1000) survived to the start of age 13, allowed power relationships between indices and population abundance for younger ages (1-3), and split the survey time series between 1994 and 1995. This model could not be fit well in previous assessments (Legault et al. 2006, Legault et al. 2007, Legault et al. 2008) due to a lack of catch at old ages creating bimodal bootstrap distributions. Following the precedent of previous assessments, the Major Change VPA was reformulated to be the same as the Base Case VPA, with the exception that the survey time series were split at 1995 (Legault et al. 2006, Legault et al. 2007, Legault et al. 2008, Legault et al. 2009). This means that indices and population abundance are assumed linearly related at all ages and that a 6+ group is used for all fish aged 6 and older in the population dynamics equations. Splitting the survey series has been sufficient to remove the retrospective pattern and pattern in residuals, and was recommended for management advice because it more closely followed the pattern observed in the indices. This Split Series formulation was used again this year to provide management advice.

The Split Series VPA used revised annual catch at age (including US and Canadian discards), $C_{a,t}$, for ages a = 1 to 6+, and time t = 1973 to 2009, where t represents the beginning of the time interval during which the catch was taken. The VPA was calibrated to bottom trawl survey indices, $I_{s,a,t}$, for:

s_1 = DFO spring, ages a = 2 to 6+, time t = 1987 to 1994
s_2 = DFO spring, ages a = 2 to 6+, time t = 1995 to 2010
(note: s_2 = DFO spring, ages a = 2 to 6+, time t = 2008 to 2009 residuals were downweighted)
s_3 = NMFS spring (Yankee 41), ages a = 1 to 6+, time t = 1973 to 1981
s_4 = NMFS spring (Yankee 36), ages a = 1 to 6+, time t = 1982 to 1994
s_5 = NMFS spring (Yankee 36), ages a = 1 to 6+, time t = 1995 to 2010
s_6 = NMFS fall, ages a = 1 to 6+, time t = 1973.5 to 1994.5
s_7 = NMFS fall, ages a = 1 to 6+, time t = 1995.5 to 2009.5
s_8 = NMFS scallop, age a = 1, time t = 1982.5 to 1994.5
s_9 = NMFS scallop, age a = 1, time t = 1995.5 to 2009.5
(note: the NMFS scallop survey was not used for years 1986, 1989, 1999, 2000, or 2008)

Splitting the survey time series between 1994 and 1995 could not be justified based on changes in the survey design or implementation. Rather the split is considered to alias unknown mechanisms causing the retrospective pattern in the Base Case VPA. Relationships between indices and population abundance for all ages were assumed to be proportional. Population abundance at age 1 in the terminal year plus one (2010) was assumed equal to the geometric mean over the most recent 10 years (2000-2009). Population abundance in the terminal year plus one (2010) was estimated directly for ages 2-5.

Building the Bridge

During the 2009 TRAC, the DFO surveys for 2008 and 2009 could not be down-weighted using the US software. The US software package has since been modified to allow this down-weighting. It was expected that down-weighting the DFO surveys in 2008 and 2009 would produce results similar to an average of the two formulations recommended by the 2009 TRAC, which were considered to bracket the true population trajectory. The two 2009 TRAC formulations were denoted “Including”, which treated these surveys as equivalent to all other survey observations (weight of one), and “Excluding” which did not include the 2008 or 2009 DFO survey observations at all (weight of zero). Applying the down-weighting approach to the data used in the 2009 TRAC (labeled T09wted) did in fact result in values at nearly the average of the "Including" (labeled T09Inc) and "Excluding" (labeled T09Exc) runs (Figs. 19-20).

There were four additional changes to the data used in the 2009 TRAC:

1) The DFO 2009 survey values were adjusted (labeled T09wted_DFO2009)
2) The US landings for 2007 were adjusted (labeled T09wted_USland2007)
3) The US discards for 2004-2008 were adjusted (labeled T09wted_USdisc200408)
4) The calibration coefficients for the Bigelow became available allowing the use of the US spring 2009 survey (labeled T09wted_HBBSpr2009).

These four changes were examined one at a time relative to the TRAC 2009 weighted approach. The first three resulted in only minor changes, causing a slight decrease in 2008 spawning stock biomass (SSB) and slight increase in 2008 F, while the inclusion of the US spring 2009 survey had a larger impact reducing the 2008 SSB below and the 2008 F above the associated TRAC 2009 "Excluding" case (Figs. 19-20b). Due to the same directional change of all four changes, employing all four changes at once (labeled T09wted_all4) resulted in the lowest 2008 SSB and highest 2008 F, although the 80% confidence intervals of these estimates encompassed the TRAC 2009 weighted scenario (Figs. 20a-20b). This run (labeled T09wted_all4) which combined all four changes and used the down-weighting approach for the DFO 2008 and 2009 surveys was the starting point for the new assessment, which then added a year of catch and survey indices. These changes contribute to the historical retrospective pattern observed in this assessment.

Diagnostics

The Split Series VPA performed similarly in terms of relative error and bias in the population abundance estimates to previous assessments with lower relative error and bias at older ages than younger ages (Table 9). This pattern of higher uncertainty in the younger ages has been seen in previous assessments and is due to having less information about these cohorts.

Survey calibration constants (q's) for the Split Series VPA also followed similar patterns to previous assessment (Table 9, Fig. 21). The most notable pattern was the increase in estimated values at nearly all ages between the pre-1995 and recent period (1995 to present), with some ages showing more than a five-fold increase and averaging a three-fold increase. There have been no changes in the survey design or operations that can explain such changes. These changes in q are considered to be aliasing unknown mechanisms and the series have been split for the sole purpose of producing a better fitting model. Management strategy evaluations have demonstrated that even if the true source of the retrospective pattern is misreported catch or changes in natural mortality, this approach of splitting the time series to address the retrospective problem produces better performance (true F closer to target F) than ignoring the retrospective pattern (ICES 2008).

The Split Series VPA residuals did not show a strong pattern, with mixed positive and negative residuals throughout the time series (Fig. 22). The plotted residuals for the 2008 and 2009 DFO survey account for the down-weighting used in the fitting, but still appear as strong positive residuals (observed values larger than predicted) except for the age 6+ value in 2008. The standard sampling protocol in 2008 did not collect any age 6+ yellowtail in the large tow that year, and so this index value was not high when the tow was included.

An alternative method to view the change in catchability is to plot the relative catchability (the survey observation divided by the estimated beginning of year population abundance) with the Split Series estimate of catchability overlaid as lines (Figs 23a-23c). These plots do not adjust the population abundance to account for the time of the survey. The changes in relative catchability appear strong and consistent for many surveys and ages, as opposed to being driven by just one or two outlier values. These consistent changes give more confidence to the approach of splitting surveys than changes due to one or two outliers would.

Retrospective analysis for the Split Series VPA did not indicate a strong tendency to over or underestimate fishing mortality on ages 4-5 or recruitment, but did indicate a moderate tendency to overestimate SSB (Table 10, Figs. 24a-24b). The retrospective pattern for SSB is considerably less strong than has been seen in the Base Case formulations of previous assessments, where retrospective rho statistics of more than 1.0 were estimated, but should still be considered when providing management advice. The recruitment retrospective pattern is noisy with both positive and negative changes, but of most concern is the change to the 2005 year class which had been estimated as strong in the recent three peels and is now estimated as only average.

Despite the moderate retrospective pattern in SSB, the Split Series VPA is recommended as the basis for providing management advice.

STOCK STATUS

Results from the Split Series VPA were used to evaluate the status of the stock in 2009 (Tables 11-12). The fishery weights at age, assumed to represent mid-year weights, were used to derive beginning of year weights at age (Table 13), and these were used to calculate beginning of year population biomass (Table 14). In the US, SSB is the legal status determination criterion and is computed assuming maturity at age and the proportion of mortality within a year that occurs prior to spawning ($p = 0.4167$).

Adult population biomass (age 3+) increased from a low of 2,100 mt in 1995 to 11,000 mt in 2003, declined to about 2,900 mt in 2006, and increased to 14,600 mt at the beginning of 2010, the highest adult biomass since 1974 (Table 14, Fig. 25). Total population biomass (age 1+) has generally tracked the three groundfish surveys, although splitting the series implies high catchability of the surveys in recent years (Table 14, Figure 26). Spawning stock biomass in 2009 was estimated to be 14,000 mt (80% confidence interval: 11,700-17,100 mt). These 2009 values are well below both the TRAC 2009 Including and Excluding estimates for 2008 and reflect a change in the perception of the 2005 year class from strong to moderate. This change in perception of cohort strength has been seen in previous assessments and when it occurred it led to strong retrospective patterns.

During 1998-2001 recruitment averaged 22.2 million fish at age 1 but has since been below 20 million fish, with the exception of the 2005 and 2006 year classes estimated at 23.9 million and 22.2 million, respectively (Table 11). The 2007 year class is well below average, and the 2008 year class is estimated to be the lowest in the time series at 6.1 million. The strong change in perception of the strength of the 2005 year class is because it did not appear in any of the

2009-2010 surveys or the 2009 catch at the expected magnitude of a strong year class (Figs. 8 and 15f).

Fishing mortality for fully recruited ages 4+ was close to or above 1.0 between 1973 and 1995, fluctuated between 0.51 and 0.97 during 1996-2003, increased in 2004 to 1.91, and then declined to 0.53 in 2007 and 0.15 in both 2008 and 2009 (80% confidence interval for 2009: 0.12-0.19), below the reference point of F_{ref} = 0.25 (Table 12). This pattern in F does not correspond with the relative fishing mortality rate pattern estimated as catch/survey (Fig. 17). The relative F pattern shows a sudden decline in 1995 and continued low levels since then. This pattern was seen in previous Base Case assessments. However, these assessments had strong retrospective patterns which increased the F as additional years became available. Given the lack of a strong retrospective pattern in the Split Series VPA for fishing mortality rate in this assessment, the 2008 and 2009 estimates of F are not expected to increase substantially with additional years of data.

Sensitivity Analyses

Five sets of sensitivity analyses were conducted to explore the robustness of the Split Series formulation:

1. Including and Excluding formulations
2. VPA options
3. Surveys
4. Alternative approaches to reduce retrospective pattern
5. Natural mortality.

The TRAC 2009 “Including” and “Excluding” formulations had the expected results of higher SSB and lower F for the “Including” case and lower SSB and higher F for the “Excluding” case, although both were within the 80% confidence intervals of the Split Series results (Figs. 27a-28b). These runs confirmed that down-weighting the 2008 and 2009 DFO surveys by 50% resulted in SSB and fishing mortality rates approximately halfway between the full weighting and zero weighting.

The second set of sensitivity analyses explored options available within the US VPA software. The Split Series formulation used the Backward solution to calculate the plus group, which results in the same F for ages 4, 5, and 6 each year, but can result in unfeasible plus group abundances (the plus group in year t is greater than the sum of the plus group and last full age in year t-1). No unfeasible solutions were found in the Split Series VPA. The US VPA software also allows Forward and Combined solutions to the plus group, which differ by the Forward solution allowing the F on the plus group to be quite different from the F on oldest true age, while the Combined solution disassociates the F on the oldest true age from younger ages. The Forward option resulted in higher SSB and lower F than the Split Series while the Combined option resulted in lower SSB and higher F than the Split Series, with both near the 80% confidence interval values (Figs. 28a-28b). These options also caused minor changes to the historical estimates of SSB and F. The distinction between these methods can be seen by examining ratios of successive ages in the estimate F matrix. The ratio of age 6+ to age 5 F in the Forward option shows a strong dome for years 1980 through 2000 followed by two large spikes in 2004 and 2006 when the age 6+ F was greater than 4 (Fig. 29). In contrast, the Combined option has the same F at ages 5 and 6+, but can vary between ages 4 and 5. The ratio of age 5 to age 4 F in the Combined option is quite stable and close to one (Fig. 29). Another US VPA setting that was explored was to estimate the age 6+ abundance at the start of 2011. This resulted in slightly higher SSB and slightly lower F than the Split Series run which did not estimate this age group, but the results were well within the 80% confidence bounds of the Split Series VPA (Figs. 28a-28b). The uncertainty on this additional parameter was relatively high (57%) and so the addition of this parameter could not be justified.

The third set of sensitivity analyses used only one survey at a time as tuning indices (Figs. 28a-28b). The US scallop survey used all ages for this sensitivity run, as opposed to using only age 1 as in the Split Series VPA. Using only the US spring survey to tune the VPA resulted in lower SSB and higher F than the Split Series, just outside the 80% confidence intervals, while using only the US fall survey to tune the VPA resulted in higher SSB and lower F than the Split Series VPA, well outside the 80% confidence intervals. In contrast, the DFO survey was well within the 80% confidence intervals, with slightly lower SSB and higher F than the Split Series VPA. Using only the US scallop survey produced the lowest SSB and highest F of all the sensitivity runs. This extreme result may be due to the missing 2008 values causing the model difficulty in estimating stock abundance parameters (CVs ranged from 53% to 83%). When ages 2 through 6+ are included in the US scallop survey along with all the other survey values, the SSB is at the lower 80% confidence interval and F is at the upper 80% confidence interval of the Split Series VPA. A final run in this set dropped all 2010 survey information, meaning the US spring survey and DFO survey values for 2010. This resulted in a higher SSB and lower F than the Split Series VPA, near the 80% confidence intervals. In summary, the US spring and scallop surveys are pushing the model towards a lower SSB and higher F, the US fall survey is pushing the model towards a higher SSB and lower F, and the DFO survey is tracking fairly well the combined Split Series VPA.

The fourth set of sensitivity analyses examined alternative ways to remove the retrospective pattern, specifically by estimating additional catch or natural mortality in recent years. In order to do this, the surveys first had to be put back into single series (e.g. eliminate the split and treat the surveys as continuous for all years available, except for the US spring Yankee 41 net). This was done and resulted in much higher SSB and much lower F than the Split Series VPA (Figs. 28a-28b). The single series run also exhibited a strong retrospective pattern, with rho of 1.36 and -0.55 for SSB and F, respectively. Using the catch multiplier option in the US VPA software resulted in much higher catch for most years since 1995, with five years hitting the user defined bound of five (meaning catch at age in those years was multiplied by five). This changed not only the SSB and F in 2009, but also the historical trends as well (this run has SSB > 30,000 mt in year 2000, Fig. 27a). This run had a much higher SSB in 2009 and a much higher F in 2009 than the Split Series VPA. The F in 2009 is well above the F_{ref} of 0.25. This run had a substantially reduced retrospective pattern, with rho of 0.45 and -0.09 for SSB and F, respectively. The other approach to reduce the retrospective pattern is to increase M in the recent years, since 1995. An exploratory analysis over a range of M values found the best fit for M=0.6 in years 1995 through 2009 at all ages, while keeping the M at 0.2 for earlier years. This run also substantially changed the historical time series of SSB and F (Figs. 27a-b) and resulted in higher 2009 SSB and lower 2009 F than the Split Series VPA. This run also reduced the retrospective pattern, with rho = 0.62 and -0.28 for SSB and F, respectively. These examples demonstrate that alternative methods can be used to reduce the retrospective pattern. However, a full analysis of these alternative approaches to reducing the retrospective pattern would require calculation of reference points and comparison of projected and realized yields, which time did not permit.

These alternatives also imply that catch is seriously underestimated, in either landings, discards, or both, or that natural mortality has changed suddenly and dramatically, neither of which can be supported by any empirical evidence.

The final set of sensitivity analyses examined changes to the full natural mortality matrix. The same value of M was used for all years and ages for a range of values from 0.05 to 0.80 in steps of 0.05. The minimum residual sum of squared residuals was found at M=0.2 and 0.25 (same RSS for these two M). As expected, increasing M led to increased estimates of N and SSB and decreased estimates of F. However, the model did not perform better, in terms of model fit, with an increased or decreased M relative to the Split Series VPA.

These sensitivity analyses demonstrate the Split Series VPA is generally robust to model assumptions and choices of data used, although the 80% confidence intervals may not fully capture the total uncertainty in the assessment (as described in the Outlook section).

FISHERY REFERENCE POINTS

Yield per Recruit Reference Points

The current reference fishing mortality rate used by the TMGC (F_{ref}=0.25, ages 4+) was derived from both $F_{0.1}$ and $F_{40\%MSP}$ calculations. Although the yield per recruit (YPR) analysis was not updated this year, both the 2002 and 2008 assessment YPR analysis (NEFSC 2002, NEFSC 2008 confirmed that both these values remain at 0.25. This is the same value as the F_{MSY} proxy of $F_{40\%MSP}$ used for US management (NEFSC 2008). This suggests that F_{ref} is robust to the changes in partial recruitment observed over the years.

Stock and Recruitment

The TMGC does not have an explicit biomass target. There is evidence of reduced recruitment at low levels (below 5,000 mt) of SSB (Fig. 30). In the US, a similar stock-recruitment relationship from the GARM assessment (NEFSC 2008) was used to estimate the B_{MSY} proxy by projecting the population for many years with $F = F_{40\%MSP}$ and recruitment randomly selecting from the cumulative distribution function of recruitment observed at SSB > 5,000 mt. The B_{MSY} level of 43,200 mt of SSB was set as the rebuilding goal in the US for this stock (NEFSC 2008). Current levels of SSB are below the rebuilding goal (SSB_{2009}/SSB_{MSY} = 32%).

OUTLOOK

This outlook is provided in terms of consequences with respect to the harvest reference points for alternative catch quotas in 2011. Uncertainty about current biomass generates uncertainty in forecast results, which is expressed here as the risk of exceeding F_{ref} = 0.25. The risk calculations assist in evaluating the consequences of alternative catch quotas by providing a general measure of the uncertainties. However, they are dependent on the data and model assumptions and do not include uncertainty due to variations in weight at age, partial recruitment to the fishery, natural mortality, systematic errors in data reporting or the possibility that the model may not reflect stock dynamics closely enough.

Due to recent trends in fishery partial recruitment patterns and survey and fishery weights at age, average values from 2007-2009 were used in the projections. As has been done in the past TRAC assessments, recruitment for the deterministic projections was set as the geometric mean of the previous ten years (1999-2008; 13.707 million age-1 fish) while stochastic projections use the two stage empirical cumulative distribution function of recruitment estimates from GARM 3 used to set the US rebuilding target (median recruitment of 24.6 million age-1 fish). These differences in recruitment assumption have only minor impact on 2011 projected catch, but would have large impact on medium or long term projections.

Assuming a catch in 2010 equal to the 1,956 mt (the sum of the individually determined quotas for USA and Canada), a combined US/Canada catch of about 3,400 mt in 2011 would result in a neutral risk (~50%) that the fishing mortality rate in 2011 will exceed F_{ref}, while catches of 3,100 mt and 3,800 mt in 2011 would result in 25% and 75% risk that fishing mortality rate will exceed F_{ref}, respectively (Fig. 31). Fishing at F_{ref} in 2011 will generate no change in age 3+ biomass from 2011 to 2012 (15,200 mt, Table 15). A catch in 2011 of 3,400 mt will result in no change in median biomass from 2011 to 2012, while catches in 2011 of 1,900 mt and 400 mt will result in 10% and 20% increases in median biomass from 2011 to 2012, respectively (Fig. 31).

Although not as strong as initially estimated, the survival of the 2005 year class has been good and this year class will enter the plus group in 2011. The average weight of yellowtail flounder in the plus group would be expected to decrease when the 2005 year class enters in 2011. As a sensitivity analysis, the average weight for the plus group in the catch was reduced from 0.962 (the three year average of the plus group) to 0.918 (the three year average of age 6 fish). In the deterministic projections, this reduction led to a loss of 65 mt of yield (<2% change) in 2011.

In the US, there is a requirement to provide rebuilding projections when stocks are overfished. The rebuilding scenario for Georges Bank yellowtail flounder requires solving for a value of F (Freb75) that, when applied in years 2011-2014, results in a 75% probability that SSB in 2014 is greater than SSBmsy (43,200 mt). Using the same starting conditions as the projection described above, it was determined that even an F of zero was insufficient, with only 36% probability of SSB being above the SSBmsy target (Table 16). Three options are currently under consideration to replace this rebuilding scenario:

A) Rebuild by 2016 with 50% probability
B) Rebuild by 2016 with 60% probability
C) Rebuild by 2016 with 75% probability.

Applying a constant fishing mortality rate during years 2011 to 2020 in the range of 0.04 to 0.15 allowed determination of appropriate rebuilding F values for each of these options: F = 0.14, 0.10, and 0.04 for options A, B, and C, respectively (Table 16). The distribution of catch under these rebuilding strategies was compared with the distribution of catch when F_{ref} was applied in 2011 and 75% of F_{ref} was applied in 2011 (Table 17). These distributions were quite different as seen by the lack of overlap of the 90% confidence intervals for many of the strategies, with the absolute range of median catch approximately 2,000 mt.

Alternative projection assumptions were explored to examine the sensitivity of catch advice. The population abundance at age in 2010 was adjusted to account for the retrospective pattern in two different ways; adjust all ages by the same amount based on the SSB retrospective rho or adjust each age according to its own retrospective rho. The SSB rho is 0.41 which means that each stock abundance at the start of 2010 is multiplied by 1/(1+0.41) = 0.70922. The age specific rho adjustments and associated multipliers for the start of 2010 stock abundance varied by age

	age1	age2	age3	age4	age5	age6+
rho	0.40	0.40	0.68	0.98	0.21	0.62
multiplier	0.714286	0.714286	0.595238	0.505051	0.826446	0.617284

These two approaches to adjust projections for retrospective patterns produced similarly reduced 2011 catch advice relative to the Split Series VPA (Table 18, Fig. 31). Additionally, these two retrospective adjustments to the projections resulted in none of the rebuilding options being possible, fishing at F=0 resulted in 75% or less probability of achieving rebuilding by 2016 (Table 19).

A second set of sensitivity projections sampled recruitments for the stochastic projections from a distribution of estimated age 1 abundance for years 1983 to 2009. This set of recruitments had a median of 14.1 million in contrast to the standard rebuilding projections which had a median of 24.6 million, which uses recruitment estimates from 1963 to 2007 (Table 20). Although catch advice for 2011 was unchanged (Table 20), the probability of achieving US rebuilding targets was reduced, e.g. under no fishing there is less than a 5% probability of SSB_{2020}>43,200 mt (note that SSBmsy assumes a median recruitment of 24.6 million, Table 21). Median catch in projected years diverged from the standard F_{ref} projections beginning in 2014 and were less than half the standard projections by 2020 (Table 21).

Age structure, fish growth, and spatial distribution reflect stock productivity. The current age structure indicates that very little rebuilding of ages 6 and older has occurred (Fig. 32). The 2009 population abundance proportions at age were above the values expected in equilibrium at F_{ref} for ages 3, 4, and 5, but this is partially due to being well below the expected proportions at ages 1 and 2. Far fewer older fish (6+) are estimated in the VPA in comparison with the population at equilibrium, which is inconsistent with the perception of recent low exploitation from the relative F calculations. The spatial distribution patterns from the DFO survey are difficult to interpret due to the large DFO tows in 2008 and 2009. These individual large tows could be indicative of a change in behavior of this species on Georges Bank, although they have not occurred in any of the NEFSC surveys and did not occur in 2010. Truncated age structure in the surveys and change in distribution indicate current productivity may be limited relative to historical levels.

MANAGEMENT CONSIDERATIONS

This assessment is hampered by inconsistencies between the age structure of the catch and the age-specific indices of abundance. Although the catch of old fish has increased in recent years, it is still less than would be expected given the increases seen in the age-specific indices of abundance. The noisy character of the indices cause difficulty in tuning age structured models.

Although the Split Series VPA is used for management decisions, the mechanisms for the large changes in survey catchability are not easily explained. These changes in survey catchability are most appropriately thought of as aliasing an unknown mechanism that produces a better fitting model. The inability to plausibly explain these survey catchability changes causes increased uncertainty in this assessment relative to other assessments. Although the intention of the split series VPA was to eliminate the retrospective pattern, the pattern has re-emerged but at a lower magnitude primarily due to change in perception of the 2005 year class.

Consistent management by Canada and the US is required to ensure that conservation objectives are not compromised.

The change in perception of this stock from previous assessments can be seen by examining the historical retrospective analysis, which plots the results from previous assessments instead of peeling back years from the current assessment (Fig. 33). The historical retrospective analysis incorporates all data and model formulation changes as well as the number of years in the assessment. The change in the strength of the 2005 year class (shown at age-1 in 2006 in the recruitment panel) is the cause of the change in perception, similar to the assessment retrospective analysis. The reduction in the 2005 year class translates into a reduced SSB and a higher fishing mortality rate than estimated in previous assessments. As noted in the 2009 TRAC assessment referring to the 2005 year class "The results of next year's assessment should indicate whether or not this strong cohort continues to contribute significantly to the adult and spawning stock biomass." Since none of the surveys now determine the 2005 year class to be strong, and the catch was not dominated by this year class in the past year, the model estimates an average instead of strong 2005 year class.

Another way to examine the impact of the change in perception of the 2005 year class is to compare the proportion of yield and biomass expected from this year class from projections of previous assessments with that now estimated. In the 2009 assessment, the 2005 year class was expected to account for 58-59% of the 2009 catch (in weight), 47-51% of the 2010 catch, and 40-44% of the 2010 age 3+ biomass. The current assessment estimates the 2005 year class to account for 40% of the 2009 catch, 33% of the 2010 catch, and 32% of the 2010 age 3+ biomass, demonstrating that the 2005 year class is not as strong as previously estimated.

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Table 1. Annual catch (mt) of Georges Bank yellowtail flounder. The bold cells indicate updated estimates of US landings for 2007 (previous value was 1061 mt).

Year	US Landings	US Discards	Canada Landings	Canada Discards	Other Landings	Total Catch	% discards
1935	300	100	0	0	0	400	25%
1936	300	100	0	0	0	400	25%
1937	300	100	0	0	0	400	25%
1938	300	100	0	0	0	400	25%
1939	375	125	0	0	0	500	25%
1940	600	200	0	0	0	800	25%
1941	900	300	0	0	0	1200	25%
1942	1575	525	0	0	0	2100	25%
1943	1275	425	0	0	0	1700	25%
1944	1725	575	0	0	0	2300	25%
1945	1425	475	0	0	0	1900	25%
1946	900	300	0	0	0	1200	25%
1947	2325	775	0	0	0	3100	25%
1948	5775	1925	0	0	0	7700	25%
1949	7350	2450	0	0	0	9800	25%
1950	3975	1325	0	0	0	5300	25%
1951	4350	1450	0	0	0	5800	25%
1952	3750	1250	0	0	0	5000	25%
1953	2925	975	0	0	0	3900	25%
1954	2925	975	0	0	0	3900	25%
1955	2925	975	0	0	0	3900	25%
1956	1650	550	0	0	0	2200	25%
1957	2325	775	0	0	0	3100	25%
1958	4575	1525	0	0	0	6100	25%
1959	4125	1375	0	0	0	5500	25%
1960	4425	1475	0	0	0	5900	25%
1961	4275	1425	0	0	0	5700	25%
1962	5775	1925	0	0	0	7700	25%
1963	10990	5600	0	0	100	16690	34%
1964	14914	4900	0	0	0	19814	25%
1965	14248	4400	0	0	800	19448	23%
1966	11341	2100	0	0	300	13741	15%
1967	8407	5500	0	0	1400	15307	36%
1968	12799	3600	122	0	1800	18321	20%
1969	15944	2600	327	0	2400	21271	12%
1970	15506	5533	71	0	300	21410	26%
1971	11878	3127	105	0	500	15610	20%
1972	14157	1159	8	515	2200	18039	9%
1973	15899	364	12	378	300	16953	4%
1974	14607	980	5	619	1000	17211	9%
1975	13205	2715	8	722	100	16750	21%
1976	11336	3021	12	619	0	14988	24%
1977	9444	567	44	584	0	10639	11%
1978	4519	1669	69	687	0	6944	34%

Table 1. continued

Year	US Landings	US Discards	Canada Landings	Canada Discards	Other Landings	Total Catch	% discards
1979	5475	720	19	722	0	6935	21%
1980	6481	382	92	584	0	7539	13%
1981	6182	95	15	687	0	6979	11%
1982	10621	1376	22	502	0	12520	15%
1983	11350	72	106	460	0	11989	4%
1984	5763	28	8	481	0	6280	8%
1985	2477	43	25	722	0	3267	23%
1986	3041	19	57	357	0	3474	11%
1987	2742	233	69	536	0	3580	21%
1988	1866	252	56	584	0	2759	30%
1989	1134	73	40	536	0	1783	34%
1990	2751	818	25	495	0	4089	32%
1991	1784	246	81	454	0	2564	27%
1992	2859	1873	65	502	0	5299	45%
1993	2089	1089	682	440	0	4300	36%
1994	1431	148	2139	440	0	4158	14%
1995	360	43	464	268	0	1135	27%
1996	743	96	472	388	0	1700	28%
1997	888	327	810	438	0	2464	31%
1998	1619	482	1175	708	0	3985	30%
1999	1818	577	1971	597	0	4963	24%
2000	3373	694	2859	415	0	7341	15%
2001	3613	78	2913	815	0	7419	12%
2002	2476	53	2642	493	0	5663	10%
2003	3236	410	2107	809	0	6562	19%
2004	5837	460	96	422	0	6815	13%
2005	3161	414	30	246	0	3851	17%
2006	1196	384	25	504	0	2109	42%
2007	**1072**	503	17	94	0	1686	35%
2008	748	370	41	117	0	1275	38%
2009	975	715	5	84	0	1778	45%

Table 2. Derivation of Georges Bank yellowtail flounder US discards (mt) calculated as the product of the ratio estimator (d:k – discard to kept all species on a trip in a stratum) and total kept (K_all) in each stratum. Coefficient of variation (CV) provided by gear and year.

		Small Mesh Trawl					Large Mesh Trawl					Scallop Dredge					Total
Year	**Half**	**ntrips**	**d:k**	**K_all (mt)**	**D (mt)**	**CV**	**ntrips**	**d:k**	**K_all (mt)**	**D (mt)**	**CV**	**ntrips**	**d:k**	**K_all (mt)**	**D (mt)**	**CV**	**D (mt)**
1994	1	1	0.0000	1090	0		16	0.0013	7698	10		1	0.0001	2739	0		11
	2	1	0.0000	1316	0		6	0.0199	6445	128		4	0.0039	2531	10		138
1994 Total		**2**			**0**	**0%**	**22**			**138**	**150%**	**5**			**10**	**6%**	**148**
1995	1	1	0.0000	2331	0		27	0.0023	6256	14		1	0.0017	522	1		15
	2	1	0.0000	919	0		10	0.0055	3844	21		2	0.0017	3634	6		28
1995 Total		**2**			**0**	**0%**	**37**			**36**	**70%**	**3**			**7**	**20%**	**43**
1996	1	2	0.0000	3982	0		12	0.0066	7094	47		2	0.0025	2132	5		52
	2	1	0.0000	1470	0		1	0.0005	7269	4		2	0.0081	4960	40		44
1996 Total		**3**			**0**	**0%**	**13**			**51**	**30%**	**4**			**45**	**0%**	**96**
1997	1	1	0.0000	2102	0		3	0.0247	8215	203		3	0.0048	4044	19		222
	2			1391	0		3	0.0019	4098	8		3	0.0250	3903	97		105
1997 Total		**1**			**0**	**0%**	**6**			**211**	**22%**	**6**			**117**	**74%**	**327**
1998	1	1	0.0000	1808	0		3	0.0219	8059	177		2	0.0065	3849	25		202
	2			3111	0		2	0.0015	5611	8		3	0.0551	4945	272		280
1998 Total		**1**			**0**	**0%**	**5**			**185**	**66%**	**5**			**297**	**46%**	**482**
1999	1	1	0.0000	3868	0		2	0.0010	9391	9		4	0.0152	8806	134		143
	2			2638	0		5	0.0005	4755	2		15	0.0176	24524	432		434
1999 Total		**1**			**0**	**0%**	**7**			**11**	**67%**	**19**			**566**	**13%**	**577**
2000	1	2	0.0000	3665	0		6	0.0014	10869	15		25	0.0457	8320	380		395
	2	2	0.0272	1665	0		11	0.0015	6421	10		154	0.0181	15991	289		299
2000 Total		**4**			**0**	**90%**	**17**			**25**	**71%**	**179**			**669**	**12%**	**694**
2001	1	5	0.0045	2347	0		13	0.0038	13047	49		16	0.0019	7728	14		63
	2	2	0.0000	3461	0		13	0.0002	6716	1			0.0019	7162	13		15
2001 Total		**7**			**0**	**105%**	**26**			**50**	**51%**	**16**			**28**	**7%**	**78**
2002	1	1	0.0000	2420	0		11	0.0010	14525	14			0.0035	2074	7		21
	2	6	0.0001	2243	0		37	0.0015	6196	10		4	0.0035	6134	22		31
2002 Total		**7**			**0**	**79%**	**48**			**24**	**42%**	**4**			**29**	**27%**	**53**
2003	1	7	0.0001	2350	0		61	0.0064	15264	97			0.0149	9612	143		241
	2	7	0.0002	4764	1		46	0.0021	8438	18		2	0.0149	10083	150		169
2003 Total		**14**			**1**	**95%**	**107**			**115**	**39%**	**2**			**293**	**0%**	**410**
2004	1	5	0.0005	2504	1		68	0.0078	14130	111		2	0.0001	2942	0		112
	2	12	0.0215	2508	54		86	0.0179	11958	214		28	0.0058	13885	81		348
2004 Total		**17**			**55**	**62%**	**154**			**324**	**20%**	**30**			**81**	**21%**	**460**

Table 2. continued

		Small Mesh Trawl					Large Mesh Trawl					Scallop Dredge					Total
Year	Half	ntrips	d:k	K_all (mt)	D (mt)	CV	ntrips	d:k	K_all (mt)	D (mt)	CV	ntrips	d:k	K_all (mt)	D (mt)	CV	D (mt)
2005	1	41	0.0206	1448	30		369	0.0092	9935	92		8	0.0032	8217	27		148
	2	36	0.0068	3207	22		200	0.0094	8988	85		55	0.0041	38751	159		266
2005 Total		**77**			**52**	**28%**	**569**			**177**	**12%**	**63**			**186**	**20%**	**414**
2006	1	11	0.0004	824	0		182	0.0074	7008	52		13	0.0015	20457	30		83
	2	6	0.0127	1995	25		121	0.0111	4963	55		54	0.0056	39378	221		301
2006 Total		**17**			**26**	**95%**	**303**			**107**	**14%**	**67**			**251**	**19%**	**384**
2007	1	8	0.0016	3501	5		147	0.0166	8366	139		17	0.0031	13186	40		185
	2	3	0.0469	2261	106		156	0.0237	5548	132		42	0.0036	22413	81		319
2007 Total		**11**			**111**	**107%**	**303**			**270**	**12%**	**59**			**121**	**25%**	**503**
2008	1	4	0.0000	1589	0		184	0.0230	5603	129		20	0.0067	6721	45		174
	2	4	0.0221	1043	23		212	0.0144	5960	86		22	0.0078	11109	87		196
2008 Total		**8**			**23**	**297%**	**396**			**215**	**7%**	**42**			**132**	**15%**	**370**
2009	1	10	0.0000	882	0		181	0.0338	8098	274		36	0.0079	12183	97		371
	2	13	0.0157	748	12		156	0.0385	8226	317		22	0.0013	11666	15		344
2009 Total		**23**			**12**	**71%**	**337**			**591**	**13%**	**58**			**112**	**16%**	**715**

Table 3. Port samples used in the estimation of landings at age for Georges Bank yellowtail flounder in 2009 from US and Canadian sources.

