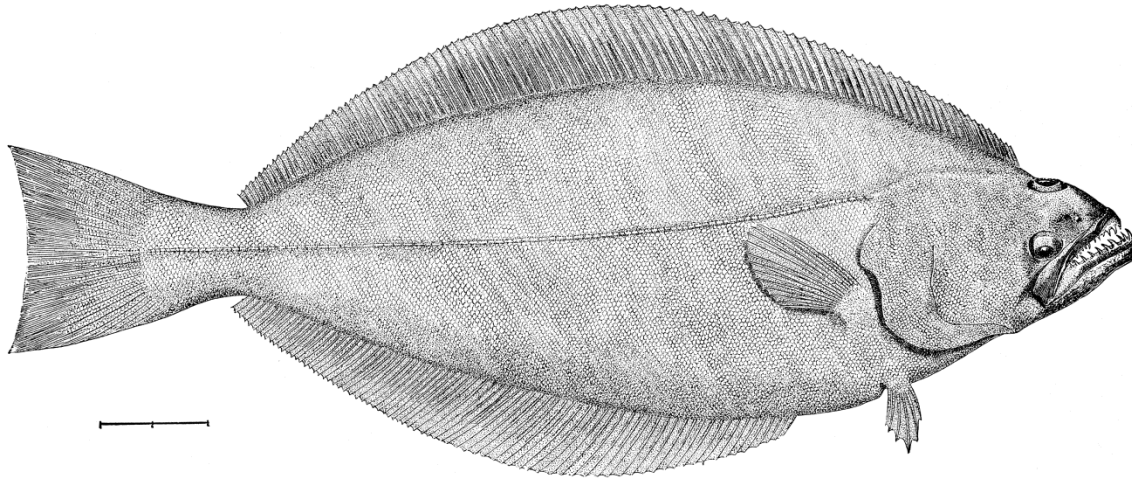# 5. Assessment of Greenland Turbot (*Reinhardtius hippoglossoides*) in the Bering Sea and Aleutian Islands

THE GREENLAND TURBOT.

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Executive Summary

Relative to last year's assessment, the following changes have been made in the current assessment.

Summary of Changes in Assessment Inputs

Change in weight at length relationship
A new weight at length relationship has been developed using the combined weight and length data from all bottom trawl surveys conducted by the Alaska Fisheries Science Center in the Bering Sea and Aleutian Islands from 1983 to 2011. The analysis presented at the September 2012 Plan team and October 2012 SSC meeting (Appendix 5.1) showed a decrease in estimated abundance due to this change of ~20%.

<u>Removal of the pre-2002 Slope survey biomass estimates</u>
Slope survey abundance index values for surveys conducted prior to 2002 were not included in this year's model. These data were removed after discussions with the current Chief Scientist for the slope survey, Dr. Jerry Hoff. The earlier surveys differed in vessel power, in gear used, and in the ability to determine whether the gear was in contact with the bottom. Therefore the older Slope survey data were considered not comparable to the more recent surveys.

<u>Addition of new fishery and survey data</u>
There were new Slope, Shelf, and Auke Bay Laboratory (ABL) longline surveys in 2012. The abundance estimate (or RPN for the ABL longline survey) and length data were added to this assessment. Fishery catch and length frequency data were updated to the 2012 numbers. The 2009 through 2012 ABL longline survey length data have become available and added to the assessment.

<u>Changes in length and age composition data</u>
Fishery length composition data were treated differently this year than in previous years. The raw Trawl and Longline fishery length composition data were proportioned to catch numbers by haul to obtain a more accurate representation of the catch composition. The proportion (P) of

fish for a particular length bin (*l*) and year (*y*) was calculated as $P_{yl} = \dfrac{\Sigma\left(\frac{n_{ylh}}{n_{yh}}N_{yh}\right)}{\Sigma N_{yh}}$, where *n* is the

number of fish in a length bin (*l*) for an individual year (*y*) and haul sample (*h*) and *N* is the total number of fish in a haul (*h*) for year (*y*) for each fleet.

<u>Change in fishery multinomial sample sizes for the length data</u>
Initial sample sizes for the two fisheries for each year were determined as the minimum of 100 + (number of hauls sampled/mean number of hauls sampled/100) or the number of hauls sampled. This scheme was intended to reduce the influence of within sample and across haul autocorrelation in very large, single year, sample sizes on model fit.

<u>Change in recruitment estimation</u>
In this year's assessment we explore four models. Model 1 is the 2011 reference model where recruitment was modeled as two separate Beverton-Holt stock recruitment (BH) curves with steepness of 0.9 and sigma R of 0.6, but with a difference in productivity (R_0) between the early recruitment (1965-1970) and later recruitment. Recruitment deviations were not estimated for the 1965-1970 recruitments and they were assumed to follow the BH curve with no error. Model 2 and Model 3 follow the models presented at the September 2012 Plan Team and October 2012 SSC meetings (Appendix 5.1). All recruitment is modeled as a single BH curve with either no autocorrelation (Model 2) or 0.6 autocorrelation (Model 3), steepness of 0.79 and sigma R of 0.6. Recruitment deviations are estimated separately for the pre-1975 and the later recruitment deviations. Recruitment is modeled back to 1945 to allow the model to ramp up to the estimated abundance levels needed to support the large pre-1975 fishery, but for which we have no length or age composition data. Model 3 follows suggestions by Dr. Grant Thompson to start the model

in 1977 and ignore the pre-1977 catches where no length or age data were available. In this model recruitment was estimated as a BH curve with steepness of 0.79, sigma r of 0.6, and no autocorrelation. Recruitment deviations from 1977-1989 were estimated separately from the post-1989 recruitment where better length composition data were available.

Changes in Selectivity for all fisheries and surveys

There was focused effort to explore appropriate selectivity curves for the 2012 assessment. The main difference between the 2011 Reference model selectivity and the 2012 candidate model selectivities is in how the male and female selectivity curves were allowed to differ. A new method for fitting curves that differ between male and females was implemented in the latest version of SS3 (V 2.24).

Summary of Results

There was a major revision of the Greenland turbot stock assessment model and data for this year. The changes in the weight at age and selectivities had the net effect of reducing the current biomass estimate while increasing the reference points for this species. In addition to changes to the assessment model and data, there was a input error in 2009-2011 projection models that resulted in underestimates of the initial female spawning biomass ($B_{100\%}$), and therefore all biomass reference points. From the 2012 Authors' preferred reference model (Model 2) this year's estimate for $B_{100\%}$ of 119,217 t is more than double last year's estimate of 53,900 t, but similar to the 2008 estimate of 109,328 t. The 2012 status of the stock is $B_{21\%}$, much lower than last year's projected status for 2012 of $B_{89\%}$ and the 2008 estimate of $B_{52\%}$. The change in status was mostly due to fixing the input error and improvements in the shapes of the selectivity curves chosen in 2012. Due to these changes the stock is now in Tier 3b and therefore the ABC and OFL recommendations were further reduced by the descending portion in the control rule. The 2013 recommended ABC is only 26% of the projected 2013 ABC from last year's model. However, the projected 2013 estimated total biomass in this year's model is higher than projected from the 2011 Reference model. This is due to strong 2008 and an especially large 2009 year classes observed in both the survey and fisheries size composition data. These two year classes are expected to be larger than any other recruitment event since the 1970's and will begin to have an increasing influence on spawning stock biomass starting in 2014. Model 2 estimated that the BSAI Greenland turbot fishery is not overfishing the stock, that the stock is not currently overfished, and that the stock is not approaching an overfished condition. It should be noted however, that Model 3 in this assessment estimates that the BSAI Greenland turbot stock is in an Overfished condition. The only difference between Model 3 and Model 2 is the inclusion of autocorrelation in the recruitment deviations. Model 3 is the best fitting model and the only reason this model was not selected by the stock assessment authors is due to the fact that inclusion of autocorrelation in SS3 has not yet been thoroughly vetted.

Quantity	As estimated or *specified last* year for:		As estimated or *recommended this* year for:	
	2012	2013	2013	2014
M (natural mortality rate)	0.112	0.112	0.112	0.112
Tier	3a	3a	3b	3b
Projected total (age 1+)	76,850	73,910	80,989	94,752
Female spawning biomass (t)				
Projected	47,687	41,441	23,485	26,537
$B_{100\%}$	53,900	53,900	119,217	119,217
$B_{40\%}$	21,560	21,560	47,686	47,686
$B_{35\%}$	18,870	18,870	41,726	41,726
F_{OFL}	0.453	0.453	0.14	0.16
$maxF_{ABC}$	0.367	0.367	0.12	0.13
F_{ABC}	0.367	0.367	0.12	0.13
OFL (t)	11,658	9,697	2,539	3,266
maxABC (t)	9,660	8,029	2,064	2,655
ABC (t)	9,660	8,029	2,064	2,655
EBS	7,226	6,006	1,612	2,074
Aleutian Islands	2,434	2,023	452	581
	As determined *last* year		As determined *this* year	
Status	2010	2011	2011	2012
Overfishing	No	n/a	No	n/a
Overfished	n/a	No	n/a	No
Approaching overfished	n/a	No	n/a	No

Responses to SSC and Plan Team Comments on Assessments in General

Retrospective analysis

From the December 2011 SSC minutes: The SSC is pleased to see that many assessment authors have examined retrospective bias in the assessment and encourages the authors and Plan Teams to determine guidelines for how to best evaluate and present retrospective patterns associated with estimates of biomass and recruitment. We recommend that all assessment authors (Tier 3 and higher) bring retrospective analyses forward in next year's assessments.

From the September 2012 Plan Team minutes: The Teams recommend that authors conduct a retrospective analysis back 10 years (thus, back to 2002 for the 2012 assessments), and show the patterns for spawning biomass (both the time series of estimates and the time series of proportional changes relative to the 2012 run). This is consistent with a December 2011 NPFMC SSC request for stock assessment authors to conduct a retrospective analysis. The base model used for the retrospective analysis should be the author's recommended model, even if it differs from the accepted model from previous year.

In response to these requests, we conducted a within-model retrospective analysis back 10 years using the recommended model (Model 2).

Responses to SSC and Plan Team Comments Specific to this Assessment

SSC Comments
The SSC commends the assessment authors for their efforts to improve this assessment model and address SSC and Plan team concerns. The SSC looks forward to additional improvements in next year's assessment.

Authors - Thank you.

Plan Team Comments
For the November meeting, the Team recommends that the author present two or possibly three models: 1) a reference model, which is the original 2011 model with updated and corrected data; 2) an alternative model similar to the author's preferred model from the preliminary assessment with a few modifications (see below for details); and 3) a third model of the author's choosing, included at the author's discretion.
1) Early recruitments.
Noting the potential influence of catches from earlier years (i.e., 1960s) on reference points, the Plan Team recommends further evaluation of that influence by starting the model at different points in time with single large catches, rather than a time series of catches, and including this change in Model 2 for November at the author's discretion and if the analysis can be completed in time. If this evaluation cannot be conducted in time for the November 2012 meeting, the Team recommends that it be completed for the September 2013 meeting.
Authors - Three model configurations were explored beyond the 2011 Reference Model. The first two start in 1945 with all catch and the third starts the model in 1977 without previous catch.

2) Selectivity patterns
The Plan Team recommends that only the logistic selectivity curve be used for the ABL longline survey in Model 2 for November.
Authors - This was done.

3) Models with fitted catchability
For November, the Plan Team recommends that the Model 2 estimate shelf survey catchability with as diffuse a prior as possible. The Team also recommends further exploration of alternative catchability assumptions for the September 2013 meeting.
Authors - Model 2 has a lognormal prior on shelf catchability of ln(q) = -0.69385 and ln(St.Dev) = 0.4. Models 3 and 4 both have more restricted priors on shelf catchability with ln(q) = -0.69385 and ln(St.Dev) = 0.1.

4) Alternative values for Sigma R.
For November, the Team recommends fixing Sigma R at a value of 0.6 in Model 2, while allowing a small amount of autocorrelation.

Authors - All candidate models had sigma R = 0.6. Model 3 allowed for a small amount of autocorrelation (rho = 0.6) in the recruitment deviations.

Introduction

This year the BSAI Greenland turbot stock assessment will be lead by Dr. Steven Barbeaux. Although the stock will continue to be modeled using the same software as previous assessments (Stock Synthesis 3) there are a number of changes within the model. This is an attempt to better capture the complex population dynamics of this species due its unique life history and distribution across two geopolitical boundaries (the US-Russian EEZ and the Northern extent of the AFSC surveys). We will present the 2011 model configuration (Model 1) fit to the most recent data as well as three alternative candidate models (Model 2, Model 3, and Model 4) with special emphasis on the author's preferred model (Model 2).

Life History

Greenland turbot (*Reinhardtius hippoglossoides*) is a Pleuronectidae (right eyed) flatfish that has a circumpolar distribution inhabiting the North Atlantic, Arctic and North Pacific Oceans.   The American Fisheries Society uses "Greenland halibut" as the common name for *Reinhardtius hippoglossoides* instead of Greenland turbot. To avoid confusion with the Pacific halibut, *Hippoglossus stenolepis*, common name of Greenland turbot which is also the "official" market name in the US and Canada (AFS 1991) is retained.

In the Pacific Ocean, Greenland turbot have been found from the Sea of Japan to the waters off Baja California. Specimens have been found across the Arctic in both the Beaufort (Chiperzak et al. 1995) and Chuchki seas. This species primarily inhabits the deeper slope and shelf waters (between 100 m to 2000 m; Fig. 5.1) in bottom temperatures ranging from -2°C to 5°C. The area of highest density of Greenland turbot in the Pacific Ocean is in the northern Bering Sea, straddling the border between US and Russian exclusive economic zones. Juveniles are believed to spend the first 3 or 4 years of their lives on the continental shelf and then move to the continental slope (Alton et al. 1988; Sohn 2009; Fig. 5.2). Adult Greenland turbot distribution in the Bering Sea appears to be dependent on size and maturity as larger more mature fish migrate to deeper warmer waters. In the annual summer shelf trawl surveys conducted by the Alaska Fisheries Science Center (AFSC) the distribution by size shows a clear preference by the smaller fish for shallower (< 100m) and colder shelf waters (< 0°C). The larger specimens were in higher concentrations in deeper (> 100 m), warmer waters (> 0°C) (Fig. 5.3 and Fig. 5.4).

Juveniles are absent in the Aleutian Islands regions, suggesting that the population in the Aleutians originates from the EBS or elsewhere. In this assessment, Greenland turbot found in the two regions are assumed to represent a single management stock. NMFS initiated a tagging study in 1997 to supplement earlier international programs. Results from conventional and archival tag return data suggest that individuals can range distances of several thousands of kilometers and spend summer periods in deep water in some years and in other years spend time on the shallower EBS shelf region.

Greenland turbot are sexually dimorphic with females achieving a larger maximum size and having a faster growth rate. For this assessment, data from the AFSC slope and shelf surveys were pooled to obtain growth curves for both male and female Greenland Turbot (Fig. 5.5). This sexual dimorphic growth is consistent with trends observed in the North Atlantic. Collections in the North Atlantic suggest that males may have higher mortality than females. Evidence from the Bering Sea shelf and slope surveys suggest males reach a maximum size much smaller than females, but that mortality may not be higher than in females.

Prior to 1985 Greenland turbot and arrowtooth flounder were managed together. Since then, the Council has recognized the need for separate management quotas given large differences in the market value between these species. Furthermore, the abundance trends for these two species are clearly distinct (e.g., Wilderbuer and Sample 1992).

Fishery

Catches of Greenland turbot and arrowtooth flounder were not reported separately during the 1960s. During that period, combined catches of the two species ranged from 10,000 to 58,000 t annually and averaged 33,700 t. Beginning in the 1970s the fishery for Greenland turbot intensified with catches of this species reaching a peak from 1972 to 1976 of between 63,000 t and 78,000 t annually (Fig. 5.6). Catches declined after implementation of the MFCMA in 1977, but were still relatively high in 1980-83 with an annual range of 48,000 to 57,000 t (Table 5.1). Since 1983, however, trawl harvests declined steadily to a low of 7,100 t in 1988 before increasing slightly to 8,822 t in 1989 and 9,619 t in 1990. This overall decline is due mainly to catch restrictions placed on the fishery because of apparent low levels of recruitment. From 1990- 1995 Council set the ABC's (and TACs) to 7,000 t as an added conservation measure citing concerns about recruitment. Since 1996 the ABC levels have varied but averaged 6,540 t (with catch for that period averaging 4,468 t).

The majority of the catch over time has been concentrated in deeper waters (> 150 m) along the shelf edge ringing the eastern Bering Sea (Fig. 5. 7 and Fig. 5. 8), but Greenland turbot has been consistently caught in the shallow water on the shelf as bycatch in the trawl fisheries (Table 5.2 and Table 5.3). Catch of Greenland turbot is generally dispersed along the shelf and shelf edge in the northern most portion of the management area. Since 2008 however at a 400km^2 resolution the cells with the highest amount of catch have been in the Eastern Aleutian Islands (Fig 5.9), suggesting high densities of Greenland turbot in these areas. These areas of high Greenland turbot catch in the Aleutians are coincident with the appearance of the Kamchatka and arrowtooth flounder fishery. This fishery has the highest catch of Greenland turbot outside of the directed fishery. For 2008 and in the preliminary catch data for 2012, Greenland turbot catch in the Arrowtooth/Kamchatka fishery has exceeded the directed catch.

In 2008 through 2012, trawl-caught Greenland turbot exceeded the level of catch by longline vessels (Table 5.3). The shift in the proportion of catch by sector was due in part to changes

arising from Amendment 80 passed in 2007. Amendment 80 to the BSAI Fishery Management Plan (FMP) was designed to improve retention and utilization of fishery resources.

The longline fleet generally targets pre-spawning aggregations of Greenland turbot; the fishery opens May 1 but usually occurs June-Aug in the EBS to avoid killer whale predation. Catch information prior to 1990 included only the tonnage of Greenland turbot retained Bering Sea fishing vessels or processed onshore (as reported by PacFIN). Discard levels of Greenland turbot have typically been highest in the sablefish fisheries (at about one half of all sources of Greenland turbot discards during 1992-2003) while Pacific cod fisheries and the "flatfish" fisheries also have contributed substantially to the discard levels (Table 5.2). About 9.2% of all Greenland turbot caught in groundfish fisheries were discarded (on average) during 2004-2012. The overall discard rate of Greenland turbot has dropped substantially in recent years from a high of 82% discarded in 1992 down to only 2% in 2011 and so far in 2012.

By gear-type and region, trawl catch was most significant in the Aleutian Islands in 2009 through 2012 (Table 5.4), whereas in the EBS there was high trawl catch in 2008, but then a switch to higher longline catches in 2009 through 2012 (Table 5.3). By target fishery, the gain in trawl-fishery has occurred primarily in the Greenland turbot target fishery in 2009 and arrowtooth flounder/Kamchatka fisheries in 2008 - 2012 (Table 5.3).

Data

Fisheries data in this assessment were split into the Longline (including all fixed gear) and Trawl fisheries. Both the Trawl and Longline data include observations and catch from targeted catch and bycatch. There are also data from three surveys, the Shelf and Slope surveys are bottom trawl surveys conducted by the RACE Division of the Alaska Fisheries Science Center and the Auke Bay Laboratory (ABL) Longline survey has been conducted by the ABL out of Juneau, Alaska. The type of data and relevant years from each can be found in Table 5.5 and Figure 5.10.

Fishery data

Catch
The catch data were used as presented above for both the longline and trawl fisheries. The early catches included Greenland turbot and arrowtooth flounder together. To separate them, the ratio of the two species for the years 1960-64 were assumed to be the same as the mean ratio caught by USSR vessels from 1965-69.

Size and age composition
Extensive length frequency compositions have been collected by the NMFS observer program from the period 1980 to 2012. The length composition data from the trawl and longline fishery are presented in the Appendix 5.2 (along with the expected values from the assessment model) and absolute sample sizes for the period of the domestic fishery by sex and fishery from 1989-2012 are given in Table 5.6

Catch totals from research and other sources
Annual research catches (t, 1977 - 2012) from NMFS longline and trawl surveys are estimated as follows:

Year	1979	1980	1981	1982	1983	1984	1985	1986	1987	1988	1989	1990	1991	1992	1993	1994	1995
NMFS BT surveys	62.5	48.3	103.0	123.6	15.0	0.6	175.1	26.1	0.5	18.5	0.6	0.7	11.4	0.9	1.4	8.5	1.4
Longline surveys	3	3	6	11	9	7	8	7	11	6	16	10	10	22	23	23	
Year	1996	1997	1998	1999	2000	2001	2002	2003	2004	2005	2006	2007	2008	2009	2010	2011	2012
NMFS BT surveys	1.5	4.6	1.4	1.0	6.6	1.1	6.6	1.1	12.8	0.7	3.0	0.6	4.8	0.4	6.6	1.0	4.9
Longline surveys											1.1	3.5	n/a	n/a	0.36	n/a	n/a

An updated database for 2010 sport and research catches indicates the following for Greenland turbot:

Source	t
2010 Aleutian Island Bottom Trawl Survey	0.530
2010 Bering Sea Acoustic Survey	0.000
2010 Bering Sea Bottom Trawl Survey	0.816
2010 Bering Sea Slope Survey	5.210
2010 Northern Bering Sea Bottom Trawl Survey	0.004
Blue King Crab Pot	0.056
IPHC (halibut commission)	2.989
NMFS LL survey	0.364

Recent analyses examining the bycatch of Greenland turbot in directed halibut fisheries indicate an average of just over 109 t from 2001-2010 with about 49 t average since 2006 (NMFS Regional Office).

EBS slope and shelf bottom trawl survey

The older juveniles and adults on the slope had been surveyed every third year from 1979-1991 (also in 1981) as part of a U.S.-Japan cooperative agreement. From 1979-1985, the slope surveys were conducted by Japanese shore-based (Hokuten) trawlers chartered by the Japan Fisheries Agency. In 1988, the NOAA ship Miller Freeman was used to survey the resources on the EBS slope region. In this same year, chartered Japanese vessels performed side-by-side experiments with the Miller Freeman for calibration purposes. However, the Miller Freeman sampled a smaller area and fewer stations in 1988 than the previous years. The Miller Freeman sampled 133 stations over a depth interval of 200-800 m while during earlier slope surveys the Japanese vessels usually sampled 200-300 stations over a depth interval of 200-1000 m. In 2002, the AFSC re-established the bottom trawl survey of the upper continental slope of the eastern Bering Sea and a second survey was conducted in 2004. Planned biennial slope surveys lapsed (the 2006 survey was canceled) but resumed in the summer of 2008, 2010, and 2012 (Table 5.7). Although the size composition data for surveys prior to 2002 were used in this assessment the abundance estimates were not. This was decided after discussions with Dr. Jerry Hoff, the current Slope survey Chief Scientist in which Dr. Hoff stated that the older Slope

survey data were not comparable to the most recent surveys, and may have not been conducted consistently enough in the early years to be considered a time series. The surveys differed in vessel power, in gear used, and in the ability of the surveyors to determine whether the gear was in contact with the bottom.

The trawl slope-surveys are likely to represent under-estimates of the BSAI-wide biomass of Greenland turbot since fish are found consistently in other regions. A similar issue likely affects the distribution of Greenland turbot on the shelf region, particularly given the extent of the cold pool and warm conditions in recent years (Ianelli et al. 2011). The Shelf and recent Slope survey biomass estimates are therefore treated as a relative abundance index and a separate catchability parameter were fit for each.

The estimated biomass of Greenland turbot in this region has fluctuated over the years. When US-Japanese slope surveys were conducted in 1979, 1981, 1982 and 1985, the combined survey biomass estimates from the shelf and slope indicate a decline in EBS abundance. After 1985, the combined shelf plus slope biomass estimates (comparable since similar depths were sampled) averaged 55,000 t, with a 2004 level of 57,500 t. The average shelf-survey biomass estimate during the last 19 years (1993-2012) was 24,600 t. The number of hauls and the levels of Greenland turbot sampling in the shelf surveys were presented in Table 5.8. In 2011 and 2010 the abundance estimates from the shelf surveys indicate a significant increase of Greenland turbot recruitment but also the proportion of tows with Greenland turbot present has increased (Fig. 5.11). These observations suggest that the extent of the spatial distribution has remained relatively constant prior to 2010 (with a slight increase) and that the most recent surveys have both higher densities and broader spatial distribution.

Although the 2012 EBS slope biomass estimate of 17,984 t was down from 2010 estimate of 19,873 t, the population numbers in 2012 of 11,839,700 fish was more than double the 2010 estimate of 5,839,126 fish. The 2012 Slope survey abundance estimate was the highest population estimate since the Slope survey was reinstated in 2002. Most of the change in population estimates is due to the changes in Greenland turbot abundance found in the two shallowest strata between 200 and 600 m depth strata (Table 5.9 and Table 5.10).   In the 200-400 m strata the population was more than 8 times that of the 2010 survey estimate and the 400-600 m strata was more than double the 2010 estimate. These high numbers, but low abundance is a reflection of the large number of smaller fish moving into the slope region from the shelf due to the large 2007 through 2009 year classes as evidenced by the large number of fish between 30 cm and 50 cm observed in this survey (Fig. 5.12).