	Landings (metric tons)					Port Sampling (Number of Lengths or Ages)						
USA	Market Category					Market Category					Lengths	Number
Half	Uncl.	Large	Small	Medium	Total	Uncl.	Large	Small	Medium	Total	per 100mt	of Ages
1	12	531	90	4	637	0	2737	3162	0	5899		1428
2	8	278	47	4	337	0	3570	2939	0	6509		1455
Total	20	809	137	8	974	0	6307	6101	0	12408	1274	2883
Canada											Lengths	Number
Quarter					Total					Total	per 100mt	of Ages
1												
2					4							
3					1							
4												
Total					5					0	0	0

Table 4. Georges Bank yellowtail flounder coefficient of variation for US landings at age by year.

Year	age 1	age 2	age 3	age 4	age 5	age 6+
1994		57%	6%	14%	27%	41%
1995		27%	11%	13%	22%	40%
1996		23%	7%	15%	26%	60%
1997		17%	11%	8%	30%	35%
1998		64%	31%	16%	36%	30%
1999	97%	21%	9%	25%	33%	34%
2000		11%	9%	11%	20%	32%
2001		17%	11%	10%	22%	48%
2002	76%	15%	11%	11%	15%	22%
2003		16%	8%	9%	11%	16%
2004		53%	8%	6%	9%	11%
2005		11%	4%	6%	12%	16%
2006		10%	5%	6%	6%	13%
2007		12%	5%	6%	14%	18%
2008		16%	4%	6%	17%	34%
2009		5%	2%	2%	2%	12%

Table 5. Total catch at age including discards (number in 000s of fish) for Georges Bank yellowtail flounder.

	Age												
Year	1	2	3	4	5	6	7	8	9	10	11	12	**Total**
1973	359	5175	13565	9473	3815	1285	283	55	23	4	0	0	34037
1974	2368	9500	8294	7658	3643	878	464	106	71	0	0	0	32982
1975	4636	26394	7375	3540	2175	708	327	132	26	14	0	0	45328
1976	635	31938	5502	1426	574	453	304	95	54	11	2	0	40993
1977	378	9094	10567	1846	419	231	134	82	37	10	0	0	22799
1978	9962	3542	4580	1914	540	120	45	16	17	7	6	0	20748
1979	321	10517	3789	1432	623	167	95	31	27	1	3	0	17006
1980	318	3994	9685	1538	352	96	5	11	1	0	0	0	16000
1981	107	1097	5963	4920	854	135	5	2	3	0	0	0	13088
1982	2164	18091	7480	3401	1095	68	20	7	0	0	0	0	32327
1983	703	7998	16661	2476	680	122	13	16	4	0	0	0	28672
1984	514	2018	4535	5043	1796	294	47	39	0	0	0	0	14285
1985	970	4374	1058	818	517	73	8	0	0	0	0	0	7817
1986	179	6402	1127	389	204	80	17	15	0	1	0	0	8414
1987	156	3284	3137	983	192	48	38	26	25	0	0	0	7890
1988	499	3003	1544	846	227	24	26	3	0	0	0	0	6172
1989	190	2175	1121	428	110	18	12	0	0	0	0	0	4054
1990	231	2114	6996	978	140	21	6	0	0	0	0	0	10485
1991	663	147	1491	3011	383	67	4	0	0	0	0	0	5767
1992	2414	9167	2971	1473	603	33	7	1	1	0	0	0	16671
1993	5233	1386	3327	2326	411	84	5	1	0	0	0	0	12773
1994	71	1336	6302	1819	477	120	20	3	0	0	0	0	10150
1995	47	313	1435	879	170	25	10	1	0	0	0	0	2880
1996	101	681	2064	885	201	13	10	5	0	0	0	0	3960
1997	82	1132	1832	1857	378	39	43	7	1	0	0	0	5371
1998	169	1991	3388	1885	1121	122	18	3	0	3	0	0	8700
1999	60	2753	4195	1548	794	264	32	4	1	0	0	0	9651
2000	132	3864	5714	3173	826	420	66	38	4	0	0	0	14237
2001	176	2884	6956	2893	1004	291	216	13	4	0	0	0	14438
2002	212	4169	3446	1916	683	269	144	57	10	6	0	0	10911
2003	160	3919	4710	2320	782	282	243	96	47	23	2	0	12585
2004	61	1152	3184	3824	1970	889	409	78	74	18	2	0	11661
2005	60	1579	4031	1707	392	132	37	16	0	0	0	0	7954
2006	152	1293	1626	947	364	124	66	14	7	3	0	0	4596
2007	53	1527	1735	663	140	46	10	1	0	0	0	0	4174
2008	28	438	1605	723	109	14	5	0	0	0	0	0	2922
2009	17	279	1254	1337	506	58	11	3	0	0	0	0	3466

Table 6. Mean weight at age (kg) for the total catch including US and Canadian discards, for Georges Bank yellowtail flounder.

	Age											
Year	1	2	3	4	5	6	7	8	9	10	11	12
1973	0.101	0.348	0.462	0.527	0.603	0.690	1.063	1.131	1.275	1.389	1.170	
1974	0.115	0.344	0.496	0.607	0.678	0.723	0.904	1.245	1.090		1.496	1.496
1975	0.113	0.316	0.489	0.554	0.619	0.690	0.691	0.654	1.052	0.812		
1976	0.108	0.312	0.544	0.635	0.744	0.813	0.854	0.881	1.132	1.363	1.923	
1977	0.116	0.342	0.524	0.633	0.780	0.860	1.026	1.008	0.866	0.913		
1978	0.102	0.314	0.510	0.690	0.803	0.903	0.947	1.008	1.227	1.581	0.916	
1979	0.114	0.329	0.462	0.656	0.736	0.844	0.995	0.906	1.357	1.734	1.911	
1980	0.101	0.322	0.493	0.656	0.816	1.048	1.208	1.206	1.239			
1981	0.122	0.335	0.489	0.604	0.707	0.821	0.844	1.599	1.104			
1982	0.115	0.301	0.485	0.650	0.754	1.065	1.037	1.361				
1983	0.140	0.296	0.441	0.607	0.740	0.964	1.005	1.304	1.239			
1984	0.162	0.239	0.379	0.500	0.647	0.743	0.944	1.032				
1985	0.181	0.361	0.505	0.642	0.729	0.808	0.728					
1986	0.181	0.341	0.540	0.674	0.854	0.976	0.950	1.250		1.686		
1987	0.121	0.324	0.524	0.680	0.784	0.993	0.838	0.771	0.809			
1988	0.103	0.328	0.557	0.696	0.844	1.042	0.865	1.385				
1989	0.100	0.327	0.520	0.720	0.866	0.970	1.172	1.128				
1990	0.105	0.290	0.395	0.585	0.693	0.787	1.057					
1991	0.121	0.237	0.369	0.486	0.723	0.850	1.306					
1992	0.101	0.293	0.365	0.526	0.651	1.098	1.125	1.303	1.303			
1993	0.100	0.285	0.379	0.501	0.564	0.843	1.130	1.044				
1994	0.193	0.260	0.353	0.472	0.621	0.780	0.678	1.148				
1995	0.174	0.275	0.347	0.465	0.607	0.720	0.916	0.532				
1996	0.119	0.276	0.407	0.552	0.707	0.918	1.031	1.216				
1997	0.214	0.302	0.408	0.538	0.718	1.039	0.827	1.136	1.113			
1998	0.178	0.305	0.428	0.546	0.649	0.936	1.063	1.195		1.442		
1999	0.202	0.368	0.495	0.640	0.755	0.870	1.078	1.292	1.822			
2000	0.229	0.383	0.480	0.615	0.766	0.934	1.023	1.023	1.296			
2001	0.251	0.362	0.460	0.612	0.812	1.011	1.024	1.278	1.552			
2002	0.282	0.381	0.480	0.665	0.833	0.985	1.100	1.286	1.389	1.483		
2003	0.228	0.359	0.474	0.653	0.824	0.957	1.033	1.144	1.267	1.418	1.505	
2004	0.211	0.292	0.438	0.585	0.726	0.883	1.002	1.192	1.222	1.305	1.421	
2005	0.119	0.341	0.447	0.597	0.763	0.965	0.993	1.198	1.578	1.578		
2006	0.100	0.310	0.415	0.557	0.761	0.917	1.066	1.185	1.263	1.224	1.599	
2007	0.148	0.291	0.409	0.539	0.785	0.970	1.244	1.216				
2008	0.042	0.300	0.414	0.533	0.687	0.903	1.015					
2009	0.153	0.329	0.434	0.537	0.700	0.882	1.070	1.323				

Table 7. Length based calibration factors for yellowtail flounder (see Brooks et al. 2010 for details of derivation). Numbers at length from Henry Bigelow tows should be divided by the calibration factor in the corresponding length bin. It is recommended that these calibration factors be applied with all 6 digits to the right of the decimal point.

Length	Calibration
≤18	3.857302
19	3.857302
20	3.857302
21	3.621597
22	3.385892
23	3.150187
24	2.914482
25	2.678777
26	2.443072
27	2.207367
28	1.971662
29	1.971657
≥30	1.971657

Table 8a. DFO spring survey indices of minimum swept area abundance for Georges Bank yellowtail flounder in thousands of fish and thousands of metric tons. Note that two vectors are presented for 2008 and 2009: 2008a and 2009a include the large tows while 2008b and 2009b do not.

Year	age1	age2	age3	age4	age5	age6+	B(000 mt)
1987	75.2	751.1	1238.5	309.7	54.9	30.9	1.250
1988	0.0	1116.5	801.9	383.6	174.9	14.8	1.235
1989	71.8	645.8	383.2	185.2	41.8	14.1	0.471
1990	0.0	1500.9	2281.1	575.0	131.3	8.6	1.513
1991	15.4	539.6	745.8	2364.1	330.3	9.1	1.758
1992	34.8	6942.1	2312.0	622.4	219.8	18.8	2.475
1993	49.4	1528.8	2568.8	2562.9	557.5	81.8	2.642
1994	0.0	3808.4	2178.6	1890.1	491.4	130.0	2.753
1995	132.0	786.5	2737.4	1600.8	406.6	63.6	2.027
1996	280.5	4491.0	5769.2	3399.8	726.5	77.2	5.303
1997	13.6	7849.2	8742.1	10293.6	2543.2	421.5	13.293
1998	561.7	2094.3	3085.9	2725.6	1250.4	351.2	4.293
1999	99.8	13118.5	13101.2	4822.9	3364.5	1383.5	17.666
2000	6.8	8655.8	17256.5	12100.9	3187.6	2319.8	19.949
2001	183.3	12511.6	26489.4	8368.0	2881.0	1507.2	22.158
2002	55.5	7522.3	19503.3	7693.6	3491.7	1781.4	20.699
2003	56.3	7476.4	15480.7	6971.1	2151.0	1249.9	16.249
2004	20.6	2263.5	10225.3	5788.7	1429.2	890.5	9.054
2005	377.3	1007.5	17581.9	12931.4	3581.9	983.8	13.357
2006	391.5	3076.8	11696.4	4132.7	515.4	149.4	6.579
2007	108.9	7646.4	17423.7	8048.5	1439.1	156.2	13.344
2008a	0.0	30382.5	107131.7	35919.3	5067.8	34.5	67.319
2008b	0.0	2907.3	6882.8	1964.6	367.1	35.9	4.105
2009a	13.4	5370.4	86753.6	73553.8	12513.9	2996.1	72.044
2009b	13.4	1184.0	16326.6	16738.5	3568.2	613.0	15.703
2010	0.0	307.6	5906.1	13170.2	2221.7	804.5	9.138

Table 8b. NEFSC spring survey indices of minimum swept area abundance for Georges Bank yellowtail flounder in thousands of fish and thousands of metric tons. (Note that values for 2009 and 2010 converted from Bigelow to Albatross units.)

Year	age1	age2	age3	age4	age5	age6+	B (000 mt)
1968	181.2	3227.3	3474.3	295.2	70.9	300.8	2.709
1969	1046.8	9067.8	10793.9	3081.4	1305.2	678.2	10.842
1970	78.4	4364.8	5853.3	2350.9	553.0	302.0	4.994
1971	810.4	3412.9	4671.6	3202.9	757.1	310.6	4.483
1972	137.0	6719.3	6843.1	3595.8	1093.7	232.0	6.266
1973	1882.9	3184.3	2309.4	1036.7	399.4	210.2	2.852
1974	308.2	2168.5	1795.5	1225.0	336.9	273.8	2.640
1975	409.2	2918.0	809.1	262.6	201.5	86.3	1.626
1976	1008.4	4259.0	1216.0	302.4	191.2	108.4	2.206
1977	0.0	654.0	1097.7	363.7	81.9	12.8	0.970
1978	912.2	778.4	494.4	213.9	25.7	7.7	0.720
1979	394.0	1956.8	395.2	328.3	58.7	88.7	1.234
1980	55.3	4528.6	5617.2	460.6	55.0	35.3	4.325
1981	11.4	995.9	1724.2	698.9	206.9	56.9	1.903
1982	44.1	3656.5	1096.5	992.5	444.5	88.3	2.426
1983	0.0	1810.0	2647.8	514.4	119.6	237.3	2.564
1984	0.0	90.3	806.0	837.9	810.4	236.5	1.598
1985	106.4	2134.2	254.4	273.4	143.4	0.0	0.959
1986	26.6	1753.0	282.6	54.6	132.9	53.2	0.823
1987	26.6	73.3	133.0	129.3	51.0	53.2	0.319
1988	75.5	266.9	355.2	234.7	193.2	26.6	0.549
1989	45.2	391.3	737.7	281.0	59.3	43.5	0.708
1990	0.0	63.7	1074.7	358.4	112.2	100.8	0.678
1991	422.5	0.0	246.9	665.1	255.5	20.0	0.612
1992	0.0	1987.7	1840.7	621.8	160.0	16.7	1.520
1993	44.7	281.1	485.8	307.9	26.0	0.0	0.468
1994	0.0	602.3	614.7	343.6	140.4	38.7	0.641
1995	39.0	1144.6	4670.4	1441.7	621.5	9.5	2.504
1996	24.4	958.1	2548.6	2621.8	591.6	56.2	2.769
1997	18.2	1134.5	3623.1	3960.7	682.3	129.7	4.231
1998	0.0	2020.1	1022.2	1123.4	737.1	339.6	2.256
1999	48.7	4606.3	10501.7	2640.5	1575.2	756.3	9.033
2000	177.3	4677.6	7440.5	2828.5	789.2	508.4	6.499
2001	0.0	2246.7	6370.5	2340.0	469.2	439.7	4.859
2002	182.4	2341.5	11971.1	3958.4	1690.3	845.4	9.282
2003	196.1	4241.4	6564.9	2791.9	428.6	836.9	6.524
2004	47.1	957.3	2114.4	659.9	247.7	263.8	1.835
2005	0.0	1953.5	4931.0	2332.7	261.8	111.4	3.307
2006	493.5	907.8	3419.2	2112.7	307.7	79.8	2.349
2007	87.1	4899.7	6079.1	2762.3	540.0	125.2	4.563
2008	0.0	2206.7	4921.5	1681.1	300.3	26.6	3.152
2009	218.8	546.4	6978.7	4456.8	964.1	186.3	4.619
2010	16.5	662.8	5181.0	8057.2	2584.0	613.9	5.662

Table 8c. NEFSC fall survey indices of minimum swept area abundance for Georges Bank yellowtail flounder in thousands of fish and thousands of metric tons. (Note that values for 2009 converted from Bigelow to Albatross units.)

Year	age1	age2	age3	age4	age5	age6+	B (000 mt)
1963.5	14289.1	7663.6	10897.1	1804.0	480.5	532.7	12.413
1964.5	1671.3	9517.3	7097.2	5791.2	2634.2	473.3	13.168
1965.5	1162.1	5537.0	5811.9	3427.8	1600.9	250.6	8.852
1966.5	11320.3	2184.4	1635.3	871.9	98.3	0.0	3.813
1967.5	8720.8	9131.0	2646.7	1006.7	299.3	132.3	7.445
1968.5	11328.3	11702.5	5588.9	722.7	936.8	56.4	10.227
1969.5	9656.7	10601.8	5064.1	1757.4	327.0	447.7	9.519
1970.5	4474.9	4981.2	3051.2	1894.7	438.2	77.8	4.833
1971.5	3520.0	6770.9	4769.9	2183.8	483.4	289.1	6.178
1972.5	2416.9	6332.8	4682.3	2032.9	592.1	331.7	6.142
1973.5	2420.4	5336.0	4954.5	2857.4	1181.2	599.9	6.299
1974.5	4486.7	2779.5	1471.6	1029.1	444.3	368.1	3.561
1975.5	4548.6	2437.3	851.7	555.2	324.4	61.1	2.257
1976.5	333.5	1863.9	460.3	113.6	118.5	97.3	1.463
1977.5	906.7	2147.1	1572.8	615.4	102.3	105.7	2.699
1978.5	4620.6	1243.3	757.2	399.2	131.6	34.9	2.274
1979.5	1282.0	2008.5	253.7	116.7	134.3	108.6	1.450
1980.5	743.6	4970.0	5912.0	662.0	212.3	250.9	6.412
1981.5	1548.2	2279.4	1592.8	570.5	76.4	52.8	2.500
1982.5	2353.3	2120.3	1543.4	410.4	86.6	0.0	2.203
1983.5	105.7	2216.4	1858.5	495.7	29.9	47.7	2.068
1984.5	641.6	388.1	296.7	236.0	72.7	60.7	0.576
1985.5	1310.2	527.5	165.9	49.1	78.3	0.0	0.688
1986.5	273.4	1075.1	338.7	71.9	0.0	0.0	0.796
1987.5	98.7	388.8	384.6	51.4	77.1	0.0	0.494
1988.5	18.2	206.7	104.0	26.6	0.0	0.0	0.165
1989.5	241.0	1934.1	750.4	76.6	54.0	0.0	0.948
1990.5	0.0	359.2	1429.9	285.8	0.0	0.0	0.703
1991.5	2038.8	267.0	426.2	347.2	0.0	0.0	0.708
1992.5	146.8	383.9	691.0	157.1	139.4	26.6	0.559
1993.5	814.6	135.2	568.8	520.4	0.0	21.4	0.529
1994.5	1159.8	214.6	954.1	692.2	254.9	54.8	0.871
1995.5	267.7	115.4	335.2	267.2	44.6	12.1	0.344
1996.5	144.3	341.3	1813.8	433.5	72.7	0.0	1.265
1997.5	1351.8	517.7	3341.0	2028.5	1039.8	79.8	3.670
1998.5	1844.4	4675.3	4078.9	1154.6	289.5	71.7	4.220
1999.5	2998.7	8175.9	5558.9	1390.3	1394.2	252.8	7.738

Table 8c. continued

Year	age1	age2	age3	age4	age5	age6+	B (000 mt)
2000.5	610.8	1647.5	4672.5	2350.3	919.7	802.6	5.666
2001.5	3414.2	6083.6	7853.7	2524.8	1667.8	1988.2	11.213
2002.5	2031.4	5581.8	2064.5	576.1	295.6	26.6	3.644
2003.5	1045.3	4882.8	2725.9	548.0	97.0	185.7	3.919
2004.5	850.3	5346.1	4862.4	2044.4	897.1	170.7	4.966
2005.5	304.0	2033.6	3652.1	595.9	179.3	0.0	2.391
2006.5	6012.1	6067.2	3556.7	1132.9	247.7	44.4	4.388
2007.5	1026.5	11110.9	7634.7	1939.6	371.3	90.9	7.912
2008.5	162.8	6963.2	9592.7	1002.8	0.0	0.0	6.900
2009.5	445.8	4169.4	11531.5	2072.0	588.3	57.9	6.797

Table 8d. NEFSC scallop survey index of abundance (stratified mean #/tow in numbers) for Georges Bank yellowtail flounder and index of total biomass (stratified mean kg/tow). Note the values for 1989 and 1999 are considered too uncertain for use as a tuning index and the 1986, 2000, and 2008 surveys did not fully cover the Canadian portion of Georges Bank (D. Hart, pers. comm.).

Year	age1	age2	age3	age4	age5	age6+	B (kg/tow)
1982.5	0.4254	0.6043	0.2588	0.1236	0.0406	0.0000	0.527
1983.5	0.0695	0.6963	0.5182	0.0956	0.0127	0.0312	0.699
1984.5	0.3698	0.1231	0.0757	0.1081	0.0391	0.0071	0.244
1985.5	0.5043	0.2212	0.0085	0.0163	0.0170	0.0000	0.143
1986.5							
1987.5	0.0990	0.1328	0.0941	0.0244	0.0069	0.0029	0.187
1988.5	0.0300	0.1077	0.0363	0.0430	0.0377	0.0000	0.108
1989.5							
1990.5	0.0000	0.1339	0.3401	0.0718	0.0141	0.0114	0.245
1991.5	1.8964	0.0208	0.1506	0.1175	0.0168	0.0000	0.377
1992.5	0.3088	0.1724	0.3781	0.1137	0.0696	0.0091	0.409
1993.5	1.1937	0.1289	0.2674	0.1963	0.0046	0.0091	0.427
1994.5	1.4744	0.2180	0.4653	0.2787	0.0780	0.0207	0.603
1995.5	0.5540	0.4299	0.7900	0.5115	0.1015	0.0121	0.846
1996.5	0.2248	0.5565	1.0252	0.5680	0.2122	0.0052	1.271
1997.5	1.0842	0.3110	1.3387	0.7959	0.2111	0.0299	1.659
1998.5	1.8253	1.0909	0.9954	0.7044	0.3290	0.0641	2.041
1999.5							
2000.5							
2001.5	0.9518	0.5907	0.9604	0.3694	0.1470	0.1345	1.525
2002.5	0.8838	0.3517	0.7741	0.3561	0.2272	0.1278	1.336
2003.5	0.7506	0.8302	0.8784	0.4788	0.1162	0.1506	1.783
2004.5	0.3904	0.5192	0.5111	0.1971	0.0774	0.0315	0.777
2005.5	0.4913	0.4154	0.5457	0.1850	0.0669	0.0090	0.623
2006.5	2.2406	0.9730	0.4886	0.1921	0.0237	0.0267	0.880
2007.5	0.5184	1.9402	0.8929	0.2327	0.0434	0.0035	1.265
2008.5							
2009.5	0.2126	0.2289	0.8925	0.4029	0.0886	0.0090	0.719

Table 9. Statistical properties of estimates for population abundance and survey calibration constants (scallop x10^3) for Georges Bank yellowtail flounder for the Split Series VPA.

		Bootstrap			
Age	Estimate	Standard Error	Relative Error	Bias	Relative Bias
	Population Abundance				
2	4980	1891	38%	316	6%
3	5245	2018	38%	384	7%
4	10724	3055	28%	313	3%
5	7338	1379	19%	82	1%
	Survey Calibration Constants				
DFO Survey: 1987-1994					
2	0.145	0.045	31%	0.007	5%
3	0.232	0.032	14%	0.002	1%
4	0.389	0.070	18%	0.006	1%
5	0.436	0.094	22%	0.011	3%
6+	0.254	0.062	24%	0.006	2%
DFO Survey: 1995-2010					
2	0.355	0.084	24%	0.009	2%
3	1.621	0.288	18%	0.026	2%
4	2.048	0.352	17%	0.016	1%
5	1.646	0.370	22%	0.032	2%
6+	1.105	0.232	21%	0.032	3%
NMFS Spring Survey: Yankee 41, 1973-1981					
1	0.007	0.006	87%	0.002	23%
2	0.076	0.013	18%	0.001	1%
3	0.096	0.016	17%	0.002	2%
4	0.093	0.011	12%	0.000	0%
5	0.076	0.015	19%	0.002	2%
6+	0.072	0.023	33%	0.003	4%
NMFS Spring Survey: Yankee 36, 1982-1994					
1	0.004	0.001	24%	0.000	2%
2	0.046	0.015	34%	0.002	5%
3	0.095	0.014	15%	0.001	1%
4	0.152	0.019	12%	0.001	1%
5	0.229	0.044	19%	0.005	2%
6+	0.423	0.090	21%	0.015	4%

Table 9. continued

		Bootstrap			
Age	Estimate	Standard Error	Relative Error	Bias	Relative Bias
NMFS Spring Survey: Yankee 36, 1995-2010					
1	0.006	0.002	37%	0.000	7%
2	0.146	0.018	12%	0.000	0%
3	0.562	0.081	14%	0.001	0%
4	0.621	0.101	16%	0.007	1%
5	0.501	0.099	20%	0.010	2%
6+	0.420	0.073	17%	0.004	1%
NMFS Fall Survey: 1973-1994					
1	0.040	0.010	25%	0.001	3%
2	0.088	0.014	16%	0.001	1%
3	0.150	0.016	10%	0.000	0%
4	0.156	0.020	13%	0.000	0%
5	0.205	0.042	20%	0.004	2%
6+	0.306	0.066	22%	0.009	3%
NMFS Fall Survey: 1995-2009					
1	0.065	0.015	23%	0.002	3%
2	0.260	0.083	32%	0.009	3%
3	0.612	0.104	17%	0.003	0%
4	0.461	0.085	18%	0.006	1%
5	0.495	0.128	26%	0.013	3%
6+	0.358	0.131	37%	0.026	7%
NMFS Scallop Survey: 1982-1994					
1	0.027	0.012	46%	0.002	8%
NMFS Scallop Survey: 1995-2009					
1	0.050	0.007	14%	0.000	1%

Table 10. Retrospective rho statistics for fishing mortality rate (ages 4+), spawning stock biomass, and age-1 recruitment based on seven peels. A peel is defined as removing annual data in succession with VPA repeated, e.g. peel 1 has a terminal year of 2008 and peel 2 has a terminal year of 2007.

Peel	F	SSB	R
1	-0.240	0.564	-0.439
2	-0.451	0.587	-0.151
3	-0.311	0.428	1.535
4	-0.067	0.631	-0.428
5	-0.011	0.652	0.321
6	1.332	-0.225	0.455
7	0.120	0.268	1.488
mean	0.05	0.41	0.40

Table 11. Beginning of year population abundance numbers (000s) for Georges Bank yellowtail flounder from the Split Series VPA.

	Age Group						
Year	1	2	3	4	5	6+	Total
1973	29384	24172	29516	17300	6966	3013	110351
1974	52184	23733	15136	12051	5732	2391	111229
1975	70632	40588	10930	5010	3079	1709	131948
1976	24731	53646	9852	2425	977	1562	93193
1977	17283	19674	15554	3171	719	850	57252
1978	54437	13809	7987	3390	956	373	80953
1979	25508	35604	8124	2468	1073	559	73336
1980	24034	20595	19711	3268	747	239	68594
1981	62997	19390	13268	7499	1302	221	104677
1982	22846	51480	14885	5535	1783	156	96685
1983	6581	16754	25937	5517	1514	345	56648
1984	10843	4755	6579	6472	2305	487	31441
1985	16749	8414	2089	1379	870	136	29636
1986	8473	12837	2991	767	402	224	25695
1987	9193	6776	4801	1440	282	201	22692
1988	22841	7386	2617	1153	309	73	34379
1989	9661	18250	3361	771	198	55	32296
1990	11217	7738	12981	1747	250	47	33980
1991	22557	8975	4437	4399	560	104	41032
1992	17518	17869	7215	2296	940	65	45903
1993	13938	12168	6459	3250	574	126	36515
1994	13179	6725	8713	2323	609	184	31732
1995	11670	10725	4304	1576	305	66	28647
1996	13468	9513	8499	2237	509	70	34294
1997	19793	10935	7174	5103	1039	246	44291
1998	22383	16131	7932	4227	2515	328	53516
1999	24521	18173	11413	3466	1777	675	60024
2000	19777	20022	12400	5586	1455	930	60170
2001	22217	16073	12916	5050	1752	916	58924
2002	15278	18031	10564	4381	1562	1110	50926
2003	10921	12317	11015	5559	1875	1662	43349
2004	8041	8797	6569	4808	2476	1848	32540
2005	14886	6529	6165	2538	583	275	30975
2006	23872	12134	3926	1477	568	334	42311
2007	22250	19407	8769	1760	370	150	52707
2008	8230	18169	14512	5619	847	148	47525
2009	6101	6713	14480	10435	3949	568	42246
2010		4980	5245	10724	7338	3176	

Table 12. Fishing mortality rate for Georges Bank yellowtail from the Split Series VPA.

	Age Group						
Year	1	2	3	4	5	6+	4-5
1973	0.01	0.27	0.70	0.90	0.90	0.90	0.90
1974	0.05	0.58	0.91	1.16	1.16	1.16	1.16
1975	0.08	1.22	1.31	1.43	1.43	1.43	1.43
1976	0.03	1.04	0.93	1.02	1.02	1.02	1.02
1977	0.02	0.70	1.32	1.00	1.00	1.00	1.00
1978	0.22	0.33	0.97	0.95	0.95	0.95	0.95
1979	0.01	0.39	0.71	0.99	0.99	0.99	0.99
1980	0.01	0.24	0.77	0.72	0.72	0.72	0.72
1981	0.00	0.06	0.67	1.24	1.24	1.24	1.24
1982	0.11	0.49	0.79	1.10	1.10	1.10	1.10
1983	0.13	0.73	1.19	0.67	0.67	0.67	0.67
1984	0.05	0.62	1.36	1.81	1.81	1.81	1.81
1985	0.07	0.83	0.80	1.03	1.03	1.03	1.03
1986	0.02	0.78	0.53	0.80	0.80	0.80	0.80
1987	0.02	0.75	1.23	1.34	1.34	1.34	1.34
1988	0.02	0.59	1.02	1.56	1.56	1.56	1.56
1989	0.02	0.14	0.45	0.93	0.93	0.93	0.93
1990	0.02	0.36	0.88	0.94	0.94	0.94	0.94
1991	0.03	0.02	0.46	1.34	1.34	1.34	1.34
1992	0.16	0.82	0.60	1.19	1.19	1.19	1.19
1993	0.53	0.13	0.82	1.47	1.47	1.47	1.47
1994	0.01	0.25	1.51	1.83	1.83	1.83	1.83
1995	0.00	0.03	0.45	0.93	0.93	0.93	0.93
1996	0.01	0.08	0.31	0.57	0.57	0.57	0.57
1997	0.00	0.12	0.33	0.51	0.51	0.51	0.51
1998	0.01	0.15	0.63	0.67	0.67	0.67	0.67
1999	0.00	0.18	0.51	0.67	0.67	0.67	0.67
2000	0.01	0.24	0.70	0.96	0.96	0.96	0.96
2001	0.01	0.22	0.88	0.97	0.97	0.97	0.97
2002	0.02	0.29	0.44	0.65	0.65	0.65	0.65
2003	0.02	0.43	0.63	0.61	0.61	0.61	0.61
2004	0.01	0.16	0.75	1.91	1.91	1.91	1.91
2005	0.00	0.31	1.23	1.30	1.30	1.30	1.30
2006	0.01	0.12	0.60	1.18	1.18	1.18	1.18
2007	0.00	0.09	0.25	0.53	0.53	0.53	0.53
2008	0.00	0.03	0.13	0.15	0.15	0.15	0.15
2009	0.00	0.05	0.10	0.15	0.15	0.15	0.15

Table 13. Beginning of year weight (kg) at age for Georges Bank yellowtail. The 2010 values are set equal to the average of the 2007-2009 values.