Survey size composition
A time series of estimated size composition of the population was available for both surveys. The slope surveys typically sample more turbot than the shelf trawl surveys; consequently, the number of fish measured in the slope surveys is greater. The shelf survey appears to be useful

for detecting some recruitment patterns that are consistent with the trends in biomass. In the last 6 years signs of recruits (Greenland turbot less than about 40 cm) is clear after an absence of small fish during 2004-2006.

Survey size-at-age data was available and used for estimating growth and growth variability were previously available from 1979-1982. Gregg et al. (2006) revised age-determination methods for Greenland turbot and this year survey age composition data from 2003-2009 were included (previously only data from 1994, 1998, and 2007 surveys were available).

Aleutian Islands survey
The 2012 Aleutian Islands bottom trawl survey estimate was 2,502 t, well below the 1991-2012 average level of 12,598 t (Table 5.11) and a decline from the 2010 estimate of 6,272 t. The distribution of Greenland turbot in 2012 indicate greatly lower abundances in the survey compared to all previous surveys (Fig. 5.11). The breakdown of area specific survey biomass for the Aleutian Islands region shows that the Eastern Aleutian Islands Area (Area 541) abundance estimate had a very dramatic drop from 3,695 t in 2010 (59% of AI biomass) to 181 t (7% of AI biomass) in 2012. The estimated proportion of Greenland turbot in the eastern area for 2012 of 7% is far below the 1980- 2010 average of 67% of the survey abundance. Only in 2004 was the area estimate lower than the other regions. We are not certain why there was such a dramatic decline in the Greenland turbot abundance estimate in the Aleutian Islands trawl survey. Lower bottom temperatures in the shallow areas in the eastern area may have been a contributing factor (Lowe et. al. 2012). The trawl-survey area-swept data for the Aleutian Islands component of the Greenland turbot stock is not presently included in the stock assessment model.

Longline survey
The Auke Bay Laboratory Longline survey for sablefish alternates years between the Aleutian Islands and the Eastern Bering Sea slope region. In 2011 the EBS region was covered but an unusually high number of orca depredation events occurred: 10 out of 16 stations were affected. Some investigations on how to account for these events highlight the need for more detailed analysis. The 2012 survey was conducted along the Aleutian Islands and saw a more than doubling of the RPN since last AI survey in 2010. The high number on the ABL longline survey compared to the AI trawl survey makes sense in light of the high numbers observed in the Slope trawl survey and expected migration of the maturing fish towards the deeper waters and the Aleutians.

The survey time series (through 2012) indicates that about 33% of the population along the combined slope regions survey is found within the northeast (NE) and southeast (SE) portions of the Aleutian Islands:

Relative Population No. (RPN)								Year								
Area	1996	1997	1998	1999	2000	2001	2002	2003	2004	2005	2006	2007	2008	2009	2010	2011	2012
Bering 4		13,491		10,068		5,123		6,206		2,297		1,235		2,612		1,821	
Bering 3		27,936		33,848		24,766		24,660		15,268		13,523		21,192		12,164	
Bering 2		6,172		6,156		5,005		3,784		1,826		1,754		640		705	
Bering 1		11,729		13,072		16,082		11,965		3,717		1,561		3,406		1,494	
NE Aleutians	23,133		23,121		12,987		10,942		8,551		3,031		3,155		2,033		4,714
NW Aleutians	7,212		7,208		4,049		3,411		2,666		945		984		634		1,470
SE Aleutians	2,142		1,791		1,201		1,397		936		566		297		163		350
SW Aleutians	6,775		5,665		3,800		4,420		2,962		1,789		939		517		1,106
Bering Sea (total)		59,328		63,144		50,975		46,616		23,107		18,074		27,850		16,184	
Aleutians (total)	39,262		37,784		22,037		20,170		15,115		6,331		5,374		3,347		7,639
Combined (/1000)	119.5	88.4	115.0	94.0	67.1	75.9	61.4	69.4	46.0	34.4	19.3	26.9	16.4	41.5	10.2	24.1	23.2

The combined time series shown above (1996-2012) was used as a relative abundance index. It was computed by taking the average RPN from 1996-2012 for both areas and computing the average proportion. The combined *RPN* in each year (RPN_t^c) was thus computed as:

$$RPN_t^c = I_t^{AI} \frac{RPN_t^{AI}}{p^{AI}} + I_t^{EBS} \frac{RPN_t^{EBS}}{p^{EBS}}$$

where I_t^{AI} and I_t^{EBS} are indicator function (0 or 1) depending on whether a survey occurred in either the Aleutian Islands or EBS, respectively. The average proportions (1996-2012) are given here by each area as: p^{AI} and p^{EBS}. Note that each year data are added to this time series, the estimate of the combined index changes (slightly) in all years and that this approach assumes that the population proportion in these regions is constant. The time series of size composition data from the ABL longline survey extends back to the cooperative longline survey and is shown in Fig. 5.12.

Analytic approach

Model Structure

A version of the stock synthesis program (Methot 1990) has been used to model the eastern Bering Sea component of Greenland turbot since 1994. The software and assessment model configuration has changed over time, particularly in the past five years as newer versions have become available.

Total catch estimates used in the model were from 1960 to 2011. Model parameters were estimated by maximizing the log posterior distribution of the predicted observations given the data. The model included two fisheries, those using fixed gear (longline and pots) and trawls, together with three surveys covering various years (Table 5.5). Three new modeling approaches as well as the 2011 Reference model configuration were examined in this year's assessment. The new models configurations primarily differ in how recruitment prior to 1975 was modeled. All continue to use the Beverton-Hold curve, but in two (Models 2 and 3) the early recruitment

series is carried back to 1945 and in one (Model 4) the time-series is truncated to 1977. The results from these models were similar.

Parameters estimated independently

All independently estimated parameters were the same for all four models presented.

Parameter	Estimate	Source
Natural Mortality	0.112	Cooper et al. (2007)
Length at Age		
L_{min} CV	8%	Gregg et al. (2006)
L_{max} CV	7%	Gregg et al. (2006)
Maturity and Fecundity		
Length 50% mature	55	D'yakov (1982), Cooper et al. (2007)
Maturity curve slope	-0.25	D'yakov (1982), Cooper et al. (2007)
Eggs/kg intercept	1	D'yakov (1982), Cooper et al. (2007)
Eggs/kg slope	0	D'yakov (1982), Cooper et al. (2007)
Length-weight		
Male		
Alpha	3.4×10^{-6}	1977-2010 NMFS Survey data
Beta	3.2189	1977-2010 NMFS Survey data
Female		
Alpha	2.43×10^{-6}	1977-2010 NMFS Survey data
Beta	3.325	1977-2010 NMFS Survey data
Recruitment		
Steepness	0.79	Myers et al. (1999)
Sigma R	0.6	Ianelli et al. (2011)

Natural mortality and length at age

The natural mortality of Greenland turbot was assumed to be 0.112 based on Cooper et al. (2007). This is also more consistent with re-analyses of age structures that suggest Greenland turbot live beyond 30 years (Gregg et al. 2006).

Parameters describing length-at-age are estimated within the model. Length at age 1 is assumed to be the same for both sexes and the variability in length at age 1 was assumed to have an 8% CV while at age 21 a CV of 7% was assumed. This appears to encompass the observed variability in length-at-age. As with last year, size-at-age information from the methods described by Gregg et al. (2006) were used and this information is summarized in Table 5.12.

Maturation and fecundity

Maturity and fecundity followed the same assumptions as last year's model. Recent studies on the fecundity of Greenland turbot indicate that estimates at length are somewhat higher than most estimates from other studies and areas (Cooper et al., 2007). In particular, the values were higher than that found from D'yakov's (1982) study. The data for proportion mature at size from the

new study suggest a larger length at 50% maturity but data were too limited to provide revised estimates. For this analysis, a logistic maturity-at-size relationship was used with 50% of the female population mature at 60 cm; 2% and 98% of the females are assumed to be mature at about 50 and 70 cm respectively. This is based on an approximation from D'yakov's (1982) study.

Weight at length relationship

A new weight at length relationship has been devised using the combined data from all surveys conducted by the Alaska Fisheries Science Center in the Bering Sea and Aleutian Islands. Last year's model used the same weight at length relationship for males and females ($w = 2.44 \times 10^{-6} L^{-3.34694}$, where $L =$ length in cm, and $w =$ weight in kilograms). Given the great deal of sexual dimorphism observed in this species it was thought that having separate weight at length relationships for males and females would better capture the diversity in this stock. This year's models use $w = 2.43 \times 10^{-6} L^{3.325}$ for females and $w = 3.40 \times 10^{-6} L^{3.2189}$ for males. This relationship is similar to the weight at length relationship observed by Ianelli et al. (1993) and used in the Greenland turbot stock assessment prior to 2002. The weight at length analysis was presented at the September 2012 Plan team and October 2012 SSC meetings (Appendix 5.1).

Size composition multinomial sample size

There is always difficulty in determining the appropriate multinomial sample size for the size composition data. This year's assessment was fit following the methods employed by many of the Northwest Fisheries Science Center groundfish assessments in that the models were tuned to match the output effective sample size. For the two fisheries initial sample size for each year was determined as the $\left(100 + \left(\frac{n_i}{\sum n_{i}/N}/100 \right), n_i \right)$, where n_i is the number of hauls sampled in year i and N is the total number of years with samples (Table 5.13). The initial annual size composition sample sizes for the surveys were set at the same values as those used in previous assessments. The shelf trawl survey sample size was set at 200, the 2002 through 2010 slope survey sample size was set at 50, while those prior to 2000 were set at 25. The ABL longline sample sizes were set at 60.

Parameters estimated conditionally

The name of key parameters estimated and number of parameters within the four candidate models were:

	Model 1	Model 2	Model 3	Model 4
Recruitment				
Early Rec. Dev.s	0	(1945-1974)	(1945-1974)	(1977-1988)
		30	30	12
Main Rec. Dev.s	(1970-2010)	(1975-2010)	(1975-2010)	(1989-2011)
	41	38	38	23
Late Rec. Dev.s	(2011-2012)	(2011-2012)	(2011-2012)	(2011-2012)
	2	2	2	2
Future Rec. Dev.s	(2013-2014)	(2013-2014)	(2013-2014)	(2013-2014)
	2	2	2	2
R_0	1	1	1	1
Early R_0 adjust	1	0	0	0
R_1 offset	1	1	1	1
Growth				
L_{min} (M and F)	2	2	2	2
L_{max} (M and F)	2	2	2	2
Von Bert K (M and F)	2	2	2	1
Catchability				
q_{Shelf}	1	1	1	1
q_{Slope}	0	1	1	1
Selectivity				
Trawl Fishery	12	21	21	21
Longline Fishery	8	7	7	7
Shelf Survey	18	17	17	17
Slope Survey	12	2	2	2
ABL Longline Survey	7	2	2	2
Total Parameters	112	129	129	96

Recruitment and generating initial conditions

Because there was a large fishery on this stock prior to there being size or age composition data available (1960 – 1977), assumptions needed to be made on the composition of the population for these early years, if the early catches were to be included in the model. In the past when selecting the most parsimonious model in SS3 using maximum likelihood, a size/age distribution with a single large recruitment event was estimated. This was not deemed satisfactory by the previous stock assessment author. In order to generate a more diverse size/age structure in the population at the time data become available and to support the early fishery, the 2011 stock assessment (Model 1 in this year's assessment) fit an adjustment to R_0 in the years 1960 through 1969. Recruitment in this model was assumed to follow a Beverton-Holt stock recruitment curve with steepness at 0.9 and sigma R at 0.6. This resulted in a different mean recruitment being assumed for years 1960 through 1969 and 1970 through 2010 and an assumption of higher productivity in these early years.

In this year's Models 2 and 3 a single R_0 was assumed for all years and fit using an uninformative log normal prior. The models were fit to Beverton-Holt stock recruitment curve with steepness (h) fixed at 0.79 and sigma R fixed at 0.6, consistent with values found for Greenland turbot stocks in the North Atlantic and Arctic Ocean (Myers et al. 1999). For Model 3 an autocorrelation parameter was investigated where the prior component due to stock-recruitment residuals (ε_i) is

$$\pi_R = \frac{\varepsilon_1^2}{2\sigma_R^2} + \sum_{i=2}^{n} \frac{\left(\varepsilon_i - \rho\varepsilon_{i-1}\right)^2}{2\sigma_R^2\left(1-\rho^2\right)} \text{ , where } \rho \text{ is the autocorrelation coefficient and } \sigma_R^2 \text{ is the assumed}$$

stock recruitment variance term. Although different ρ-values were explored in September, ρ was fixed at 0.6 for Model 3 in this document. For both Model 2 and 3 the starting year was pushed back to 1945 to allow the models more time to build a diverse population size distribution as expected from a species with an assumed natural mortality of 0.112. Recruitment deviations for 1945-1975 (Early Rec. Dev.s) were estimated separately from the post-1975 recruitment deviations (Main Rec. Dev.s).

For Model 4 we ignored all early catch and began the Model in 1977. A single R_0 was assumed for all years again fit with an uninformative prior. The model was fit to Beverton-Holt stock recruitment curve with steepness (h) fixed at 0.79 and sigma R fixed at 0.6. Recruitment deviations prior to 1989 (Early Rec Devs) are estimated separately from the recruitment deviations after 1989 (Main Rec. Dev.s).

Catchability in the Slope Survey
In the 2011 Reference Model, and in Model 1 for this year, catchability (q) for the slope survey was fixed at q_{slope}= 0.75 and the shelf survey (q_{shelf}) was fit with an uninformative log uniform prior with a starting value of -0.6938. In this year's three candidate models we explored loosening the assumption on the Slope survey catchability and tightening them on the shelf survey. In Model 2 and Model 3 the Shelf survey was fit with a lognormal prior (log(q) = -0.6938, log SD = 0.4) and an informative lognormal prior on the slope survey (log(q) = -0.28768, log SD = 0.1). For Models 4 the slope survey catchability remained the same, but we tightened the prior on q_{shelf} with a log SD = 0.1 to help with model stability. For all of the new models there was a tipping point for the catchabilities, when a more diffuse prior was allowed, the model tended to fit at unrealistically low catchability values (q < 0.001) and biomass estimates were therefore greatly inflated.

Selectivity
Sex-specific size-based selectivity functions were estimated for the two trawl surveys and the two fisheries. The different time blocks for the fisheries and surveys are shown in the table below. These blocks were the same as those used in the 2011 Reference Model. Since data on sex were not available for the Auke Bay Laboratory longline survey a combined sex size-based selectivity function was estimated.

	Sex specific?	Number of blocks	Block years
Trawl Fishery	Yes	3	*-1988, 1989-2005, 2005-2012
Longline Fishery	Yes	2	*-1990, 1991-2012
Shelf Survey	Yes	4	*-1991, 1992-1995, 1996-2000, 2001-2012
Slope Survey	Yes	1	*-2012
ABL Longline Survey	No	1	*-2012

* Model 1 = 1960, Model 2 and 3 = 1945, Model 3 = 1977

There was much effort expended on exploring appropriate selectivity curves in this year's alternative models presented in September and October (Appendix 5.1). A new method for fitting different curves between male and females was implemented in the latest version of SS3 (V 3.24) that provided substantial improvement in model performance. In previous SS3 iterations the male and female selectivity curves had to be the same shape, but could be altered using four parameters :

P1 – size at which a dogleg occurs
P2 – log(relative selectivity) at the minimum size
P3 – log(relative selectivity) at the dogleg
P4 – log(relative selectivity) at maximum size

In the latest version of SS3 (3.24) more flexibility in the selectivity curves of the opposite sex is available. If the size selectivity pattern logistic, then SS3 requires 3 parameters to differentiate the curve from the opposite sex:
p1 is added to the first selectivity parm (inflection)
p2 is added to the second selectivity parm (width of curve)
p3 is the asymptotic selectivity

If the size selectivity pattern is the double normal, then five parameters are needed to differentiate from the opposite sex:
p1 is added to the first selectivity parameter (peak)
p2 is added to the third selectivity parameter (width of ascending side)
p3 is added to the fourth selectivity parameter (width of descending side)
p4 is added to the sixth selectivity parameter (selectivity at final size bin)
p5 is the apical selectivity

This new method was explored for all fisheries and surveys with separate sex data. In addition, the Longline fishery and Slope survey selectivity assumptions were simplified to a single logistic curve since the curve fit in last year's assessment, although fit as a double normal, were in affect simple logistic curves. The Auke Bay Laboratory longline survey catch at size data is somewhat difficult to fit since the data are from combined sexes and appear to have a bimodal distribution, one for males and another mode for females. Although a simple logistic model can be fit to the data, patterns in the residuals suggest some deficiencies in the fit.

Results

Model Evaluation

Four models are presented in this year's assessment. Model 1 is the 2011 Reference Model fit to the new dataset and weight at length estimates presented at the (Appendix 5.1) Plan team and SSC meeting. The main differences from Model 1 to the new candidate models were in how early recruitments were estimated, changes in selectivity, and how catchability was estimated for the Shelf and Slope surveys. Model 2 models recruitment as a Beverton-Holt spawner recruit curve with steepness at 0.79 and sigma R at 0.6. Catchability for the shelf survey was estimated using a lognormal prior with $\log(q_{shelf})$ = -0.69385 and $\log(\sigma_{qShelf})$ = 0.4 and catchability for the slope survey was estimated using a lognormal prior with $\log(q_{Slope})$ = -0.28768 and $\log(\sigma_{qslope})$ = 0.1. For Model 2 and Model 3 early recruitment deviations were estimated for 1945 through 1975 and main recruitment deviations were estimated for 1976 through 2010. Model 3 was the same as Model 2 except recruitment was modeled with an autocorrelation parameter (Rho = 0.6). Model 4 was the same as Model 2 except catch data prior to 1977 were excluded from the model, early recruitment deviations were estimated for 1977-1989, and main recruitment deviations were estimated for 1990-2010.

Table 5.14 includes the likelihood values for all four models, key parameter fits, reference points, and key model results. The tuning of the size and age composition sample size for Model 1 was different from Models 2, 3, and 4 and therefore direct comparisons of size and age composition likelihood estimates were not possible. Further the numbers of recruitment deviations differed and should not be compared. Therefore, the overall likelihoods could only be compared between Models 2 and 3. Because the input data differed among models we could not use information criterion techniques such as AIC for model selection and relied on professional judgment to select the model that best captures the stock dynamics of the Bering Sea and Aleutian Islands Greenland turbot stock. Table 5.15 provides measures of model fit to the individual component of each of the models including survey index RMSE, mean effective N for the age and size composition data and the recruitment variability for the candidate models. Again it needs to be noted that the size and age composition values are sensitive to tuning of the input sample size.

Choosing between Model 1 and the other models presented was based on the shapes of the selectivity curves. In selecting among models we relied on our understanding of the biology of Greenland turbot, the characteristics of the gear used in the fisheries and surveys, and the interaction of the two. Male and female Greenland turbot reach maturity at different sizes and migrate to deeper waters at different sizes (Fig. 5.3 and Fig. 5.12). Males migrate at smaller sizes than females, but a lower proportion of males make the migration off the shelf. This can be shown in the proportion of females observed in each of the surveys and fisheries (Fig. 5.13). The Longline fishery was mostly conducted in the deeper waters of the shelf break and encountered a higher proportion of females, however the smallest fish encountered was male. The Longline

selectivity curves fit in Model 1 do not reflect what we understand about Greenland turbot biology. Longline selectivity fit in models 2, 3, and 4 better reflect what we observed in this fishery (Fig. 5.14). For the Trawl fishery in which most of the catch occurred on the shelf in shallower waters, we should expect a dome shaped selectivity for both males and females, but from archival tagging data (Ianelli unpublished data) we know that a proportion of the large males remain or at least occasionally migrate back to the shelf, so we should expect the peak selectivity to be higher for males (Fig. 5.15). In addition, selectivity for females should also account for the larger females in the population, Model 1 would overestimate the number of larger females on the shelf because the model forces the female curve to mimic the male curve. Model 2, 3, and 4 provided justifiable differences between the male and female curves with the female extended towards the larger fish, unlike that fit in Model 1. Similarly the Slope survey female selectivity in Model 1 is forced to mimic the male selectivity pattern (Fig. 5.16), which is not the case for models 2, 3, and 4. There is little difference in the Shelf survey selectivities (Fig. 5.17). The use of the double normal in the ABL Longline survey selectivity creates a domed shape selectivity pattern where one is not expected. The ABL longline survey should be surveying all of the larger fish, we would not expect there to be a large drop in selectivity in the largest fish as fit in Model 1 (Fig. 5.18). This has the potential of inflating the abundance estimates. The logistic curve fit in models 2, 3, and 4 provide a more justifiable selectivity pattern in that it asymptotes at 1.0 for the largest fish as one would expect for this species from a deep water survey.

The choice between Model 1 and the other three models was clear based on the selectivity curves. The choice between Models 2, 3, and 4 was more difficult. Models 2 and 3 had the same error and data structure and therefore could be compared using model likelihoods. The only difference between these two models was the inclusion of an autocorrelation parameter for recruitment deviations. Model 3 had a marginally better fit to the size composition data, while Model 2 had an even more marginally improved fit to the indices and size at age data.   The inclusion of an autocorrelation parameter made a difference in the pre-1975 recruitment deviations. To have enough Greenland turbot to support the early fishery Model 1 created a single large positive deviation in 1965, while Model 2 created a series of lesser positive deviations between 1961 and 1967. Because these models were mostly size based, there was great uncertainty in the age structure of the population in the 1970's and early 1980's when no age data were available. This allowed the two models to choose different recruitment scenarios for these years and have very similar likelihoods. Given there were no size or age composition data for the early time period (1945-1974), there really was no clear choice between the two models. At its September meeting, The Plan team was reluctant to accept a model with autocorrelation due to the novelty of approach, and the sensitivity of reference points to the assumed autocorrelation parameter. Therefore, the authors consider Model 2 as the preferred reference model over Model 3.

Model 4 had the same selectivity patterns as Models 2 and 3, but started the Greenland turbot model in 1977 and did not include catch data prior to 1977. The spawning biomass estimates and recruitment between Models 2, 3, and 4 were surprisingly similar (Fig. 5.19 and Fig. 5.20). A major difference between the two models was that for Model 4 it was necessary to have large 1977 and 1978 year classes in order to fit the high abundance of large turbot observed in the fisheries and surveys of the 1980's. In Model 2 this was handled by larger recruitment for 1972 through 1978 with peaks at 1975 and 1978. Although there was no age data for this time period, Model 3 had a marginally better fit to the length composition data for the late 1970's and mid-1980s. In addition Model 2 had a better fit to the index data as well, although the change between the two models was only slight. Model 4 had the benefit of not inventing the 1960's recruitment, but provided a worse fit to the size composition data overall. Although the authors choose Model 2 as the best model for this year's assessment, there is promise in the methods applied in Model 4. We would like to continue to explore Model 4 in the future with different starting points.

Model 2 diagnostics and suggestions for future improvement
For the remainder of this document we will present Model 2 as the Author's recommended model. In this section we will discuss the model fit to the data. Model predicted numbers at size, number at age, and size selectivities for each fishery and survey are presented in an Excel spreadsheet in supplemental Appendix 5.2. The overall fit of Model 2 to the data were better than the 2011 Reference model mostly due to improvements in the selectivity curves and fit to the size and age composition data. However, due to complex nature of the Greenland turbot's biology (i.e. differential migration and sexual dimorphism), and limitations of our data, there is still room for improvement. Although the authors feel this model is appropriate for managing the BSAI Greenland turbot stock and is an improvement to the model fit from last year's configuration, we provide suggestions for exploring possible alternative models for next year that may further improve the model.

Survey indices
The fit to all the surveys is about the same as the fit to last year's models. The Shelf survey continues to not fit the high 1994 shelf survey biomass estimate (Fig. 5.21) and also does not fit the drop in biomass observed between 2007 through 2009. The predicted shelf biomass values do however fit the general trend including the latest increase in biomass due to the high numbers of small fish observed in the 2008 through 2012 Shelf surveys. We know that the larger fish are migrating off the shelf and the model may not be able to adequately capture the drop in shelf biomass due to this movement. This may suggest that the time-varying selectivity curves (Fig. 5.22) used for the Shelf survey do not adequately address the low availability of larger Greenland turbots to this survey. Future models should explore the sensitivity of the shelf survey index fits to lower Shelf survey selectivity at size for the larger fish.

The Slope survey index used in this year's assessment now consists of only 5 points (Fig. 5.23). Model 2 follows the drop in biomass observed between 2002 and 2012 but misses the 95%

confidence bounds of the low 2008 value. Again this fluctuation in abundance may be due to migration into and out of the survey area, which is not captured well by the assessment model. Besides the ontogenetic movement of fish from shallow to deeper water which confounds the Shelf survey, the stock also straddles the US/Russian border and it is unknown whether fish migrate between the two political regions. Such migration would have a profound effect on survey biomass estimates. The slope survey selectivity is not time varying and therefore does not address this issue of availability, but because true population fluctuations and migration inside and outside of the US EEZ could be confounded, this issue can't be addressed at this time. Additional tagging studies should be conducted to address the issue of adult Greenland turbot movement. The tagging studies should be conducted cooperatively between the US and Russian management agencies if at all possible.