	Age Group					
Year	1	2	3	4	5	6+
1973	0.055	0.292	0.403	0.465	0.564	0.778
1974	0.069	0.186	0.416	0.530	0.598	0.832
1975	0.068	0.191	0.410	0.524	0.613	0.695
1976	0.061	0.188	0.415	0.557	0.642	0.861
1977	0.071	0.192	0.404	0.587	0.704	0.931
1978	0.057	0.191	0.418	0.601	0.713	0.970
1979	0.068	0.183	0.381	0.578	0.713	0.950
1980	0.056	0.192	0.403	0.551	0.732	1.072
1981	0.078	0.184	0.397	0.546	0.681	0.840
1982	0.072	0.192	0.403	0.564	0.675	1.082
1983	0.107	0.185	0.364	0.543	0.694	1.010
1984	0.109	0.183	0.335	0.470	0.627	0.797
1985	0.132	0.242	0.347	0.493	0.604	0.800
1986	0.135	0.248	0.442	0.583	0.741	1.015
1987	0.074	0.242	0.423	0.606	0.727	0.875
1988	0.058	0.199	0.425	0.604	0.758	0.975
1989	0.059	0.184	0.413	0.633	0.776	1.053
1990	0.070	0.170	0.359	0.552	0.706	0.845
1991	0.078	0.158	0.327	0.438	0.650	0.877
1992	0.060	0.188	0.294	0.441	0.563	1.110
1993	0.062	0.170	0.333	0.428	0.545	0.863
1994	0.162	0.161	0.317	0.423	0.558	0.775
1995	0.138	0.230	0.300	0.405	0.535	0.768
1996	0.075	0.219	0.335	0.438	0.573	1.012
1997	0.179	0.190	0.336	0.468	0.630	0.947
1998	0.124	0.256	0.360	0.472	0.591	0.966
1999	0.147	0.256	0.389	0.523	0.642	0.901
2000	0.182	0.278	0.420	0.552	0.700	0.954
2001	0.204	0.288	0.420	0.542	0.707	1.027
2002	0.250	0.309	0.417	0.553	0.714	1.068
2003	0.202	0.318	0.425	0.560	0.740	1.048
2004	0.166	0.258	0.397	0.527	0.689	0.956
2005	0.074	0.268	0.361	0.511	0.668	0.991
2006	0.059	0.192	0.376	0.499	0.674	0.996
2007	0.104	0.171	0.356	0.473	0.661	1.022
2008	0.015	0.211	0.347	0.467	0.609	0.932
2009	0.199	0.118	0.361	0.472	0.611	0.931
2010	0.106	0.166	0.355	0.470	0.627	0.962

Table 14. Beginning of year biomass (mt) and spawning stock biomass (mt) for Georges Bank yellowtail from the Split Series VPA.

	Beginning Biomass		
Year	1+	3+	SSB
1973	34860	26207	22161
1974	26134	18088	14780
1975	22722	10183	9014
1976	18984	7408	10024
1977	14447	9448	8350
1978	12145	6417	6169
1979	14069	5817	8500
1980	15820	10540	10885
1981	18891	10430	10143
1982	21995	10493	12973
1983	17637	13841	11103
1984	9122	7075	3846
1985	6283	2040	2558
1986	6629	2294	3211
1987	5599	3282	2749
1988	4904	2113	2197
1989	6004	2088	4169
1990	7946	5844	4750
1991	7003	3833	3485
1992	8154	3736	4473
1993	6893	3964	3965
1994	7444	4229	2824
1995	6229	2145	2941
1996	7276	4186	4991
1997	11305	5683	6380
1998	13543	6650	7260
1999	16246	7998	9594
2000	19370	10201	10263
2001	19490	10337	9262
2002	18519	9126	10127
2003	17042	10922	10083
2004	12213	8608	5541
2005	7035	4187	3497
2006	6660	2930	3538
2007	9980	4355	6219
2008	12264	8313	10562
2009	15089	13085	13966
2010		14561	

Table 15. Deterministic projection input assumptions and results for Georges Bank yellowtail for F_{ref} from the Split Series VPA.

	Age Group							
Year	1	2	3	4	5	6+	1+	3+
Jan-1 Population Numbers (000s)								
2010	13707	4980	5245	10724	7338	3176		
2011	13707	11195	3950	3905	7597	7449		
2012	13707	11176	8679	2744	2490	9594		
Partial Recruitment to the Fishery								
	0.017	0.219	0.657	1	1	1		
Fishing Mortality								
2010	0.002	0.032	0.095	0.145	0.145	0.145		
2011	0.004	0.055	0.164	0.250	0.250	0.250		
Jan-1 Weight for Population (kg)								
	0.106	0.166	0.355	0.470	0.627	0.962		
Maturity			Fraction of Z before Spawning =			0.4167		
	0	0.462	0.967	1	1	1		
Jan-1 Population Biomass (mt)								
2010	1453	828	1860	5045	4600	3055	16841	14560
2011	1453	1861	1401	1837	4762	7163	18478	15163
2012	1453	1858	3078	1291	1561	9226	18467	15155
Spawning Stock Biomass (mt)								
2010	0	641	1879	4982	4602	2646	14750	
2011	0	1426	1375	1736	4560	5939	15036	
Catch Numbers (000s)								
2010	30	141	432	1313	898	389		
2011	51	540	544	786	1529	1500		
Average Weight for Catch (kg)								
	0.114	0.307	0.419	0.536	0.724	0.962		
Fishery Yield (mt including discards)								
2010	3	43	181	704	650	374	**1956**	
2011	6	166	228	422	1107	1442	**3370**	

Table 16. Probability of spawning stock biomass being greater than 43,200 mt for a range of fishing mortality rates and projection years. The bolded cells correspond to the first four strategies in Table 19.

	Fishing Mortality Rate 2011-2020												
Year	0.00	0.04	0.05	0.06	0.07	0.08	0.09	0.10	0.11	0.12	0.13	0.14	0.15
2010	0	0	0	0	0	0	0	0	0	0	0	0	0
2011	0	0	0	0	0	0	0	0	0	0	0	0	0
2012	0	0	0	0	0	0	0	0	0	0	0	0	0
2013	0.106	0.077	0.071	0.066	0.059	0.053	0.049	0.044	0.040	0.035	0.031	0.028	0.025
2014	**0.357**	0.291	0.272	0.257	0.242	0.227	0.211	0.196	0.182	0.170	0.156	0.143	0.131
2015	0.638	0.544	0.522	0.499	0.477	0.454	0.434	0.410	0.386	0.364	0.343	0.319	0.297
2016	0.835	**0.748**	0.724	0.701	0.676	0.651	0.628	**0.603**	0.579	0.552	0.522	**0.494**	0.467
2017	0.929	0.865	0.842	0.823	0.803	0.780	0.757	0.731	0.700	0.672	0.645	0.617	0.587
2018	0.973	0.924	0.908	0.892	0.873	0.851	0.829	0.803	0.778	0.752	0.723	0.692	0.662
2019	0.989	0.957	0.945	0.931	0.914	0.895	0.874	0.851	0.826	0.798	0.771	0.740	0.707
2020	0.996	0.976	0.967	0.954	0.939	0.920	0.900	0.878	0.855	0.829	0.801	0.774	0.741

Table 17. Percentiles of the distributions of catch (mt) in 2011 under a range of strategies for rebuilding or harvest rates. The first four strategies correspond to US rebuilding options where year denotes the time and P(reb) the probability when the spawning stock biomass should be greater than 43,200 mt. The median catch values are bolded. Relative Change in B denotes the relative change in age 3+ Jan-1 biomass from 2011 to 2012 (used as a measure of the risk of stock increase).

				Catch 2011 (mt)									Relative
Strategy	Year	P(reb)	F	1%	5%	10%	25%	**50%**	75%	90%	95%	99%	Change B
Current	2014	75	NA	0	0	0	0	**0**	0	0	0	0	22.6%
Option A	2016	50	0.14	1367	1560	1644	1804	**2025**	2255	2505	2641	2941	9.2%
Option B	2016	60	0.10	994	1134	1195	1311	**1472**	1640	1822	1921	2139	12.8%
Option C	2016	75	0.04	408	466	491	539	**605**	674	749	789	879	18.6%
75%Fmsy	NA	NA	0.1875	1794	2047	2156	2366	**2656**	2958	3285	3463	3857	5.0%
F_{ref}	NA	NA	0.25	2329	2658	2799	3070	**3446**	3837	4261	4493	5003	-0.3%

Table 18. Median 2011 catch (mt) and relative change in age 3+ Jan-1 biomass from 2011 to 2012 for three projection scenarios under three values of F in 2011.

	Median 2011 Catch			Rel Change B		
Scenario	SS	SSBrho	Nrho	SS	SSBrho	Nrho
Fzero	0	0	0	22.6%	23.8%	22.7%
75%Fmsy	2656	1788	1614	5.0%	6.1%	5.6%
F_{ref}	3446	2320	2096	-0.3%	0.9%	0.6%

Table 19. Probability of rebuilding (SSB>43,200 mt) under F=0 for three projection scenarios: SS=Split Series, SSBrho=adjust starting population abundance by the SSB retrospective statistic, Nrho=adjust starting population abundance by age specific retrospective statistics.

Year	SS	SSBrho	Nrho
2010	0	0	0
2011	0	0	0
2012	0	0	0
2013	0.106	0.034	0.026
2014	**0.357**	**0.238**	**0.219**
2015	0.638	0.525	0.508
2016	**0.835**	**0.764**	**0.753**
2017	0.929	0.896	0.89
2018	0.973	0.957	0.954
2019	0.989	0.983	0.982
2020	0.996	0.993	0.992

Table 20. Distribution of recruitment (millions of fish) and catch in 2011 when fished at F = F_{ref} = 0.25 for the standard projections and the recent (1983-2009) recruitment projections.

	Percentiles of Recruitment (millions)								
Recruitment	1%	5%	10%	25%	**50%**	75%	90%	95%	99%
Standard	7.81	10.64	11.6	19.94	**24.61**	53.54	87.63	100.86	116.57
Recent	6.26	7.16	8.18	10.26	**14.06**	20.89	22.66	23.6	24.36

	Catch 2011 (mt) under F_{ref} = 0.25								
Recruitment	1%	5%	10%	25%	**50%**	75%	90%	95%	99%
Standard	2329	2658	2799	3070	**3446**	3837	4261	4493	5003
Recent	2305	2649	2787	3060	**3434**	3826	4252	4486	4998

Table 21. Probability spawning stock biomass is greater than the rebuilding target of 43,200 mt and median catch by year under two assumptions regarding recruitment in the projections. Note that the rebuilding projections are not a "fair" comparison for the recent recruitment because the standard recruitment assumption was used to set the rebuilding target.

	P(SSB>43,200) F=0		**Median Catch**	
Year	Standard	Recent	Standard	Recent
2010	0	0	1956	1956
2011	0	0	3446	3434
2012	0	0	3534	3266
2013	0.106	0	4049	3184
2014	0.357	0	5138	3212
2015	0.638	0	6366	3301
2016	0.835	0	7314	3373
2017	0.929	0.002	7853	3419
2018	0.973	0.008	8202	3441
2019	0.989	0.024	8445	3463
2020	0.996	0.046	8613	3476

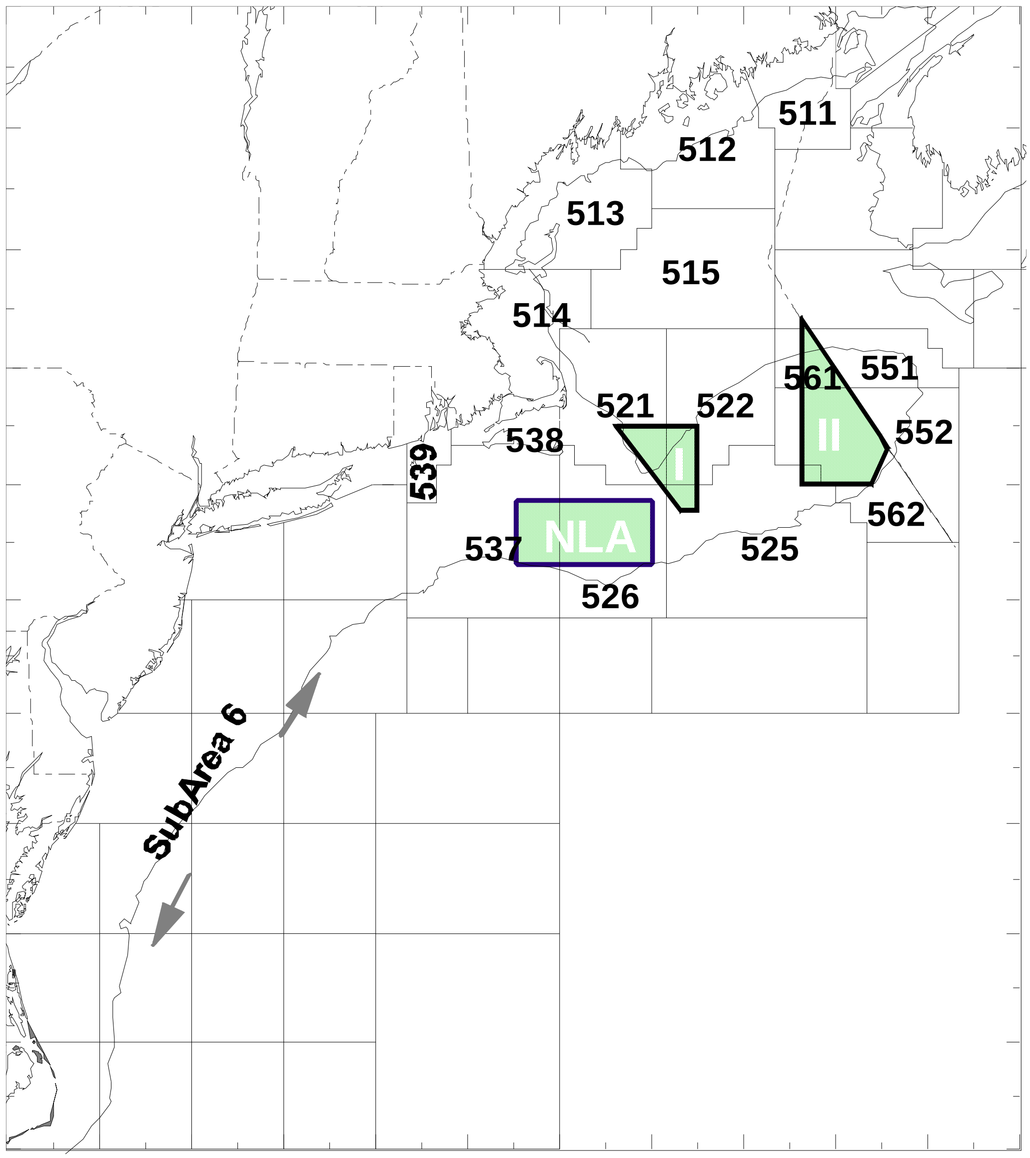

Figure 1a. Statistical areas used for monitoring northeast U.S. fisheries. Catches from areas 522, 525, 551, 552, 561 and 562 are included in the Georges Bank yellowtail flounder assessment. Shaded areas have been closed to fishing year-round since 1994, with exceptions.

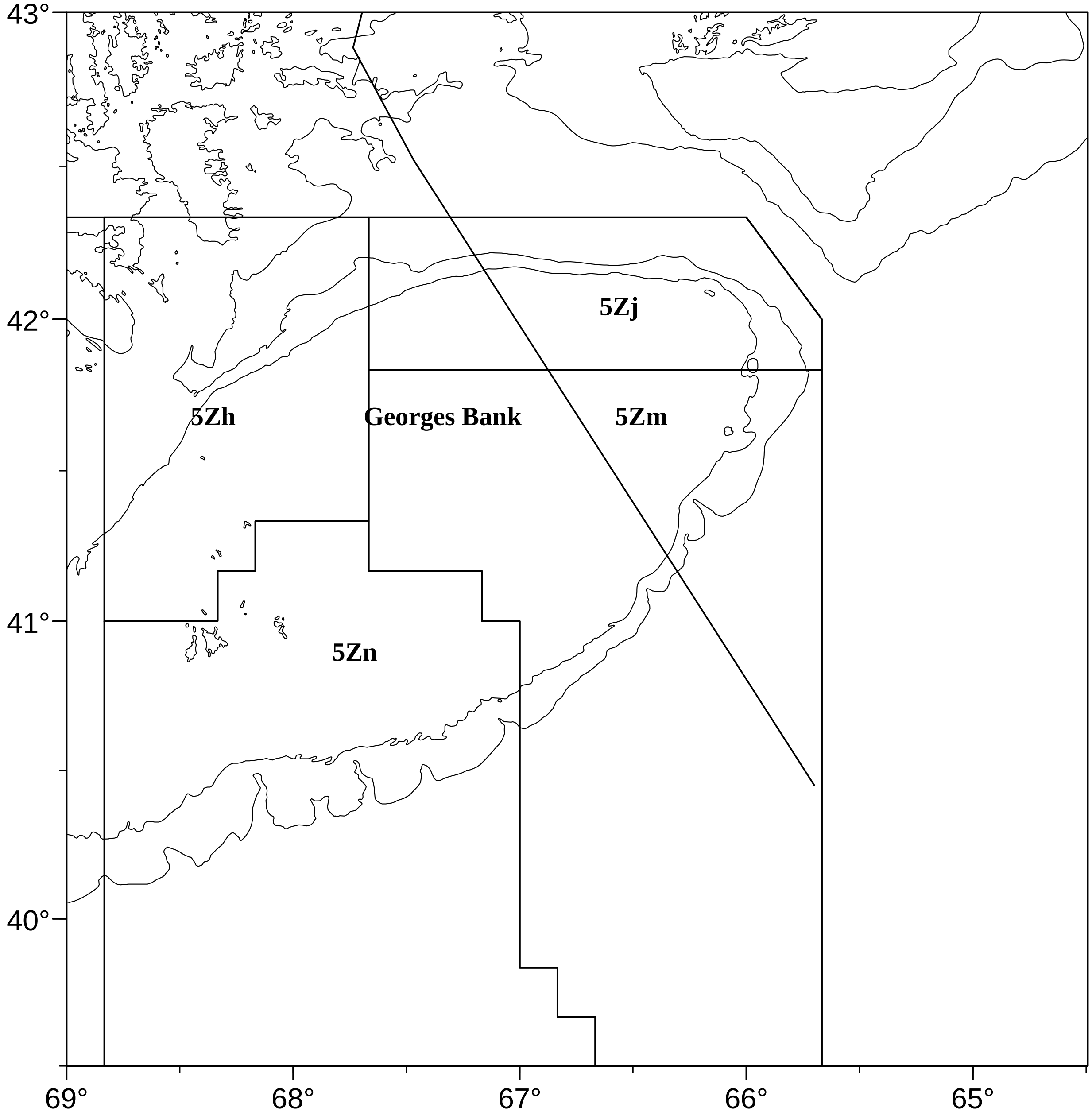

Figure 1b. Location of statistical unit areas for Canadian fisheries in NAFO Subdivision 5Ze.

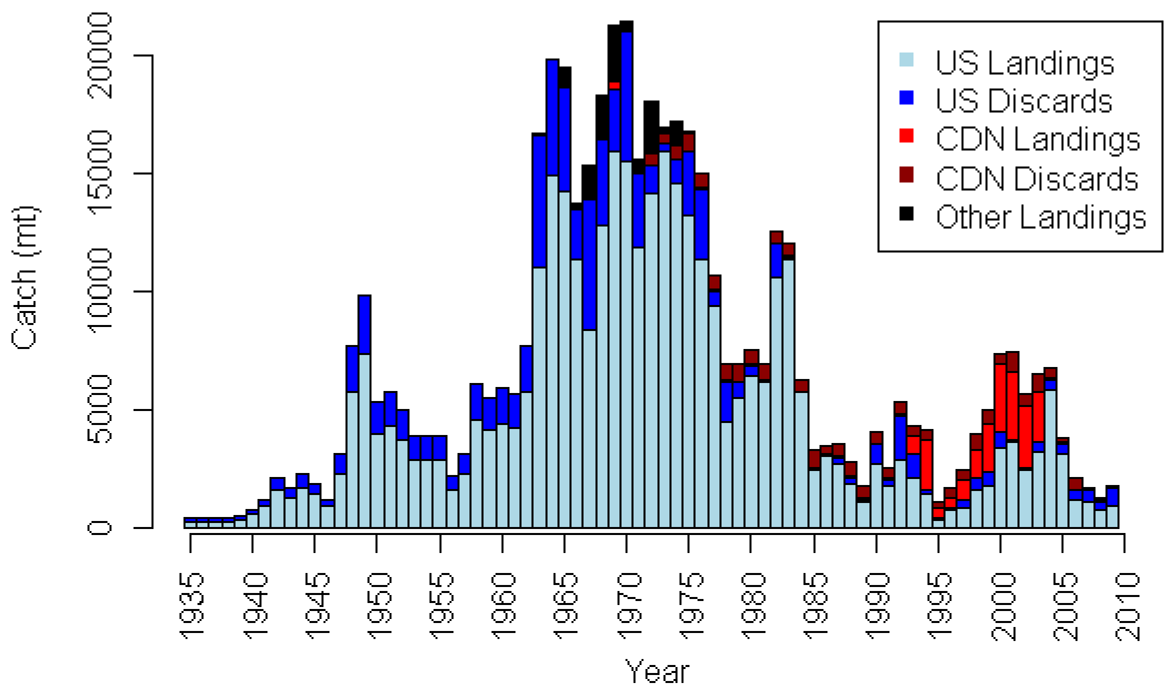

Figure 2. Catch (landings plus discards) of Georges Bank yellowtail flounder by nation.

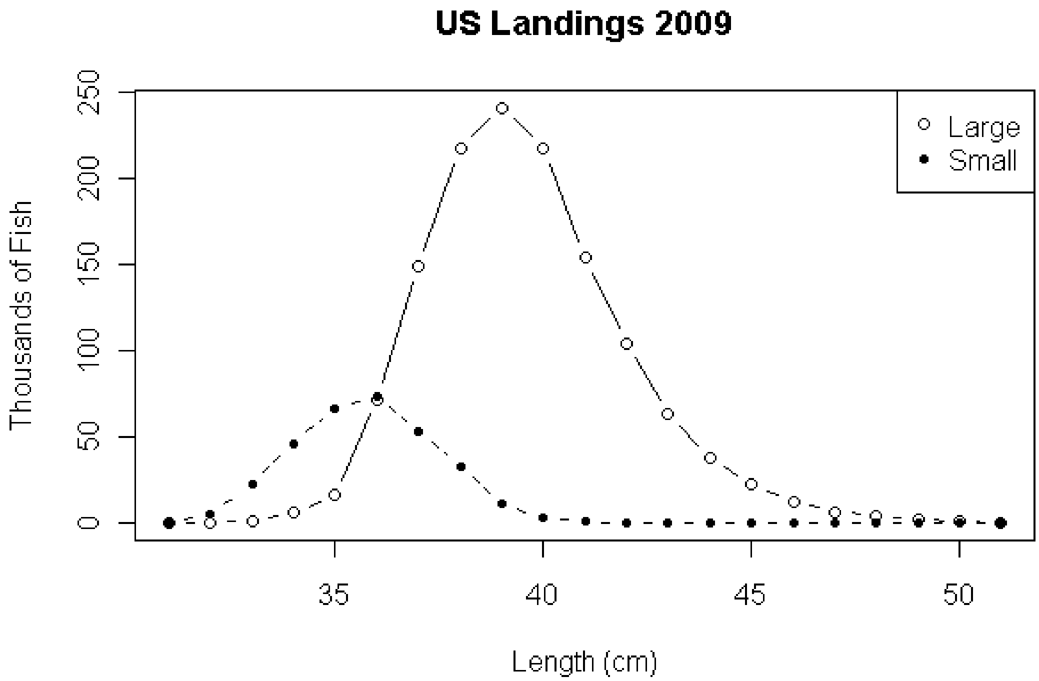

Figure 3. US landings of Georges Bank yellowtail by market category.

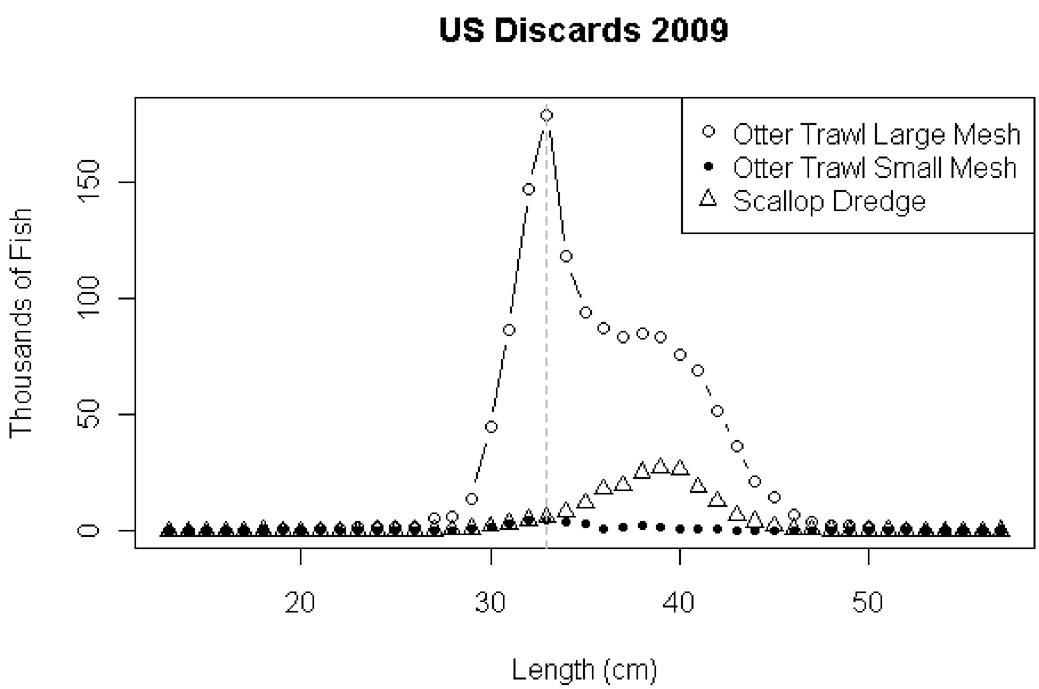

Figure 4. US yellowtail flounder discard length frequencies by gear. The vertical line at 33 cm denotes the US minimum legal size for landing yellowtail flounder.

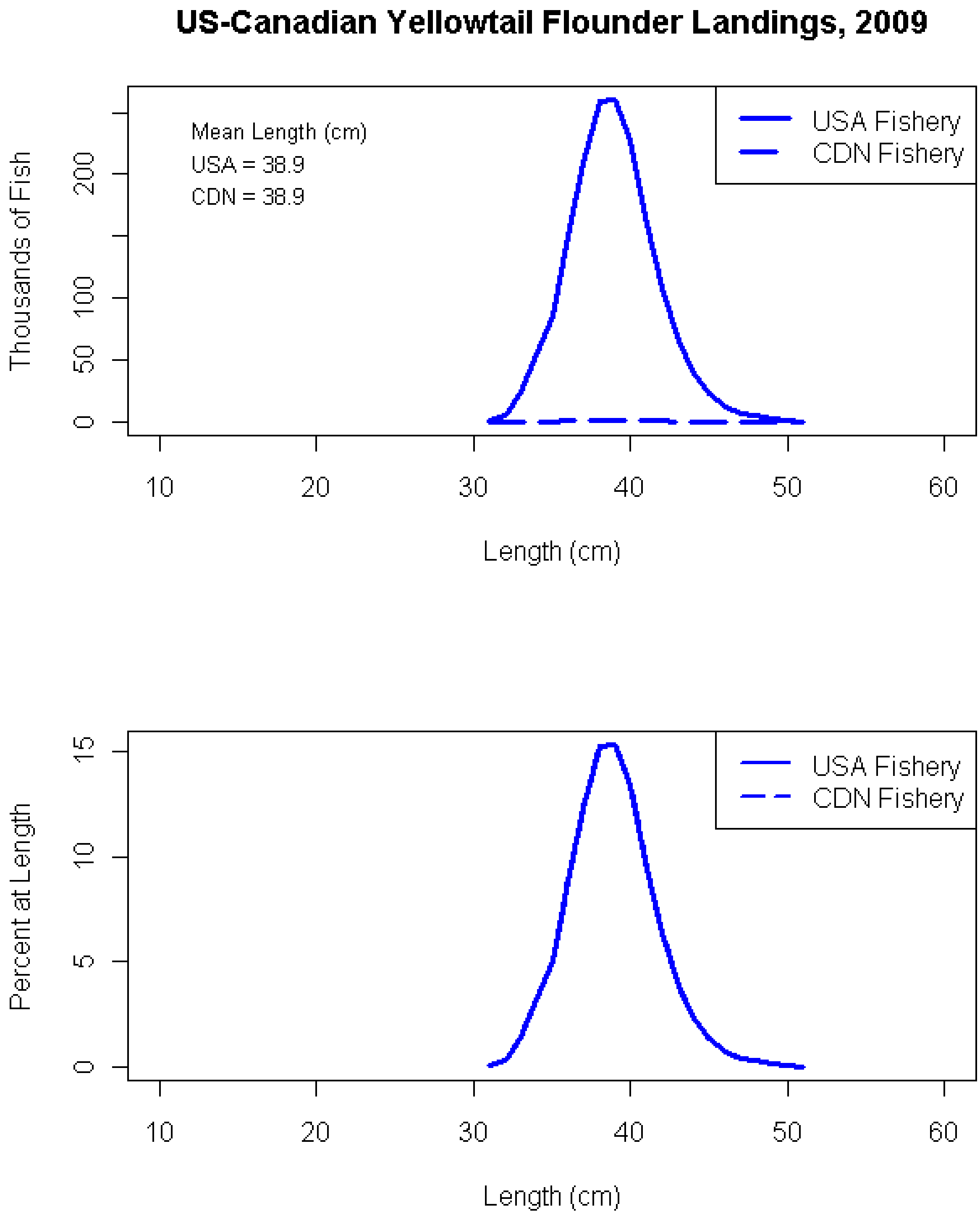

Figure 5. Comparison of US and Canadian landings at length for Georges Bank yellowtail flounder. Note the lines in the bottom plot completely overlap because the Canadian landings were just expanded by the US length proportions.

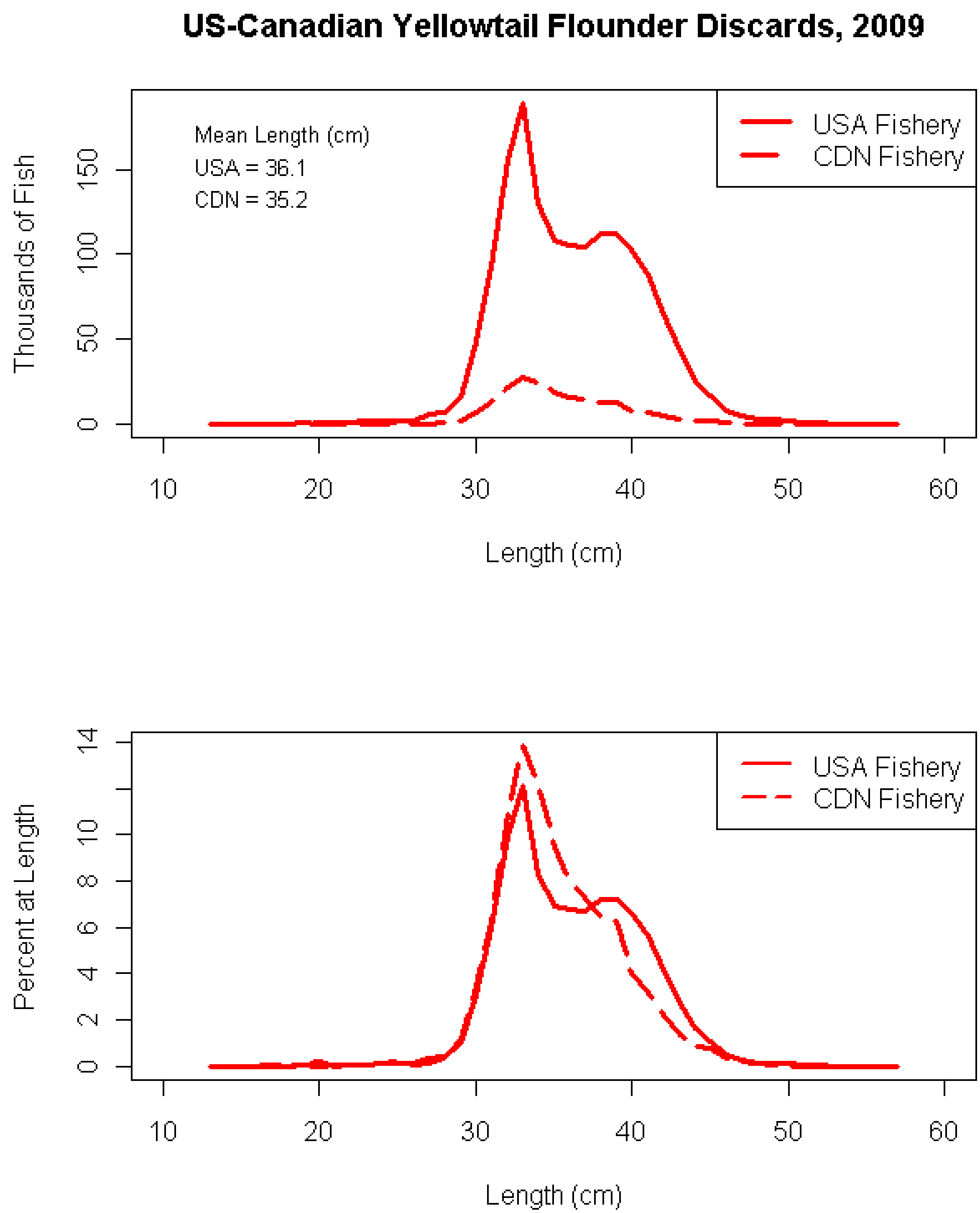

Figure 6. Comparison of US and Canadian discards at length for Georges Bank yellowtail flounder.