The Model 2 fit to the Auke Bay Laboratory longline survey index of abundance mimics the 1996- 2005 index decline, but does less well with the flattening out of the decline between 2006 and 2010 (Fig. 5.24). There is a trend in the residual where the earlier high values tended to be underestimated and the later low values overestimated. The RPN index values are highly variable between years in the later time period. It should be noted that the uncertainty used for all of the survey index values in this model was CV = 0.2 (except for 2009 and 2011 due to increased whale predation where a value of 0.3 was used). Because the 2006 through 2010 values were low compared to the earlier surveys, the uncertainty around these points was also lower. The point estimates for this time period are likely less precise then what we assumed in Model 2. A geostatistical based estimate of variability should be explored for this index which could provide a better starting point for the uncertainty used in our assessment.

Age composition
The Model 2 shelf age composition predictions mimicked the data well for both males and females (Fig. 5. 25). The model consistently underestimated the peak proportion at age for the younger fish and overestimated the proportion at age for older fish. The difference was more inflated in the females then the males. However, except for the 1998 age composition data, this disagreement was generally small. The large proportion of aged 2 and 3 fish were not predicted for 1998 as the size groups for these ages were not observed in high proportion in the shelf survey size composition data. The high numbers of young fish observed in the shelf survey for 2007 through 2009 were consistent with the size composition data and well captured in the model.

Length at age
 Model 2, like all the other models examined this year, did well at fitting the length at age data for both males and females (Fig. 5. 26). There was some annual variability that was not captured by the models, but mainly due to low sample sizes for those age classes and years. However the fits are within the data confidence intervals for the majority of points. The potential miss fitting is most prevalent in the 2005-2007 males where the model may be underestimating the size at age.

<u>Size composition</u>

Overall Model 2 size composition fit was better than the fits achieved with the 2011 Reference Model configuration (Fig. 5.27) and Model 2 did a reasonable job of capturing the large trends observed in the size composition data (Fig. 5.28). Although the fits to the Trawl fishery size composition data (Fig. 5.29 and Fig. 5.30) were better than the fit with last year's configuration; this fishery remains difficult to model. There was a large shift in the trawl fishery selectivity between the foreign and domestic fisheries (Fig. 5.31 and Table 5.16) and another less severe change in 2008 when the Arrowtooth/Kamchatka fishery started. Even with the additional flexibility in fitting the two sexes with time varying selectivity, there remains patterns in the residuals for females that are problematic in the early years of the size data (1979-1989; Fig. 5.29). The trawl fishery size composition data are pooled from the directed fishery and from fish caught in other fisheries. The directed fishery targeted the larger fish (predominantly females) on the slope, while the bycatch fishery mostly caught smaller fish (predominantly males) on the shelf resulting in very different expected selectivity patterns for the two sexes. Currently SS3 can't handle such a large difference in selectivity patterns between sexes for the same fishery. In the future the authors would like to try to separate out the bycatch trawl data from the targeted trawl fishery data to see if the patterns in the size composition data for these early years can be rectified in future assessments. Since target is not included in these older data, this task may be difficult to accomplish.

The Model 2 fit to the longline data (Fig. 5.32. Fig. 5.33, and Table 5.16) was an improvement from last year's model fit (Fig. 5.27), particularly to the female size composition data from the 1980s. There was only a small shift in selectivity to smaller fish between the two time blocks (Fig. 5.34) used for modeling this fishery. The ability of the model to fit a lower selectivity for large males while keeping high selectivity for large females ,which are targeted by the fishery, allowed tighter fits to the data. Having higher selectivity for smaller males than females does a better job of mimicking the migration of males to deeper waters at smaller size than females than previous year's models were able to accomplish. Next year we would like to investigate different time blocks to address some of the patterns in the residuals that remain.

The Model 2 fit to the shelf survey data although slightly better, was nearly the same as the fit to the 2011 Reference Model configuration (Fig. 5.27). Where the model does poorly is in 1999 through 2005 when there were a higher proportion of large fish on the shelf than previously or later (Fig. 5.35 and Fig. 5.36). In this case the model appears to consistently underestimate the proportion of larger fish, particularly for larger females. In next year's model we would like to investigate different time blocks to see if we can improve model fits for these data.

The slope survey size composition selectivity was modeled as a logistic model (Fig. 5.17) with no time blocks, but separate selectivity for males and females. The model fits (Fig. 5.37) were somewhat better than last year's reference model for the females, but no real change for males. That said, the fits were rather poor and generally underestimated the peak of the highest

abundance size bins, particularly for males (Fig. 5.36). This may therefore underestimate the large males in the population. No other survey or fishery encounters these large males. It may be useful in next year's model to explore different sample sizes for these data that are not tuned as they were this year. Although the model predicts there to have been a larger proportion of males to females (males:female ratio up to 2:1) in the population between 50 cm and 70 cm (Fig. 5.38), Model 2 may be underestimating this pool of large males as the raw Slope survey data in aggregate for all years show a male: female ratio of nearly 9:1 (Fig. 5.13; female proportion of 0.1). Although less severe an increase in the male:female ratio at this size range was also consistently observed in both the longline and trawl fisheries size composition data.

The Auke Bay Laboratory size composition data (Fig. 5.39) were from combined sexes and as such very difficult to model using standard selectivity curves. Better model fits were achieved in models presented at the September plan team that used splines. These were rejected by the Plan Team and the authors agree that using splines has the problem of overfitting the data and making selectivity curves that are not easily interpretable. There is not real improvement to the model fit from last year. We fit the model using a single logistic curve, but these data were bimodal and the model tends to fit a single mode to these data resulting in overfitting between the male and female peaks and underfitting the two peaks for all years. Splitting the selectivity for males and females and increasing the weight to the slope survey may improve the fit slightly, but short of this or using splined selectivity, there are no further options available for improving the fit to these data. These options will be explored in next year's model.

Time Series Results
In this section we will present the results from Model 2 and predicted time series. In all instances in this section "total biomass" refers to age 1+ biomass, spawning biomass is the female spawning biomass, and recruitment is age 0 numbers from the model unless otherwise specified.

Recruitment
The most striking feature of the Model 2 recruitment (Fig. 5.40, Table 5.17, and Table 5.18) is the extremely large 1965 year class with 1.37 billion age 0 recruits. This is an artifact of the model as there were no size or age composition data prior to 1977 to steer recruitment in these early years. A larger than average abundance was needed for the large 1960's fishery and to leave enough large fish in the 1970s and 1980s to account for the large fish observed in the size composition data. In SS3, due to how the recruitment deviations likelihood is specified, the model will always fit a single large recruitment instead of multiple events when it does not have data to inform the model. Model 3 was intended as a means to spread these recruitment events out without assuming changes in early productivity. This model configuration was rejected by the Plan Team in September because the inclusion of autocorrelation in SS3 has not been thoroughly vetted.

After 1970, Model 2 fits three large recruitment events (1973 = 92.2 million age 0 , 1975= 300.0 million age 0 , and 1978 =126.8 million age 0). As there were no size composition data prior to 1977, the basis for these large year classes was the existence of many large fish in the early longline fishery. Because Greenland turbot appear to reach a terminal size, the exact ages were not know and therefore the exact years for these recruitment events were not known and may change in future models under different configurations. The 1978 year class was well documented and can be traced from the trawl fishery through to the longline fishery and surveys. It should be noted that for the projection model, used for determining the reference points and setting catch levels, we only use age 1 recruitment from1977 onward.

Recruitment from 1979 through to 2005 was low. The mean Age 0 recruitment for 1977 through 2012 was estimated at 13.2 million fish (rec. var. = 1.33), for the period between 1979 and 2007, the average was 5.8 million fish (rec. var.= 1.06). In 2008 recruitment of age 0 fish was estimated at 32.5 million fish and in 2009 at 78.1 million age 0 fish . These were the largest recruitment since 1978. These recent recruitment events were captured over multiple years in the Shelf survey size and age composition data, in the size composition from the last two slope surveys, and in the size composition data from the last two years in the Trawl fishery. The longline fishery should begin seeing these fish starting in 2014. The influx of new recruits in 2008 and 2009 cause a sharp drop in the predicted population mean size and mean age (Fig. 5.41 and Fig. 5.42).

Biomass and fisheries exploitation
The BSAI Greenland turbot spawning biomass in Model 2 was projected for 2013 at 24,455 t to be at its lowest level since its peak of 253,256 t in 1975 (Table 5.19, Table 5.20, Fig.5.43 and Fig. 5.44). The large early 1980s fishery combined with a lack of good recruitment in the mid- to late-1980s and through the 1990s drove the steepest part of the decline in spawning biomass. The mean age 0 recruitment for 1986 to 2006 was 3.6 million fish (27% of the overall 1977-2012 mean recruitment) . In 1990 the NPFMC cut ABCs to 7,000 t until through 1996 to account for low recruitment; however the ABCs were exceeded in 5 of the 7 years (Table 5.1). The stock continued to decline in the 1990s as poor recruitment continued. In 1997 the NPFMC started managing the stock as a Tier 3 stock and the ABCs were allowed to increase (Table 5.1). The mean ABC between 1997 and 2002 was 9,783 t, the mean catch however was lower and averaged about 6,355 t per year over this time period. From 2003 to 2008 the ABC levels remained relatively low with a high of 4,000 t in 2003 and a low of 2,440 t in 2007. The catch dropped even lower to an average of just 2,417 t per year in this time period. In 2008 with Amendment 80 an arrowtooth/ Kamchatka fishery emerged that more than doubled the catch of Greenland turbot in 2008 and continued to double the catch of Greenland turbot through 2012. The average catch for 2008 through 2011 was 3,678 t. The ABCs during this time period, due to a clerical error in the projection model, went from 2,500 t in 2008 to 7,380 in 2009. From 2009 to 2012 the ABC averaged 7,325 t with a high at 9,660 t in 2012. Although the decline in spawning biomass began to slow in 2005 through 2007, the decline in spawning biomass again

steepened post-2008. This decline may be correlated with increased fishing pressure during this time period. One thing that should be noted is that throughout this decline the fishing exploitation rate has been relatively low. Between 1986 and 2007 the mean total exploitation was estimated at 0.05 with a maximum total exploitation rate of 0.07 (Table 5.17 and Fig. 5.45). The increased fishing exploitation rate in 2009 and 2010, that may have steepened the most recent decline, was only 0.08. The catch levels in 2008 through 2012 however exceeded the OFL control rule levels projected from Model 2 (Fig. 5.46). The large 2008 and 2009 year classes have not yet made it into the spawning population and therefore the spawning population is seen to continue to decline through 2013. Projections for 2014 and onward predict a steep increase in spawning biomass with these incoming year classes.

The 2012 Model 2 Total age 1+ biomass timeseries was similar history as female spawning biomass with a steep decline from an estimated peak in 1972 of 493,857 t to its lowest point in 2010 at 51,507 t (Fig. 5.44). The difference between the two is that the Total biomass began to show the impact of the 2008 and 2009 recruitments in 2011. Since its low point in 2010 total Age +1 biomass is projected to have increased to 68,574 t in 2012 and projected to be at 80,989 t in 2013. The estimated total age-1+ biomass and female spawning biomass were both smaller than estimated in previous stock assessments. This is due to both the change in weight at age relationship from the previous assessments (Table 5.21)and to the changes in selectivities. A more thorough treatment of the affects of the changes in the model to changes in the spawning biomass was presented at the 2012 September Plan Team and October 2012 SSC meetings (Appendix 5.1).

Retrospective analysis
The retrospective analysis was conducted in SS3 by removing data systematically by year from the model (Fig. 5.47). The largest change in the retrospective was between -4 and -5 years (from 2008 to 2009). At this point the model would no longer converge with a less constrained prior on the Shelf survey catchability. We needed to change the log(St.dev.) from 0.4 to 0.1 to achieve convergence. As we removed data, catchability for both the shelf and the slope trended lower until between -4 and -5 where the slope increased and shelf catchability continued to decreased (Fig. 5.48). At -5 and below both slope and shelf catchability trended together at between 0.49 and 0.52. This means that the data added post-2007 provided information on catchability and enabled us to loosen our assumptions on the Slope catchability. With the post-2007 dataset we see a consistent pattern of decreasing estimated spawning biomass as we add more recent data to the model (Fig. 5.49).   This retrospective analysis suggests that the model would have been biased high in previous years without the more recent data.

Harvest Recommendations

Amendment 56 Reference Points
The $B_{40\%}$ value using the mean recruitment estimated for the period 1977-2011 gives a long-term average female spawning biomass of 47,686 t. The estimated 2012 female spawning biomass is about 25,144 t or $B_{21\%}$ well below the estimate of $B_{35\%}$ (41,726 t). Because the projected spawning biomass in year 2012 is below $B_{40\%}$ Greenland turbot ABC and OFL levels will be determined at Tier 3b of Amendment 56.

Specification of OFL and Maximum Permissible ABC and ABC Recommendation
In the past several years, the ABC has been set below the maximum permissible estimates. For example, in 2008 the ABC recommendation was 21% of the maximum permissible level. The rationale for these lower values have been generally due to concerns over stock structure uncertainty, lack of apparent recruitment, and modeling issues. This year a slope survey was conducted and while some areas show lower abundances (i.e., the Aleutian Islands) the signs of recruitment are the best ever seen for this stock. Therefore we recommend that the ABC be set to the maximum permissible.

The projected Greenland turbot maximum permissible ABC and OFL levels for 2013 and 2014 are shown below (catch for 2012 was set to 5,000 t):

Year	Catch (for projection)	Maximum permissible ABC	Recommended ABC	OFL	Female spawning biomass
2013	2,064 t	2,064 t	2,064 t	2,539 t	23,485 t
2014		2,655 t	2,655 t	3,266 t	26,537 t

The estimated overfishing level based on the adjusted $F_{35\%}$ rate is 2,539 t corresponding to a full-selection F of 0.115. The value of the Council's overfishing definition depends on the age-specific selectivity of the fishing gear, the somatic growth rate, natural mortality, and the size (or age) -specific maturation rate. As this rate depends on assumed selectivity, future yields are sensitive to relative gear-specific harvest levels. Because harvest of this resource is unallocated by gear type, the unpredictable nature of future harvests between gears is an added source of uncertainty. However, this uncertainty is considerably less than uncertainty related to treatment of survey biomass levels, i.e., factors which contribute to estimating absolute biomass (Ianelli et al. 1999).

Subarea Allocation
In this assessment, the hypothesis proposed by Alton et al. (1989) regarding the stock structure of Greenland turbot in the eastern Bering Sea and Aleutian Islands regions was adopted. Briefly, spawning is thought to occur throughout the adult range with post-larval settlement occurring on the shelf in shallow areas. The young fish on the shelf begin to migrate to the slope region at about age 4 or 5. In our treatment, the spawning stock includes adults in the Aleutian Islands and the eastern Bering Sea. In support of this hypothesis, the length compositions from the Aleutian

Islands surveys appear to have few small Greenland turbot, which suggests that these fish migrate from other areas (Ianelli et al. 1993). Historically, the catches between the Aleutian Islands and eastern Bering Sea has varied (Table 5.22).

Recent research on recruitment processes holds promise for clearer understanding (e.g., Sohn et al. (In Review) and Sohn 2009). Stock structure between regions remains uncertain and therefore the policy has been to harvest the "stock" evenly by specifying region-specific ABCs. Based on eastern Bering Sea slope survey estimates and Aleutian Islands surveys, the proportions of the adult biomass in the Aleutian Islands region over the past four surveys (when both areas were covered) were 26.4%, 23.7%, 25.5%, and 12.2%. These average 21.9% which when applied to the BSAI ABC gives the following region-specific allocation:

	2013 ABC	2014 ABC
Aleutian Islands ABC	452	581
Eastern Bering Sea ABC	1,612	2,074
Total	2,064	2,539

Standard harvest scenarios and projections

A standard set of projections for population status under alternatives were conducted to comply with Amendment 56 of the FMP. This set of projections encompasses seven harvest scenarios designed to satisfy the requirements of Amendment 56, the National Environmental Protection Act, and the Magnuson-Stevens Fishery Conservation and Management Act (MSFCMA).

For each scenario, the projections begin with the vector of 2012 numbers at age estimated in the assessment. This vector is then projected forward to the beginning of 2013 using the schedules of natural mortality and selectivity described in the assessment and the best available estimate of total (year-end) catch for 2012 (here assumed to be 5,000 t). In each subsequent year, the fishing mortality rate is prescribed based on the spawning biomass in that year and the respective harvest scenario. In each year, recruitment is drawn from an inverse Gaussian distribution whose parameters consist of maximum likelihood estimates determined from recruitments estimated in the assessment. Spawning biomass is computed in each year based on the time of peak spawning and the maturity and weight schedules described in the assessment. Total catch is assumed to equal the catch associated with the respective harvest scenario in all years. This projection scheme is run 1,000 times to obtain distributions of possible future stock sizes, fishing mortality rates, and catches.

Five of the seven standard scenarios will be used in an Environmental Assessment prepared in conjunction with the final SAFE. These five scenarios, which are designed to provide a range of harvest alternatives that are likely to bracket the final TAC for 2013, are as follow ("*max F_{ABC}*" refers to the maximum permissible value of F_{ABC} under Amendment 56):

Scenario 1: In all future years, F is set equal to *max F_{ABC}*. (Rationale: Historically, TAC has been constrained by ABC, so this scenario provides a likely upper limit on future TACs.)

Scenario 2: In all future years, F is set equal to the author's recommend level. Due to current conditions of strong recruitment and a projected increasing biomass, the recommendation is set equal to the maximum permissible ABC.

Scenario 3: In all future years, F is set equal to the 2007-2011 average F. (Rationale: For some stocks, TAC can be well below ABC, and recent average F may provide a better indicator of F_{TAC} than F_{ABC}.)

Scenario 4: In all future years, F is set equal to the $F_{75\%}$. (Rationale: This scenario was developed by the NMFS Regional Office based on public feedback on alternatives.

Scenario 5: In all future years, F is set equal to zero. (Rationale: In extreme cases, TAC may be set at a level close to zero.)

Two other scenarios are needed to satisfy the MSFCMA's requirement to determine whether a stock is currently in an overfished condition or is approaching an overfished condition. These two scenarios are as follows (for Tier 3 stocks, the MSY level is defined as $B_{35\%}$):

Scenario 6: In all future years, F is set equal to F_{OFL}. (Rationale: This scenario determines whether a stock is overfished. If the stock is expected to be above half of its MSY level in 2012 and above its MSY level in 2025 under this scenario, then the stock is not overfished.)

Scenario 7: In 2013 and 2014, F is set equal to *max F_{ABC}*, and in all subsequent years, F is set equal to F_{OFL}. (Rationale: This scenario determines whether a stock is approaching an overfished condition. If the stock is expected to be above its MSY level in 2025 under this scenario, then the stock is not approaching an overfished condition.)

Scenarios 1 through 7 were projected 13 years from 2012 (Table 5.23). Fishing at the maximum permissible rate indicate that the spawning stock (Fig. 5.50) will continue to decline in 2013 but will steeply increase after 2014 with the incoming large year classes.

Our projection model run under these conditions indicates that for Scenario 6, the Greenland turbot stock is not overfished based on the first criterion (year 2012 spawning biomass estimated at 25,144 t relative to $0.5B_{35\%} = 20,863$ t) and will be above its MSY value (41,726 t) in 2025 at 52,119 t.

Projections with fishing at the maximum permissible level result in an expected value of spawning biomass of 52,167 t by 2025. These projections illustrate the impact of the recent recruitment observed in the survey. For example, under all scenarios, the spawning biomass is

expected to increase starting in 2014 when the recruits in recent years mature. In both Scenario 6 and 7 spawning biomass peaks in 2020 and then begins to drop again as the influence of the 2008 and 2009 year classes begins to wane and the projection relies on mean recruitment.

Under Scenarios 6 and 7 of the 2012 Reference Model, the projected spawning biomass for Greenland turbot is not currently overfished, nor is it approaching an overfished status.

Ecosystem Considerations

Greenland turbot have undergone dramatic declines in the abundance of immature fish on the EBS shelf region compared to observations during the late 1970's. It may be that the high level of abundance during this period was unusual and the current level is typical for Greenland turbot life history pattern. Without further information on where different life-stages are currently residing, the plausibility of this scenario is speculation. Several major predators on the shelf were at relatively low stock sizes during the late 1970's (e.g., Pacific cod, Pacific halibut) and these increased to peak levels during the mid 1980's. Perhaps this shift in abundance has reduced the survival of juvenile Greenland turbot in the EBS shelf. Alternatively, the shift in recruitment patterns for Greenland turbot may be due to the documented environmental regime that occurred during the late 1970's. That is, perhaps the critical life history stages are subject to different oceanographic conditions that affect the abundance of juvenile Greenland turbot on the EBS shelf.

Data Gaps and Research Priorities

Besides the assessment model improvements suggested above a number of research issues continue to require further consideration. These include:

- An evaluation of possible differential natural mortality between males and females,
- Spatial distribution and migration needs to be better explored through tagging experiments,
- Evaluating the extent that Greenland turbot are affected by temperature and environmental conditions relative to survey gear.

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Tables

Table 5.1   Catch estimates of Greenland turbot by gear type (t; including discards) and ABC
and TAC values since implementation of the MFCMA.

Year	Trawl	Longline & Pot	Total	ABC	TAC
1977	29,722	439	30,161	40,000	
1978	39,560	2,629	42,189	40,000	
1979	38,401	3,008	41,409	90,000	
1980	48,689	3,863	52,552	76,000	
1981	53,298	4,023	57,321	59,800	
1982	52,090	31.8	52,122	60,000	
1983	47,529	28.8	47,558	65,000	
1984	23,107	12.6	23,120	47,500	
1985	14,690	40.6	14,731	44,200	
1986	9,864	0.4	9,864	35,000	33,000
1987	9,551	34	9,585	20,000	20,000
1988	6,827	281	7,108	14,100	11,200
1989	8,293	529	8,822	20,300	6,800
1990	12,119	577	12,696	7,000	7,000
1991	6,245	1,617	7,863	7,000	7,000
1992	749	3,003	3,752	7,000	7,000
1993	1,145	7,323	8,467	7,000	7,000
1994	6,426	3,845	10,272	7,000	7,000
1995	3,978	4,215	8,194	7,000	7,000
1996	1,653	4,902	6,555	7,000	7,000
1997	1,209	5,989	7,199	9,000	9,000
1998	1,830	7,319	9,149	15,000	15,000
1999	1,799	4,057	5,857	9,000	9,000
2000	1,946	5,027	6,973	9,300	9,300
2001	2,149	3,163	5,312	8,400	8,400
2002	1,033	2,605	3,638	8,000	8,000
2003	908	2,605	3,513	4,000	4,000
2004	675	1,544	2,220	3,500	3,500
2005	729	1,831	2,559	3,500	3,500
2006	360	1,605	1,965	2,740	2,740
2007	429	1,400	1,829	2,440	2,440
2008	1,935	806	2,741	2,540	2,540
2009	3,080	1,417	4,196	7,380	7,380
2010	1,978	2,160	4,138	6,120	6,120
2011	1,618	2,019	3,636	6,140	5,060
2012*	2,591	1,314	3,905	9,660	8,660

*Catch estimated as of October 2012

Table 5.2.   Estimates of discarded and retained (t) Greenland turbot based on NMFS estimates by "target" fishery, 1992-2012 (the "arrowtooth/Kamchatka" fishery was combined with the Greenland turbot fishery from 2003-2009).

Fishery:	Greenland turbot		Sablefish		Pacific cod		Rockfish		Flatfish		Arrowtooth/Kamchatka		Others		Combined	
Year	Retain	Discard	Retain	Discard	Retain	Discard	Retain	Discard	Retain	Discard	Retain	Discard	Retain	Discard	Retain	Discard
1992	62	13	196	2,121	135	557	180	103	13	3			107	261	693	3,058
1993	5,685	332	235	880	160	108	572	87	19	185			10	194	6,681	1,786
1994	6,316	368	194	2,305	149	211	316	37	27	235			38	76	7,040	3,232
1995	5,093	327	157	1,546	145	284	362	25	5	102			28	121	5,790	2,405
1996	3,451	173	200	1,026	170	307	598	113	171	63			143	140	4,733	1,822
1997	4,709	521	129	619	270	283	202	19	212	92			18	125	5,540	1,659
1998	6,905	301	125	171	278	154	42	2	628	249			123	171	8,101	1,048
1999	4,009	227	179	120	180	50	25	2	600	269			134	61	5,127	729
2000	4,798	177	192	253	130	108	39	1	838	176			186	75	6,183	790
2001	2,727	89	171	325	203	92	431	30	764	337			95	47	4,391	920
2002	1,979	73	144	207	210	139	175	18	301	217			124	49	2,933	703
2003	1,842	95	98	534	165	95	198	5	114	176			79	55	2,497	961
2004	1,244	37	78	24	221	79	72	3	154	158			99	50	1,868	352
2005	1,677	28	63	19	156	30	134	5	179	69			149	49	2,359	200
2006	1,340	33	62	52	65	31	69	8	107	19			135	46	1,778	188
2007	1,091	28	59	71	127	91	36	13	30	35			198	50	1,541	288
2008	1,537	417	42	82	17	70	142	1	96	30			203	103	2,038	703
2009	3,649	336	69	54	65	21	69	8	52	13			148	14	4,053	445
2010	1,913	17	62	27	115	19	57	2	23	72	1,662	81	8	78	3,910	228
2011	1,759	8	49	7	165	9	27	1	31	5	1,466	17	83	10	3,553	83
2012*	1,387	8	31	13	5	0	12	3	46	5	2,289	12	230	22	4,067	77

Table 5.3.   Estimates of Greenland turbot catch (t) by gear and "target" fishery, 2004-2012. Source: NMFS AK Regional Office catch accounting system. Note for 2010-2012 the Arrowtooth fishery includes the Kamchatka fishery.