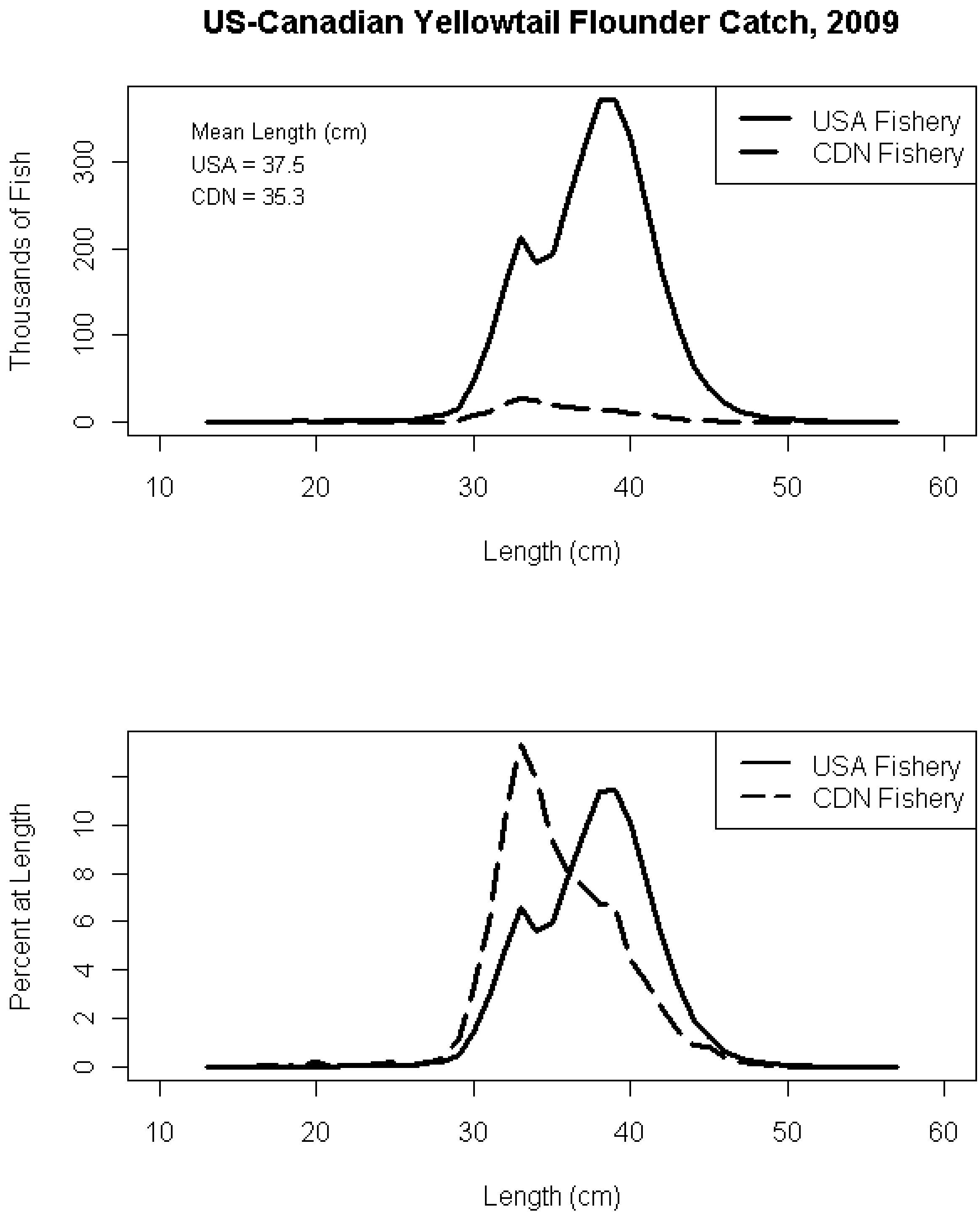

Figure 7. Comparison of US and Canadian catch (landings plus discards) at length for Georges Bank yellowtail flounder in 2008.

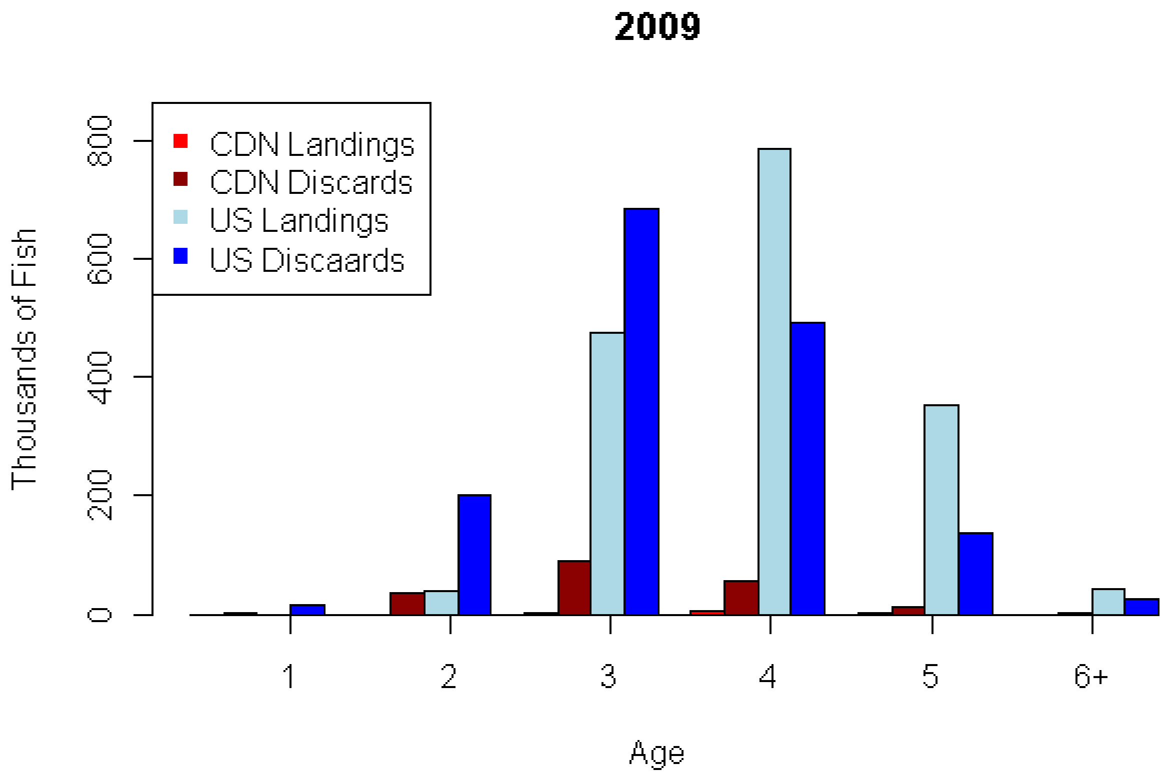

Figure 8. Catch at age of Georges Bank yellowtail flounder in 2009 from the four components of Canadian and US landings and discards.

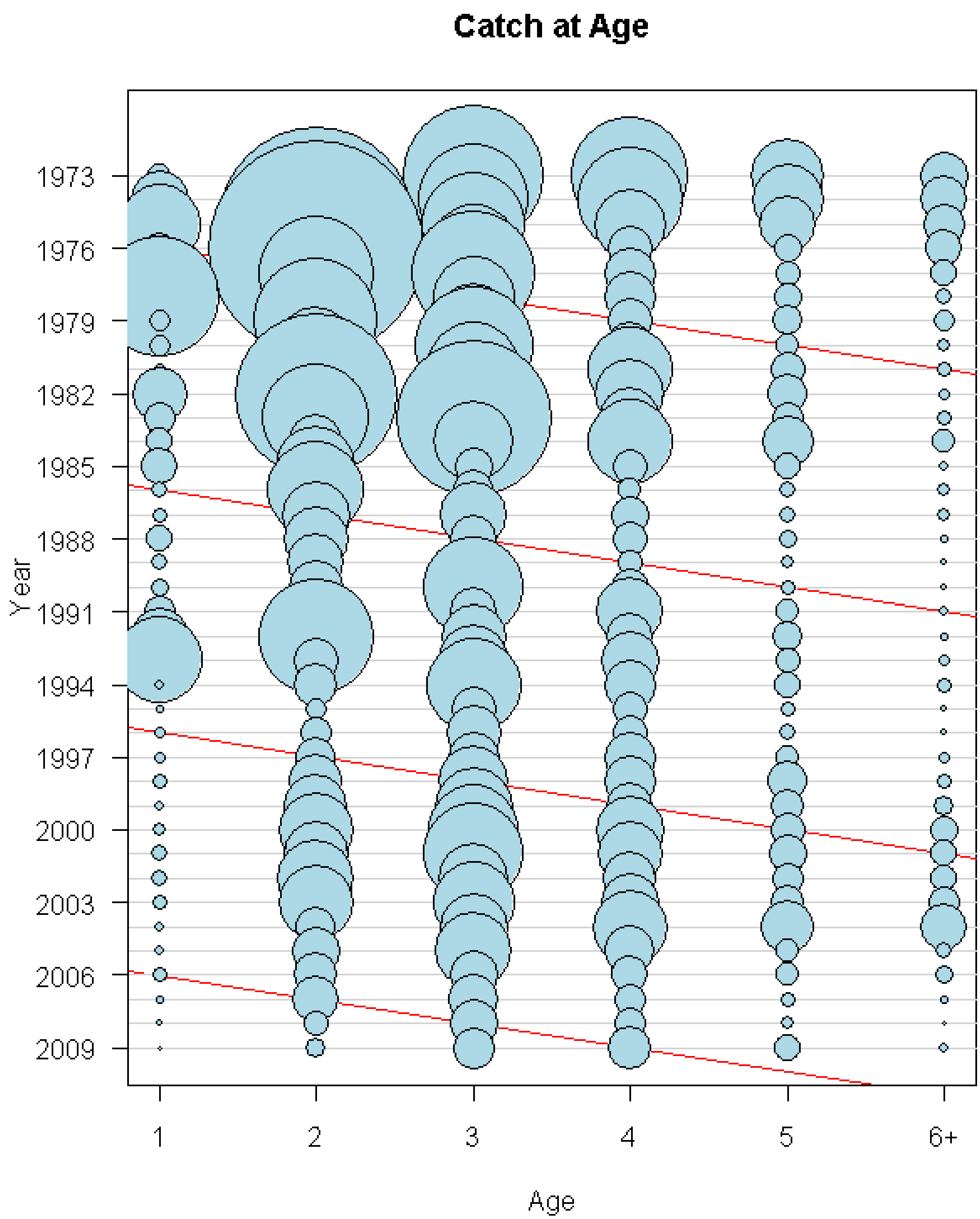

Figure 9. Catch at age for Georges Bank yellowtail flounder, Canadian and USA fisheries combined. (The area of the bubble is proportional to the magnitude of the catch). Diagonal red lines denote the 1975, 1985, 1995, and 2005 year classes.

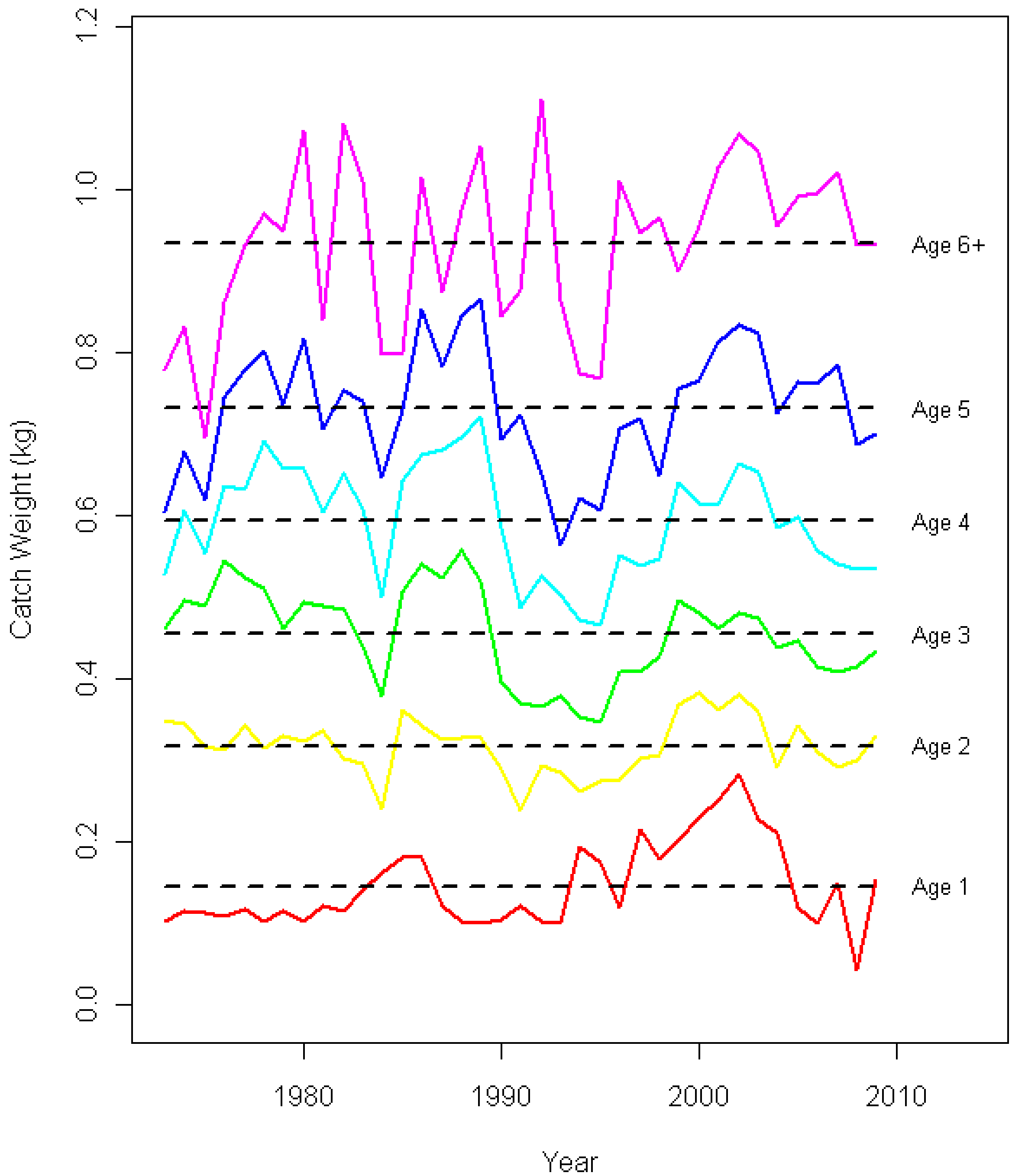

Figure 10. Trends in mean weight at age from the Georges Bank yellowtail fishery (Canada and USA combined, including discards). Dashed lines denote average of time series.

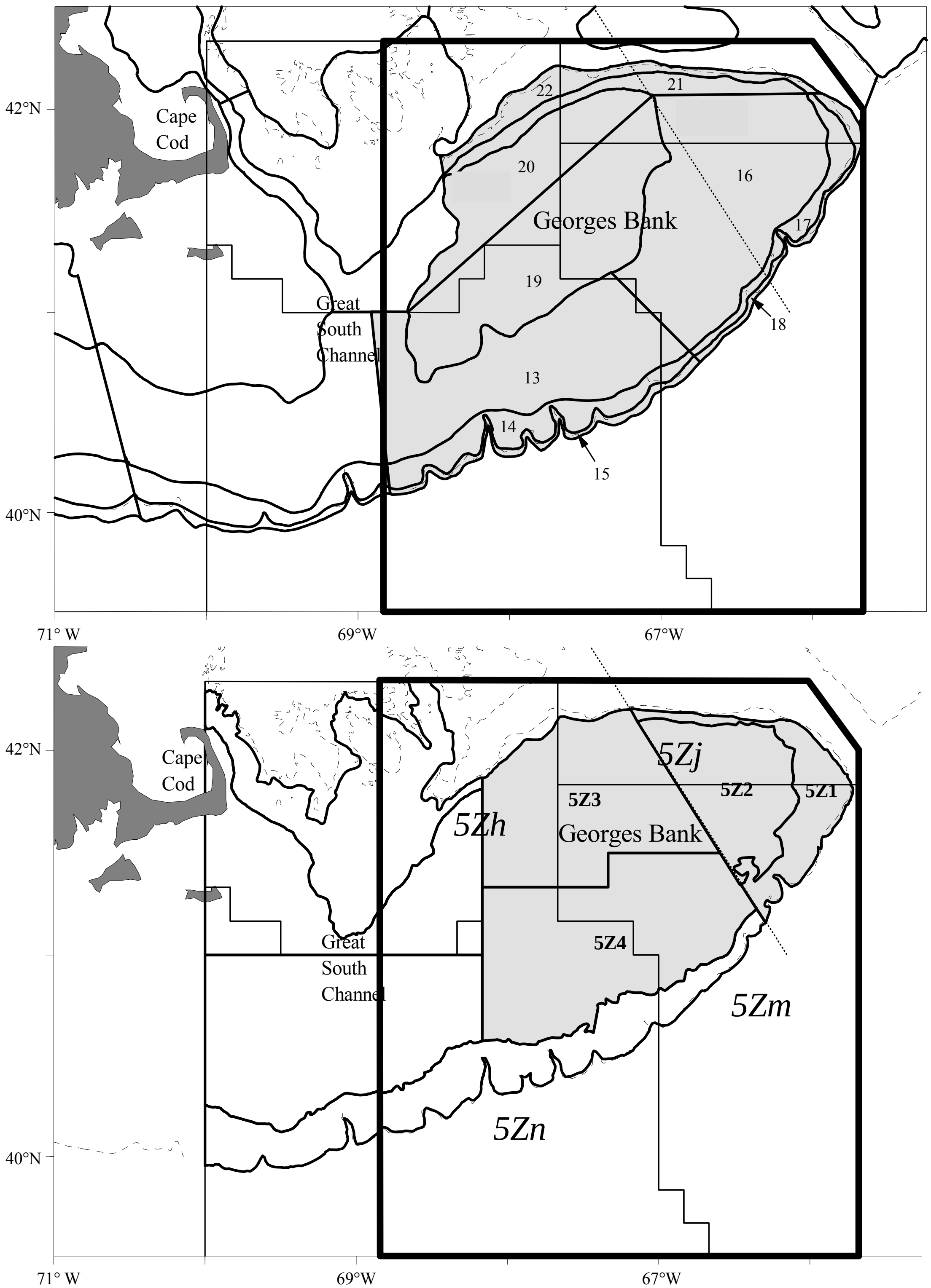

Figure 11. NMFS (top) and DFO (bottom) strata used to derive research survey abundance indices for Georges Bank groundfish surveys. Note NMFS stratum 22 is not used in assessment.

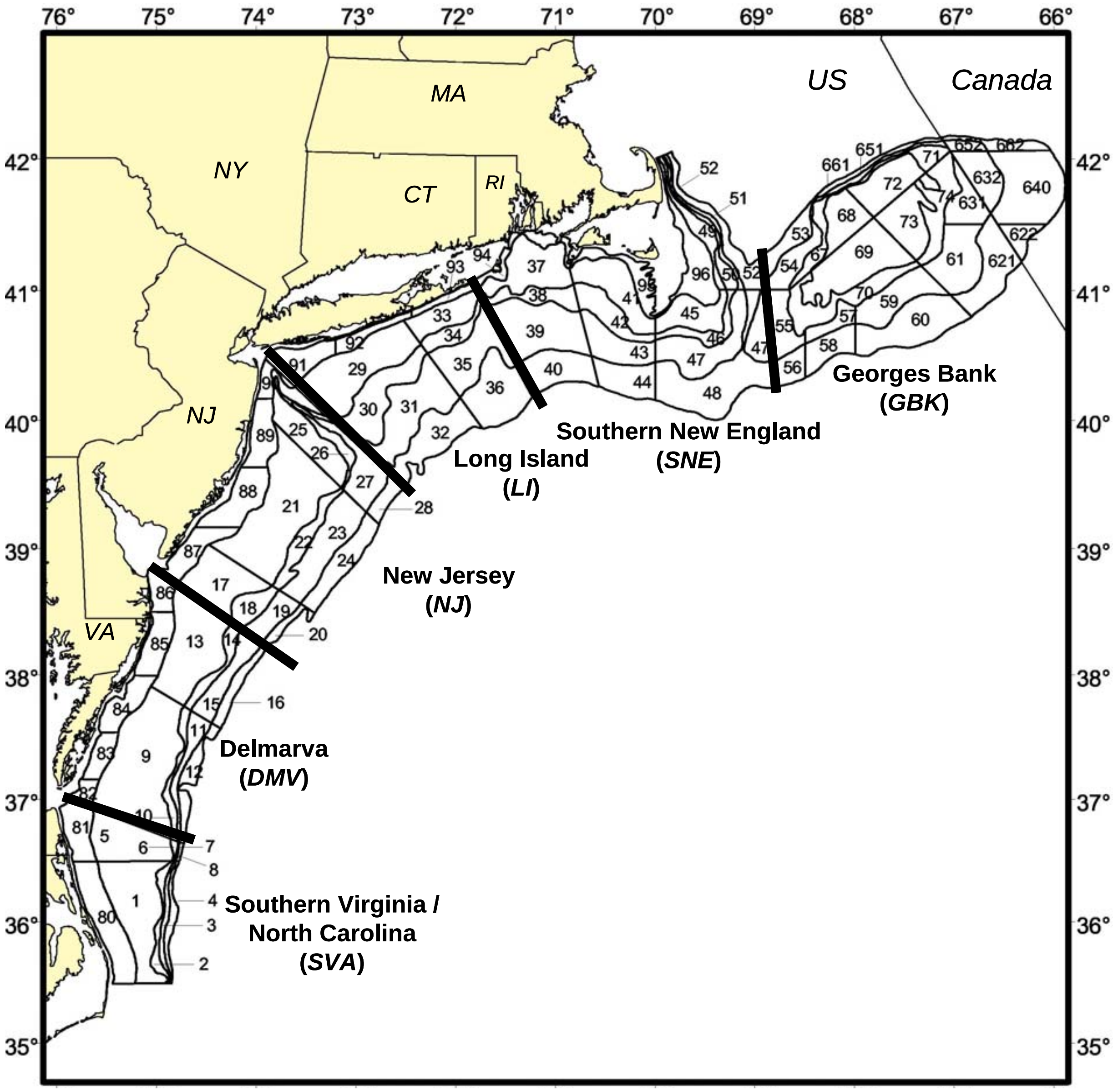

Figure 11. (continued) NMFS scallop survey strata used to derive research survey abundance indices.

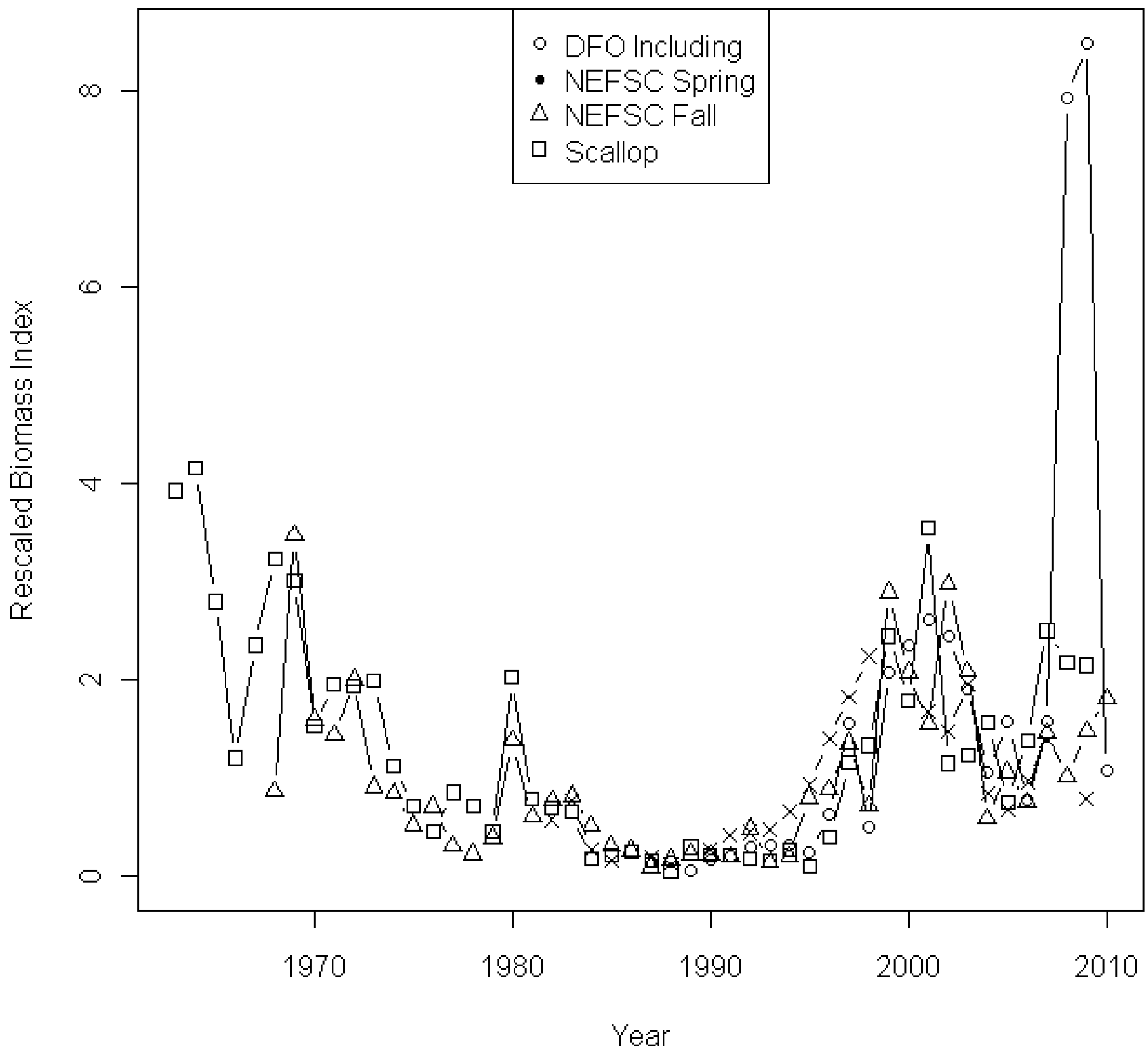

Figure 12a. Four survey biomass indices for yellowtail flounder on Georges Bank rescaled to their respective means for years 1987-2005.

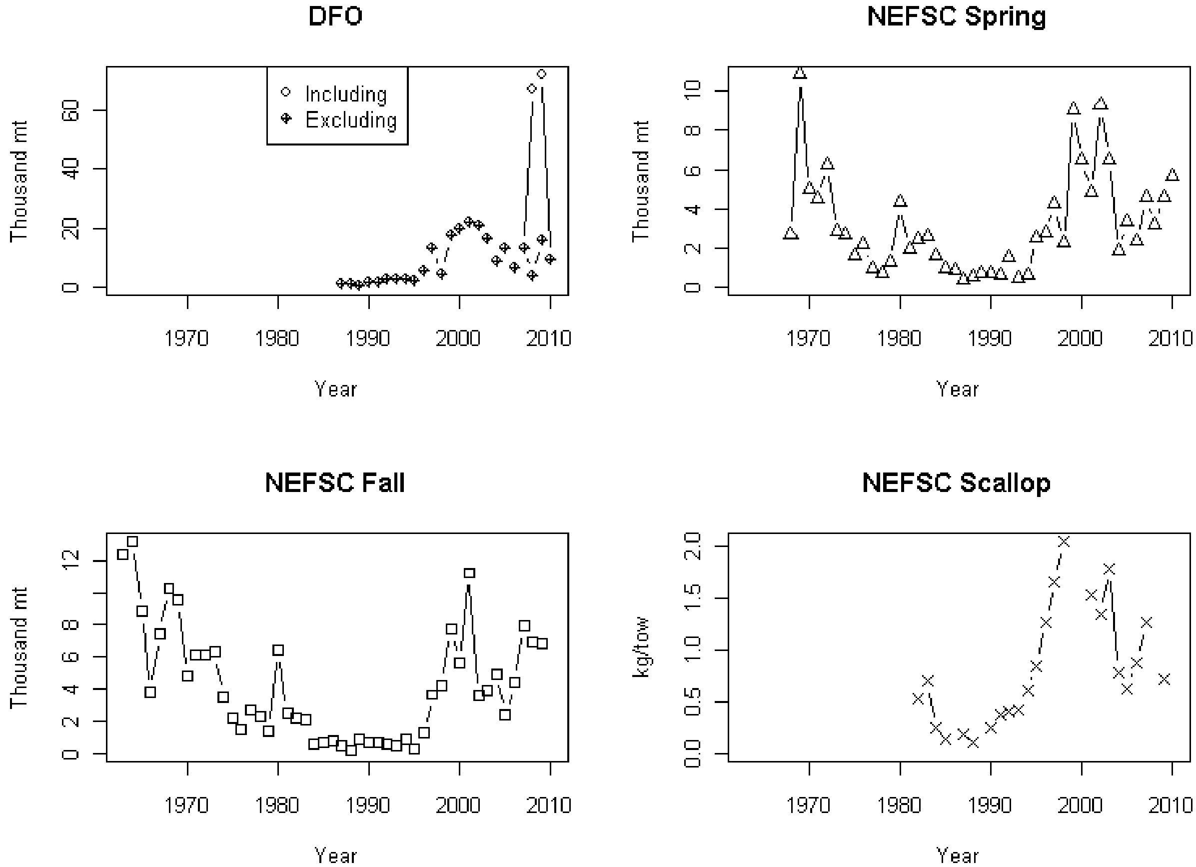

Figure 12b. Survey biomass for yellowtail flounder on Georges Bank in units of thousand metric tons (DFO, NEFSC spring, NEFSC fall, all three are minimum swept area biomass values) or kg/tow (NEFSC scallop, stratified mean catch per tow).

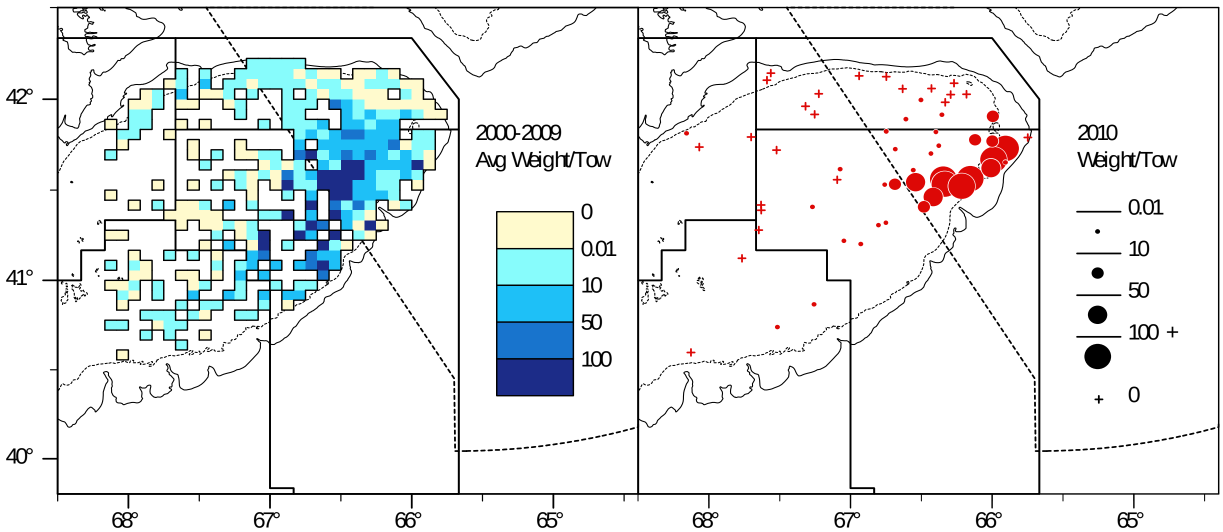

Figure 13a. Catch of yellowtail in weight (kg) per tow for DFO survey. Left panel shows previous 10 year averages, right panel most recent data.