	"Target" fishery	2004	2005	2006	2007	2008	2009	2010	2011	2012*
	Greenland turbot	1,168	1,527	1,212	1,097	573	1,192	1,813	1,763	1,394
	Sablefish	90	75	114	130	119	122	90	56	44
Longline	Pacific cod	221	170	77	129	76	84	127	174	77
and pot	Shallow-water flatfish	64	57	61	15	15	7	0	0	0
	Arrowtooth flounder	0	2	140	16	0	9	53	0	8
	Others	1	0	3	12	22	4	78	26	12
	Greenland turbot	61	24	0	2	205	1,349	118	4	0
	Pacific cod	79	15	19	89	11	2	8	0	1
	Arrowtooth flounder	53	154	21	3	1,176	1,435	1,689	1,483	2,293
	Atka mackerel	123	167	117	130	201	118	62	64	203
	Flathead sole	191	150	28	30	98	49	13	2	46
Trawl	Pollock	18	31	65	107	82	44	23	88	46
	Rockfish	74	139	74	47	143	73	59	28	13
	Other Flatfish	51	34	1	12	11	4	1	1	1
	Rock sole	4	1	27	8	0	2	3	1	0
	yellowfin sole	1	7	8	1	1	4	1	6	4
	Sablefish	12	7	0	0	6	0	0	0	0
	Others	8	0	0	0	0	0	0	0	0

* Through October 2012

Table 5.4.   Estimates of Greenland turbot catch by gear and area based on NMFS Regional Office estimates, 2003-2012.

Area	Gear	2003	2004	2005	2006	2007	2008	2009	2010	2011	2012*
Aleutian Islands	Fixed	650	218	138	346	338	111	97	213	89	50
	Trawl	315	196	301	179	178	712	2,164	1,653	442	1,595
Aleutian Islands Total		965	414	439	525	516	824	2,261	1,866	531	1,645
EBS	Fixed	1,918	1,326	1,693	1,259	1,061	694	1,321	1,947	1,929	1,486
	Trawl	575	479	427	181	251	1,222	916	325	1,176	1,013
EBS Total		2,493	1,805	2,120	1,440	1,313	1,917	2,237	2,272	3,105	2,499
Grand Total		3,458	2,220	2,559	1,965	1,829	2,741	4,497	4,138	3,636	4,144

* Estimated through Oct. 2012.

Table 5.5.   Data sets used in the stock synthesis (SS3) model for Greenland Turbot in the EBS. All size and age data except for the ABL longline survey are specified by sex .

Data source	Data type	Years of data
Trawl fisheries		
	Catch	1960-2012
	Size composition	1977-1987, 1989-1991,1994-2012
Longline fisheries		
	Catch	1960-2012
	Size composition	1979-1985,1993-2012
Shelf Survey		
	Abundance Index	1987-2012
	Size composition	1982-2012
	Age composition	1998,2003-2009
Slope Survey		
	Abundance Index	2002,2004,2008,2010,2012
	Size composition	1979,1981,1982,1985,1988,1991,2002,2004,2008, 2010,2012
ABL Longline survey		
	RPN abundance index	1996-2012
	Size composition	1979-2012

Table 5.6. Greenland turbot BSAI fishery length sample sizes by gear type and sex, 1989-2012. Source: NMFS observer program data. The % female do not include unidentified fish.

Year	Trawl fishery				Longline fishery			
	Female	Male	Unident.	% Female	Female	Male	Unident.	% Female
1989	1,405	5,568	947	20%	0	0	0	
1990	3,864	5,762	6,100	40%	0	0	0	
1991	1,851	1,752	9,295	51%	0	0	0	
1992	0	0	0		0	0	71	
1993	0	0	425		3,921	915	12,464	81%
1994	1,122	1,027	5,956	52%	503	150	1,200	77%
1995	245	363	4,086	40%	1,870	715	5,630	72%
1996	0	0	0		941	442	7,482	68%
1997	112	390	0	22%	2,393	1,014	14,833	70%
1998	307	696	822	31%	3,510	2,127	22,794	62%
1999	1,044	1,556	0	40%	8,033	2,899	266	73%
2000	724	1,328	25	35%	6,550	2,962	73	69%
2001	467	892	43	34%	4,054	1,550	271	72%
2002	186	433	0	30%	4,725	1,811	40	72%
2003	197	325	1	38%	4,624	2,113	2	69%
2004	179	433	10	29%	4,340	2,612	1	62%
2005	118	211	0	36%	4,650	1,902	43	71%
2006	15	76	0	16%	3,339	1,474	32	69%
2007	34	23	0	60%	3,833	2,130	134	64%
2008	421	1,572	1	21%	1,577	1,481	0	52%
2009	1,017	2,993	26	25%	3,492	2,709	39	56%
2010	298	3,562	174	8%	3,290	2,860	108	53%
2011	853	2,025	37	30%	2,494	1,694	7	60%
2012	1,733	3,131	14	36%	994	652	0	60%

Table 5.7.   Survey estimates of Greenland turbot biomass (t) for the Eastern Bering Sea shelf
and slope areas and for the Aleutian Islands region, 1975-2008. Note that the
shelf-survey estimates from 1985, and 1987-2008 include the northwestern strata
(8 and 9) and these were the values used in the model. The Aleutian Islands
surveys prior to 1990 used different operational protocols and may not compare
well with subsequent surveys. The 1988 and 1991 slope estimates are from 200-
800 m whereas the other slope estimates are from 200 - 1,000m.

| Year | Eastern Bering Sea | | Aleutian Islands |
	Shelf	Slope	Survey
1975	126,700		
1979	225,600	123,000	
1980	172,200		48,700*
1981	86,800	99,600	
1982	48,600	90,600	
1983	35,100		63,800*
1984	17,900		
1985	7,700	79,200	
1986	5,600		76,500*
1987	11,787		
1988	13,353	42,700	
1989	13,209		
1990	16,199		
1991	12,484	40,500	11,925
1992	28,638		
1993	35,690		
1994	57,170		28,227
1995	37,636		
1996	40,591		
1997	35,303		28,334
1998	34,885		
1999	21,529		
2000	23,184		9,359
2001	27,280		
2002	24,000	27,589	9,891
2003	31,010		
2004	28,287	36,557	11,334
2005	21,302		
2006	20,933		20,934
2007	16,723		
2008	13,511	17,901	
2009	10,953		
2010	23,414	19,873	6,795
2011	26,156		
2012	21,792	17,984	2,600

Table 5.8.　Levels of Greenland turbot biological sampling from the EBS shelf surveys. Note that in 1982-1984, and 1986 the northwestern stations were not sampled.

Year	Total Hauls	Hauls w/ turbot	Length samples	Otolith sample hauls	Hauls w/age	Otolith Samples	Ages
1982	334	41	1,228	11	11	292	292
1983	353	55	951				
1984	355	27	536	20		263	
1985	358	46	200				
1986	354	53	195				
1987	360	36	354				
1988	373	63	414				
1989	373	69	376				
1990	371	78	544				
1991	372	74	658				
1992	356	64	616	5		7	
1993	375	73	632	7		179	
1994	376	53	530	17		196	
1995	376	49	343				
1996	375	73	450	8		100	
1997	376	66	298	11		79	
1998	375	73	445	25	22	200	127
1999	373	47	128	8		11	
2000	372	61	248	31		188	
2001	375	61	270	36		215	
2002	375	70	455	19		71	
2003	376	71	622	46	27	435	192
2004	375	64	606	37	38	290	280
2005	373	64	441	41	41	293	277
2006	376	56	427	47	48	262	239
2007	376	84	499	66	67	334	311
2008	375	79	406	48	48	245	235
2009	376	104	856	61	61	351	344
2010	376	145	3,199	74		362	
2011	376	156	4,381	53		427	
2012	376	110	2,133	52		418	

Table 5.9.   Eastern Bering Sea slope survey estimates of Greenland turbot biomass (t), 2002, 2004, 2008, 2010, and 2012 by depth category.

Depth (m)	2002	2004	2008	2010	2012
200-400	4,081	2,889	4,553	1,166	2,420
400-600	**14,174**	**25,360**	**6,707**	**10,352**	**10,268**
600-800	4,709	5,303	4,373	5,235	3,822
800-1000	2,189	1,800	1,487	2,041	1,018
1000-1200	1,959	1,206	781	1,079	456
Total	27,113	36,557	17,901	19,873	17,984

Table 5.10.   Eastern Bering Sea slope survey estimates of Greenland turbot numbers, 2002, 2004, 2008, 2010, and 2012 by depth category.

Depth (m)	2002	2004	2008	2010	2012
200-400	993,994	745,401	1,740,599	421,257	3,374,545
400-600	3,668,882	4,885,557	1,913,410	3,428,133	7,055,925
600-800	1,070,165	998,631	1,196,717	1,330,889	1,089,539
800-1000	504,257	360,764	273,120	432,937	228,151
1000-1200	374,192	224,570	126,498	225,910	91,540
Total	6,611,490	7,214,922	5,250,344	5,839,126	11,839,700

Table 5.11.   Time series of Aleutian Islands survey sub-regions estimates of Greenland turbot biomass (t), 1980-2012.

Year	Western Aleutian	Central Aleutian	Eastern Aleutian	Southern Bering Sea	Total
1980	0	799	2,720	79	3,598
1983	525	2,357	5,747	1,094	9,722
1986	1,747	2,495	19,580	7,937	31,759
1991	2,195	3,280	4,607	1,803	11,885
1994	2,401	4,007	15,862	5,966	28,235
1997	2,137	3,130	22,708	359	28,334
2000	839	2,351	5,703	467	9,359
2002	793	1,658	6,996	444	9,891
2004	2,588	2,947	2,564	3,234	11,333
2006	1,973	1,937	15,742	1,282	20,934
2010	1,071	1,507	3,698	486	6,795
2012	1,091	1,231	181	98	2,600
Avg. since 1991	1,678	2,454	8,673	1,571	14,376

Table 5.12.   Summary of the length-at-age information used for this BSAI Greenland turbot assessment (see Gregg et al. 2006 for methods).

| | 1982 | | | | 1991 | | | | 1998 | | | |
| | Females | | Males | | Females | | Males | | Females | | Males | |
Age	Avg. length (cm)	N	Ave. length (cm)	N	Avg. length (cm)	N	Ave. length (cm)	N	Avg. length (cm)	N	Ave. length (cm)	N
1	16.75	20	16.61	23					17.67	3		
2	24.45	33	24.79	43					24.94	18	25.58	19
3	32.70	33	33.67	30					33.14	7	34.00	11
4	40.26	38	40.03	31					32.00	1	33.80	5
5	46.36	14	45.70	10	59.00	1			35.00	2	36.50	2
6	48.11	9	50.00	3	46.00	1	54	2			50.00	1
7	52.50	4	52.00	1	57.33	3	49	5				
8					60.50	4	56.625	8			49.00	1
9					59.00	7	59.375	16			58.00	1
10					64.90	10	63.625	8	65.80	5	58.33	3
11					65.63	8	65.71429	14	65.00	5		
12					67.36	11	68.28571	7	78.67	3	59.75	4
13					75.43	7	70.42857	7			66.75	4
14					80.67	3	72	1	75.00	1	75.00	1
15					79.57	7	71	1			67.50	2
16					80.60	15			76.00	2		
17					86.71	7			81.00	1	71.00	3
18					86.75	4						
19					86.60	5					74.00	2
20					87.33	3			80.33	3		
21					91.00	1			82.00	1		
22					88.00	1						
23									79.00	1		
24					100.00	1			79.00	2	69.50	2
25									79.00	2		
26									95.00	1		
27												
28												
29												
30											81	2

Table 5.12(Cont.) Summary of the length-at-age information used for this BSAI Greenland turbot assessment (see Gregg et al. 2006 for methods).

	2003				**2004**				**2005**			
	Females		Males		Females		Males		Females		Males	
Age	Avg. length (cm)	N	Ave. length (cm)	N	Avg. length (cm)	N	Ave. length (cm)	N	Avg. length (cm)	N	Ave. length (cm)	N
1	14.00	2	13.00	3	15.00	1	16.25	4			13.50	2
2	22.44	16	22.88	16	21.80	5	23.89	9	25.00	1	24.00	2
3	28.73	15	27.40	15	29.90	29	30.30	40	32.20	10	33.19	16
4	33.18	11	36.07	15	35.50	12	34.83	18	35.95	38	36.97	35
5	37.27	11	38.31	13	41.09	22	42.85	26	42.58	31	41.33	27
6	47.00	3	39.75	4	43.14	7	43.50	22	48.85	13	47.10	10
7	42.00	2	39.50	4	53.00	4	51.23	13	53.33	9	48.00	5
8	46.25	4	40.50	2	58.33	3	52.33	3	62.50	6	51.83	6
9	54.00	1	48.50	2	66.00	1	64.23	13	62.00	1	52.00	1
10					70.83	6	63.86	14	67.50	2	72.00	1
11	60.00	2	57.00	1	77.00	4	66.60	5	86.00	1	64.67	3
12			72.00	1	79.57	7	70.67	9	77.00	3		
13					85.67	9	68.17	12	88.00	1	72.50	2
14	83.50	2			83.36	11	69.13	8	81.33	3	76.00	1
15					86.93	15	68.58	19	85.50	2	79.00	1
16	83.00	2	65.00	1	81.67	12	69.14	14			75.50	4
17	80.00	2			83.91	22	70.00	13	85.00	2	76.00	1
18	85.33	3			86.17	18	69.29	14	92.00	3	76.00	1
19	84.67	3			89.33	15	72.33	9	84.60	5	74.33	3
20	91.00	1	79.00	1	85.87	15	69.05	21	90.20	5	79.00	1
21	87.00	2			87.25	24	71.47	17	89.00	2		
22	88.67	3	83.00	1	89.13	15	69.10	10	87.00	1		
23	89.25	4			89.40	10	71.58	12	82.00	1		
24	88.00	2	76.50	2	88.46	13	72.25	4	88.00	2	74.00	1
25					90.30	23	68.69	16	86.75	4	75.50	2
26	89.00	1	79.00	2	92.67	12	70.33	6	96.50	2		
27	92.50	2	74.00	1	89.26	19	68.13	8			73.00	1
28	92.50	2			91.70	10	71.25	8			78.00	1
29	91.67	3	78.00	1	91.00	7						
30	89.75	4			93.78	27	78.50	6	88.00	1		

Table 5.12(Cont.) Summary of the length-at-age information used for this BSAI Greenland turbot assessment (see Gregg et al. 2006 for methods).

	2006				2007				2008			
	Females		Males		Females		Males		Females		Males	
Age	Avg. length (cm)	N	Ave. length (cm)	N	Avg. length (cm)	N	Ave. length (cm)	N	Avg. length (cm)	N	Ave. length (cm)	N
1			11.50	2	12.17	18	12.50	26	12.81	16	13.10	21
2	24.33	3	21.00	1	22.50	4	21.00	8	18.94	17	19.64	36
3	30.33	3			30.00	1	28.67	6	23.13	8	23.36	11
4	39.00	2	39.50	2	39.50	2	35.00	4	28.50	2	30.00	4
5	38.00	11	38.38	16	46.18	17	44.40	15	34.50	2	35.50	4
6	42.69	16	43.75	20	47.00	17	47.18	22	49.60	5	47.50	6
7	46.60	25	44.33	15	50.72	18	51.70	23	52.14	14	51.83	12
8	54.53	19	47.25	16	54.67	15	52.67	15	56.68	25	52.15	20
9	57.90	10	53.18	11	59.75	12	56.00	4	61.73	22	56.79	19
10	65.67	3	64.25	4	62.33	6	55.00	3	64.50	20	58.95	20
11	62.00	1	62.25	4	63.00	1	62.75	4	64.36	14	60.76	17
12	71.00	6	74.00	1	62.00	3			68.90	10	62.64	14
13	56.50	2			65.00	7			71.56	9	63.67	6
14	77.00	1							79.83	6	67.17	6
15	78.00	2	73.00	1	61.67	3			79.80	5	66.22	9
16	84.67	3	77.00	2	80.00	1	69.00	1	85.67	6	72.75	8
17	86.25	4	74.00	1	90.00	4	75.50	4	77.00	5	69.71	7
18	88.67	3	76.00	1	85.00	1	77.50	2	83.13	8	72.82	11
19	87.60	5	79.00	1	91.67	3			90.50	4	69.00	5
20	90.33	6	79.00	1	89.00	3			86.75	8	72.00	14
21	91.00	2			90.67	3	76.50	2	91.56	9	68.00	5
22	90.00	2	74.00	1			77.00	1	91.30	10	74.13	8
23	88.00	1	88.00	1	87.00	1			93.88	8	70.71	7
24			77.00	1			84.00	1	90.56	9	73.00	7
25	88.50	2	83.00	2			72.00	1	89.92	13	69.50	6
26					92.00	3			90.67	3	72.50	6
27									90.50	4	71.86	7
28									94.67	9	71.70	10
29					92.00	1	82.00	1	91.07	15	76.14	7
30	107.00	1			90.00	1	79.00	1	91.74	35	70.52	31

Table 5.12(Cont.) Summary of the length-at-age information used for this BSAI Greenland turbot assessment (see Gregg et al. 2006 for methods).

	2009				
	Females			Males	
Age	Avg. length (cm)	N		Ave. length (cm)	N
1	15.00	6		14.25	12
2	22.05	41		21.93	73
3	29.72	29		28.60	47
4	33.30	10		33.27	11
5	35.50	2		45.00	1
6				42.50	2
7	56.00	3		52.00	1
8	56.00	1		53.75	4
9	59.56	9		58.33	3
10	63.75	4		54.50	2
11	64.00	4			
12					
13	74.50	2			
14	78.00	2			
15					
16					
17					
18					
19	88.00	1		78.50	2
20	90.50	2		79.00	1
21	87.67	3		70.00	1
22	94.00	1		77.00	2
23	92.50	4			
24	100.00	1			
25	89.00	2		71.00	1
26	93.00	1		78.00	1
27	83.00	2			
28	93.33	3			
29					
30	89.75	4		76.75	4

Table 5.13. Starting multinomial sample sizes for size composition data by fishery and survey.

Year	1977	1978	1979	1980	1981	1982	1983	1984	1985	1986	1987	1988
Trawl	100	101	101	101	101	105	110	107	104	101	100	
Longline			100	100	100	100	100	100	94			
Shelf						200	200	200	200	200	200	200
Slope			25		25	25			25			25
ABL Longline			60	60	60	60	60	60	60	60	60	60
Shelf-Age												

Year	1989	1990	1991	1992	1993	1994	1995	1996	1997	1998	1999	2000
Trawl	100	100	100			100	100	100		100	100	100
Longline					102	100	101	101	102	103	102	102
Shelf	200	200	200	200	200	200	200	200	200	200	200	200
Slope												
ABL Longline	60	60	60	60	60	60		60	60	60	60	60
Shelf-Age										100		

Year	2001	2002	2003	2004	2005	2006	2007	2008	2009	2010	2011	2012
Trawl	100	100	100	100	100	31	27	100	100	100	100	100
Longline	101	101	101	101	101	101	101	101	101	101	101	100
Shelf	200	200	200	200	200	200	200	200	200	200	200	200
Slope		50		50				50		50		50
ABL Longline	60	60	60	60	60	60	60	60	60	60	60	60
Shelf-Age			100	100	100	100	100	100	100			

Table 5.14. Candidate model likelihoods components, main parameters, and results. Please note that the likelihood components are not comparable across all models due to sample size tuning for each and differences in recruitment estimation. Likelihoods for Models 2 and 3 are comparable.

		Model 1	Model 2	Model 3	Model 4
Likelihoods					
	Total	3093.5	3065.2	3003.7	3246.5
	Survey	-36.2	-33.1	-34.4	-30.9
	Length Composition	1962.6	1807.3	1800.3	1962.2
	Age Composition	127.5	123.3	122.6	124.8
	Size at Age	6.7	4.4	1.2	5.9
	Recruitment	87.8	147.3	90.6	151.9
	Parameter priors	6.7	4.4	1.2	5.9
Parameters					
	$LN(R_0)$	9.31	9.25	9.57	9.99
	Steepness	0.90	0.79	0.79	0.79
	Natural Mortality	0.112	0.112	0.112	0.112
	q_{Shelf}	0.54	0.65	0.76	0.61
	q_{Slope}	0.75	0.56	0.66	0.53
	Mean q_{ABLL}	0.69	0.80	0.94	0.77
	L_{max} Female	88.23	88.34	88.24	87.98
	L_{max} Male	72.28	72.49	72.43	72.13
	Von Bert K Female	0.14	0.13	0.13	0.13
	Von Bert K Male	0.18	0.18	0.18	0.18
Results					
Model					
	SSB_{1978} (t)	396,738	224,680	227,881	288,801
	SSB_{2011} (t)	53,596	27,263	21,231	28,148
Projection					
	$SSB_{100\%}$ (t)	129,577	119,217	127,063	159,013
	SSB_{2012} (t)	50,078	25,144	19,204	26,234
	$SSB_{2012\%}$	0.386	0.211	0.151	0.165
	SSB_{2013} (t)	47,471	23,485	17,594	25,066
	$SSB_{2013\%}$	0.366	0.197	0.138	0.158
2013					
	ABC (t)	7,444	2,064	928	1,722
	F_{ABC}	0.34	0.12	0.06	0.09
	OFL (t)	9,038	2,539	1,285	2,117
	F_{OFL}	0.41	0.14	0.07	0.13
2014					
	ABC (t)	7,511	2,655	1,279	2,372
	F_{ABC}	0.40	0.13	0.07	0.10
	OFL (t)	9,133	3,266	1,888	2,915
	F_{OFL}	0.44	0.16	0.11	0.13

Table 5.15.   Model index RMSE , tuning diagnostics, and recruitment variability for candidate models.

		Model 1	Model 2	Model 3	Model 4
Index RMSE					
	Shelf	0.226	0.238	0.242	0.246
	Slope	0.204	0.200	0.208	0.200
	ABL Longline	0.415	0.397	0.369	0.405
Size Comp					
Mean EffN	Trawl	52.5	56.9	55.9	55.7
	Longline	50.9	66.4	66.9	63.6
	Shelf	77.0	82.1	82.0	80.0
	Slope	37.7	39.2	39.5	43.5
	ABL Longline	65.2	35.9	35.2	33.3
Mean input N	Trawl	53.1	55.0	55.0	55.0
	Longline	50.3	65.4	65.4	65.4
	Shelf	80	90	90	90
	Slope	40	40	40	40
	ABL Longline	64.2	36	36	36
Age Comp					
	Mean EffN	49.9	52.0	51.2	52.1
	Mean input N	50	50	50	50
Rec. Var. (1975-2012)					
	Std.dev(ln(No. Age 1)	1.39	0.64	0.72	0.65

Table 5.16. Age-equivalent sex-specific selectivity estimates (as estimated for 2011) from each gear type for Greenland turbot in the BSAI. Note that selectivity processes are modeled as a function of size and that some selectivities-at-length are allowed to vary over time.

Age	Trawl Fishery Female	Trawl Fishery Male	Longline fishery Female	Longline fishery Male
1	0.0067	0.0067	0	0
2	0.0067	0.0067	0	0
3	0.0077	0.0080	0	0
4	0.0156	0.0184	0.0003	0.0001
5	0.0442	0.0554	0.0027	0.0038
6	0.1015	0.1290	0.0157	0.0263
7	0.1771	0.2302	0.0567	0.0786
8	0.2510	0.3393	0.1361	0.1490
9	0.3083	0.4390	0.2452	0.2202
10	0.3439	0.5204	0.3647	0.2822
11	0.3594	0.5815	0.4785	0.3324
12	0.3597	0.6249	0.5778	0.3718
13	0.3498	0.6544	0.6603	0.4024
14	0.3340	0.6740	0.7267	0.4261
15	0.3154	0.6870	0.7795	0.4448
16	0.2958	0.6957	0.8211	0.4595
17	0.2766	0.7018	0.8540	0.4714
18	0.2583	0.7065	0.8801	0.4812
19	0.2414	0.7106	0.9008	0.4892
20	0.2260	0.7146	0.9174	0.4960
21	0.2120	0.7188	0.9309	0.5018
22	0.1993	0.7234	0.9418	0.5068
23	0.1878	0.7285	0.9507	0.5112
24	0.1775	0.7341	0.9581	0.5150
25	0.1687	0.7354	0.9630	0.5174
26	0.1616	0.7323	0.9660	0.5184
27	0.1554	0.7295	0.9684	0.5192
28	0.1500	0.7272	0.9704	0.5198
29	0.1454	0.7251	0.9721	0.5204
30	0.1370	0.7221	0.9749	0.5211

Table 5.17.   Time series of age-0 recruits (number in 1,000s) with lower (LCI) and upper (UCI) 95% confidence intervals for 1960-2012.