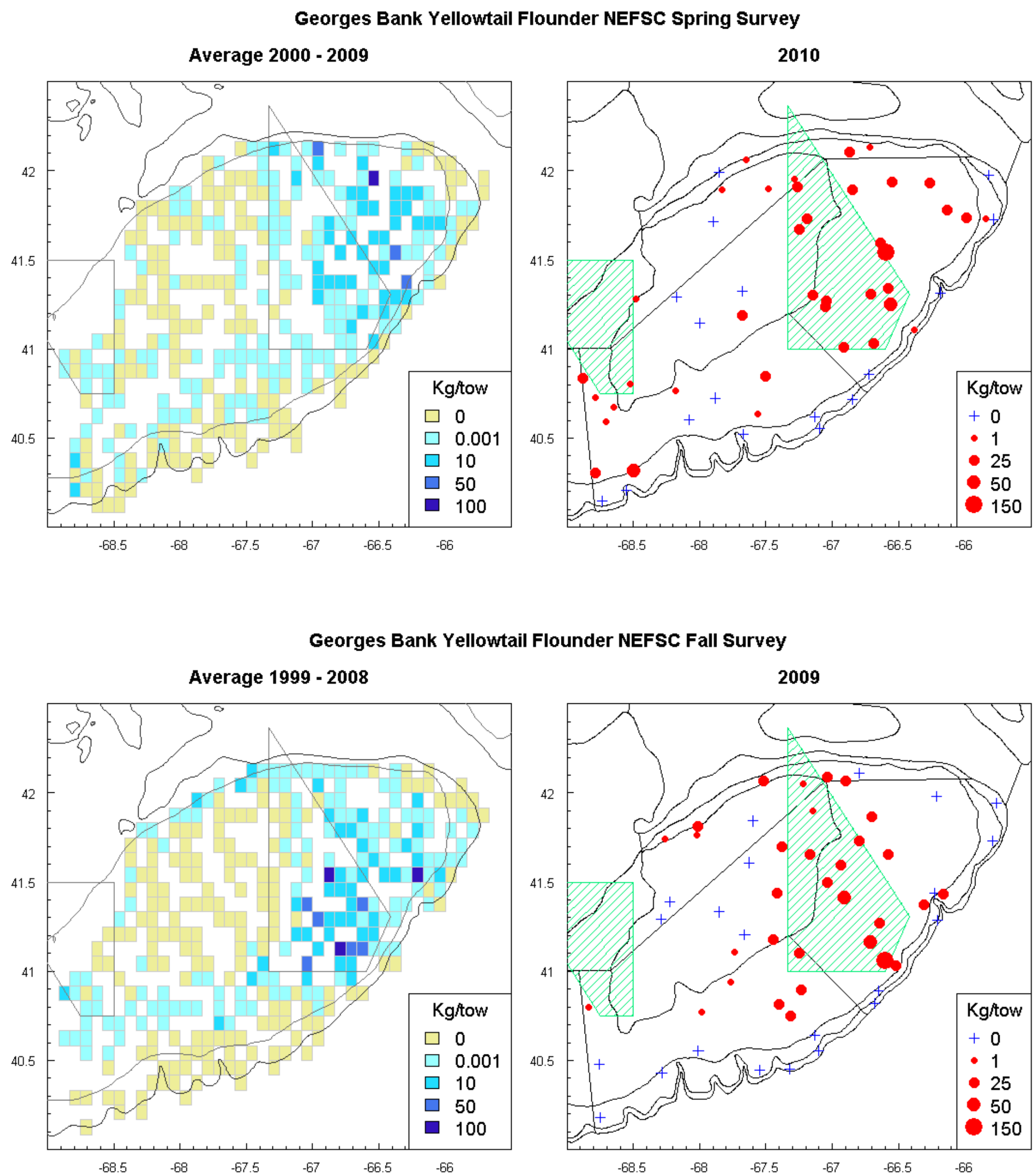

Figure 13b. Catch of yellowtail in weight (kg) per tow for NEFSC spring and NEFSC fall surveys. Left panels show previous 10 year averages, right panels most recent data. Note the 2009 and 2010 survey values were adjusted from Bigelow to Albatross IV equivalents by dividing Bigelow catch in weight by 2.244 (spring) or 2.402 (fall).

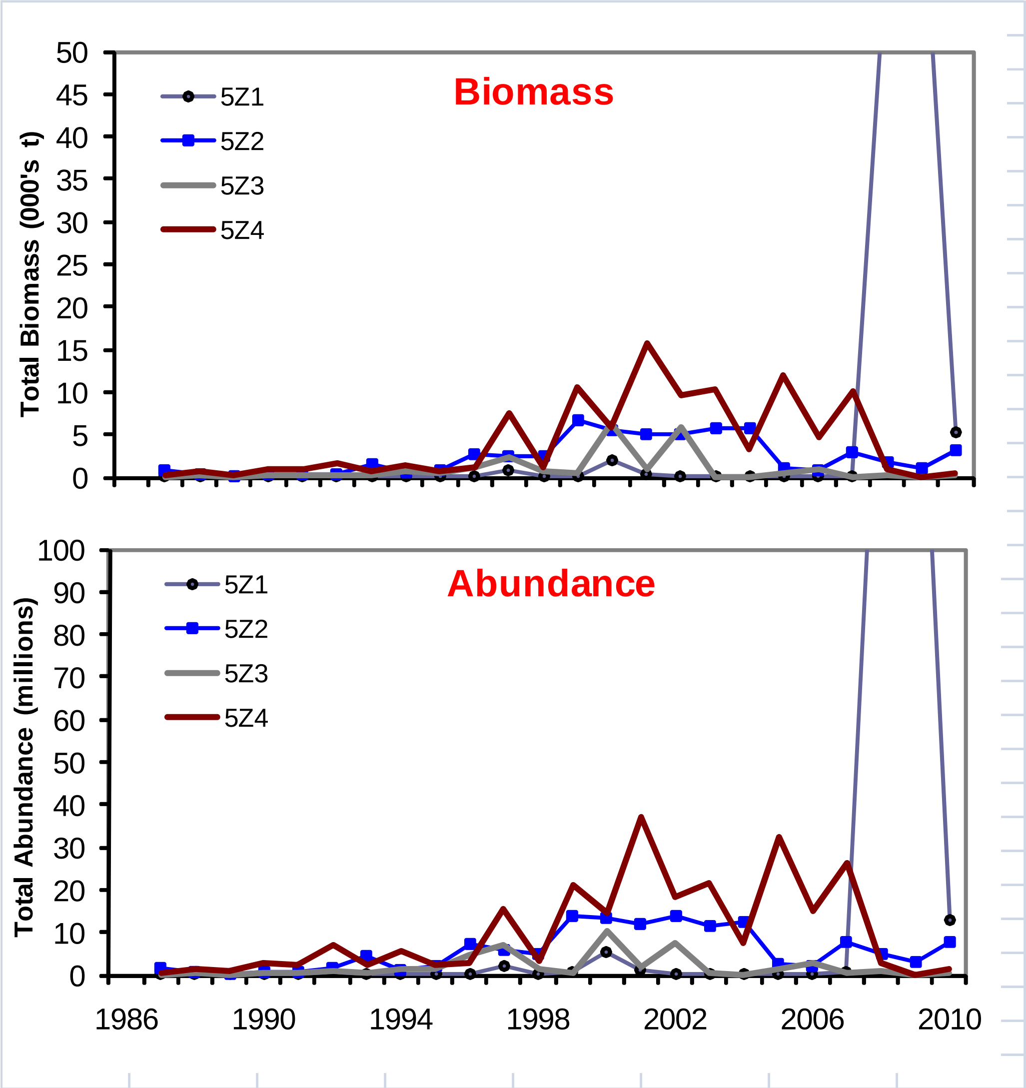

Figure 14a. DFO spring survey estimates of total biomass (top panel) and total abundance (bottom panel) by stratum area for yellowtail flounder on Georges Bank.

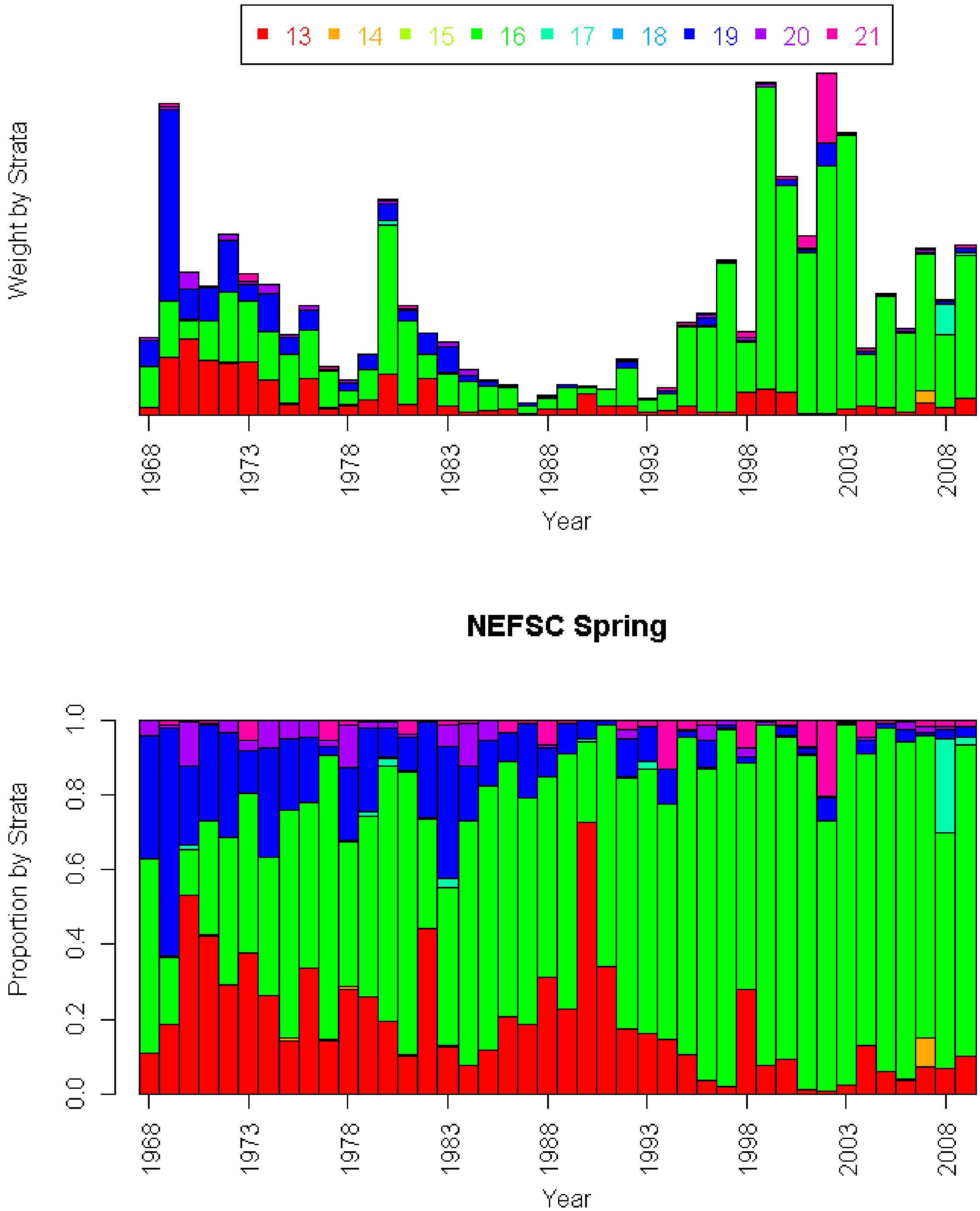

Figure 14b. NEFSC spring survey estimates of total biomass (top panel) and proportion (bottom panel) by stratum for yellowtail flounder on Georges Bank.

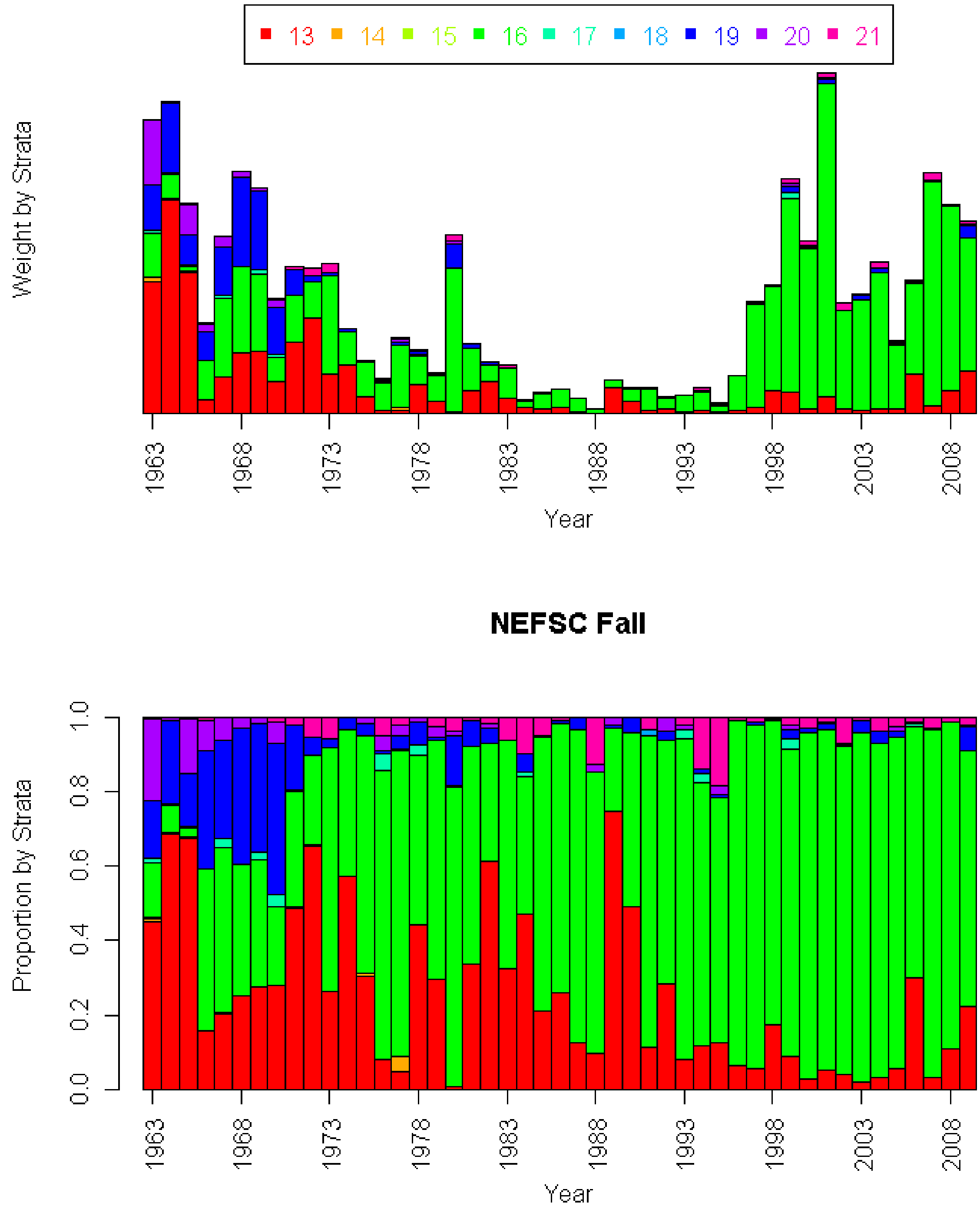

Figure 14c. NEFSC fall survey estimates of total biomass (top panel) and proportion (bottom panel) by stratum for yellowtail flounder on Georges Bank.

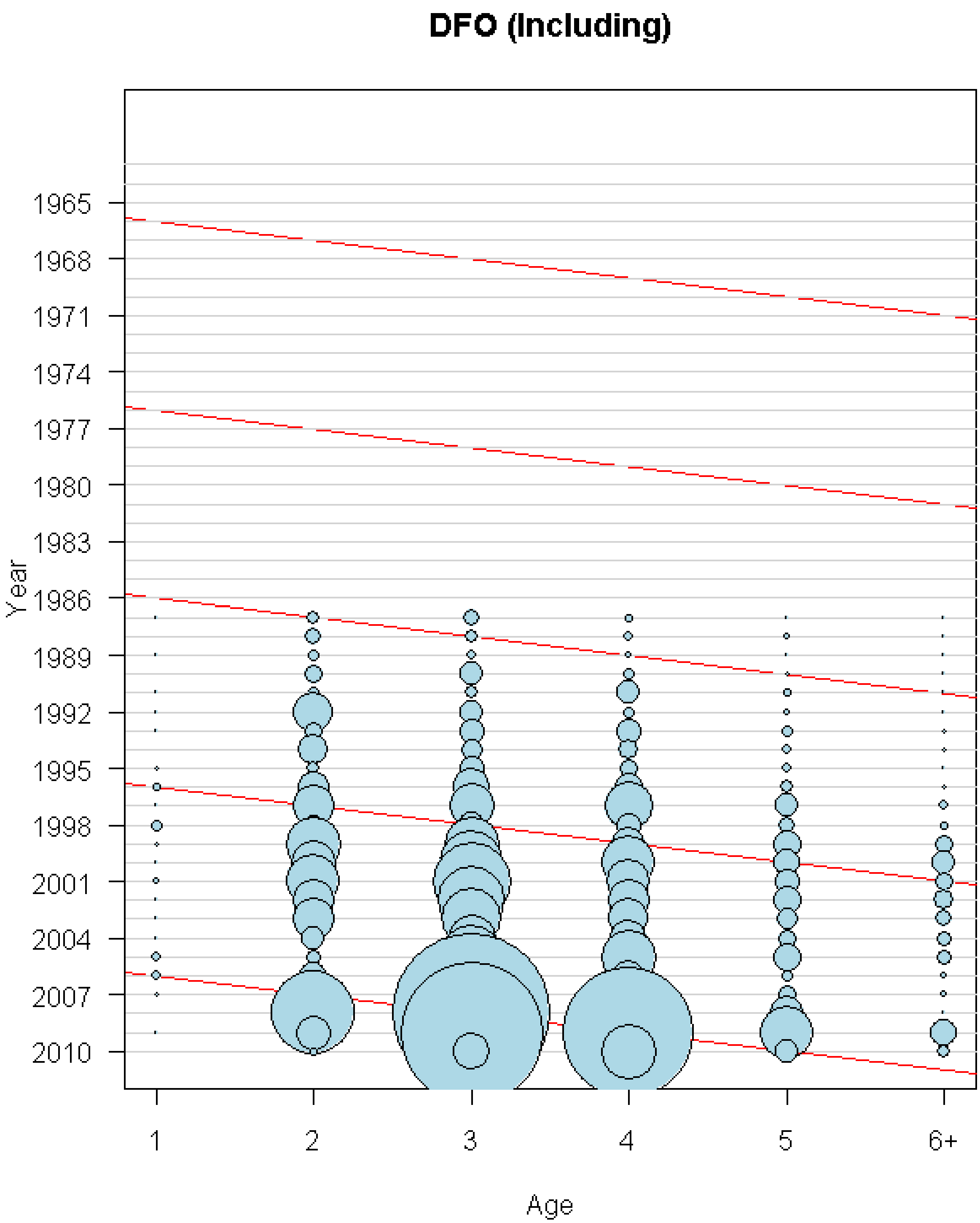

Figure 15a. Age specific indices of abundance for the DFO spring survey including the large tows in 2008 and 2009 (the area of the bubble is proportional to the magnitude). Diagonal red lines denote the 1965, 1975, 1985, 1995, and 2005 year classes.

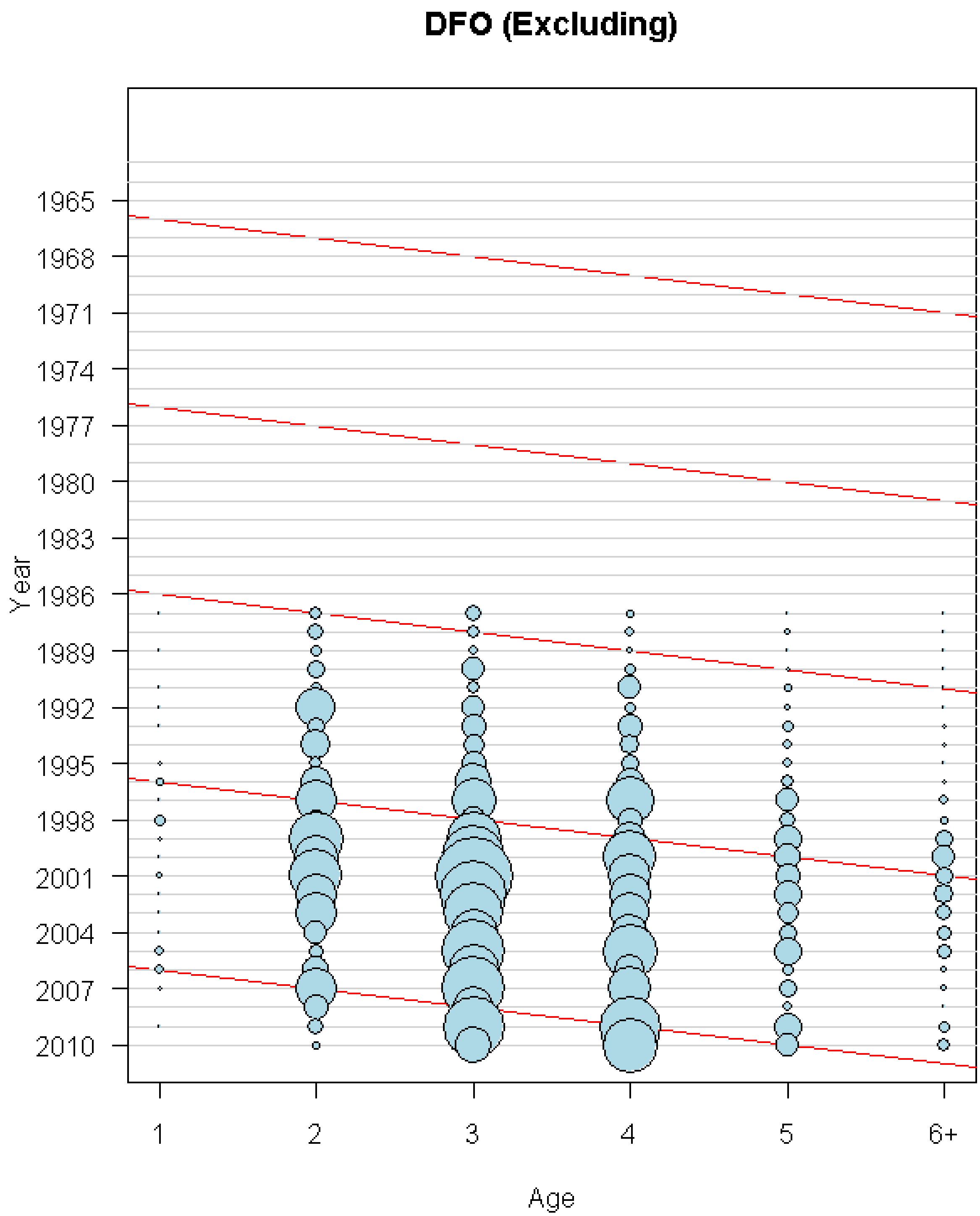

Figure 15b. Age specific indices of abundance for the DFO spring survey excluding the large tows in 2008 and 2009 (the area of the bubble is proportional to the magnitude). Diagonal red lines denote the 1965, 1975, 1985, 1995, and 2005 year classes.

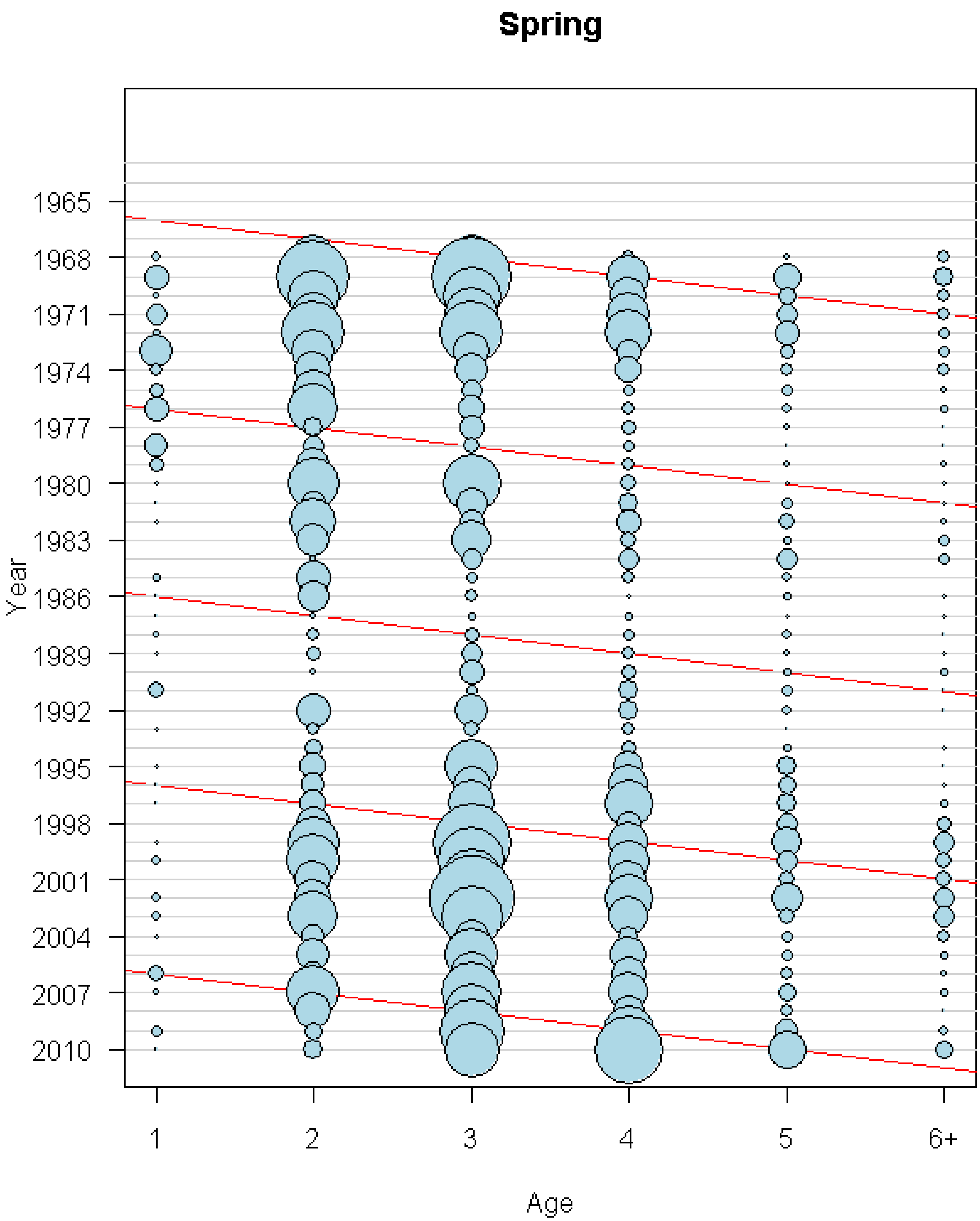

Figure 15c. Age specific indices of abundance for the NMFS spring survey (the area of the bubble is proportional to the magnitude). Diagonal red lines denote the 1965, 1975, 1985, 1995, and 2005 year classes.

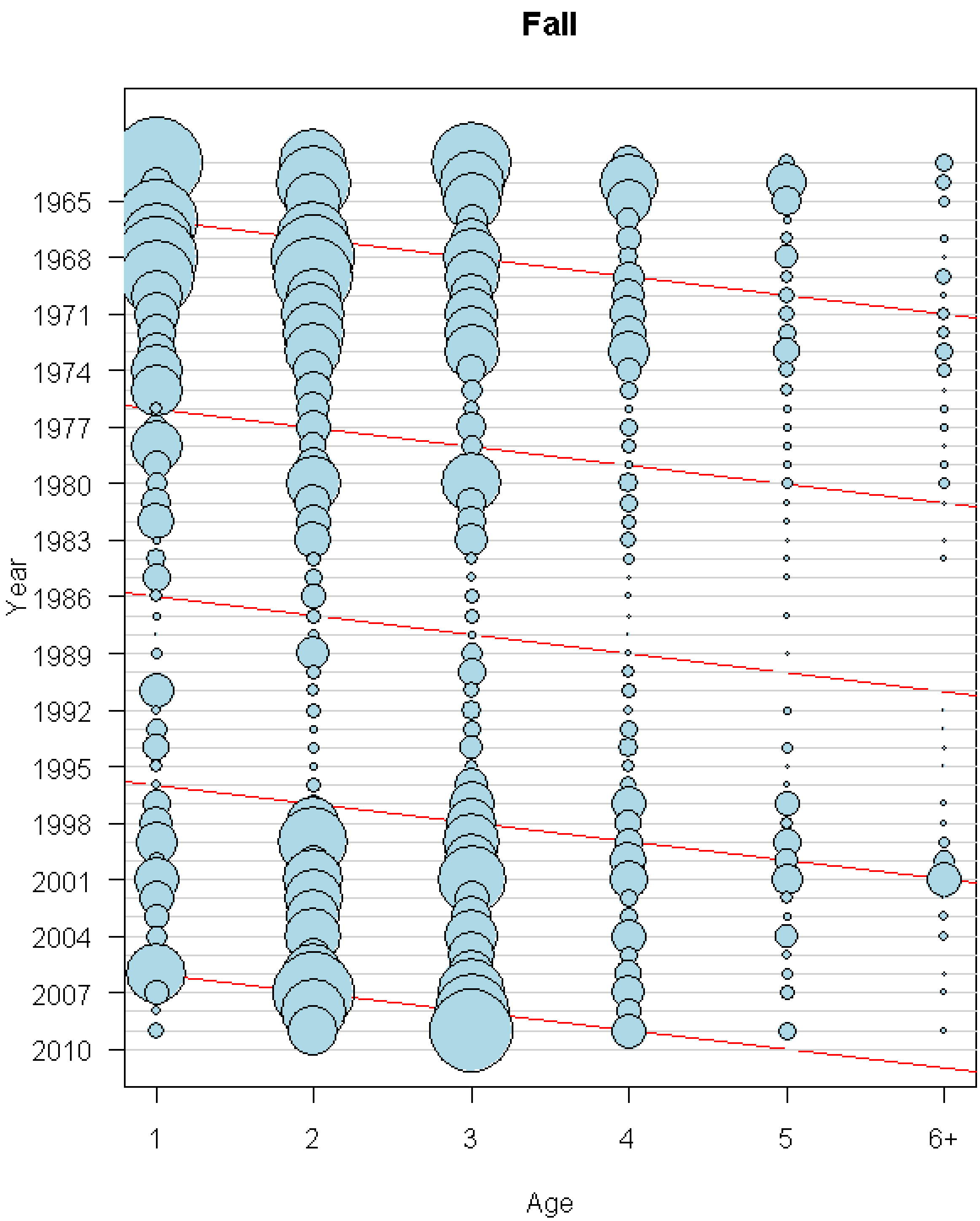

Figure 15d. Age specific indices of abundance for the NMFS fall survey (the area of the bubble is proportional to the magnitude). Diagonal red lines denote the 1965, 1975, 1985, 1995, and 2005 year classes.

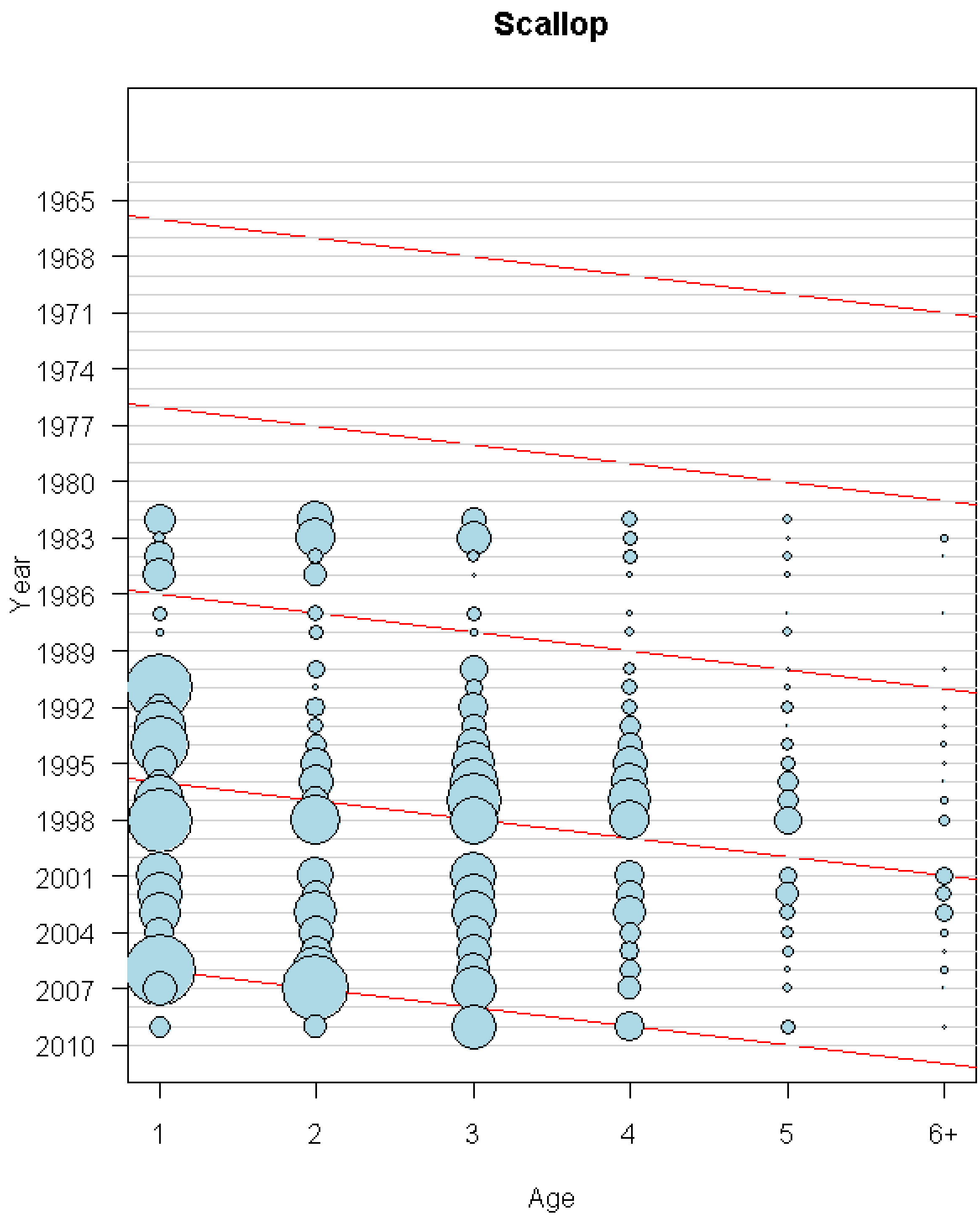

Figure 15e. Age specific indices of abundance for the NMFS scallop survey, note years 1986, 1989, 1999, 2000, and 2008 are not included (the area of the bubble is proportional to the magnitude). Diagonal red lines denote the 1965, 1975, 1985, 1995, and 2005 year classes.