Year	Age-0 Recruits	LCI	UCI	Year	Age-0 Recruits	LCI	UCI
1960	11,647	0	26,053	1994	1,202	558	1,846
1961	11,401	0	25,382	1995	3,915	2,662	5,168
1962	11,105	0	24,630	1996	1,980	1,087	2,873
1963	10,700	0	23,649	1997	1,951	1,024	2,878
1964	10,304	0	22,694	1998	2,467	1,283	3,651
1965	**1,365,600**	**1,267,326**	**1,463,874**	1999	6,865	4,816	8,914
1966	9,082	0	19,871	2000	7,016	4,971	9,061
1967	8,462	0	18,424	2001	8,427	6,412	10,442
1968	7,780	0	16,834	2002	1,154	516	1,792
1969	7,477	0	16,068	2003	651	267	1,036
1970	8,097	0	17,300	2004	705	295	1,116
1971	8,947	0	19,163	2005	915	395	1,435
1972	10,049	0	22,132	2006	10,534	7,717	13,351
1973	92,181	41,699	142,663	2007	13,259	9,216	17,302
1974	17,229	0	46,019	2008	32,549	22,570	42,528
1975	299,960	243,310	356,610	2009	78,108	53,688	102,528
1976	18,407	0	45,112	2010	13,136	5,294	20,978
1977	36,778	0	88,377	2011	10,334	2,876	17,792
1978	126,750	87,209	166,291	2012	8,831	0	19,267
1979	7,753	0	15,706				
1980	25,807	16,925	34,689	**1977-2012 Average**	**13,200**		
1981	3,335	859	5,811				
1982	5,965	3,396	8,533				
1983	2,713	1,065	4,360				
1984	7,701	4,939	10,464				
1985	19,266	14,966	23,566				
1986	2,351	866	3,836				
1987	4,524	2,684	6,364				
1988	4,696	2,744	6,648				
1989	18,019	14,292	21,746				
1990	2,439	1,026	3,852				
1991	1,214	492	1,937				
1992	1,090	497	1,683				
1993	787	320	1,254				

Table 5.18.   Estimated beginning of year numbers (1×10^7) of Greenland turbot by age and sex (billions).

Females

Yr	0	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20+
1977	1.84	0.82	11.74	0.57	2.46	0.21	0.15	0.11	0.08	0.07	0.07	0.05	6.16	0.03	0.02	0.02	0.01	0.01	0.01	0.00	0.05
1978	6.34	1.64	0.73	10.15	0.48	2.07	0.18	0.13	0.09	0.07	0.06	0.05	0.05	5.13	0.03	0.02	0.01	0.01	0.01	0.00	0.04
1979	0.39	5.67	1.45	0.62	8.46	0.39	1.69	0.15	0.10	0.08	0.06	0.05	0.04	0.04	4.15	0.02	0.02	0.01	0.01	0.01	0.04
1980	1.29	0.35	4.99	1.24	0.52	6.96	0.32	1.38	0.12	0.08	0.06	0.05	0.04	0.04	0.03	3.35	0.02	0.01	0.01	0.01	0.04
1981	0.17	1.15	0.30	4.21	1.01	0.42	5.54	0.26	1.09	0.09	0.07	0.05	0.04	0.03	0.03	0.02	2.62	0.01	0.01	0.01	0.03
1982	0.30	0.15	1.01	0.25	3.40	0.80	0.33	4.33	0.20	0.85	0.07	0.05	0.04	0.03	0.02	0.02	0.02	2.01	0.01	0.01	0.03
1983	0.14	0.27	0.13	0.84	0.20	2.68	0.62	0.25	3.36	0.15	0.66	0.06	0.04	0.03	0.02	0.02	0.02	0.01	1.58	0.01	0.03
1984	0.39	0.12	0.23	0.11	0.68	0.16	2.09	0.49	0.20	2.61	0.12	0.51	0.04	0.03	0.02	0.02	0.01	0.01	0.01	1.24	0.03
1985	0.96	0.34	0.11	0.20	0.09	0.57	0.13	1.74	0.40	0.16	2.17	0.10	0.43	0.04	0.03	0.02	0.01	0.01	0.01	0.01	1.07
1986	0.12	0.86	0.31	0.09	0.17	0.08	0.48	0.11	1.48	0.34	0.14	1.85	0.09	0.36	0.03	0.02	0.02	0.01	0.01	0.01	0.93
1987	0.23	0.11	0.77	0.27	0.08	0.15	0.07	0.42	0.10	1.28	0.30	0.12	1.60	0.07	0.31	0.03	0.02	0.01	0.01	0.01	0.81
1988	0.23	0.20	0.09	0.67	0.23	0.07	0.13	0.06	0.36	0.09	1.11	0.26	0.10	1.39	0.06	0.27	0.02	0.02	0.01	0.01	0.72
1989	0.90	0.21	0.18	0.08	0.59	0.21	0.06	0.11	0.05	0.32	0.07	0.97	0.22	0.09	1.21	0.06	0.24	0.02	0.01	0.01	0.63
1990	0.12	0.81	0.19	0.16	0.07	0.53	0.18	0.06	0.10	0.05	0.28	0.06	0.83	0.19	0.08	1.04	0.05	0.20	0.02	0.01	0.56
1991	0.06	0.11	0.72	0.17	0.14	0.07	0.47	0.16	0.05	0.09	0.04	0.23	0.05	0.70	0.16	0.07	0.88	0.04	0.17	0.02	0.49
1992	0.05	0.05	0.10	0.64	0.15	0.13	0.06	0.42	0.14	0.04	0.08	0.03	0.20	0.05	0.60	0.14	0.06	0.76	0.04	0.15	0.44
1993	0.04	0.05	0.05	0.09	0.57	0.13	0.11	0.05	0.37	0.13	0.04	0.07	0.03	0.18	0.04	0.53	0.12	0.05	0.66	0.03	0.52
1994	0.06	0.04	0.04	0.04	0.08	0.51	0.12	0.10	0.05	0.33	0.11	0.03	0.06	0.03	0.15	0.03	0.45	0.10	0.04	0.56	0.46
1995	0.20	0.05	0.03	0.04	0.04	0.07	0.46	0.11	0.09	0.04	0.28	0.10	0.03	0.05	0.02	0.13	0.03	0.38	0.09	0.04	0.86
1996	0.10	0.18	0.05	0.03	0.03	0.03	0.06	0.41	0.09	0.08	0.04	0.24	0.08	0.02	0.04	0.02	0.11	0.02	0.32	0.07	0.76
1997	0.10	0.09	0.16	0.04	0.03	0.03	0.03	0.06	0.36	0.08	0.07	0.03	0.21	0.07	0.02	0.03	0.02	0.09	0.02	0.27	0.70
1998	0.12	0.09	0.08	0.14	0.04	0.02	0.03	0.03	0.05	0.32	0.07	0.06	0.03	0.18	0.06	0.02	0.03	0.01	0.08	0.02	0.81
1999	0.34	0.11	0.08	0.07	0.12	0.03	0.02	0.02	0.02	0.04	0.28	0.06	0.05	0.02	0.15	0.05	0.01	0.02	0.01	0.06	0.68
2000	0.35	0.31	0.10	0.07	0.06	0.11	0.03	0.02	0.02	0.02	0.04	0.24	0.05	0.04	0.02	0.13	0.04	0.01	0.02	0.01	0.62
2001	0.42	0.31	0.27	0.09	0.06	0.06	0.10	0.03	0.02	0.02	0.02	0.03	0.20	0.04	0.04	0.02	0.10	0.03	0.01	0.02	0.52
2002	0.06	0.38	0.28	0.24	0.08	0.06	0.05	0.09	0.02	0.01	0.02	0.02	0.03	0.17	0.04	0.03	0.01	0.09	0.03	0.01	0.45
2003	0.03	0.05	0.34	0.25	0.22	0.07	0.05	0.04	0.08	0.02	0.01	0.01	0.01	0.02	0.14	0.03	0.03	0.01	0.07	0.02	0.38
2004	0.04	0.03	0.05	0.30	0.22	0.20	0.06	0.04	0.04	0.07	0.02	0.01	0.01	0.01	0.02	0.12	0.03	0.02	0.01	0.06	0.34
2005	0.05	0.03	0.03	0.04	0.27	0.20	0.17	0.06	0.04	0.04	0.06	0.02	0.01	0.01	0.01	0.02	0.11	0.02	0.02	0.01	0.35
2006	0.53	0.04	0.03	0.02	0.04	0.24	0.18	0.16	0.05	0.03	0.03	0.05	0.01	0.01	0.01	0.01	0.01	0.09	0.02	0.02	0.30
2007	0.66	0.47	0.04	0.03	0.02	0.03	0.21	0.16	0.14	0.04	0.03	0.03	0.05	0.01	0.01	0.01	0.01	0.01	0.08	0.02	0.27
2008	1.63	0.59	0.42	0.03	0.02	0.02	0.03	0.19	0.14	0.12	0.04	0.03	0.02	0.04	0.01	0.01	0.01	0.01	0.01	0.07	0.25
2009	3.91	1.46	0.53	0.38	0.03	0.02	0.02	0.03	0.17	0.12	0.10	0.03	0.02	0.02	0.03	0.01	0.00	0.01	0.01	0.01	0.27
2010	0.66	3.49	1.30	0.47	0.34	0.03	0.02	0.01	0.02	0.14	0.10	0.09	0.03	0.02	0.02	0.03	0.01	0.00	0.00	0.00	0.23
2011	0.52	0.59	3.12	1.16	0.42	0.30	0.02	0.02	0.01	0.02	0.12	0.09	0.07	0.02	0.01	0.01	0.02	0.01	0.00	0.00	0.19
2012	0.44	0.46	0.52	2.79	1.04	0.38	0.27	0.02	0.01	0.01	0.02	0.10	0.07	0.06	0.02	0.01	0.01	0.02	0.00	0.00	0.16

Table 5.18 (cont.) Estimated beginning of year numbers (1×10^7) of Greenland turbot by age and sex.

Males

Yr	0	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20+
1977	1.84	0.82	11.78	0.57	2.44	0.21	0.14	0.09	0.06	0.05	0.04	0.03	3.19	0.02	0.01	0.01	0.00	0.00	0.00	0.00	0.00
1978	6.34	1.64	0.73	10.19	0.48	2.01	0.17	0.11	0.07	0.05	0.04	0.03	0.02	2.47	0.01	0.01	0.00	0.00	0.00	0.00	0.00
1979	0.39	5.67	1.45	0.62	8.41	0.38	1.57	0.13	0.08	0.06	0.04	0.03	0.02	0.02	1.80	0.01	0.01	0.00	0.00	0.00	0.00
1980	1.29	0.35	5.00	1.24	0.51	6.75	0.30	1.21	0.10	0.06	0.04	0.03	0.02	0.02	0.01	1.31	0.01	0.00	0.00	0.00	0.00
1981	0.17	1.15	0.30	4.23	1.00	0.40	5.10	0.22	0.88	0.07	0.04	0.03	0.02	0.01	0.01	0.01	0.89	0.00	0.00	0.00	0.00
1982	0.30	0.15	1.01	0.26	3.36	0.77	0.30	3.65	0.16	0.60	0.05	0.03	0.02	0.01	0.01	0.01	0.01	0.59	0.00	0.00	0.00
1983	0.14	0.27	0.13	0.85	0.20	2.55	0.56	0.21	2.54	0.11	0.41	0.03	0.02	0.01	0.01	0.01	0.01	0.00	0.38	0.00	0.00
1984	0.39	0.12	0.23	0.11	0.67	0.15	1.87	0.40	0.15	1.75	0.07	0.28	0.02	0.01	0.01	0.01	0.00	0.00	0.00	0.25	0.00
1985	0.96	0.34	0.11	0.20	0.09	0.55	0.12	1.48	0.31	0.11	1.35	0.06	0.21	0.02	0.01	0.01	0.00	0.00	0.00	0.00	0.19
1986	0.12	0.86	0.31	0.09	0.17	0.08	0.46	0.10	1.22	0.26	0.09	1.10	0.05	0.17	0.01	0.01	0.01	0.00	0.00	0.00	0.16
1987	0.23	0.11	0.77	0.27	0.08	0.15	0.07	0.39	0.09	1.03	0.22	0.08	0.92	0.04	0.14	0.01	0.01	0.00	0.00	0.00	0.13
1988	0.23	0.20	0.09	0.67	0.23	0.07	0.13	0.06	0.33	0.07	0.86	0.18	0.07	0.77	0.03	0.12	0.01	0.01	0.00	0.00	0.11
1989	0.90	0.21	0.18	0.08	0.59	0.20	0.06	0.11	0.05	0.28	0.06	0.73	0.15	0.06	0.65	0.03	0.10	0.01	0.00	0.00	0.10
1990	0.12	0.81	0.19	0.16	0.07	0.53	0.18	0.05	0.10	0.04	0.24	0.05	0.62	0.13	0.05	0.54	0.02	0.08	0.01	0.00	0.08
1991	0.06	0.11	0.72	0.17	0.14	0.07	0.47	0.16	0.05	0.08	0.03	0.20	0.04	0.50	0.10	0.04	0.43	0.02	0.07	0.01	0.07
1992	0.05	0.05	0.10	0.64	0.15	0.13	0.06	0.42	0.14	0.04	0.07	0.03	0.17	0.04	0.41	0.09	0.03	0.36	0.01	0.06	0.06
1993	0.04	0.05	0.05	0.09	0.57	0.13	0.11	0.05	0.37	0.13	0.04	0.06	0.03	0.15	0.03	0.36	0.08	0.03	0.32	0.01	0.11
1994	0.06	0.04	0.04	0.04	0.08	0.51	0.12	0.10	0.05	0.33	0.11	0.03	0.05	0.02	0.13	0.03	0.31	0.06	0.02	0.27	0.10
1995	0.20	0.05	0.03	0.04	0.04	0.07	0.46	0.11	0.09	0.04	0.28	0.09	0.03	0.04	0.02	0.10	0.02	0.25	0.05	0.02	0.30
1996	0.10	0.18	0.05	0.03	0.03	0.03	0.06	0.41	0.09	0.08	0.03	0.23	0.08	0.02	0.04	0.02	0.08	0.02	0.21	0.04	0.27
1997	0.10	0.09	0.16	0.04	0.03	0.03	0.03	0.06	0.36	0.08	0.07	0.03	0.20	0.07	0.02	0.03	0.01	0.07	0.02	0.18	0.27
1998	0.12	0.09	0.08	0.14	0.04	0.02	0.03	0.03	0.05	0.32	0.07	0.06	0.03	0.17	0.06	0.02	0.03	0.01	0.06	0.01	0.38
1999	0.34	0.11	0.08	0.07	0.12	0.03	0.02	0.02	0.02	0.04	0.27	0.06	0.05	0.02	0.14	0.05	0.01	0.02	0.01	0.05	0.32
2000	0.35	0.31	0.10	0.07	0.06	0.11	0.03	0.02	0.02	0.02	0.04	0.23	0.05	0.04	0.02	0.12	0.04	0.01	0.02	0.01	0.32
2001	0.42	0.31	0.27	0.09	0.06	0.06	0.10	0.03	0.02	0.02	0.02	0.03	0.20	0.04	0.03	0.01	0.10	0.03	0.01	0.02	0.27
2002	0.06	0.38	0.28	0.24	0.08	0.06	0.05	0.09	0.02	0.01	0.02	0.02	0.03	0.16	0.04	0.03	0.01	0.08	0.03	0.01	0.23
2003	0.03	0.05	0.34	0.25	0.22	0.07	0.05	0.04	0.08	0.02	0.01	0.01	0.01	0.02	0.14	0.03	0.02	0.01	0.07	0.02	0.20
2004	0.04	0.03	0.05	0.30	0.22	0.20	0.06	0.04	0.04	0.07	0.02	0.01	0.01	0.01	0.02	0.12	0.03	0.02	0.01	0.06	0.19
2005	0.05	0.03	0.03	0.04	0.27	0.20	0.17	0.06	0.04	0.03	0.06	0.02	0.01	0.01	0.01	0.02	0.10	0.02	0.02	0.01	0.22
2006	0.53	0.04	0.03	0.02	0.04	0.24	0.18	0.16	0.05	0.03	0.03	0.05	0.01	0.01	0.01	0.01	0.01	0.09	0.02	0.02	0.19
2007	0.66	0.47	0.04	0.03	0.02	0.03	0.21	0.16	0.14	0.04	0.03	0.03	0.05	0.01	0.01	0.01	0.01	0.01	0.07	0.02	0.18
2008	1.63	0.59	0.42	0.03	0.02	0.02	0.03	0.19	0.14	0.12	0.04	0.03	0.02	0.04	0.01	0.01	0.01	0.01	0.01	0.06	0.17
2009	3.91	1.46	0.53	0.38	0.03	0.02	0.02	0.03	0.17	0.12	0.10	0.03	0.02	0.02	0.03	0.01	0.00	0.01	0.00	0.01	0.19
2010	0.66	3.49	1.30	0.47	0.34	0.03	0.02	0.01	0.02	0.14	0.10	0.08	0.03	0.02	0.01	0.02	0.01	0.00	0.00	0.00	0.15
2011	0.52	0.59	3.12	1.16	0.42	0.30	0.02	0.02	0.01	0.02	0.12	0.08	0.07	0.02	0.01	0.01	0.02	0.01	0.00	0.00	0.12
2012	0.44	0.46	0.52	2.79	1.04	0.38	0.27	0.02	0.01	0.01	0.02	0.09	0.07	0.05	0.02	0.01	0.01	0.02	0.00	0.00	0.10

Table 5.19. Total harvest rate (catch / mid-year biomass), spawning and total biomass (compared with the 2011 assessment) for BSAI Greenland turbot, 1960-2013. 2012 and 2013 biomass estimates are from the projection model Alt. 1.

Year	Apical Fishing Mortality	Total Exploitation	1-SPR.	Female Spawning Biomass 2011 Assessment	Current Assessment	Total Age 1+ Biomass 2011 Assessment	Current Assessment
1960	0.26	0.14	0.77	118,843	110,445	220,366	199,834
1961	0.51	0.25	0.92	113,381	101,477	194,345	174,641
1962	0.76	0.33	0.97	102,327	84,028	157,311	133,674
1963	0.61	0.26	0.95	85,826	62,757	129,006	91,748
1964	0.99	0.37	0.98	74,723	49,586	133,337	69,827
1965	0.40	0.16	0.88	66,321	33,763	150,022	45,929
1966	0.55	0.18	0.93	74,009	28,992	196,743	55,366
1967	0.58	0.25	0.94	92,187	23,570	253,541	71,949
1968	0.35	0.18	0.85	118,828	19,240	311,592	145,167
1969	0.19	0.11	0.69	150,934	19,164	367,441	239,545
1970	0.10	0.06	0.46	187,110	33,366	426,328	338,440
1971	0.16	0.10	0.62	227,388	82,282	495,239	435,861
1972	0.26	0.16	0.78	263,160	155,330	544,065	493,857
1973	0.22	0.13	0.73	288,527	214,251	551,959	492,438
1974	0.29	0.16	0.81	315,374	253,256	557,812	480,773
1975	0.28	0.16	0.80	333,284	261,445	535,080	436,632
1976	0.30	0.16	0.82	344,128	253,606	510,665	396,175
1977	0.16	0.08	0.62	342,858	234,214	484,585	356,064
1978	0.23	0.12	0.73	344,621	224,680	489,050	358,135
1979	0.23	0.12	0.73	336,226	207,496	483,658	354,747
1980	0.30	0.15	0.80	327,888	194,380	482,781	352,956
1981	0.34	0.17	0.83	316,764	183,775	472,334	341,241
1982	0.32	0.16	0.83	305,743	176,013	454,325	320,126
1983	0.32	0.16	0.83	300,647	171,046	434,625	296,950
1984	0.17	0.09	0.64	296,896	165,230	410,716	270,387
1985	0.11	0.06	0.50	300,123	167,996	401,782	261,427
1986	0.07	0.04	0.38	302,051	171,438	393,764	255,657
1987	0.07	0.04	0.38	300,666	173,465	384,540	250,514
1988	0.06	0.03	0.31	294,188	171,754	371,096	242,842
1989	0.14	0.04	0.29	284,481	168,124	356,651	235,214
1990	0.22	0.06	0.41	271,102	160,849	338,026	224,057
1991	0.13	0.04	0.31	254,463	149,935	314,078	207,457
1992	0.04	0.02	0.18	238,886	141,323	294,602	195,665
1993	0.08	0.05	0.34	224,266	134,597	279,179	187,959
1994	0.19	0.06	0.43	206,306	123,962	259,257	175,370
1995	0.15	0.05	0.39	189,773	113,408	237,313	160,272
1996	0.10	0.04	0.35	174,729	104,164	217,654	146,807
1997	0.10	0.05	0.38	160,564	95,928	199,870	134,972
1998	0.15	0.07	0.46	145,984	87,007	181,958	122,644
1999	0.12	0.05	0.38	130,564	76,667	162,914	108,715
2000	0.16	0.07	0.45	118,109	68,949	147,730	98,258
2001	0.16	0.06	0.42	105,568	60,598	132,537	87,227
2002	0.11	0.05	0.35	95,251	53,933	120,324	78,548
2003	0.11	0.05	0.36	86,466	48,669	111,554	72,508
2004	0.08	0.03	0.29	78,554	43,867	104,569	67,598
2005	0.10	0.04	0.34	72,690	40,576	99,974	64,526
2006	0.06	0.03	0.30	67,853	37,634	95,501	61,263
2007	0.07	0.03	0.31	64,537	35,836	91,825	58,784
2008	0.14	0.05	0.41	61,791	34,473	88,135	56,380
2009	0.23	0.08	0.55	59,031	32,826	83,822	53,738
2010	0.20	0.08	0.54	55,288	30,121	78,586	51,507
2011	0.19	0.07	0.53	51,278	27,263	75,026	52,610
2012	0.25	0.07	0.57		25,143		68,574
2013					23,485		80,989

Table 5.20.   Spawning biomass with lower (LCI) and upper (UCI) 95% confidence intervals
for 1977-2012for BSAI Greenland turbot, 1960-2012. Confidence bounds are
based on 1.96×standard error.