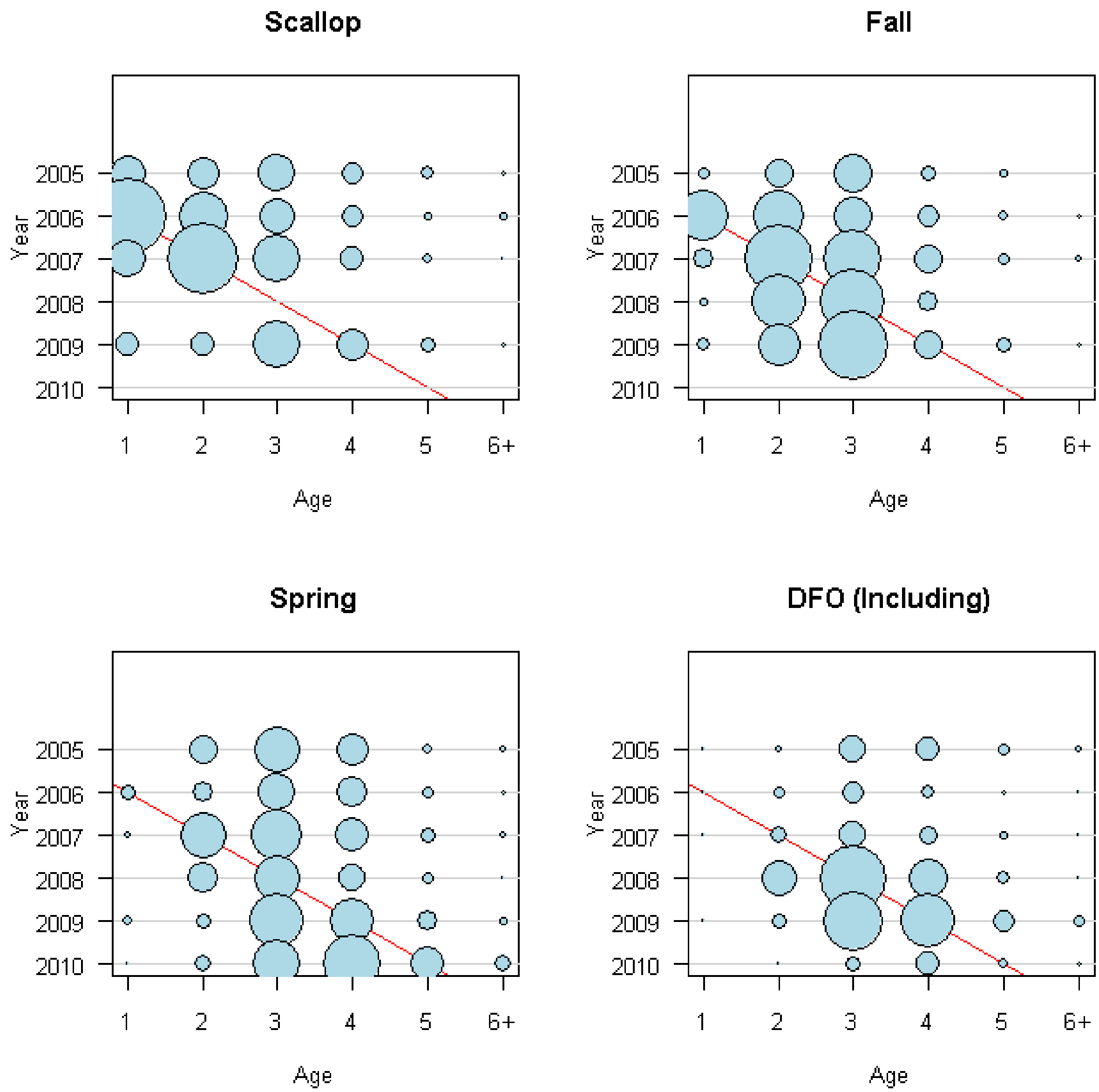

Figure 15f. Age specific indices of abundance for the recent years of the four surveys, note year 2008 is not included in the scallop plot (the area of the bubble is proportional to the magnitude). The red diagonal line denotes the 2005 year class.

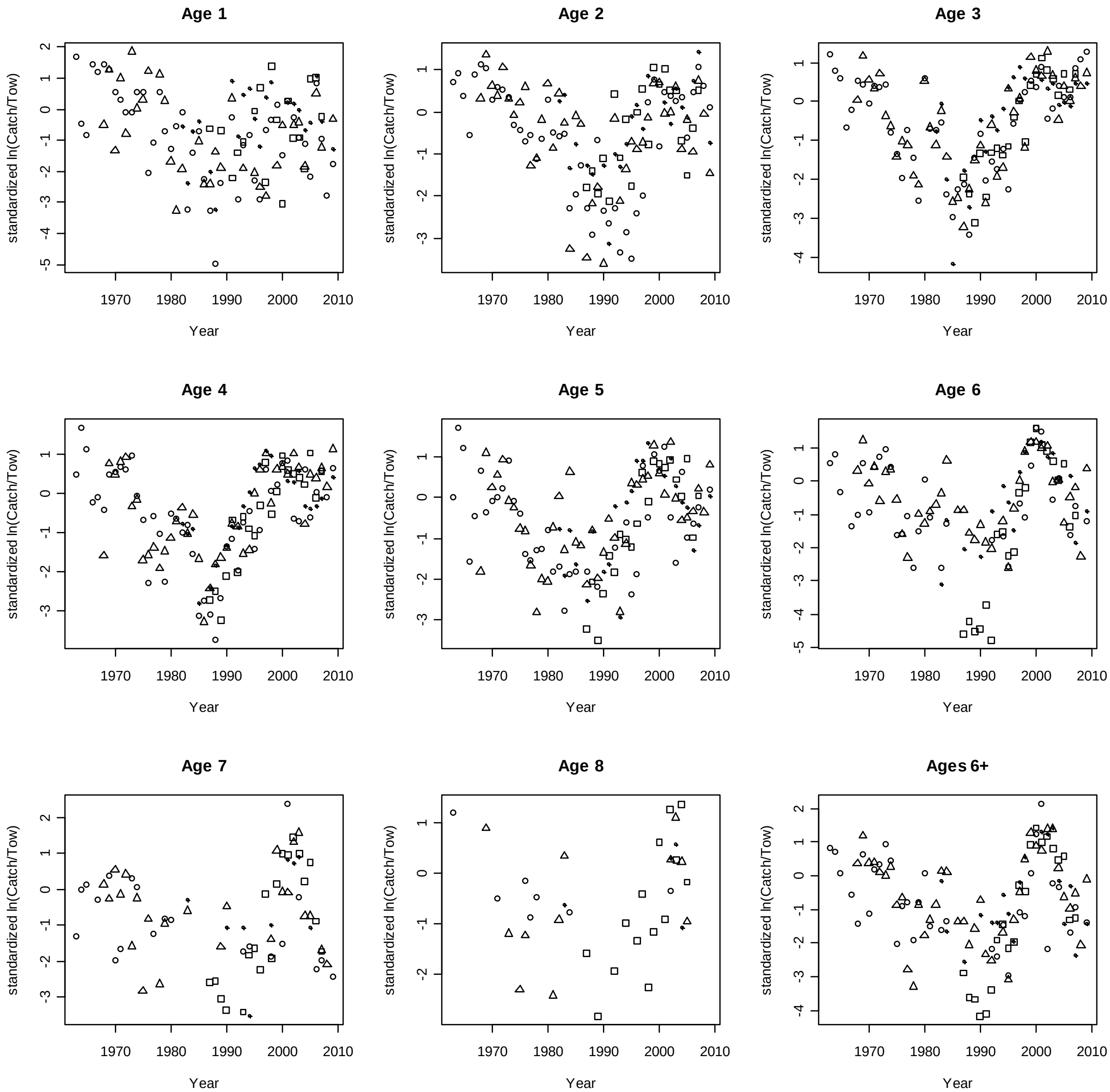

Figure 16. Standardized catch/tow in numbers at age for the four surveys plotted on natural log scale. The standardization was merely the division of each index value by the mean of the associated time series. Squares denote the DFO survey, triangles the NEFSC spring survey, open circles the NEFSC fall survey, and closed circles the NEFSC scallop survey.

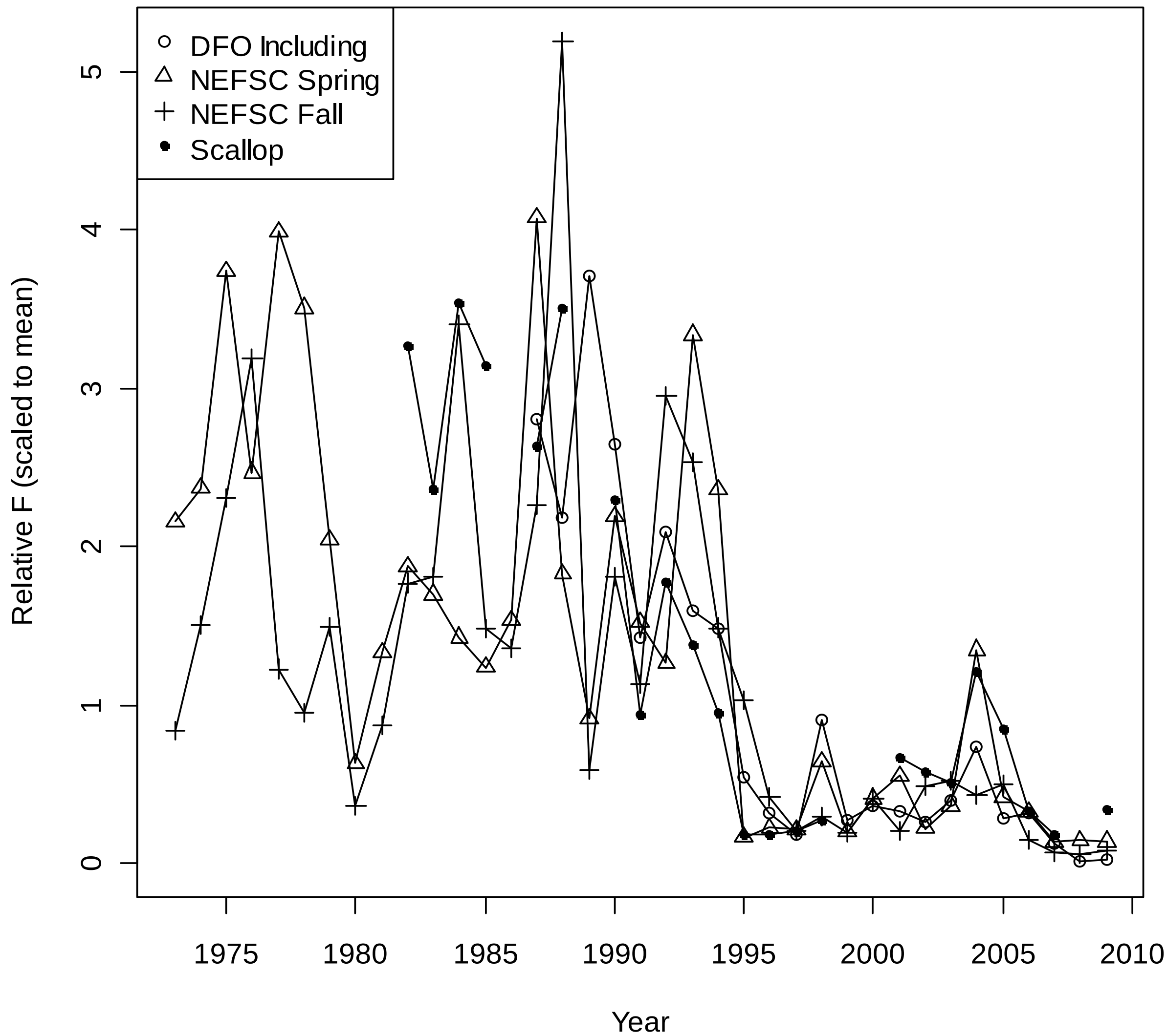

Figure 17. Trends in relative fishing mortality (catch biomass/survey biomass), standardized to the mean for 1987-2009.

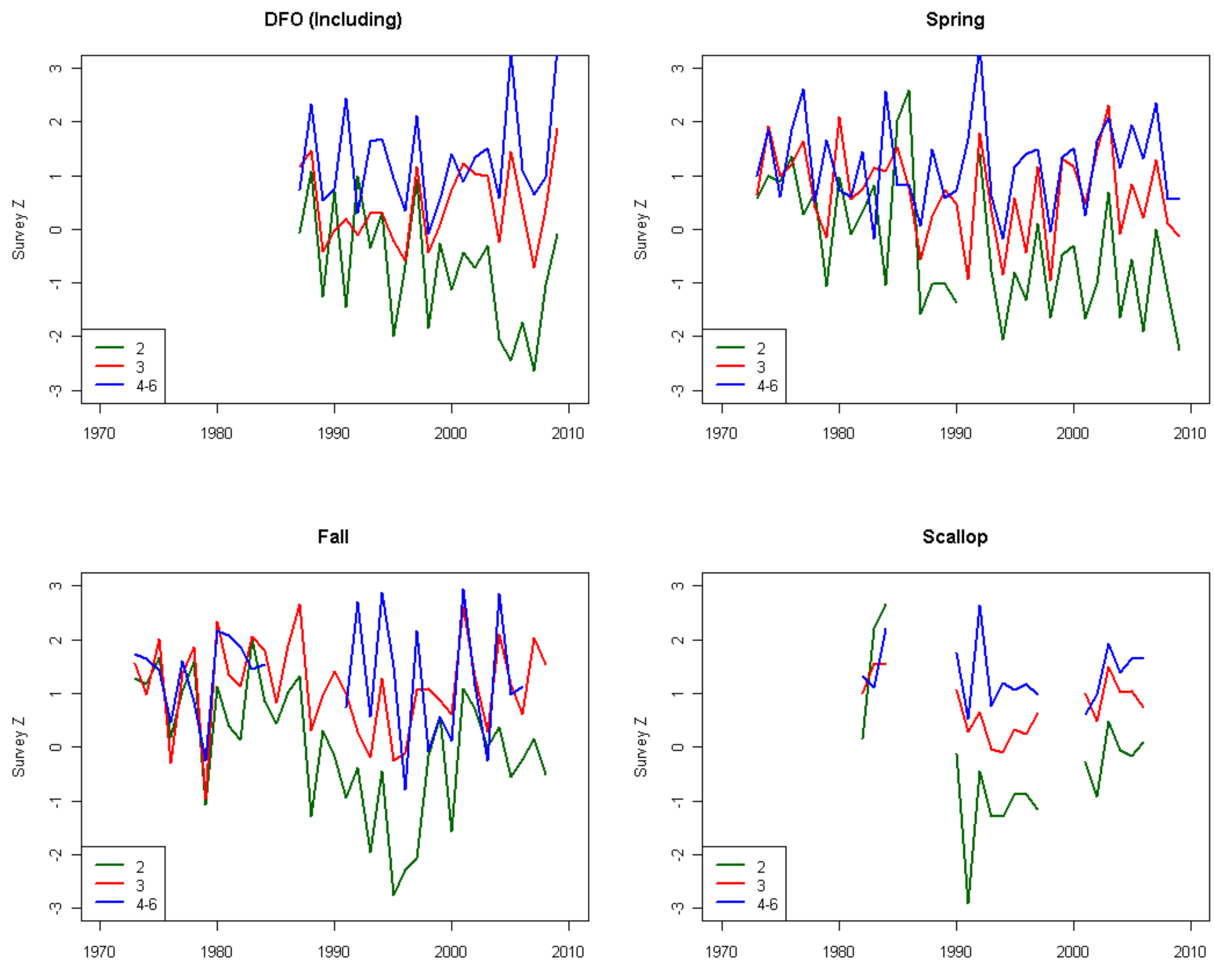

Figure 18. Trends in total mortality (Z) for ages 2, 3, and 4-6 from the four surveys.

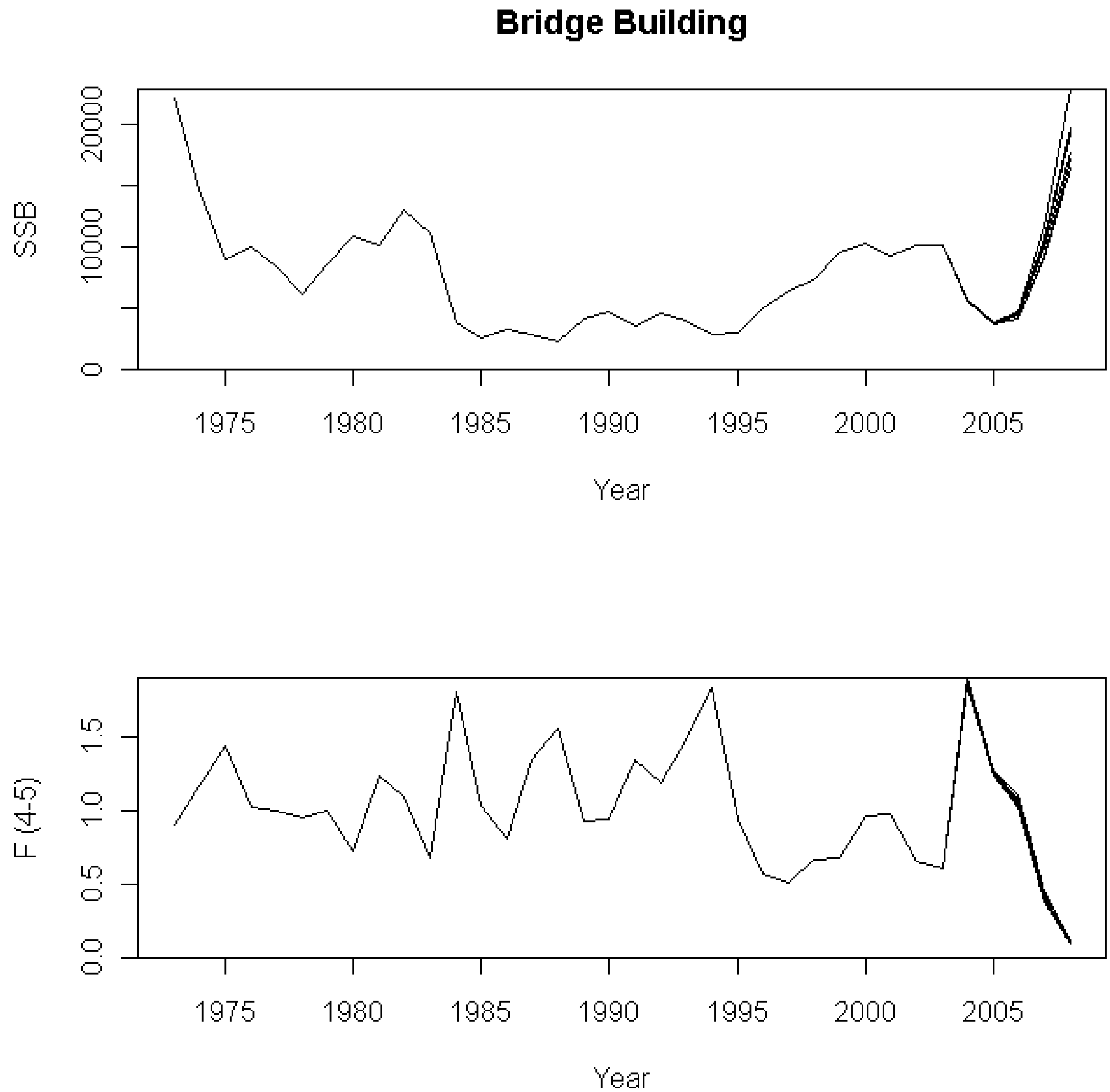

Figure 19. Spawning stock biomass (mt, top panel) and fishing mortality rate (ages 4+, bottom panel) for the TRAC 2009 assessment and four data updates since then (see text for details).

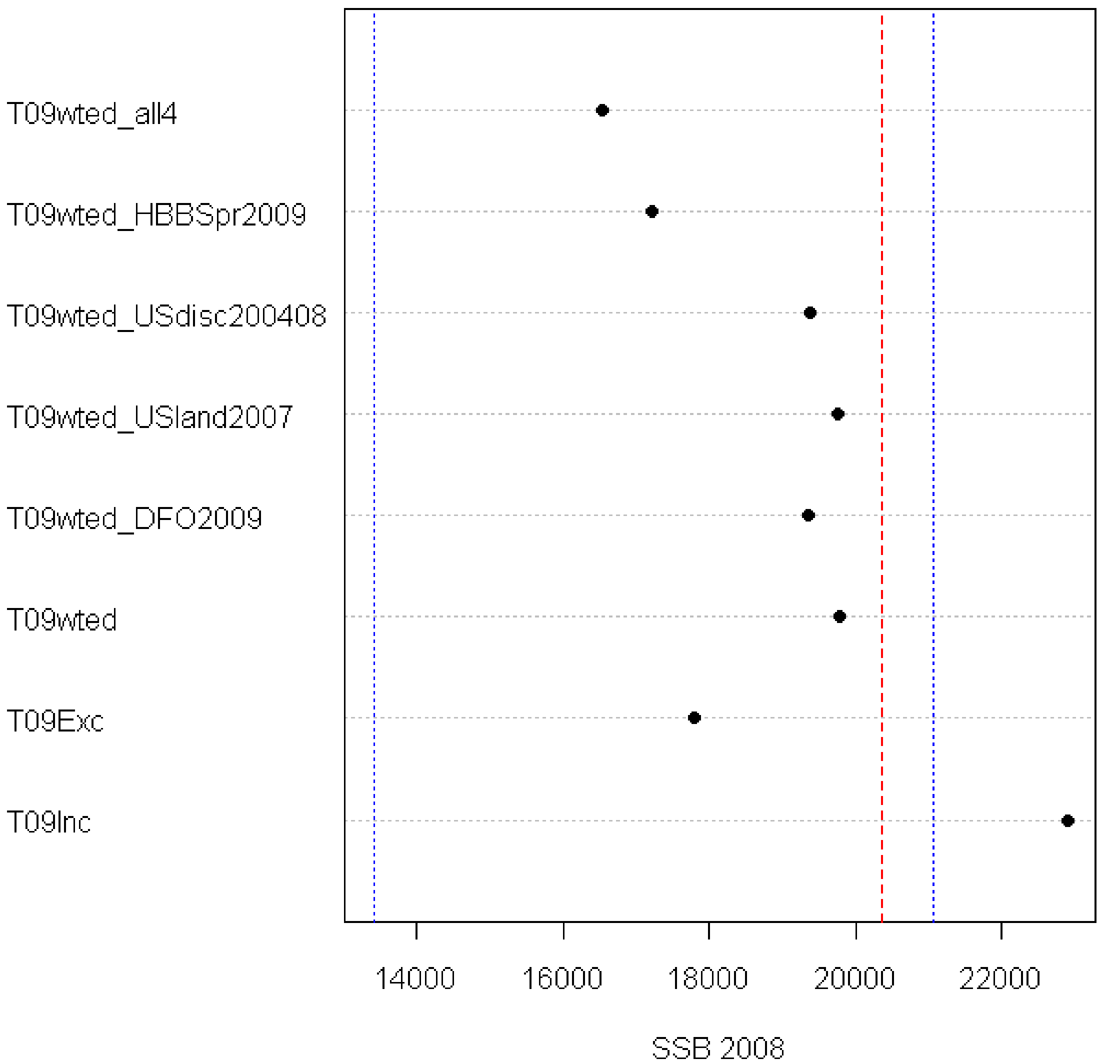

Figure 20a. Spawning stock biomass (mt) in 2008 from the TRAC 2009 assessment and four data updates since then (see text for details). The vertical dashed red line denotes the average of the two TRAC 2009 assessments. The vertical dotted blue lines denote the 80% confidence interval for the run with all four updates (T09wted_all4).

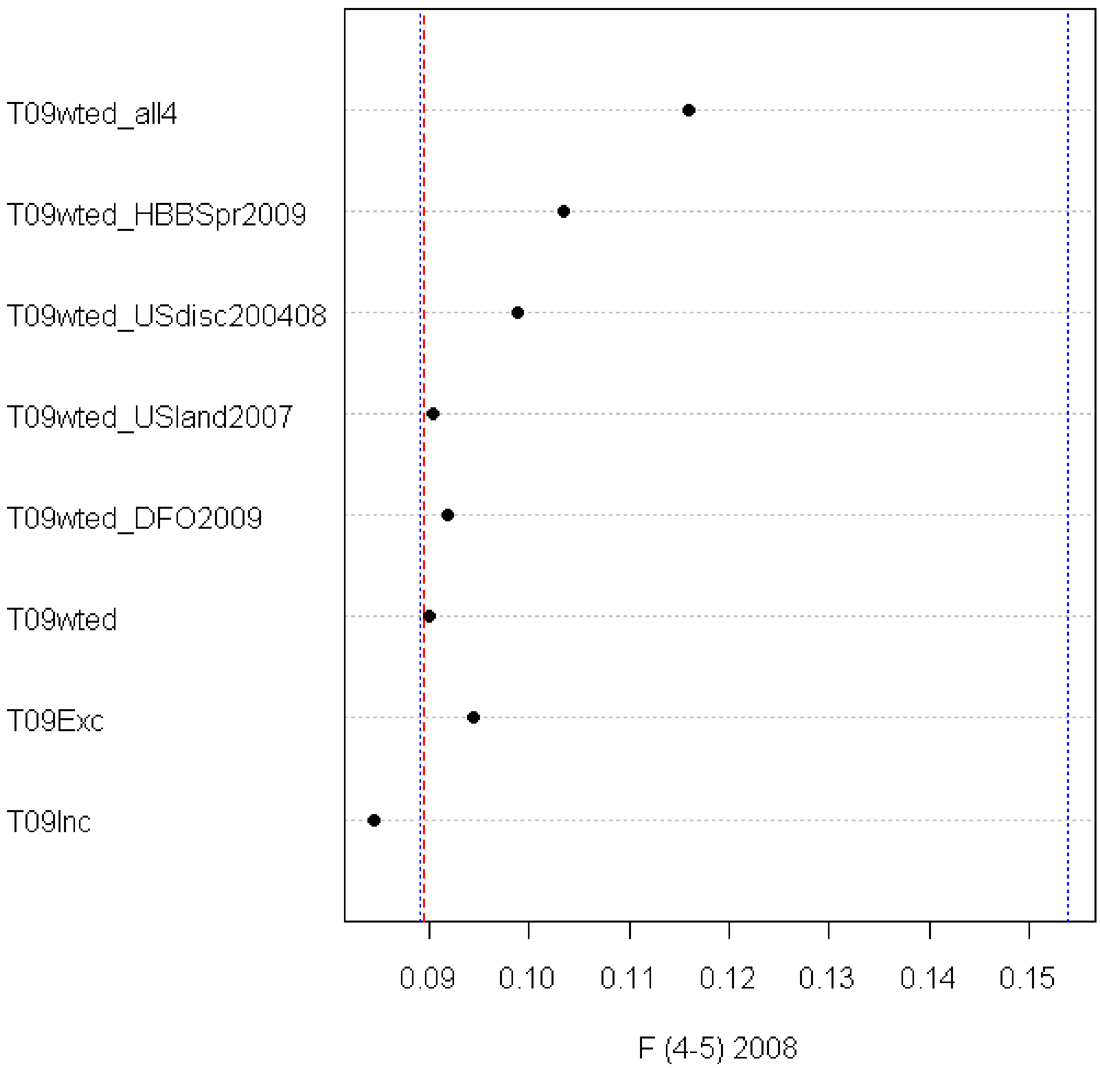

Figure 20b. Fishing mortality rate (ages 4+) in 2008 from the TRAC 2009 assessment and four data updates since then (see text for details). The vertical dashed red line denotes the average of the two TRAC 2009 assessments. The vertical dotted blue lines denote the 80% confidence interval for the run with all four updates (T09wted_all4).

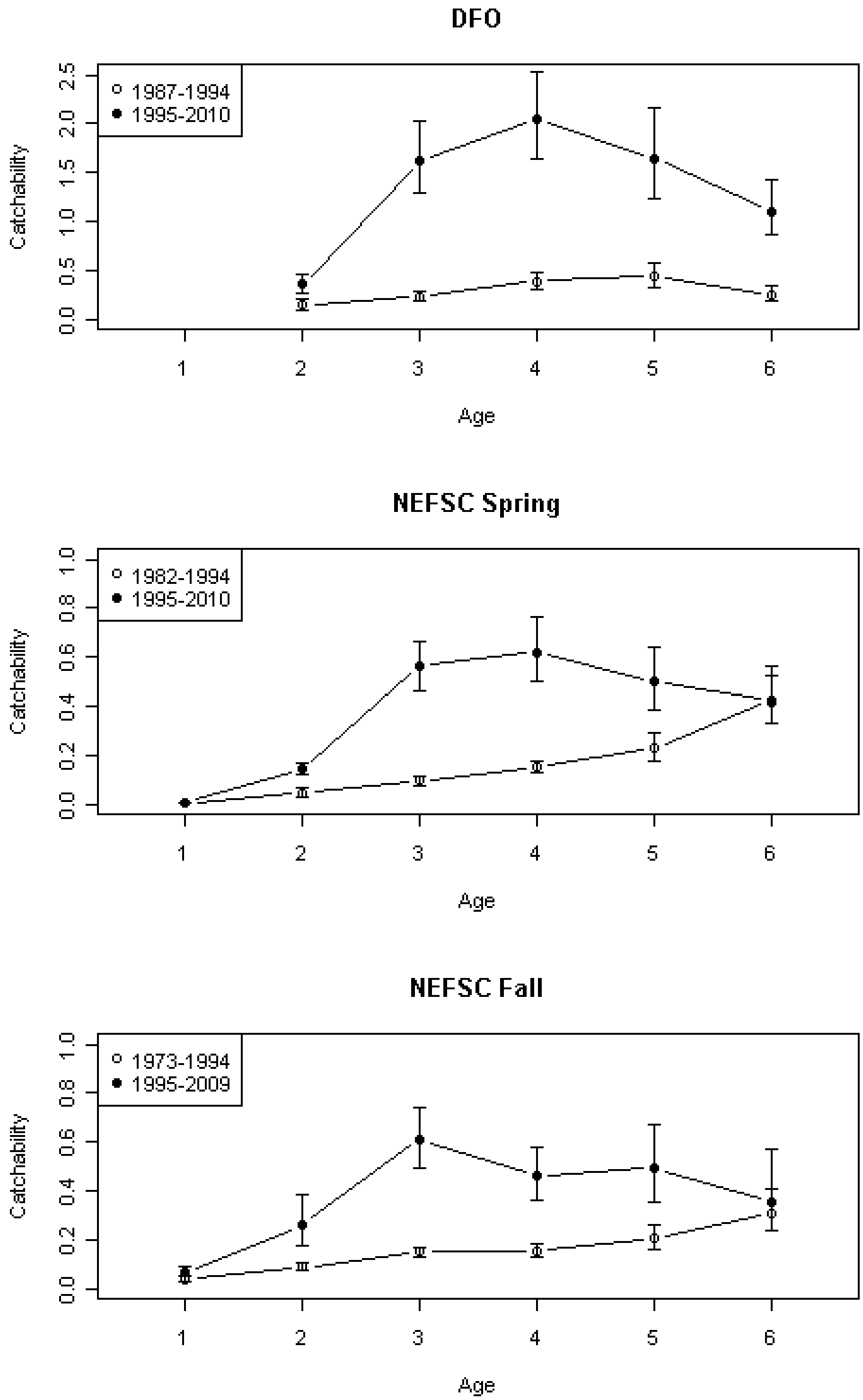

Figure 21. Catchability coefficients (q) from the Split Series VPA with bootstrapped 80% confidence intervals.