Year	Spawning Biomass	LCI	UCI
1977	234,210	206,078	262,342
1978	224,680	196,627	252,733
1979	207,500	180,454	234,546
1980	194,380	168,767	219,993
1981	183,780	159,707	207,853
1982	176,010	153,113	198,907
1983	171,050	148,959	193,141
1984	165,230	143,776	186,684
1985	168,000	146,905	189,095
1986	171,440	150,699	192,181
1987	173,470	153,166	193,774
1988	171,750	152,019	191,481
1989	168,120	149,085	187,155
1990	160,850	142,670	179,030
1991	149,940	132,677	167,203
1992	141,320	124,964	157,676
1993	134,600	119,148	150,052
1994	123,960	109,403	138,517
1995	113,410	99,665	127,155
1996	104,160	91,201	117,119
1997	95,928	83,703	108,153
1998	87,007	75,497	98,517
1999	76,667	65,864	87,470
2000	68,949	58,832	79,066
2001	60,598	51,135	70,061
2002	53,933	45,079	62,787
2003	48,669	40,381	56,957
2004	43,867	36,102	51,632
2005	40,576	33,256	47,896
2006	37,634	30,700	44,568
2007	35,836	29,202	42,470
2008	34,473	28,085	40,861
2009	32,826	26,669	38,983
2010	30,121	24,187	36,055
2011	27,263	21,564	32,962
2012	25,143	19,624	30,662

Table 5.21. Age and sex-specific mean length and weights-at-age estimates for BSAI Greenland turbot from the 2011 stock assessment (Ianelli et al. 2011) and for the 2012 Model 2.

| | Mid-year length (cm) | | | | Mid-year weight (kg) | | | |
| | 2011 Reference | | 2012 Model 2 | | 2011 Reference | | 2012 Model 2 | |
Age	Females	Males	Females	Males	Females	Males	Females	Males
1	12.36	12.36	13.70	13.64	0.01	0.01	0.02	0.02
2	22.06	21.98	21.94	22.34	0.08	0.08	0.08	0.08
3	30.84	30.41	30.27	30.74	0.26	0.25	0.22	0.22
4	38.5	37.51	37.61	37.75	0.54	0.49	0.45	0.43
5	45.17	43.5	44.09	43.61	0.92	0.81	0.77	0.69
6	50.98	48.54	49.80	48.51	1.37	1.16	1.15	0.97
7	56.04	52.78	54.84	52.60	1.87	1.53	1.58	1.25
8	60.45	56.36	59.29	56.02	2.41	1.90	2.04	1.53
9	64.29	59.37	63.21	58.87	2.95	2.26	2.52	1.80
10	67.63	61.9	66.67	61.26	3.49	2.59	3.00	2.04
11	70.55	64.04	69.72	63.25	4.00	2.90	3.47	2.25
12	73.09	65.84	72.41	64.92	4.49	3.17	3.92	2.44
13	75.3	67.35	74.78	66.31	4.95	3.41	4.36	2.61
14	77.23	68.63	76.88	67.48	5.36	3.62	4.76	2.75
15	78.91	69.71	78.72	68.45	5.74	3.80	5.14	2.88
16	80.37	70.61	80.35	69.26	6.09	3.96	5.48	2.98
17	81.65	71.38	81.79	69.94	6.39	4.09	5.80	3.07
18	82.76	72.02	83.06	70.50	6.66	4.21	6.08	3.15
19	83.72	72.56	84.17	70.98	6.91	4.31	6.34	3.21
20	84.57	73.02	85.16	71.37	7.12	4.39	6.57	3.26
21	85.3	73.4	86.03	71.70	7.31	4.45	6.77	3.31
22	85.94	73.72	86.80	71.98	7.47	4.51	6.95	3.34
23	86.5	74	87.47	72.21	7.62	4.56	7.12	3.37
24	86.98	74.22	88.07	72.40	7.75	4.59	7.26	3.39
25	87.41	74.42	88.60	72.56	7.86	4.63	7.39	3.41
26	87.77	74.58	89.06	72.70	7.96	4.66	7.51	3.44
27	88.1	74.72	89.47	72.81	8.05	4.69	7.61	3.45
28	88.38	74.83	89.83	72.91	8.13	4.72	7.70	3.47
29	88.62	74.93	90.15	72.98	8.20	4.74	7.78	3.48
30	89.04	75.08	90.74	73.10	8.32	4.77	7.92	3.50

Table 5.22.   Estimated total Greenland turbot harvest by area, 1977-2012. Values for 2012 are through Oct. 14th, 2012 and are preliminary.

Year	EBS	Aleutians	Year	EBS	Aleutians
1977	27,708	2,453	1995	4,499	5,855
1978	37,423	4,766	1996	4,258	4,844
1979	34,998	6,411	1997	5,730	6,435
1980	48,856	3,697	1998	7,839	8,329
1981	52,921	4,400	1999	5,179	5,391
1982	45,805	6,317	2000	5,667	5,888
1983	43,443	4,115	2001	4,102	4,252
1984	21,317	1,803	2002	3,011	3,153
1985	14,698	33	2003	2,467	960
1986	7,710	2,154	2004	1,805	414
1987	6,519	3,066	2005	2,120	439
1988	6,064	1,044	2006	1,440	525
1989	4,061	4,761	2007	1,313	516
1990	7,702	2,494	2008	1,917	824
1991	3,781	4,397	2009	2,237	2,261
1992	1,767	2,462	2010	2,272	1,866
1993	4,878	6,330	2011	3,108	531
1994	3,875	7,141	2012	2,499	1,645

Table 5.23.   Mean spawning biomass, F, and yield projections for Greenland turbot, 2012-2025. The full-selection fishing mortality rates (*F's*) between longline and trawl gears were assumed to be **50:50**.

SSB	Max F$_{abc}$	F$_{abc}$	5-year avg.	F$_{75\%}$	No Fishing	Scenario 6	Scenario 7
2012	25,144	25,144	25,144	25,144	25,144	25,144	25,144
2013	23,485	23,485	23,485	23,485	23,485	23,485	23,485
2014	26,537	26,537	27,051	27,131	27,714	26,267	26,537
2015	33,631	33,631	34,802	34,961	36,131	33,097	33,631
2016	43,388	43,388	45,705	45,953	47,794	42,508	42,946
2017	52,561	52,561	57,023	57,384	60,088	51,152	51,490
2018	59,243	59,243	66,862	67,373	71,224	57,002	57,280
2019	63,197	63,197	74,667	75,368	80,679	59,983	60,210
2020	64,822	64,822	80,576	81,498	88,537	60,600	60,783
2021	64,833	64,833	84,955	86,118	95,072	59,681	59,828
2022	63,829	63,829	88,094	89,502	100,463	57,908	58,024
2023	62,262	62,262	90,235	91,882	104,856	55,791	55,879
2024	60,490	60,490	91,621	93,494	108,417	53,800	53,865
2025	58,816	58,816	92,465	94,543	111,308	52,119	52,167
F							
2012	0.27	0.27	0.27	0.27	0.27	0.27	0.27
2013	0.11	0.11	0.06	0.06	0.00	0.14	0.11
2014	0.13	0.13	0.06	0.06	0.00	0.16	0.13
2015	0.17	0.17	0.06	0.06	0.00	0.21	0.21
2016	0.22	0.22	0.06	0.06	0.00	0.27	0.27
2017	0.25	0.25	0.06	0.06	0.00	0.31	0.31
2018	0.25	0.25	0.06	0.06	0.00	0.31	0.31
2019	0.25	0.25	0.06	0.06	0.00	0.31	0.31
2020	0.25	0.25	0.06	0.06	0.00	0.31	0.31
2021	0.25	0.25	0.06	0.06	0.00	0.31	0.31
2022	0.25	0.25	0.06	0.06	0.00	0.30	0.30
2023	0.25	0.25	0.06	0.06	0.00	0.29	0.29
2024	0.24	0.24	0.06	0.06	0.00	0.28	0.28
2025	0.24	0.24	0.06	0.06	0.00	0.27	0.27
Catch							
2012	5,000	5,000	5,000	5,000	5,000	5,000	5,000
2013	2,064	2,064	1,162	1,020	0	2,539	2,064
2014	2,655	2,655	1,334	1,175	0	3,197	2,655
2015	4,281	4,281	1,697	1,497	0	5,091	5,263
2016	7,250	7,250	2,248	1,984	0	8,535	8,715
2017	9,950	9,950	2,893	2,557	0	11,862	11,940
2018	11,558	11,558	3,513	3,109	0	13,602	13,666
2019	12,583	12,583	4,025	3,569	0	14,581	14,634
2020	13,019	13,019	4,403	3,913	0	14,837	14,879
2021	13,023	13,023	4,662	4,153	0	14,595	14,629
2022	12,767	12,767	4,828	4,311	0	14,040	14,071
2023	12,365	12,365	4,925	4,408	0	13,161	13,188
2024	11,807	11,807	4,976	4,463	0	12,321	12,342
2025	11,251	11,251	4,995	4,489	0	11,641	11,655

Figures

Greenland Turbot Habitat Bathymetry
- 2000 Meters
- 100 Meters
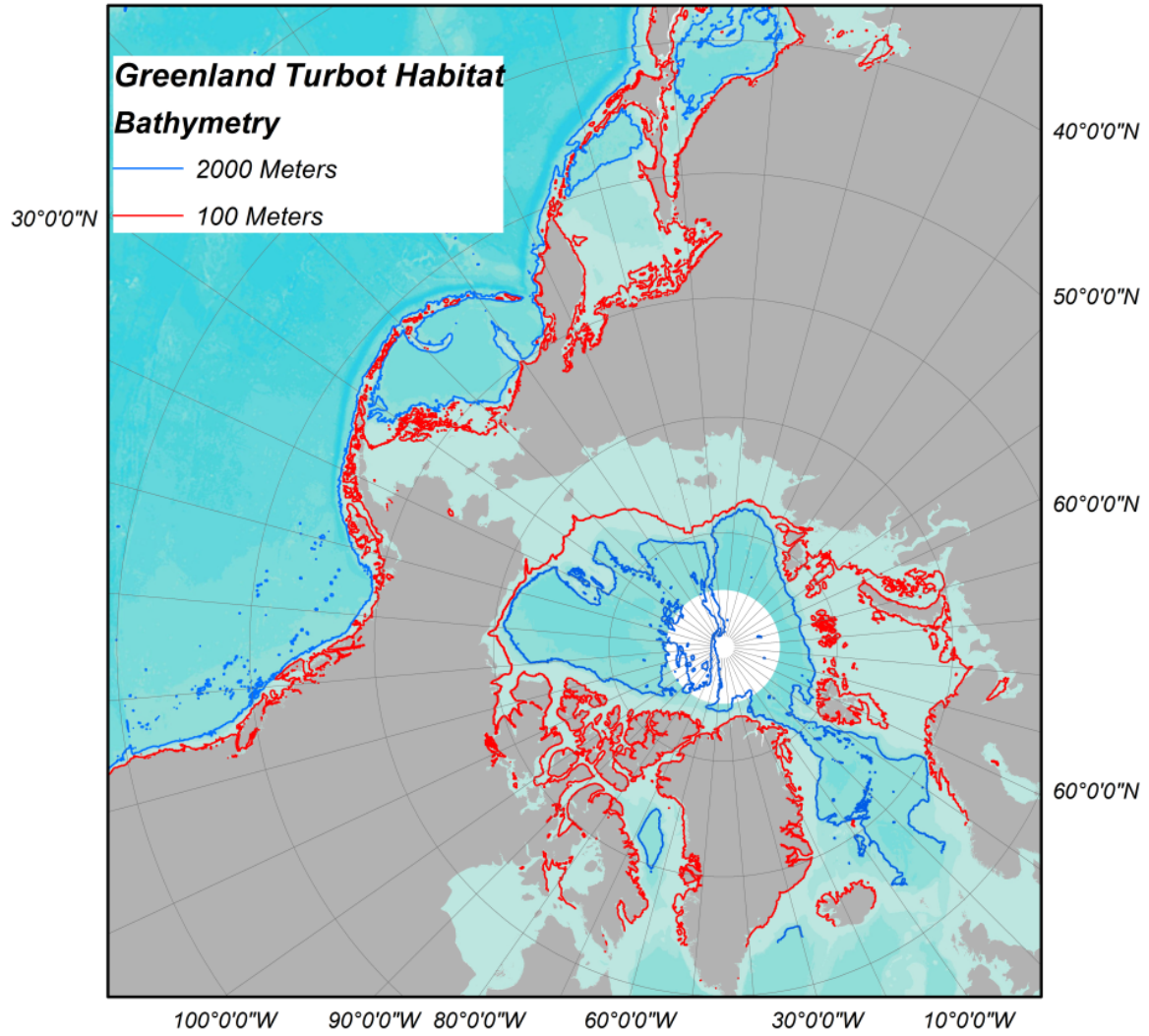
Figure 5.1.   Map of the northern oceans with bathymetry at 100 meters (red) and 2000 meters (blue), possible Greenland turbot habitat.

(a)
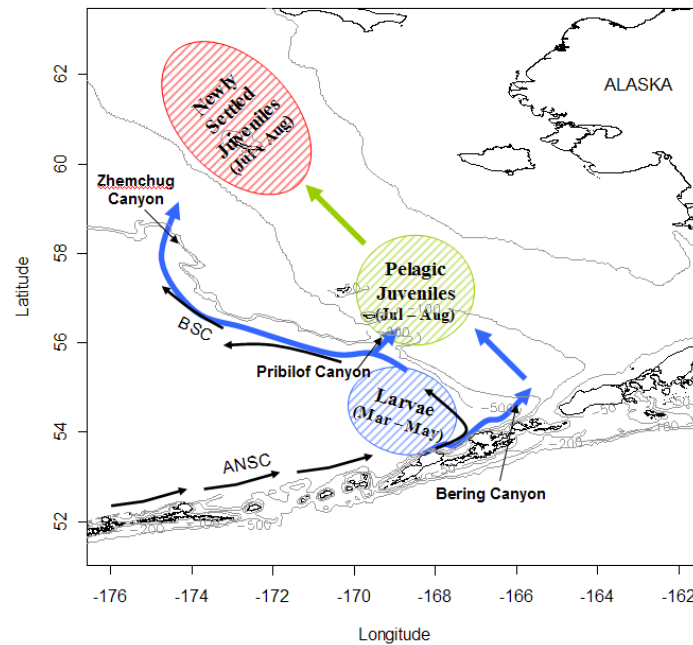
(b)
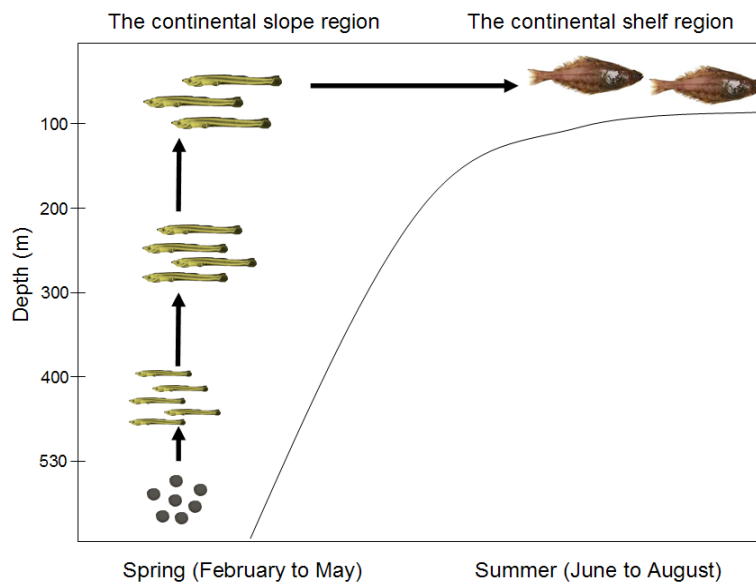
Figure 5.2.   Schematic representation of Greenland halibut distribution and connectivity from larvae to settled juveniles. (a) Horizontally changed distribution through different life history stages (Blue circle: slope spawning ground, Green circle: shelf nursery ground of pelagic juveniles, Red circle: settlement ground). Blue arrows: possible larval transport routes from slope to shelf. (b) Vertically changed distribution as they develop. *Source: Sohn (2009).*

Greenland turbot 10–20cm
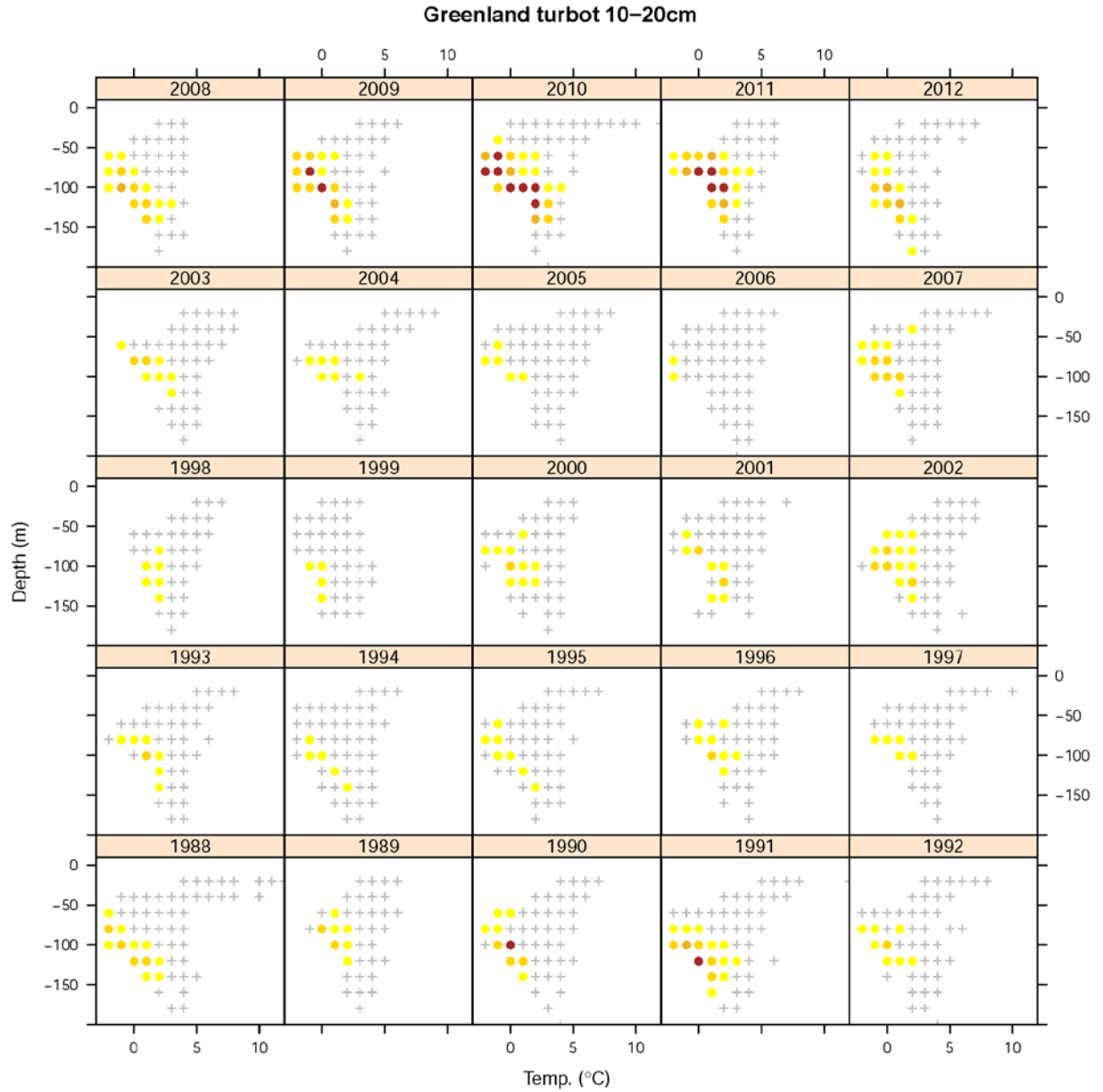
Figure 5.3.   Greenland turbot (10-20 cm) density distribution by temperature and depth (left) for 1988 – 2012 shelf bottom trawl survey. Darker color indicates higher CPUE by number, gray are sampled locations with no catch.
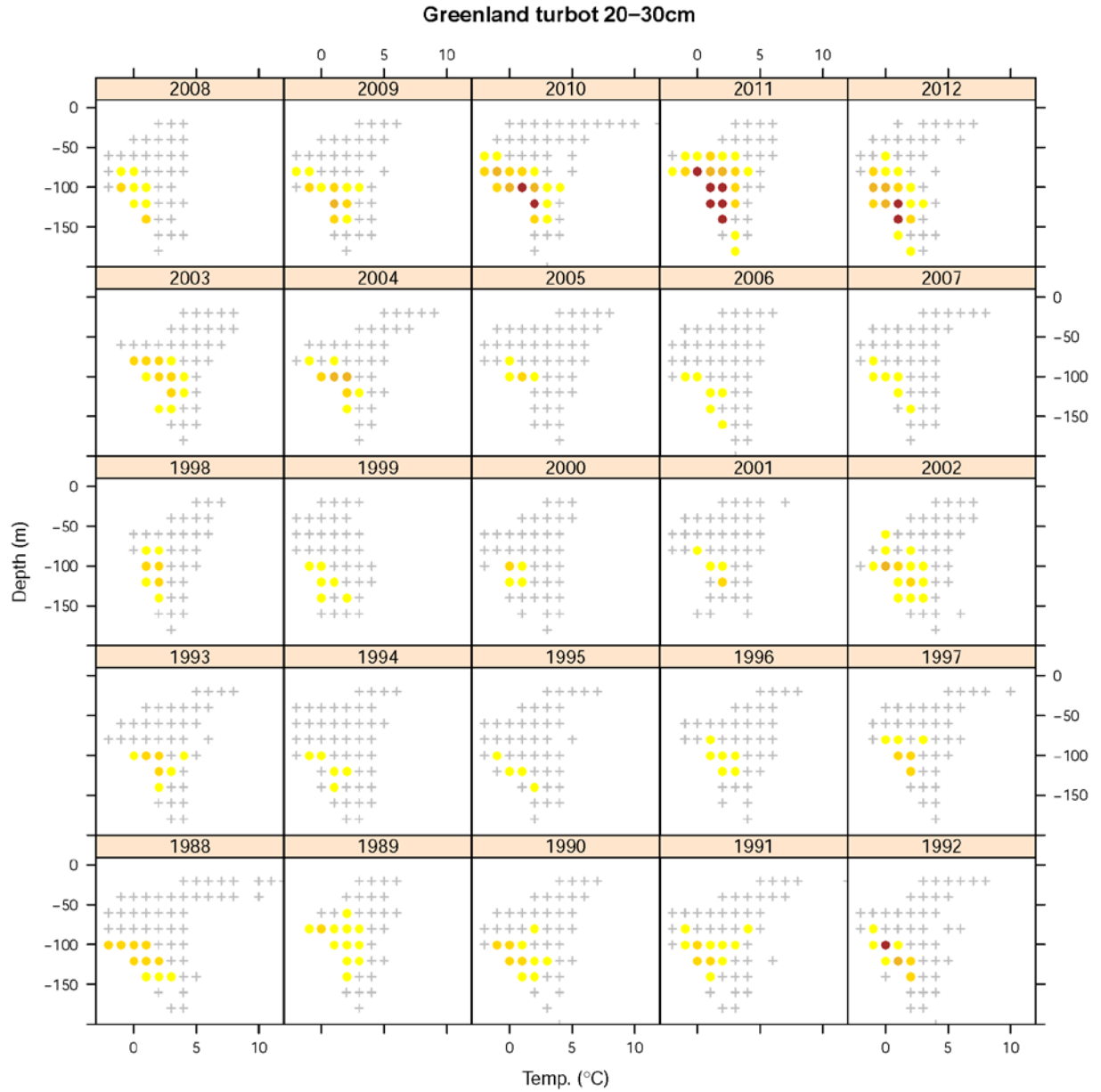
Figure 5.3.(Cont.) Greenland turbot (20-30 cm) density distribution by temperature and depth for 1988 – 2012 shelf bottom trawl survey. Darker color indicates higher CPUE by number, gray are sampled locations with no catch.

Greenland turbot 30–50cm

Figure 5.3.(Cont.) Greenland turbot (20-30 cm) density distribution by temperature and depth for 1988 – 2012 shelf bottom trawl survey. Darker color indicates higher CPUE by number, gray are sampled locations with no catch.