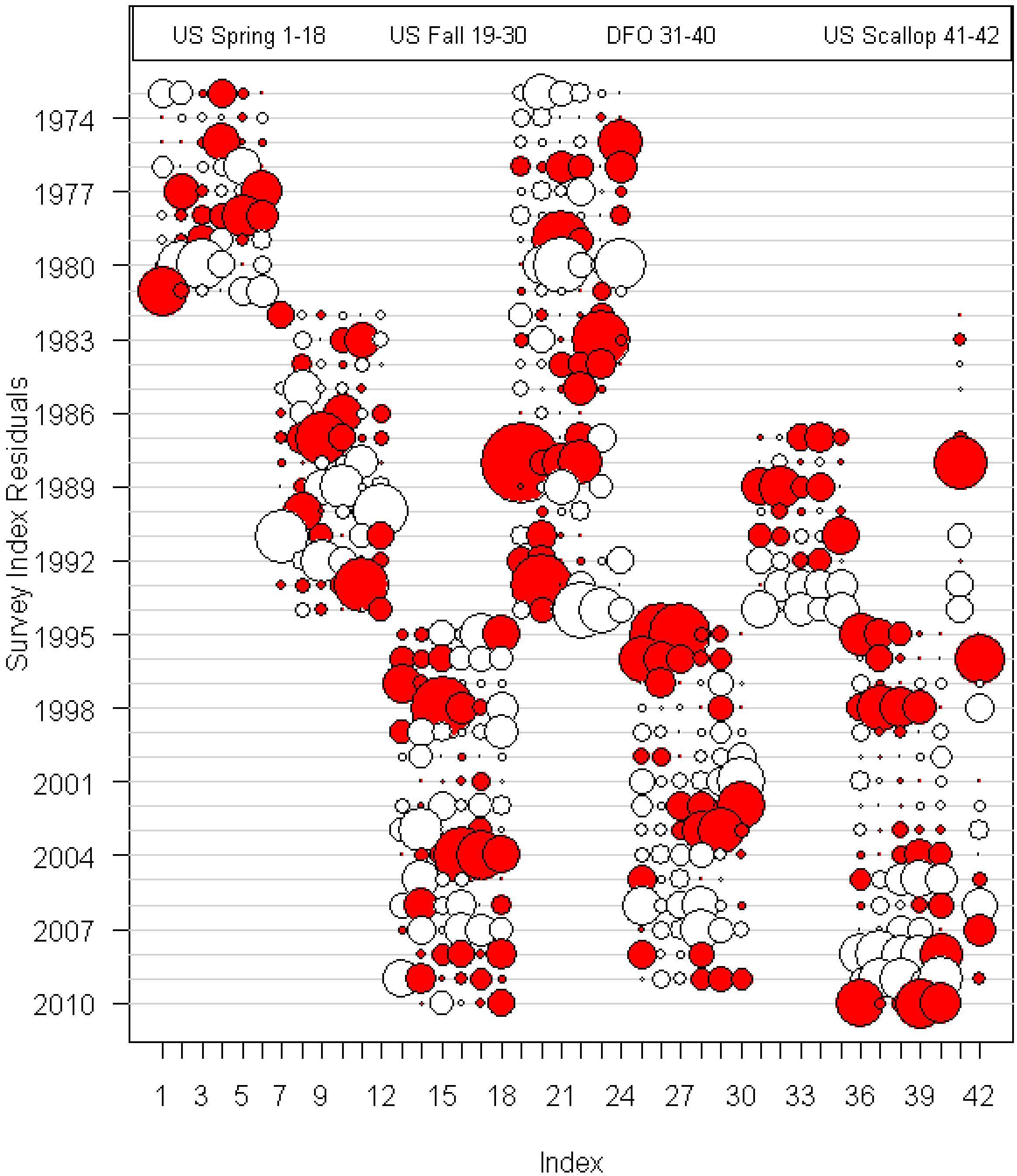

Figure 22. Georges Bank yellowtail flounder age by age residuals from the Split Series VPA for *ln* abundance index minus *ln* population numbers (bubble size is proportional to magnitude). The red symbols denote negative residuals, and white symbols denote positive residuals.

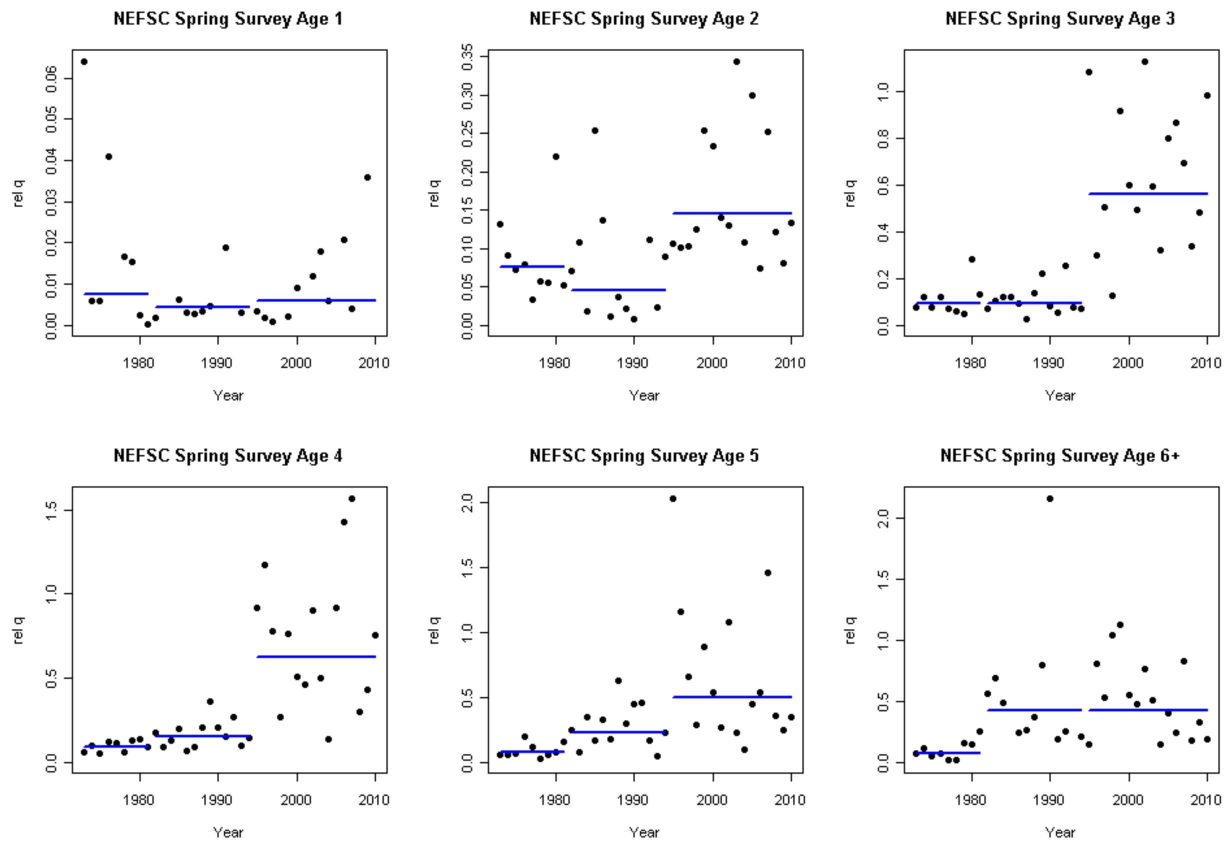

Figure 23a. Age specific relative catchability plots (survey index divided by the estimated abundance in numbers at that age and year) for the NEFSC spring survey. Horizontal bars denote the estimated catchability value from the Split Series VPA. No adjustments have been made to the estimated abundance to account for the timing of the survey.

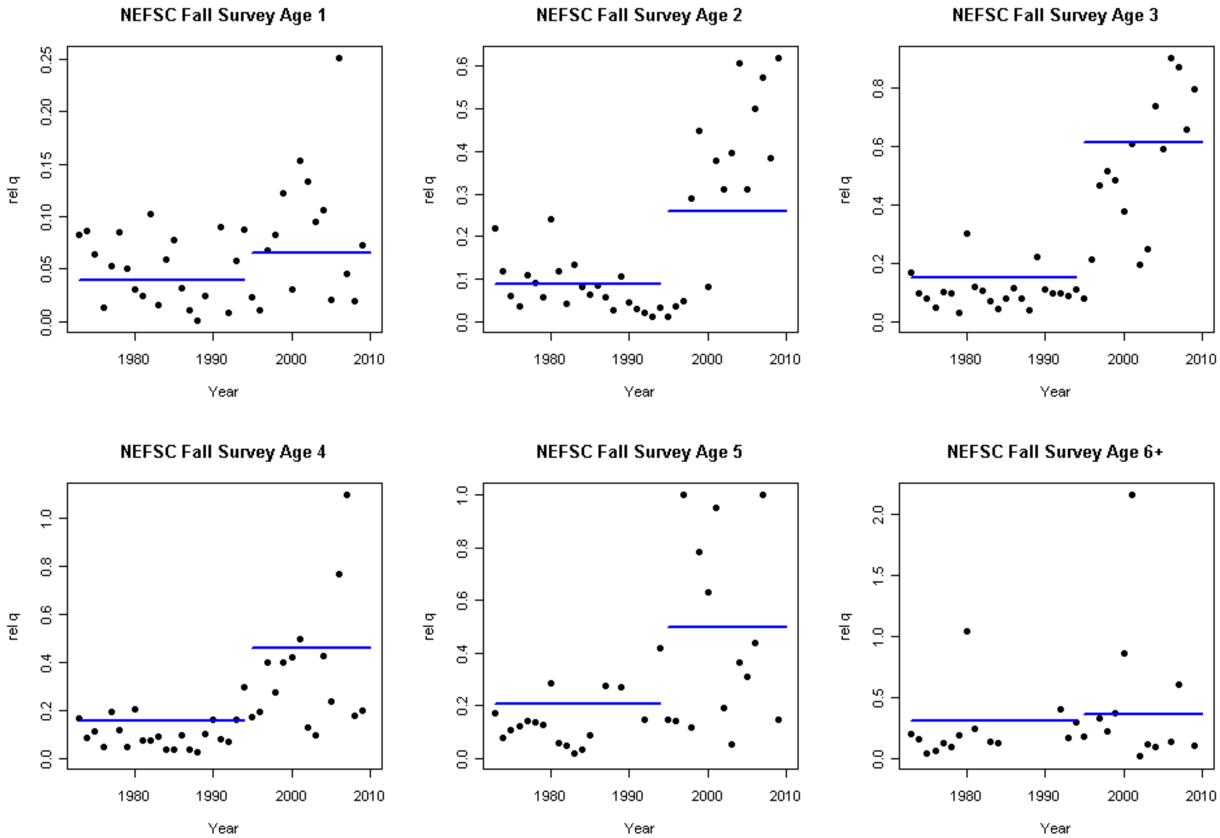

Figure 23b. Age specific relative catchability plots (survey index divided by the estimated abundance in numbers at that age and year) for the NEFSC fall survey. Horizontal bars denote the estimated catchability value from the Split Series VPA. No adjustments have been made to the estimated abundance to account for the timing of the survey.

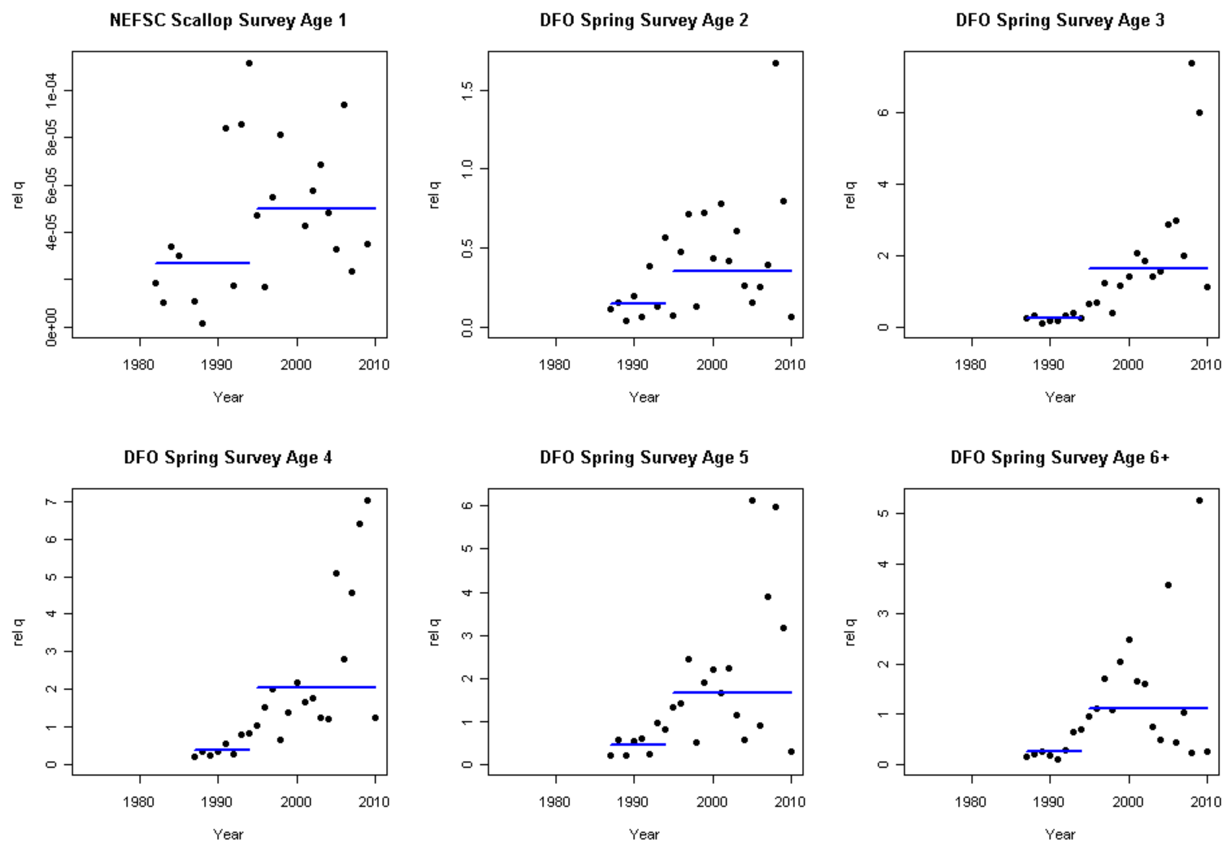

Figure 23c. Age specific relative catchability plots (survey index divided by the estimated abundance in numbers at that age and year) for the NEFSC scallop survey (age 1) and DFO survey (ages 2-6+). Horizontal bars denote the estimated catchability value from the Split Series VPA. No adjustments have been made to the estimated abundance to account for the timing of the survey.

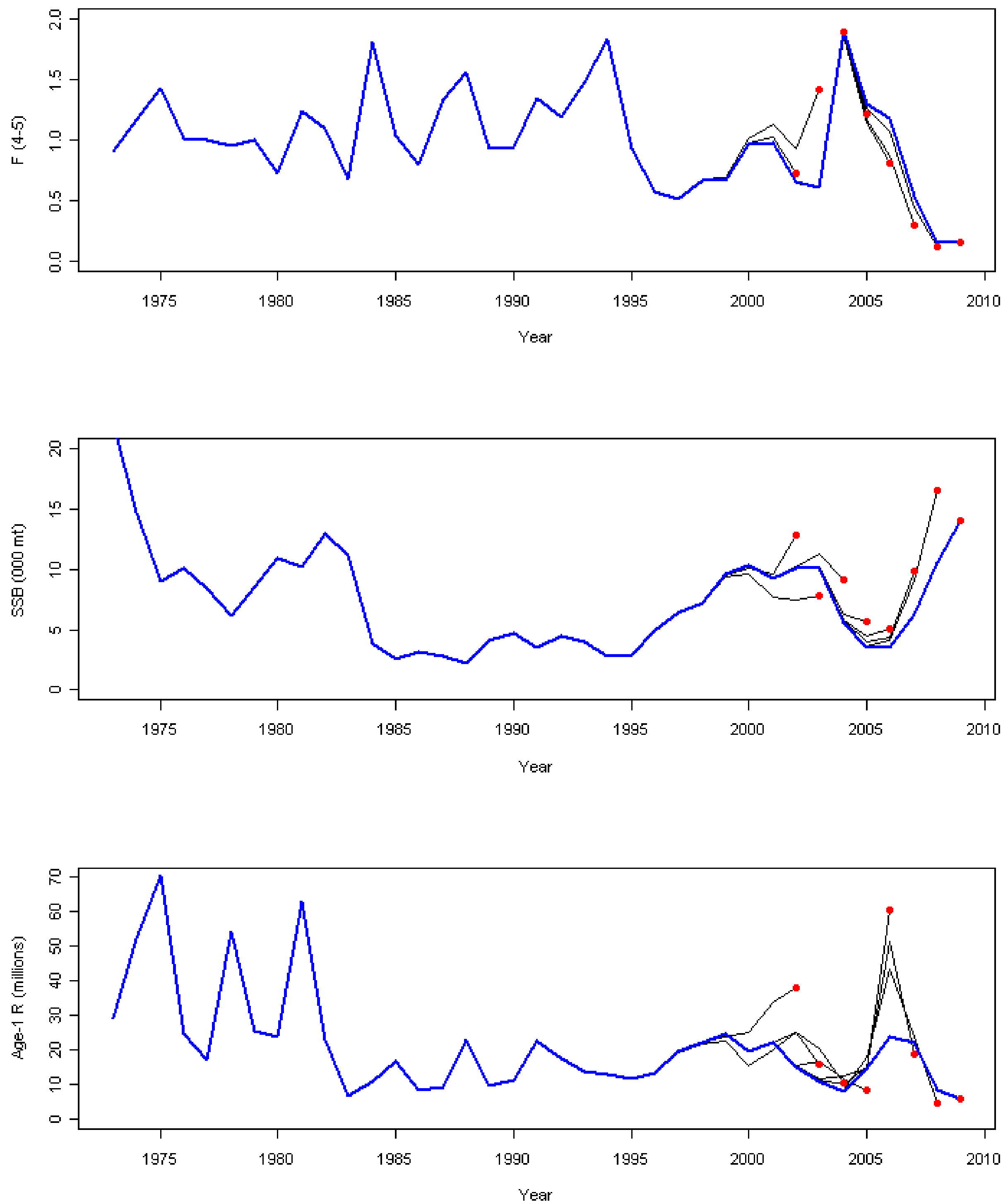

Figure 24a. Retrospective analysis of Georges Bank yellowtail flounder from the Split Series VPA for age 4+ fishing mortality (top panel), spawning stock biomass (middle panel), and age-1 recruitment (lower panel).

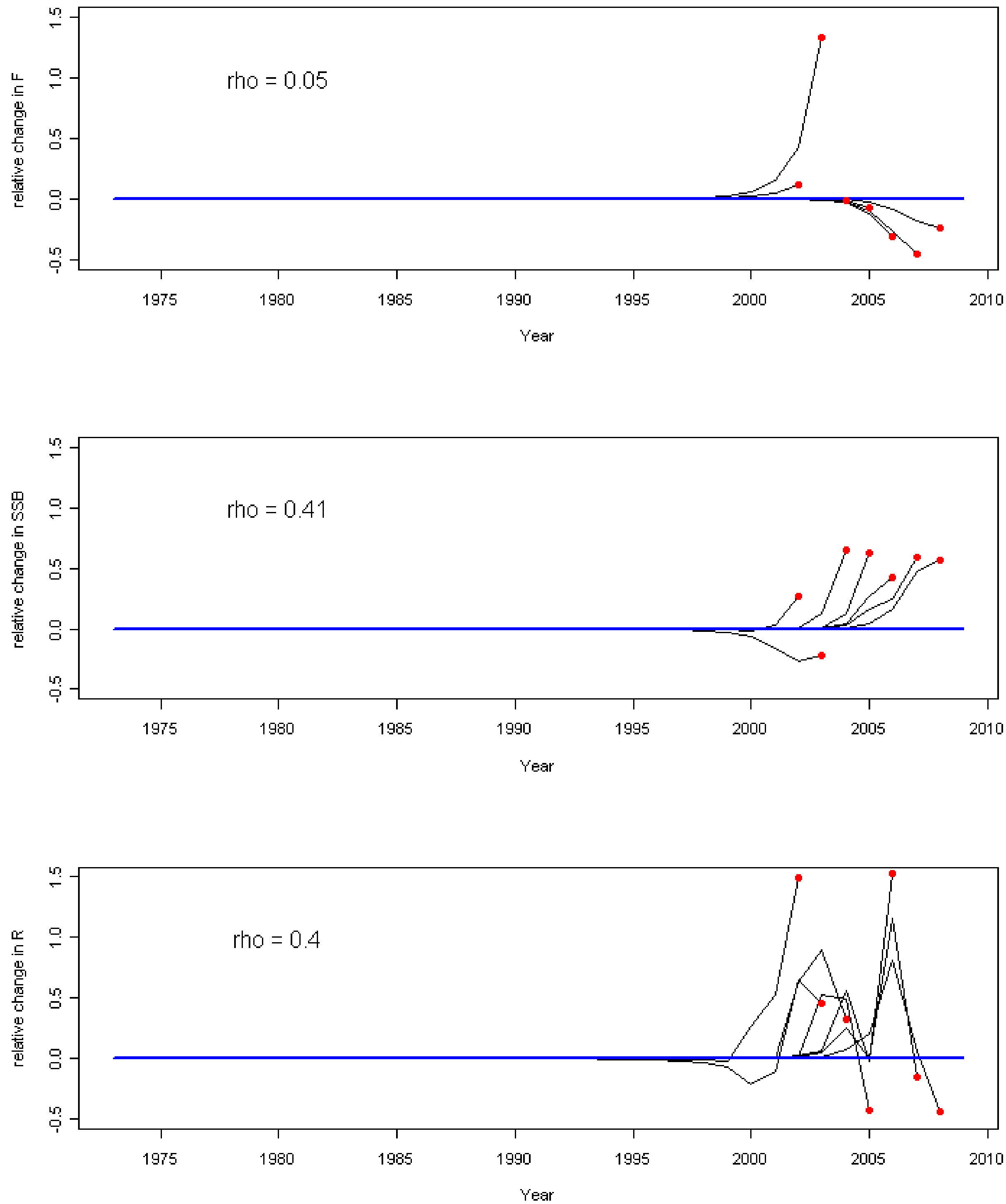

Figure 24b. Relative retrospective plots for Georges Bank yellowtail flounder from Split Series VPA with retrospective rho calculated from seven year peel.

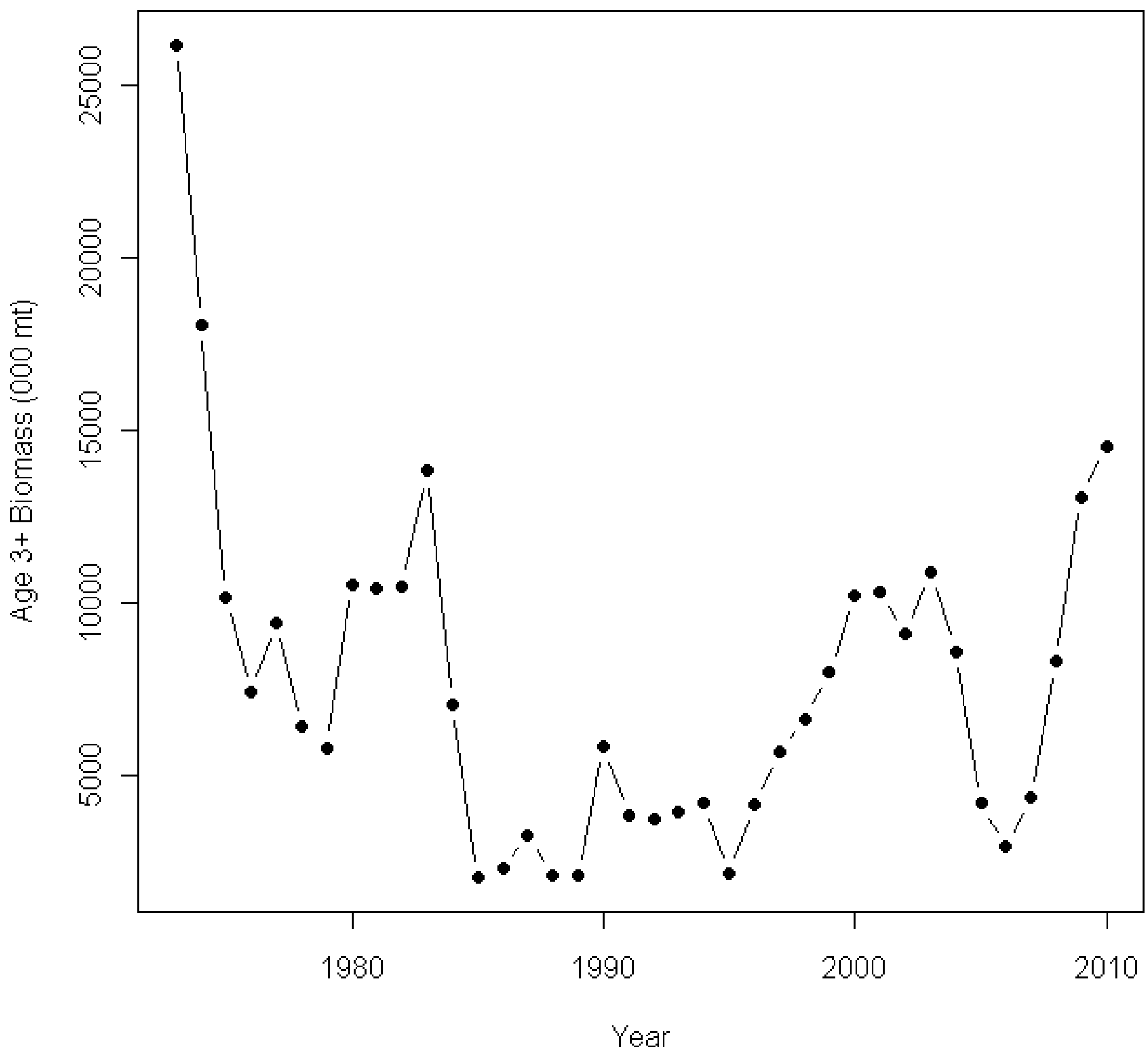

Figure 25. Adult biomass (ages 3+, Jan-1) from the Split Series VPA.

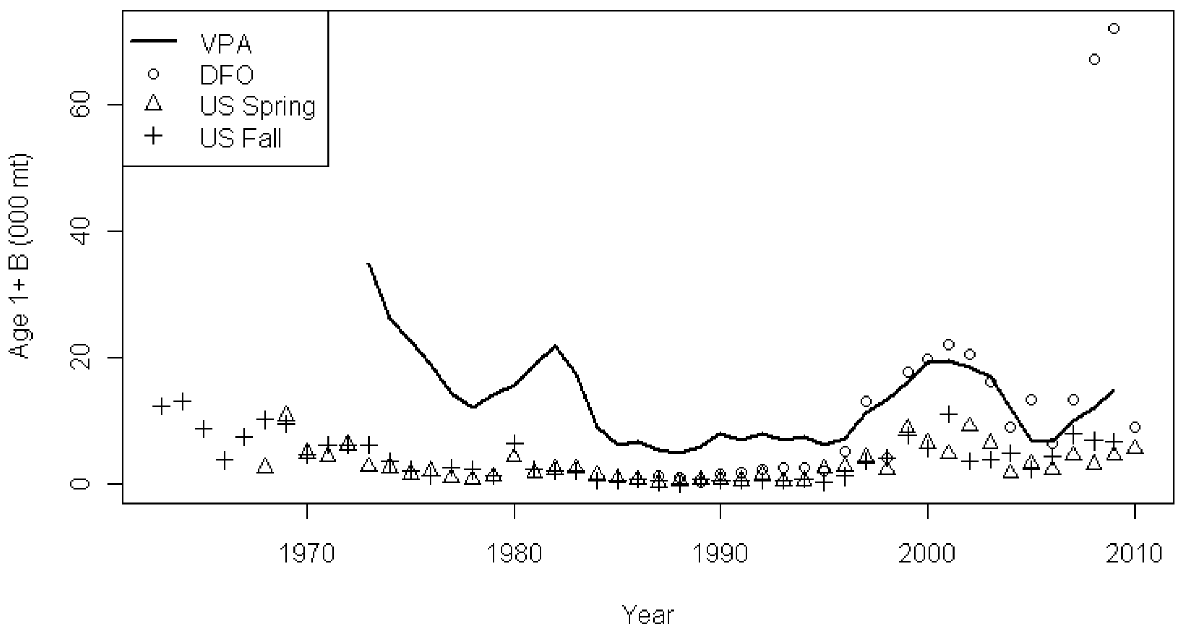

Figure 26. Total biomass (ages 1+, Jan-1) from the Split Series VPA compared to the survey biomass.

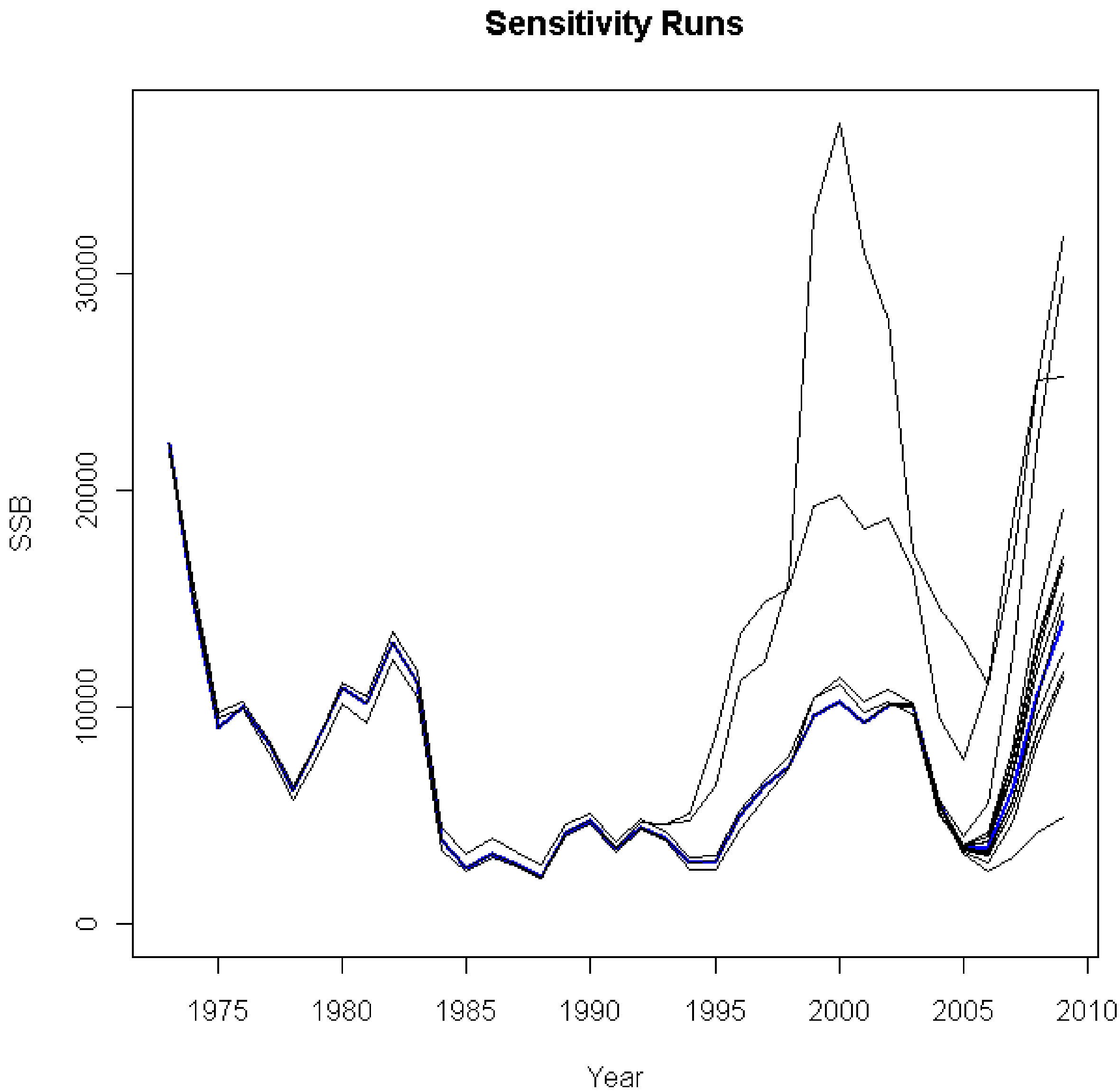

Figure 27a. Spawning stock biomass (mt) from the Split Series VPA (heavy blue line) and 14 sensitivity runs (black lines).

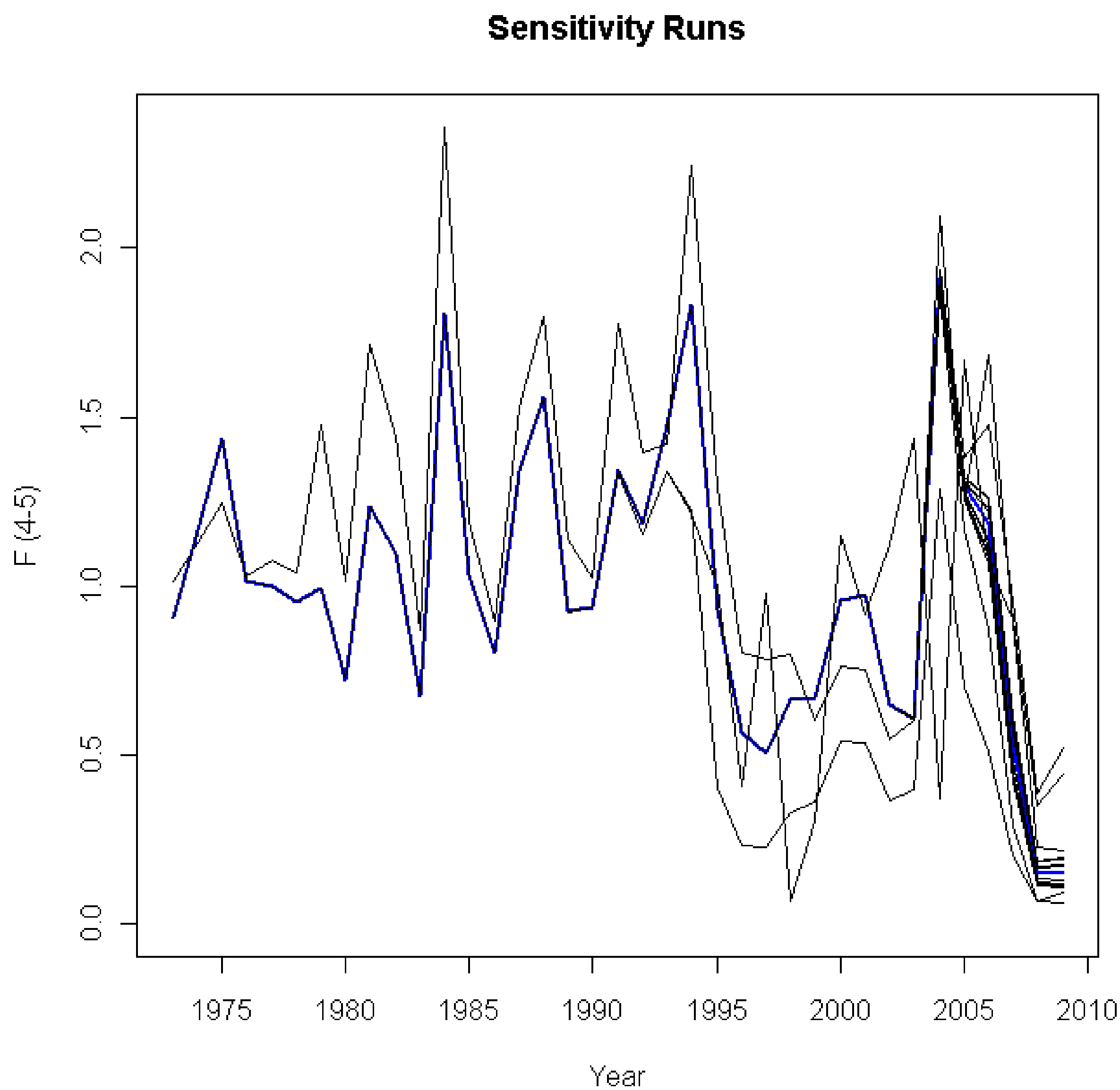

Figure 27b. Fishing mortality rate (ages 4+) from the Split Series VPA (heavy blue line) and 14 sensitivity runs (black lines).

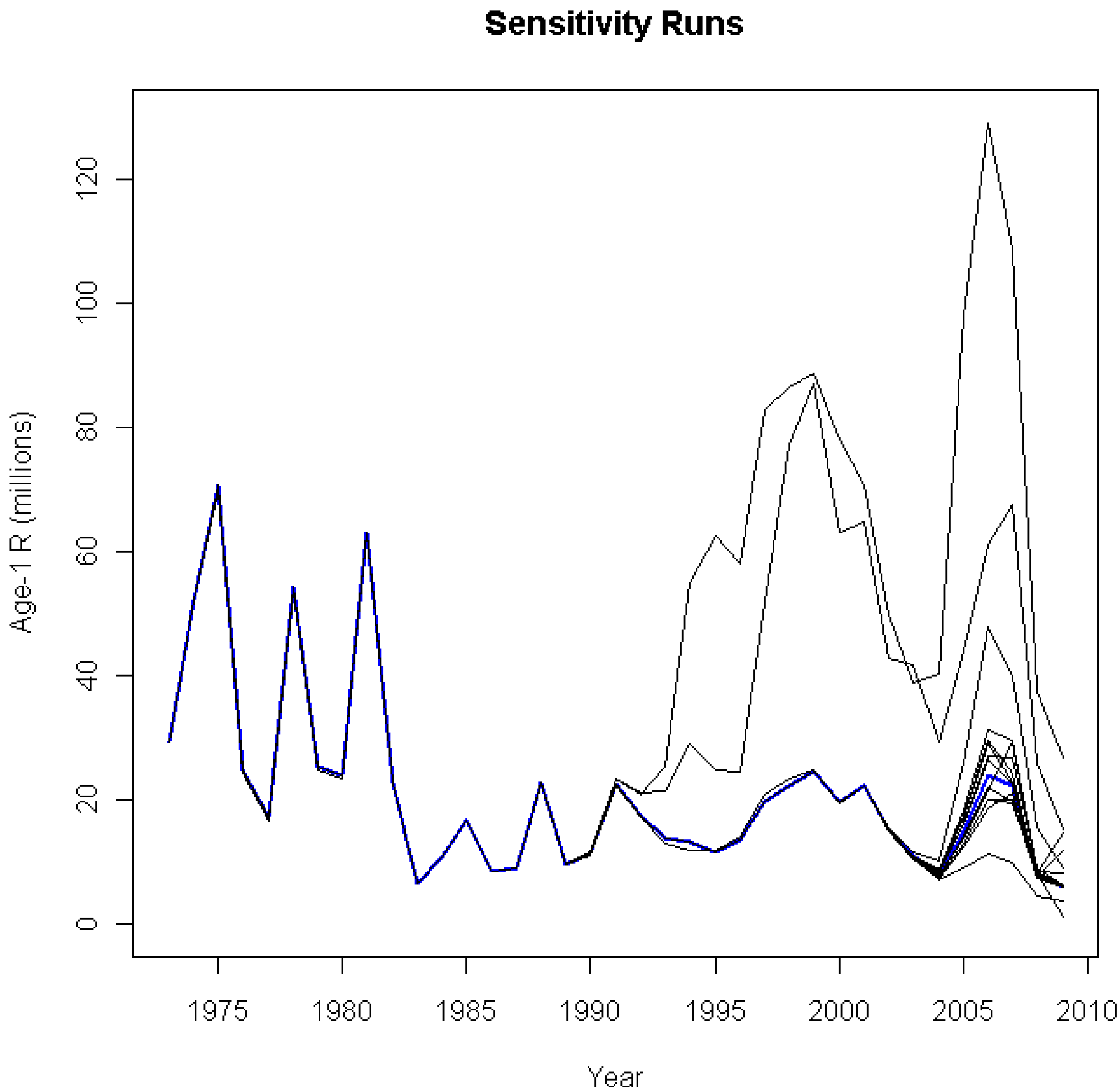

Figure 27c. Age 1 recruitment (millions of fish) from the Split Series VPA (heavy blue line) and 14 sensitivity runs (black lines).

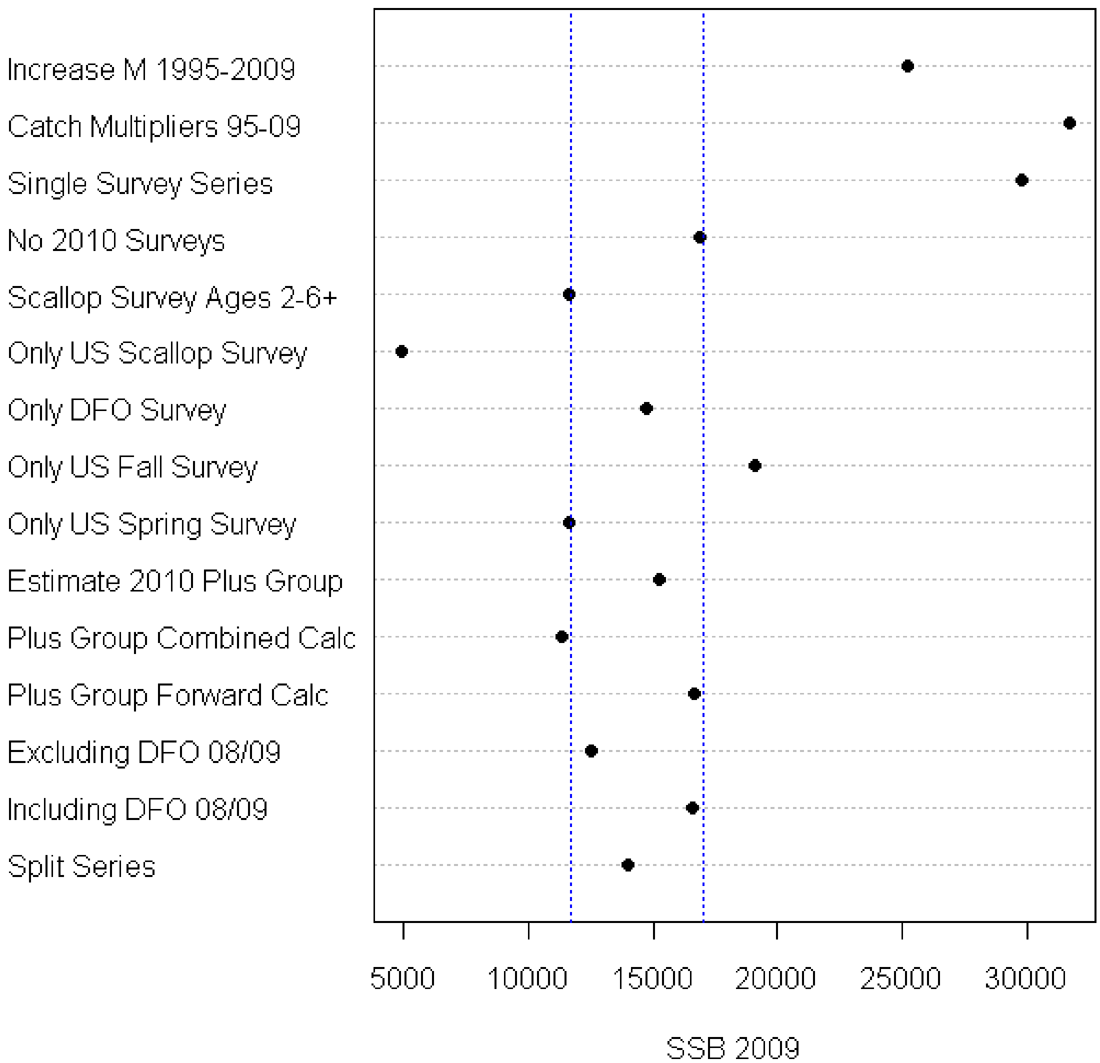

Figure 28a. Spawning stock biomass (mt) in 2009 from the Split Series VPA and 14 sensitivity runs. The vertical dotted blue lines denote the 80% confidence interval for the Split Series VPA.

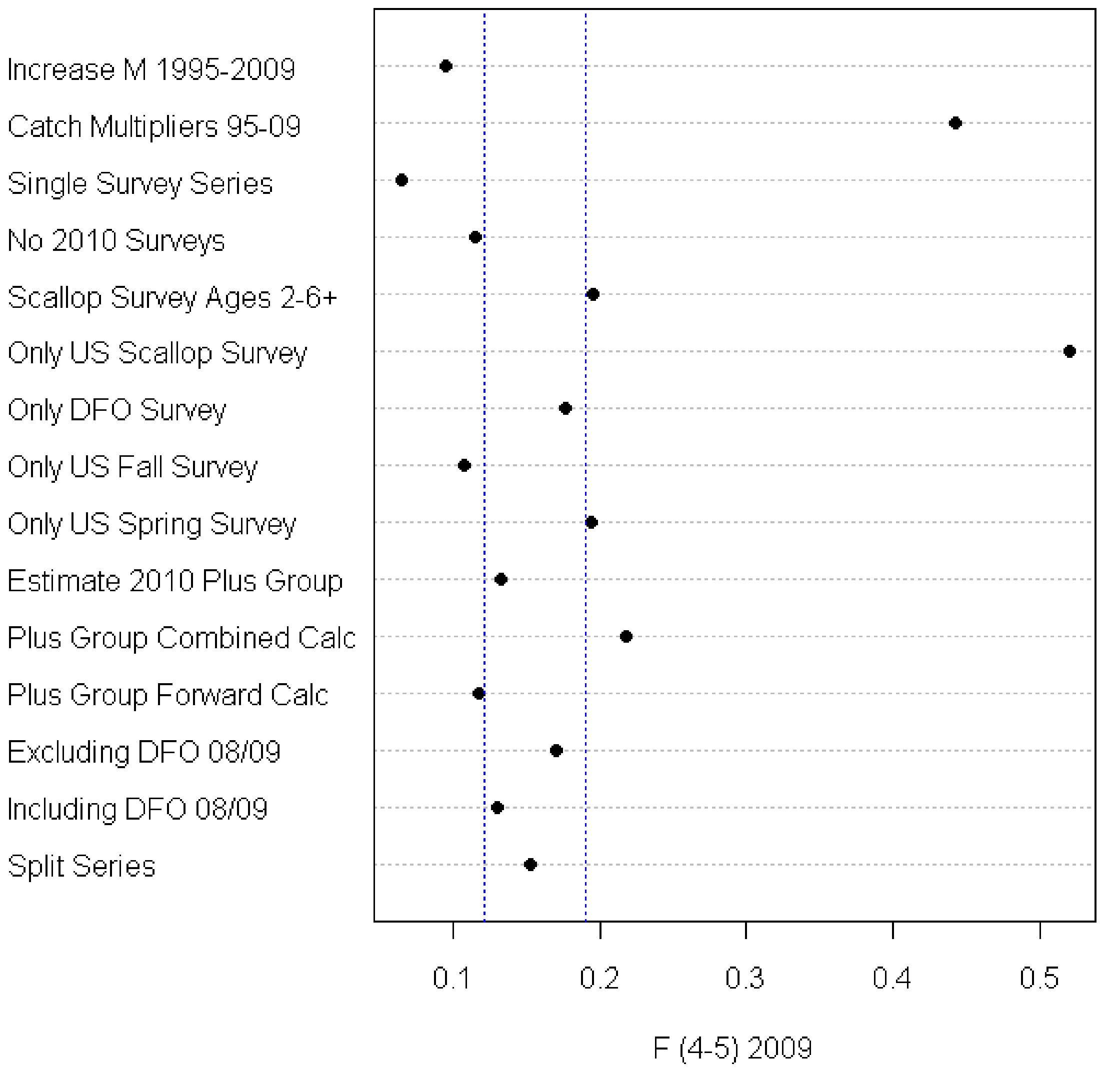

Figure 28b. Fishing mortality rate (ages 4+) in 2009 from the Split Series VPA and 14 sensitivity runs. The vertical dotted blue lines denote the 80% confidence interval for the Split Series VPA.

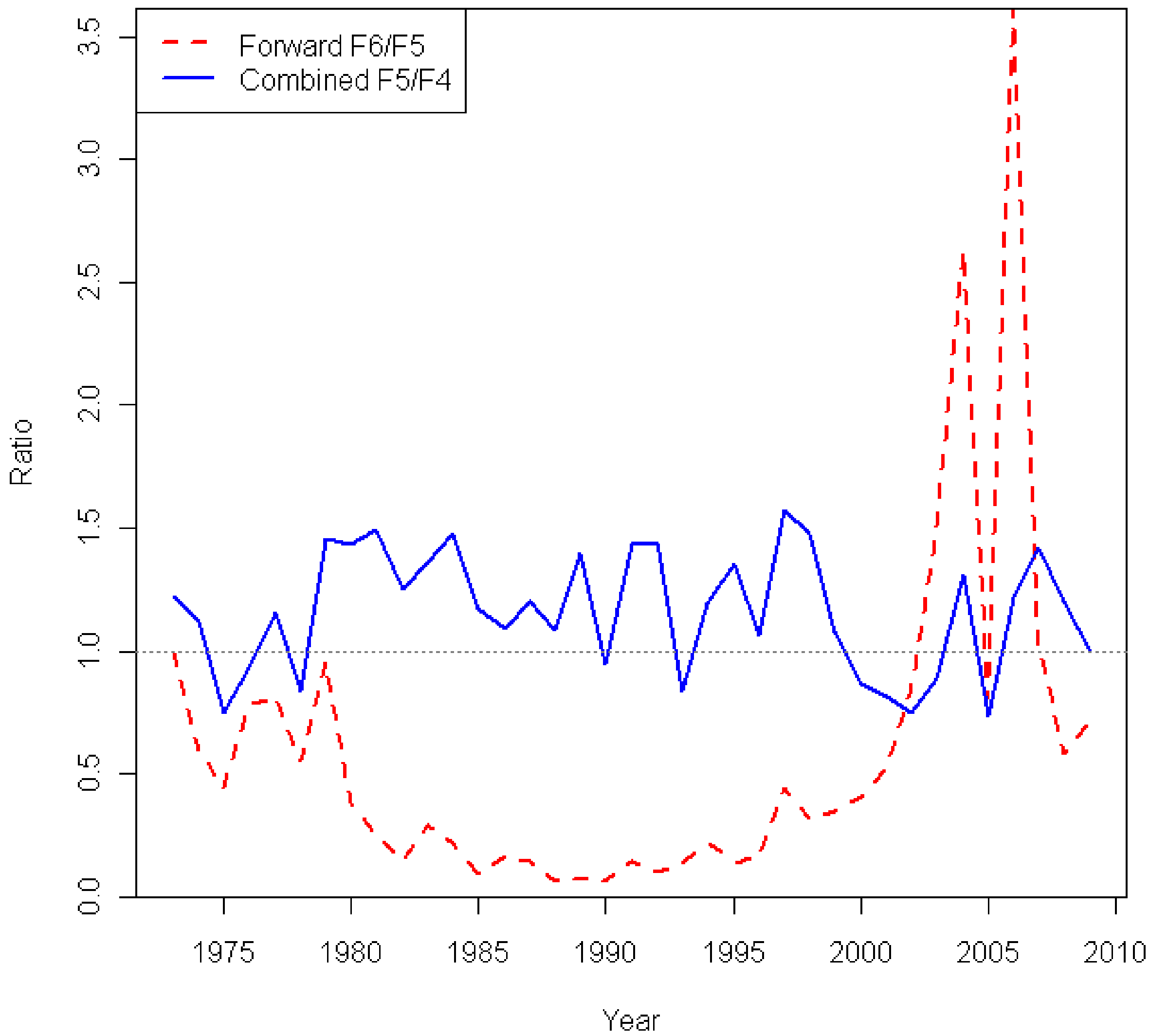

Figure 29. Ratio of fishing mortality rates at age 6 to age 5 for the forward solution to the plus group calculations (red dashed line) and ratio of fishing mortality rates at age 5 to age 4 for the combined solution to the plus group calculation (blue solid line).

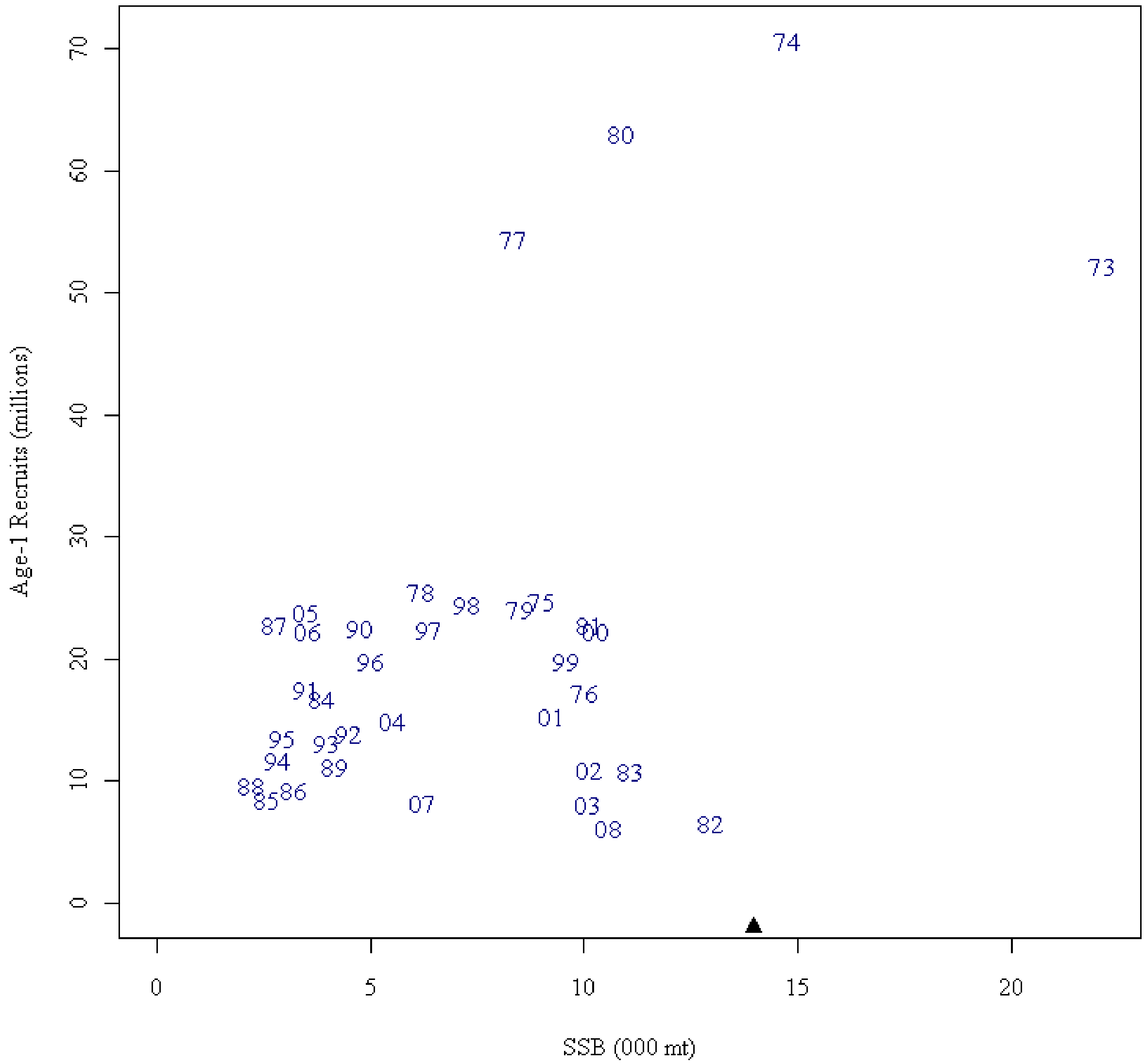

Figure 30. Stock recruitment relationship from the Split Series VPA. The number denotes year class (age of SSB at age-0). The triangle denotes the spawning stock biomass in 2009.

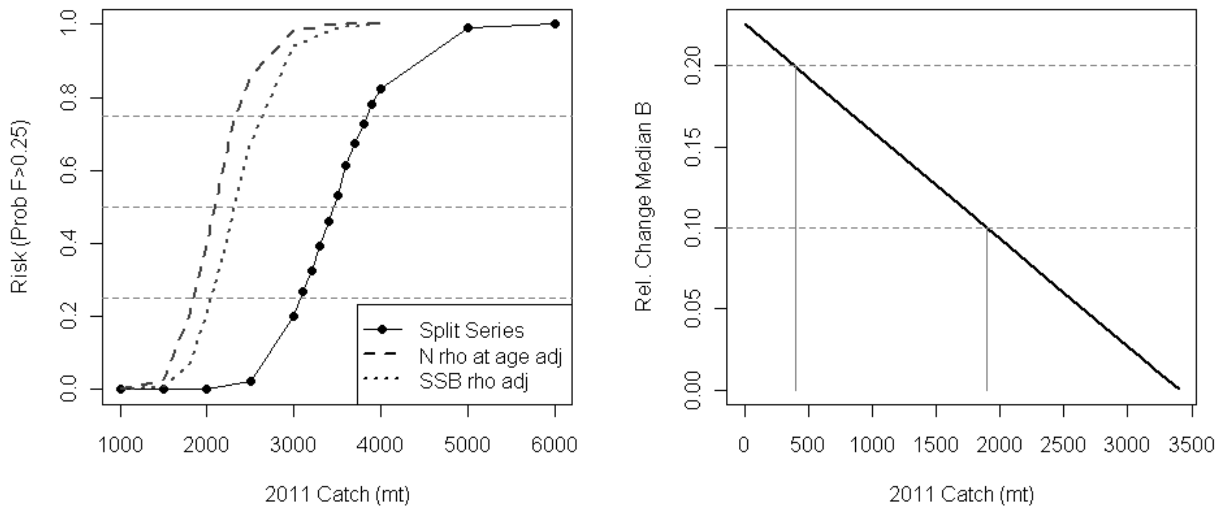

Figure 31. Risk of F exceeding F_{ref}=0.25 for a range of 2011 catch (left panel). Catches between 3000 and 4000 mt are shown by symbols in 100 mt increments. Horizontal dashed lines denote 25%, 50%, and 75% risks. Relative change in median biomass from 2011 to 2012 for a range of 2011 catch (right panel). Horizontal dashed lines denote 10% and 20% increases.

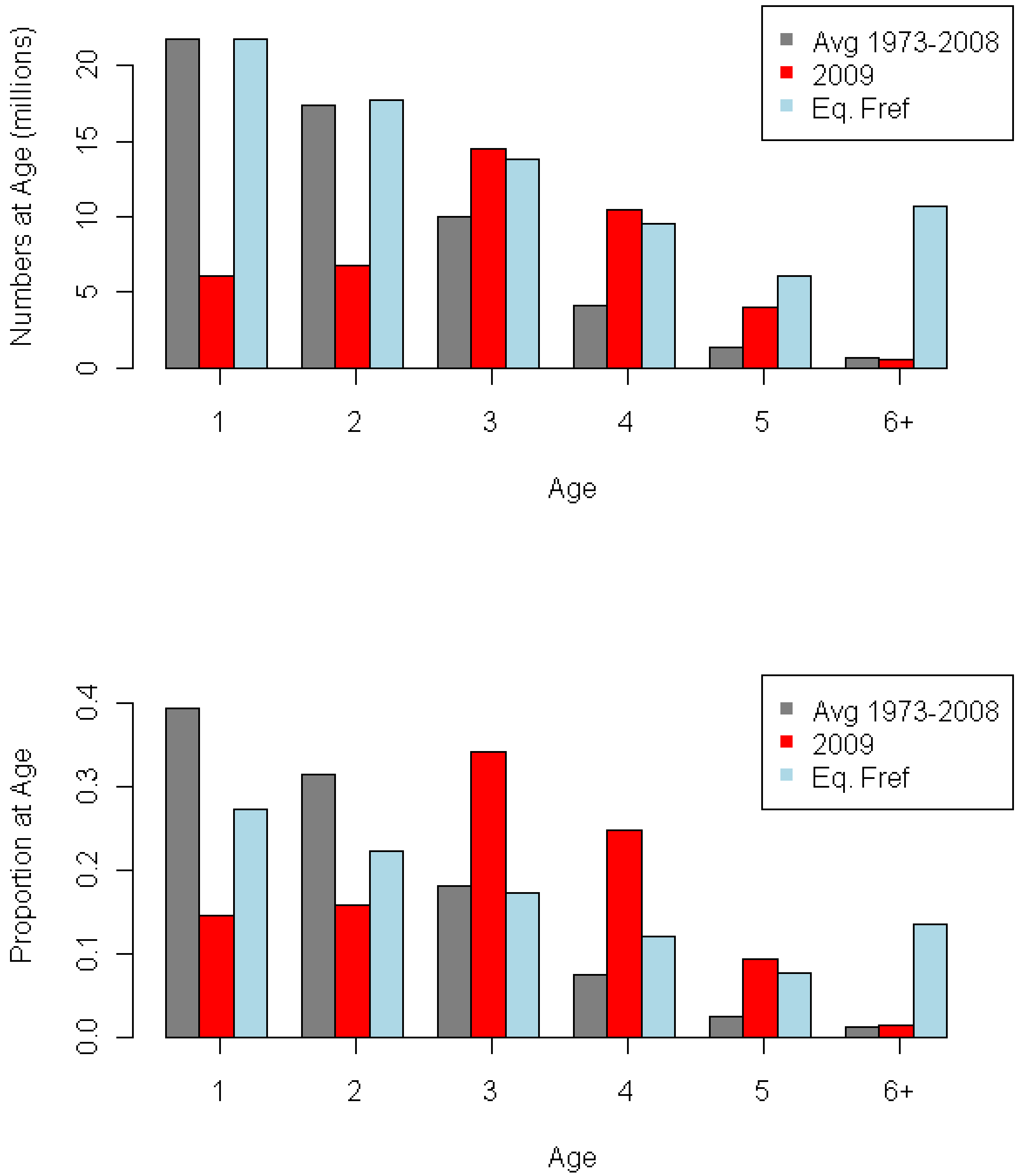

Figure 32. Comparison of the population abundance at age distributions for the Split Series VPA among the average of 1973-2008, 2009, and that expected when the population is fished in equilibrium at F_{ref}=0.25. The equilibrium numbers at age-1 in the top panel are set equal to the average for years 1973-2008. The bottom panel shows the proportions at age instead of numbers.

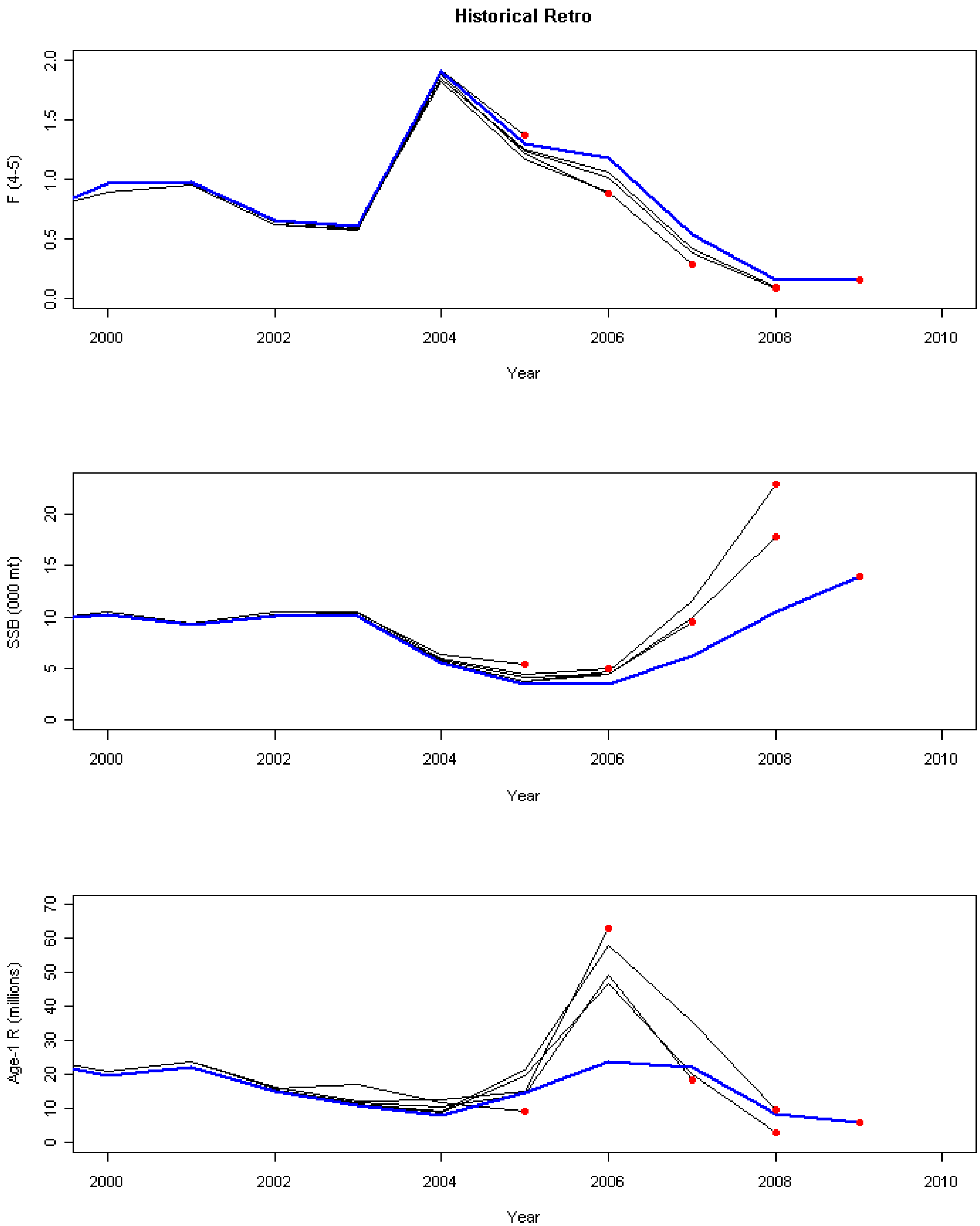

Figure 33. Historical retrospective analysis of Georges Bank yellowtail flounder assessments from this and the previous four TRAC VPAs for age 4+ fishing mortality (top panel), spawning stock biomass (middle panel), and age-1 recruitment (lower panel). Note there are two lines plotted for TRAC 2009 (terminal year 2008), the Including and Excluding formulations.