Greenland turbot > 50cm
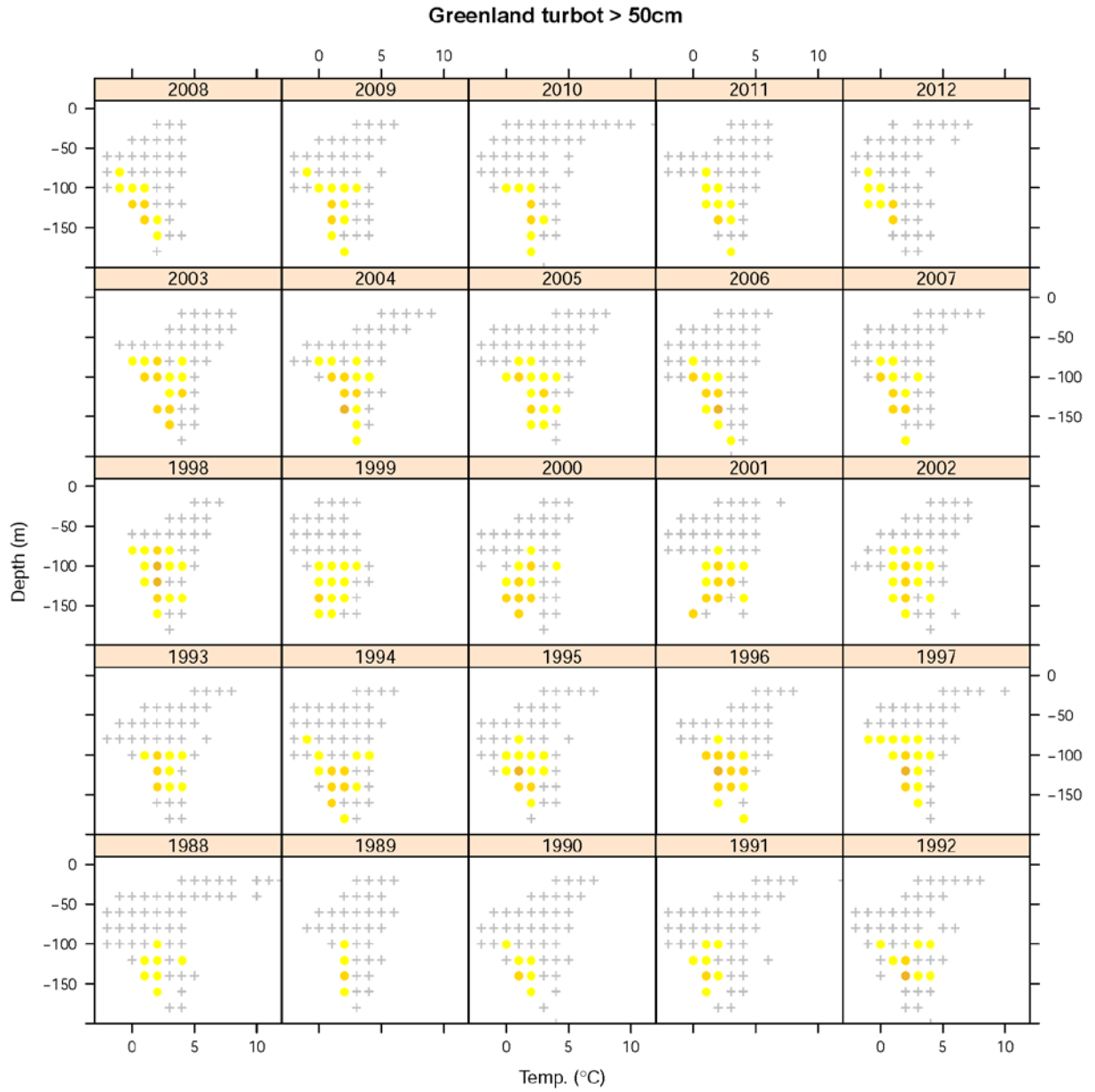
Figure 5.3.(Cont.) Greenland turbot (20-30 cm) density distribution by temperature and depth for 1988 – 2012 shelf bottom trawl survey. Darker color indicates higher CPUE by number, gray are sampled locations with no catch.
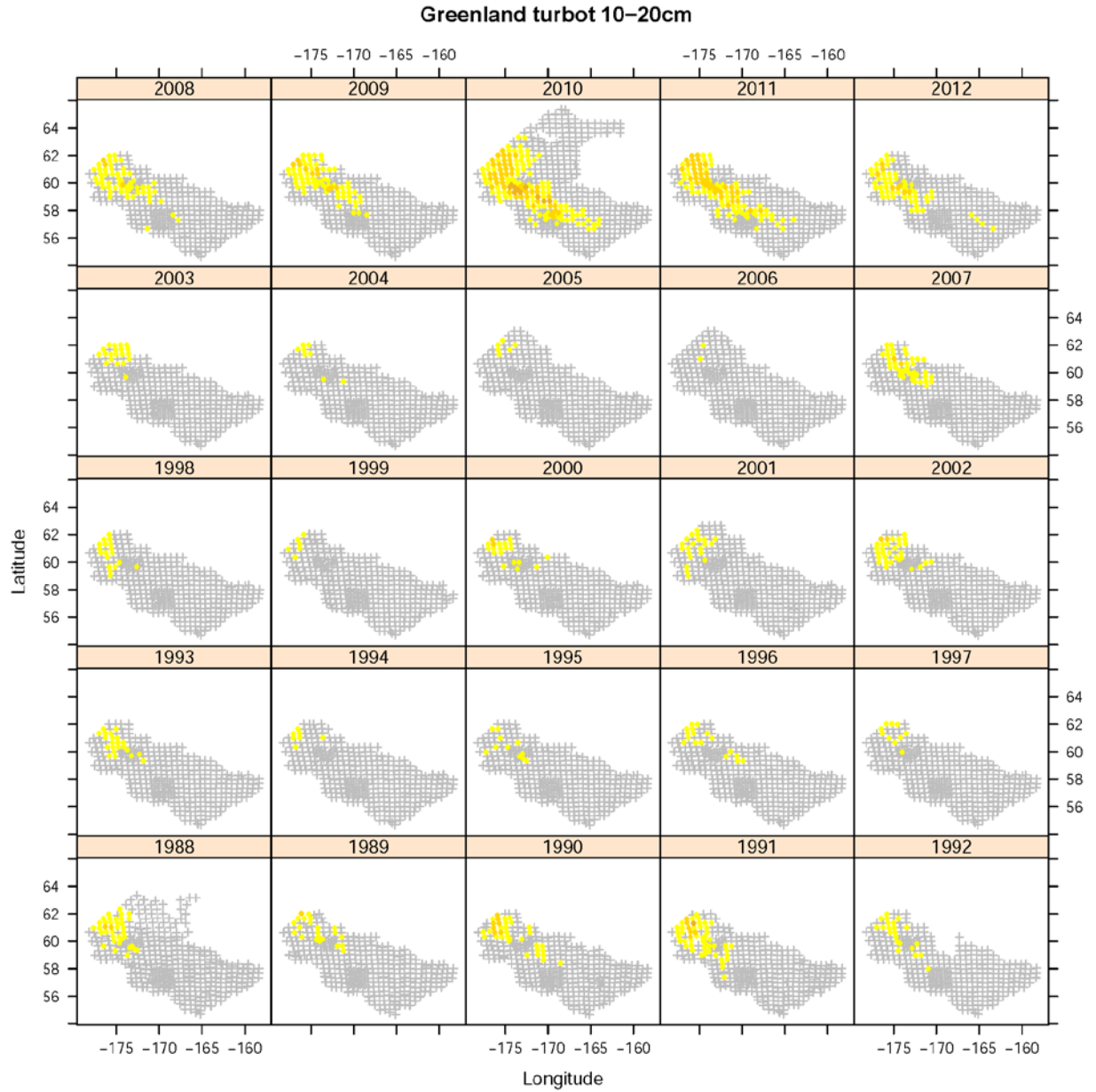
Figure 5.4. Greenland turbot (10-20 cm) density distribution by latitude and longitude for 1988 – 2012 shelf bottom trawl survey. Darker color indicates higher CPUE by number, gray are sampled locations with no catch.
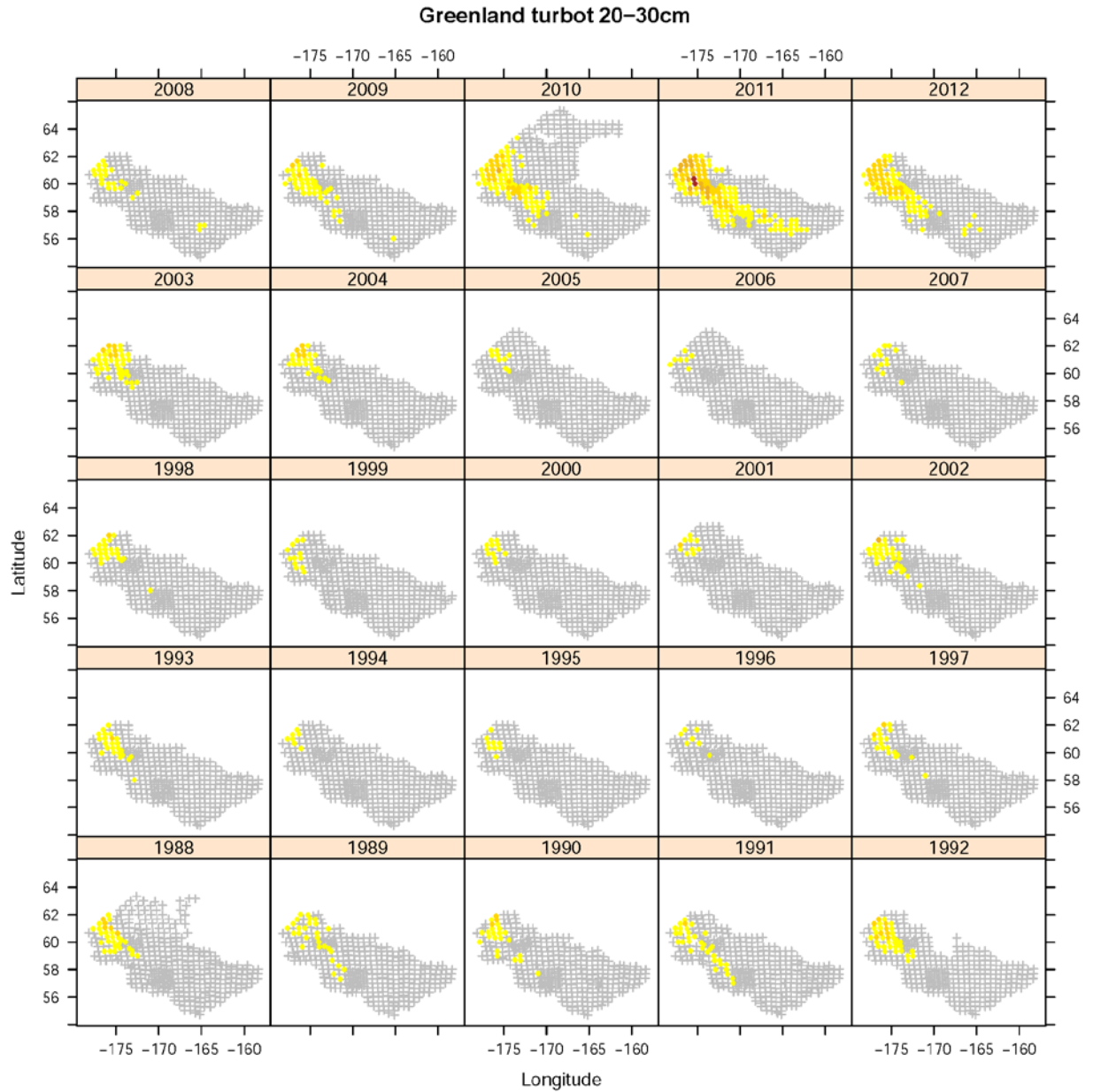
Figure 5.4.(Cont.) Greenland turbot (20-30 cm) density distribution by latitude and longitude for 1988 – 2012 shelf bottom trawl survey. Darker color indicates higher CPUE by number, gray are sampled locations with no catch.
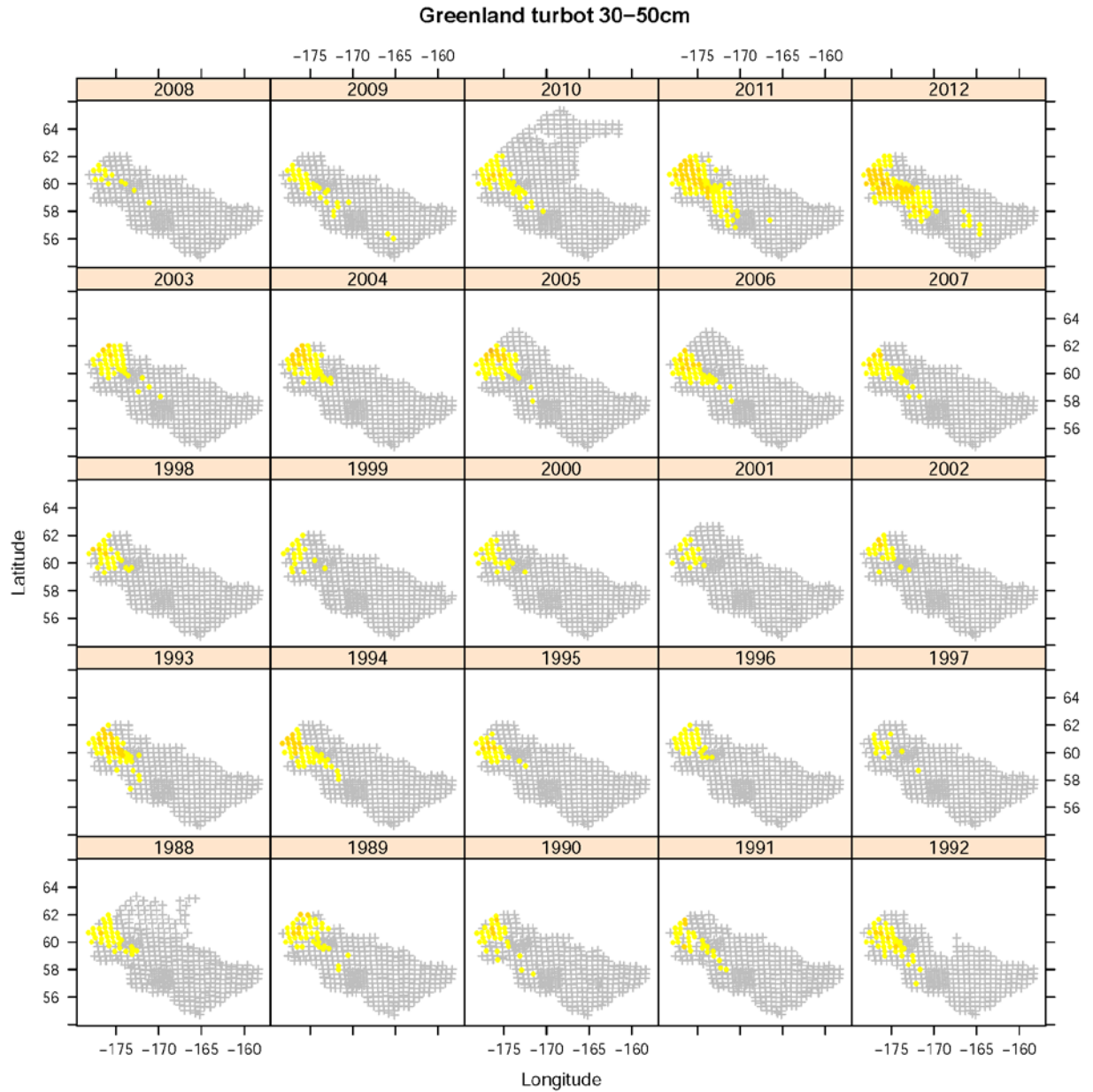
Figure 5.4.(Cont.) Greenland turbot (30-50 cm) density distribution by latitude and longitude for 1988 – 2012 shelf bottom trawl survey. Darker color indicates higher CPUE by number, gray are sampled locations with no catch.
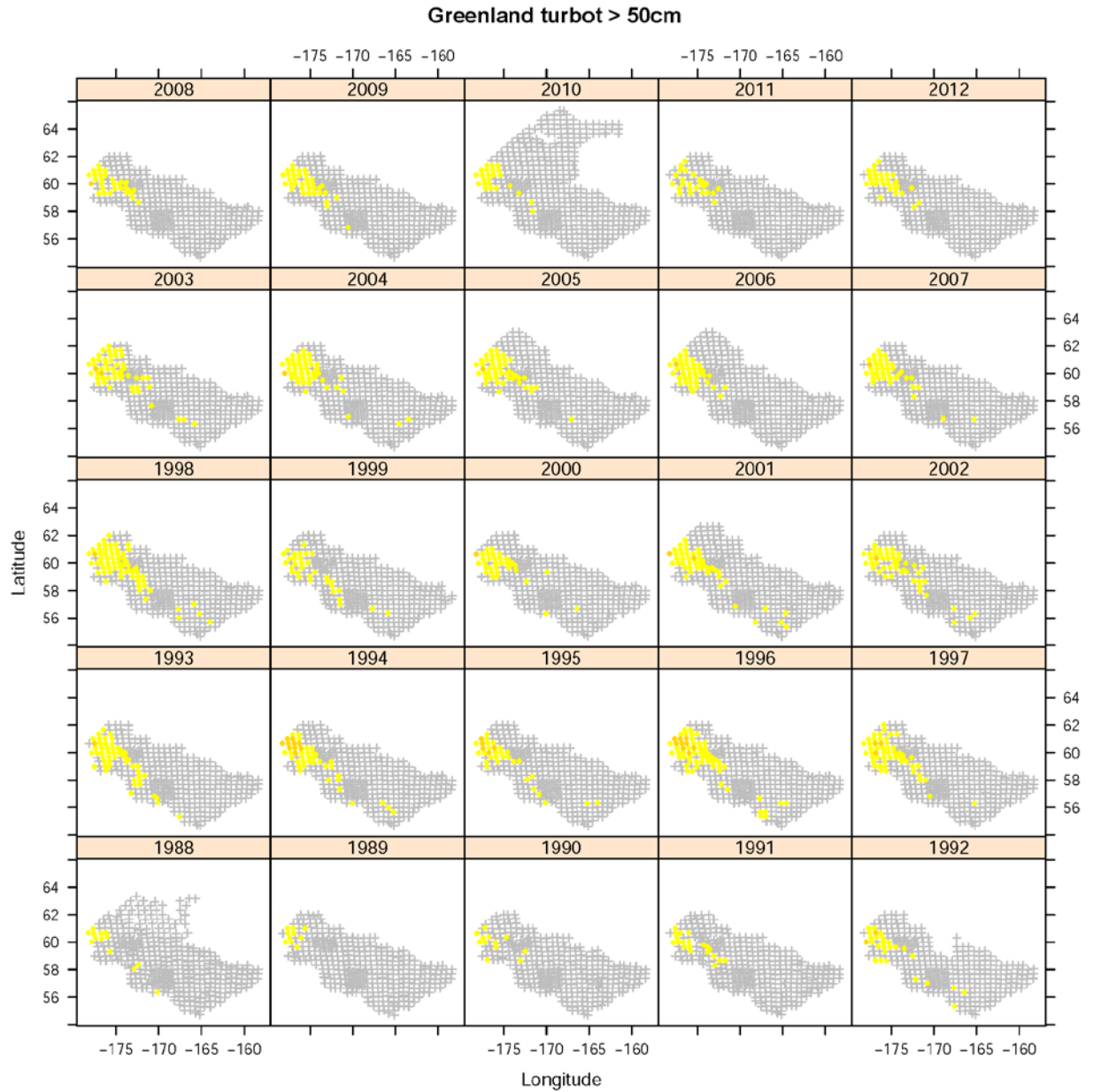
Figure 5.4.(Cont.) Greenland turbot (> 50 cm) density distribution by latitude and longitude for 1988 – 2012 shelf bottom trawl survey. Darker color indicates higher CPUE by number, gray are sampled locations with no catch.
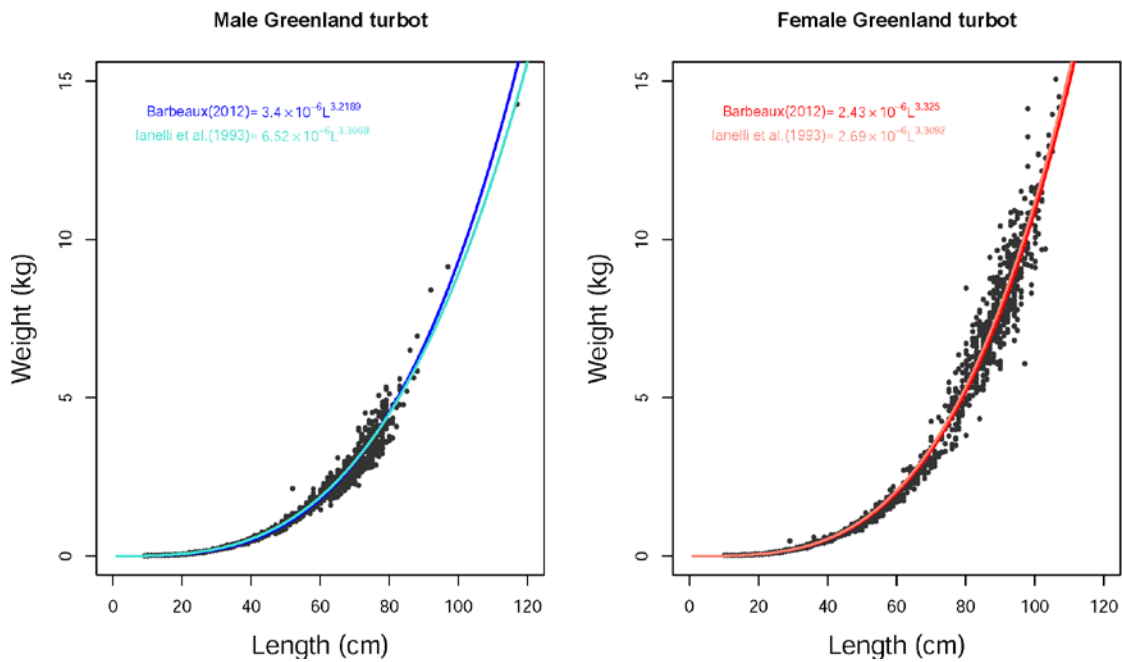
Figure 5. 5. Weight at length relationship for male and female Greenland turbot fit to all AFSC survey data from the Bering Sea and Aleutian Islands area. The weight at length relationships from Ianelli et al. (1993) are shown for comparison.
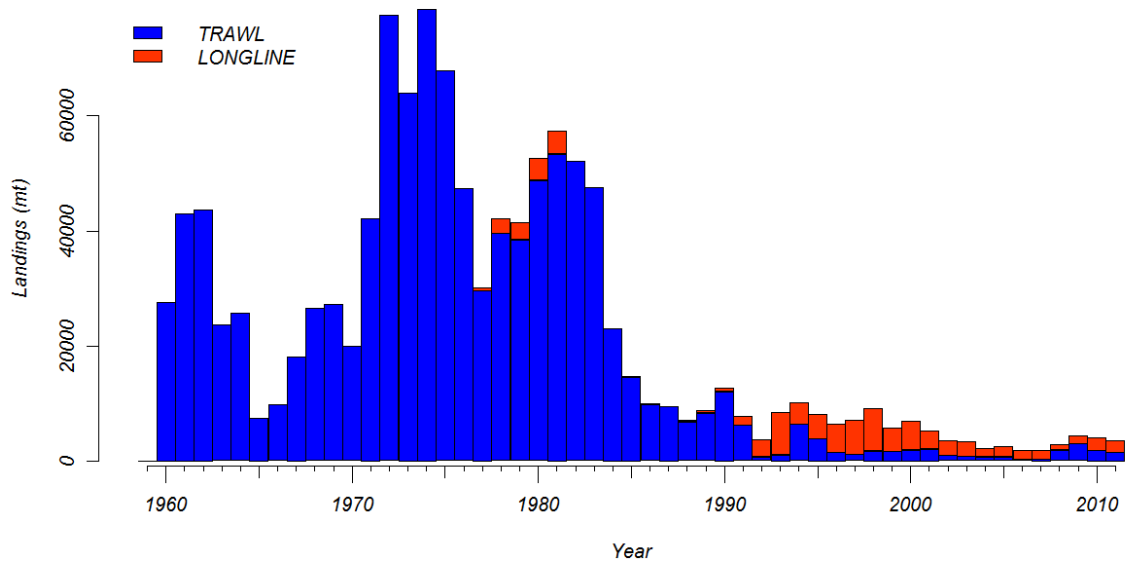
Figure 5. 6. Greenland turbot longline and trawl catch in the Bering Sea and Aleutian Islands area from 1960 through 2011. This data includes targeted catch and bycatch.
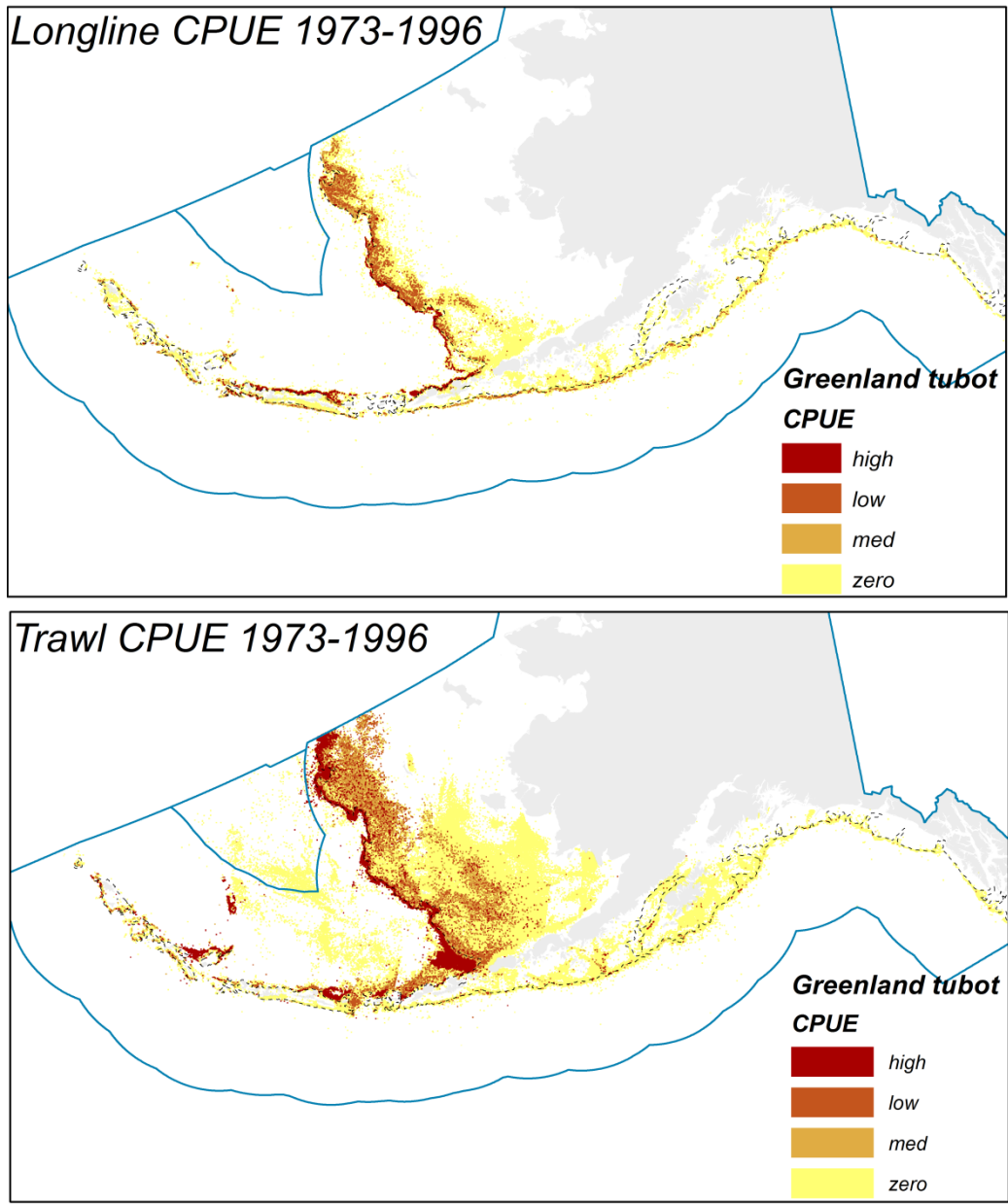
Figure 5.7. Distribution of Greenland turbot fishing CPUE 1973- 1996 from observer data (Fritz et al 1998).
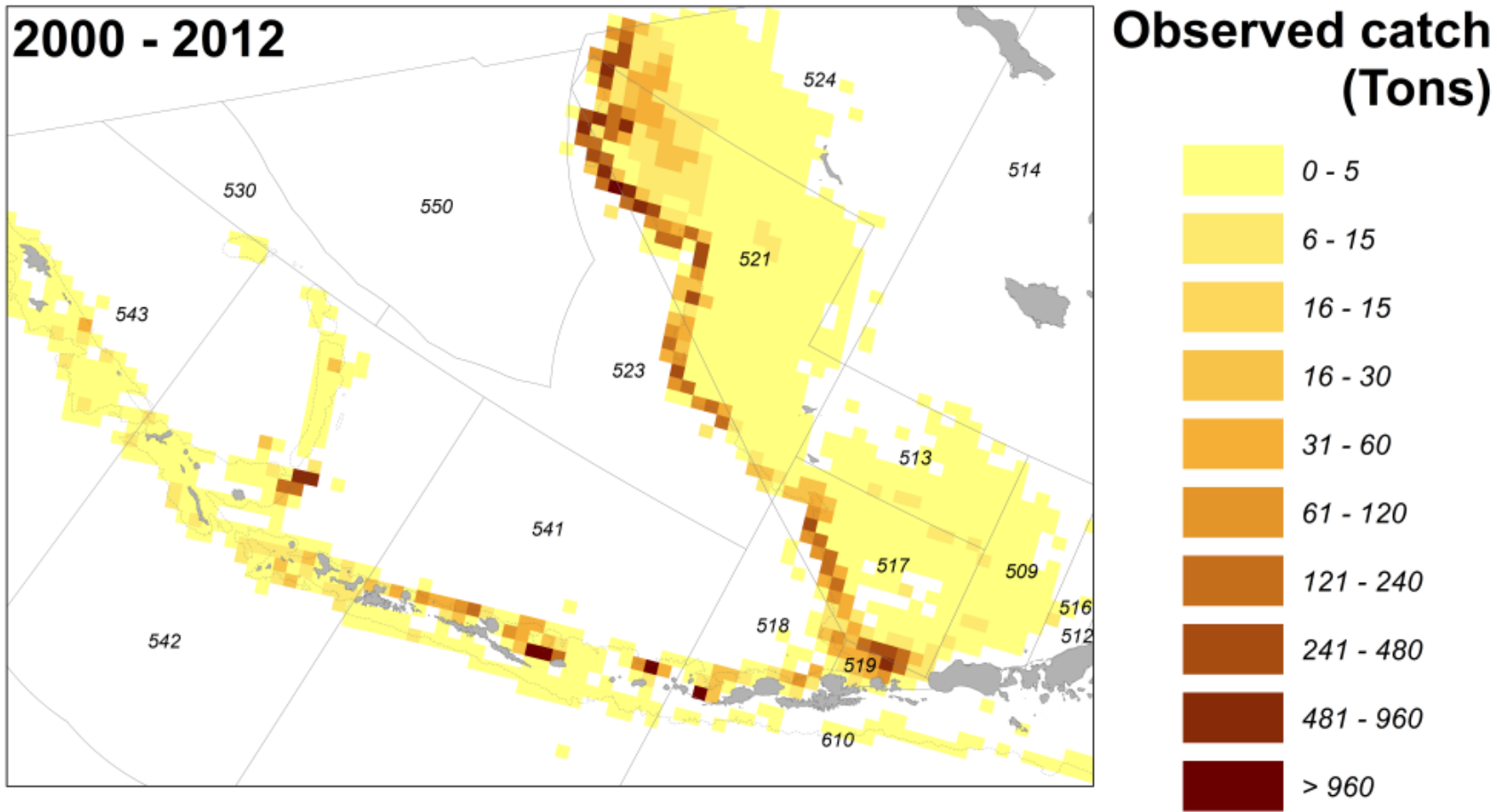
Figure 5.8   All observed catch for 2000 through 2012, data are aggregated spatially at a 400 km^2 grid.
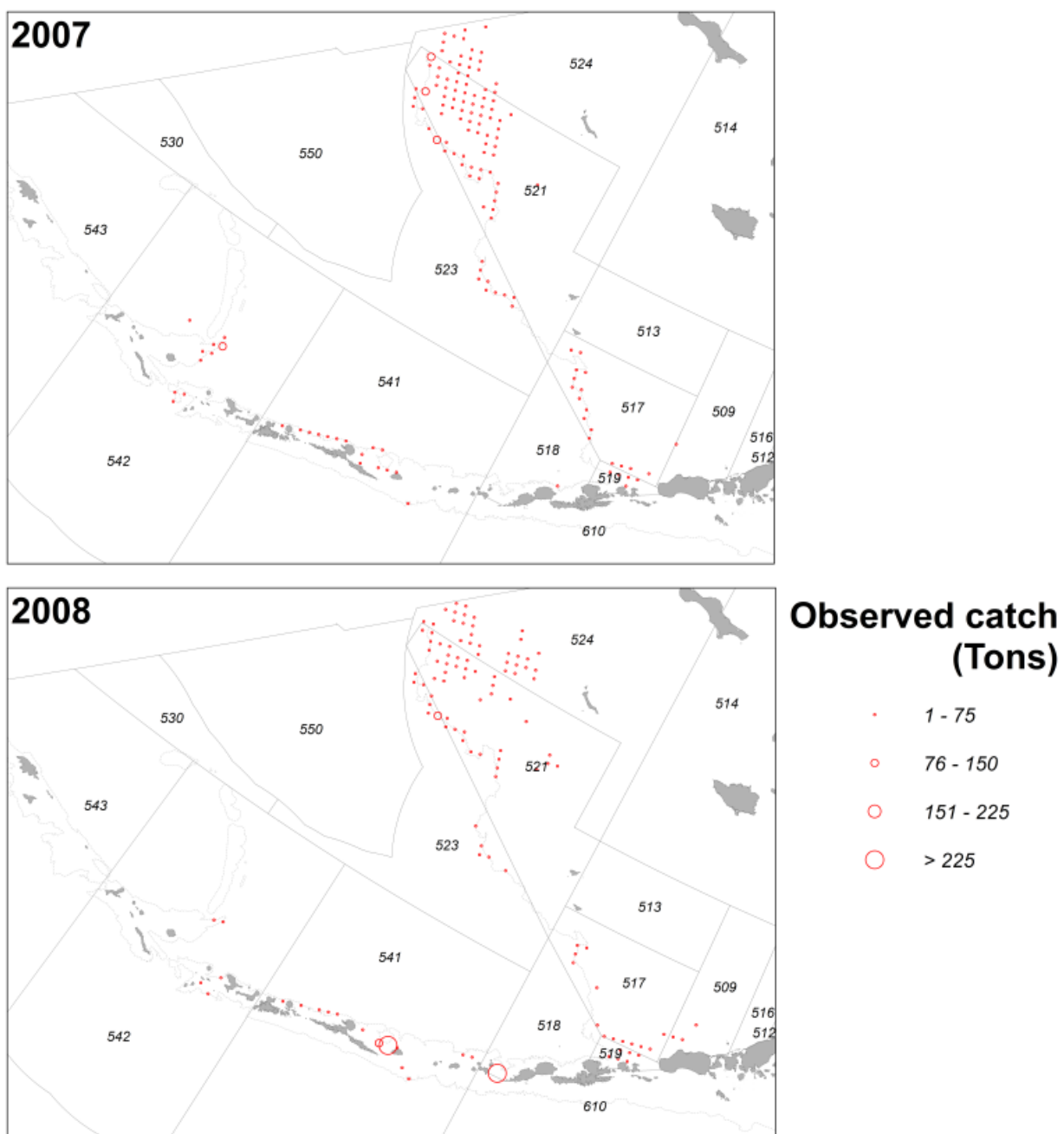
Figure 5.9. All observed Greenland turbot catch for 2007 and 2008. Data are aggregated for each year at 400 km^2. Note that areas with less than 1t are not shown.
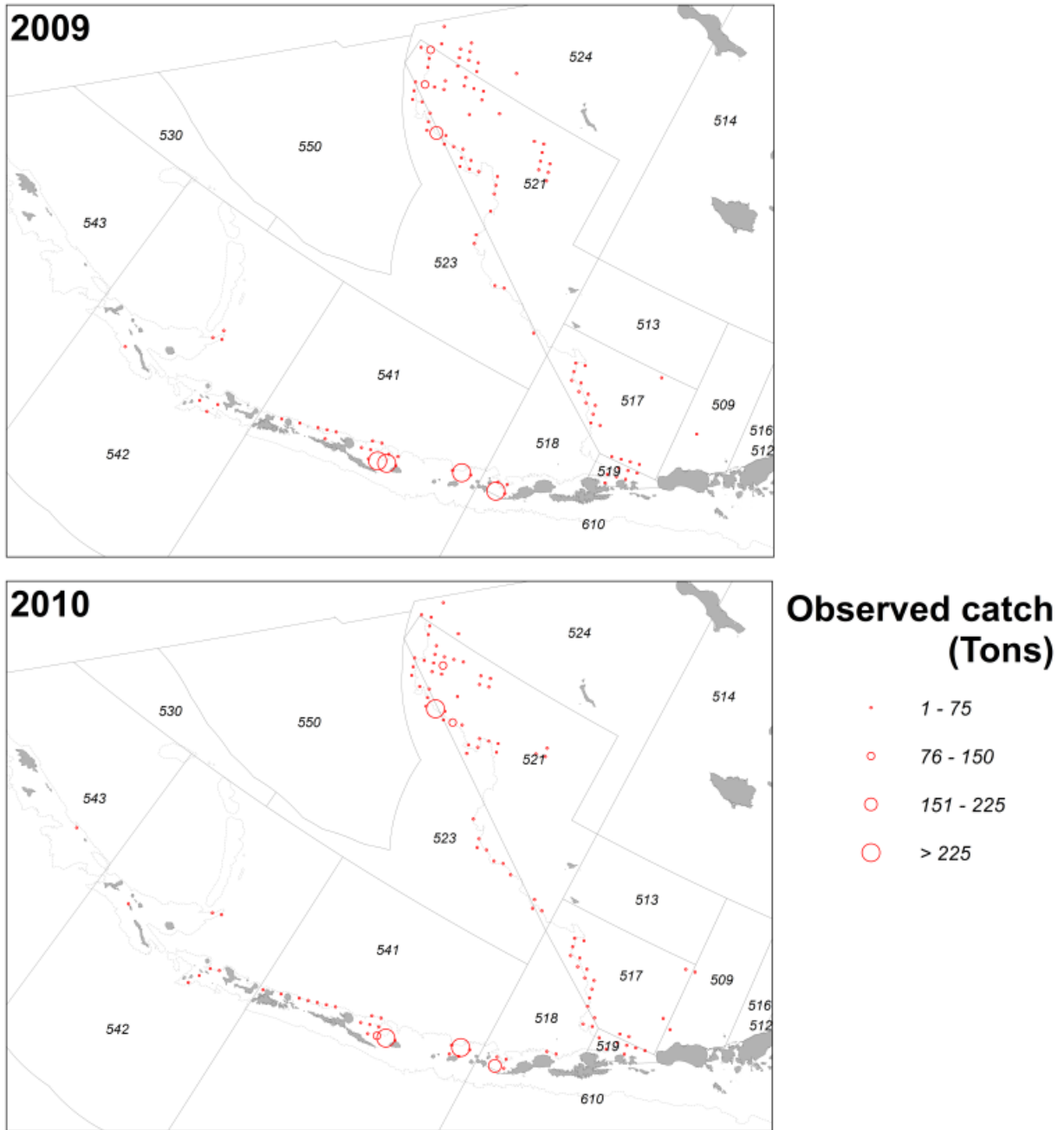
Figure 5.9.(cont.) All observed Greenland turbot catch for 2009 and 2010. Data are aggregated for each year at 400 km². Note that areas with less than 1t are not shown.
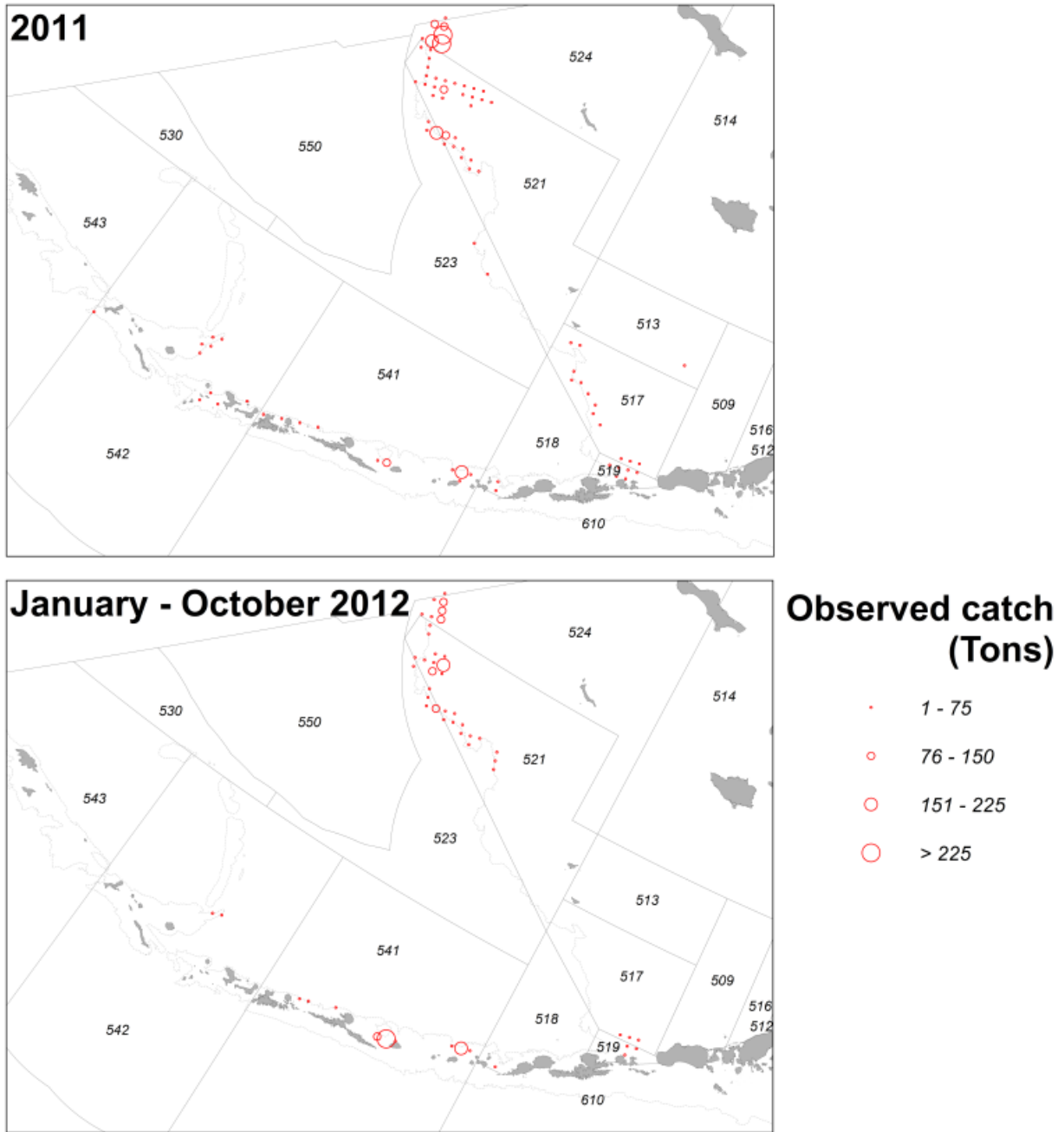
Figure 5.9.(cont.) All observed Greenland turbot catch for 2011through October 16, 2012. Data are aggregated for each year at 400 km^2. Note that areas with less than 1t are not shown.
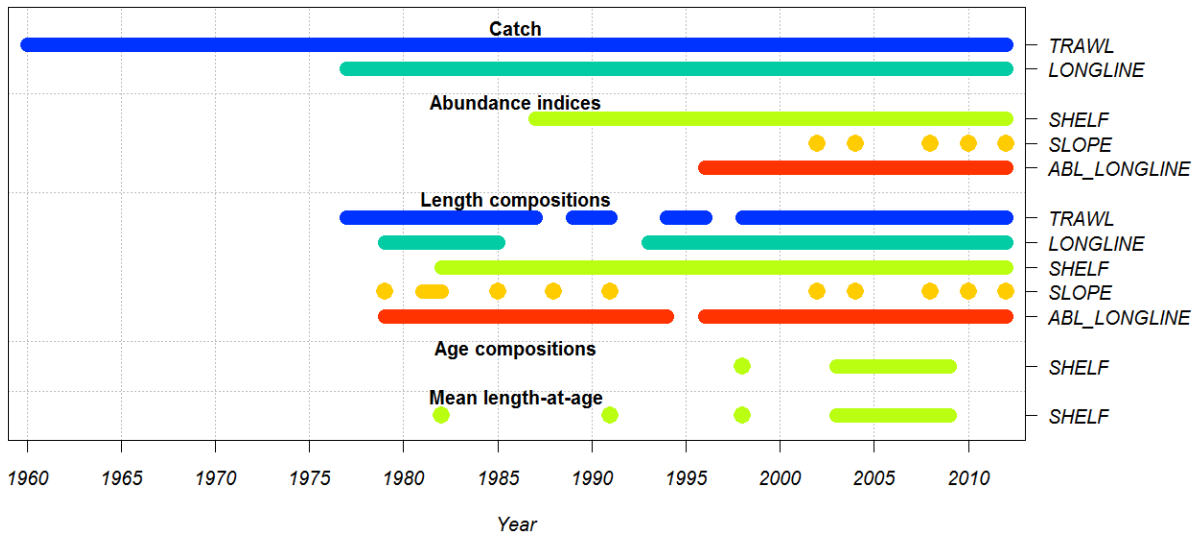
Figure 5.10. Timeline of all data included in the 2012 stock assessment models. Please note that Model 4 does not include data from prior to 1977.
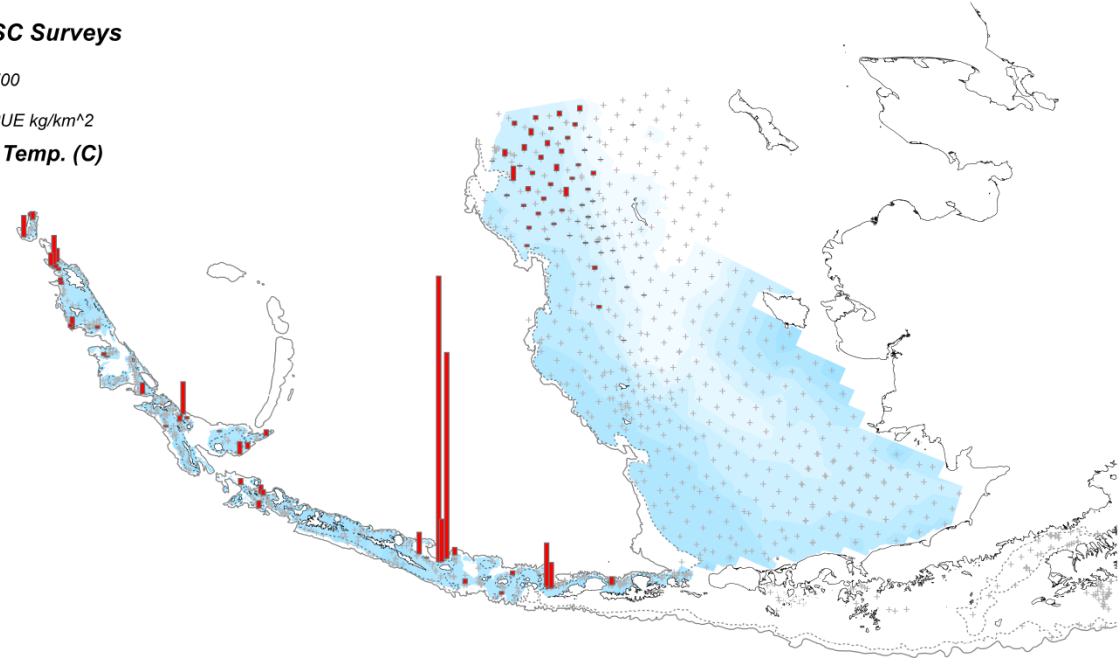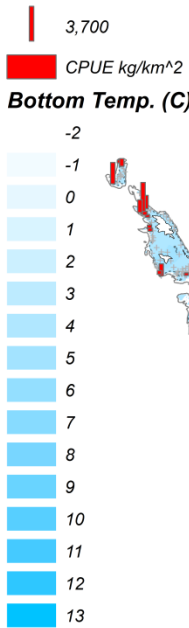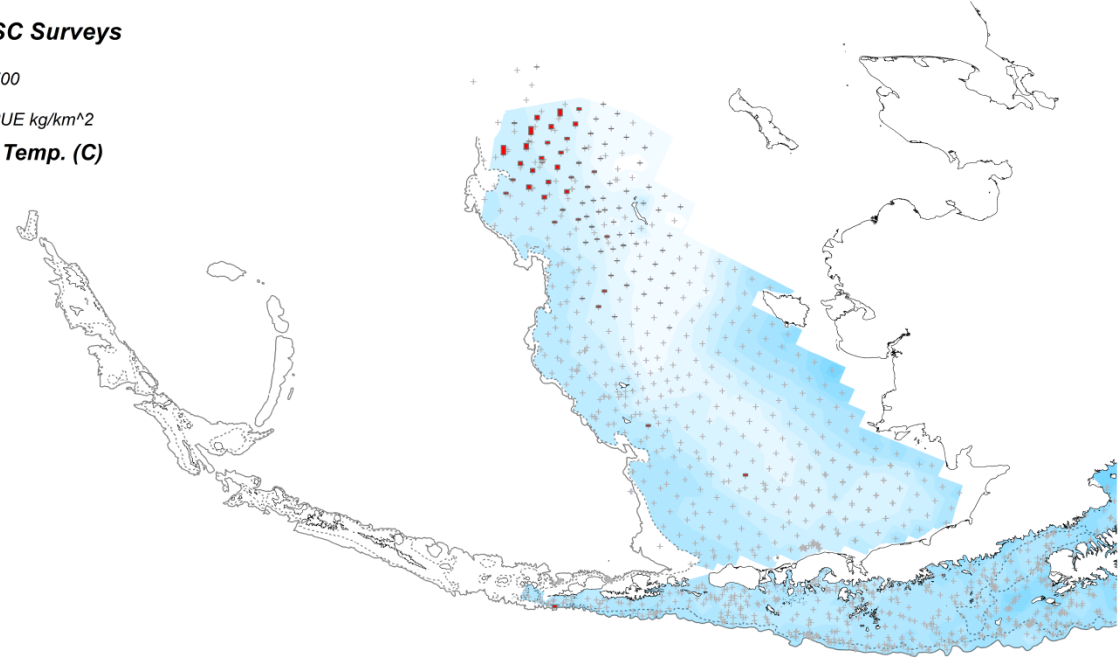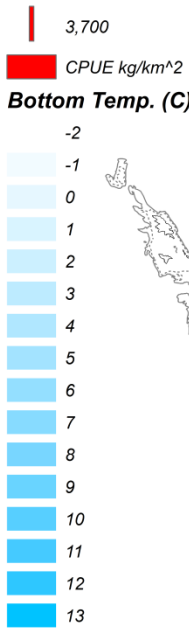
Figure 5.11. Greenland turbot CPUE kg/km^2 for all Alaska Fisheries Science Center surveys combined for each year with bottom temperature in celcius and 200m (dashed line) and 1000 m (solid gray line) isobaths. Surveyed locations are marked with gray +, while areas with turbot are maked with red bars. All CPUE bars are on the same scale for all surveys.

2008 AFSC Surveys
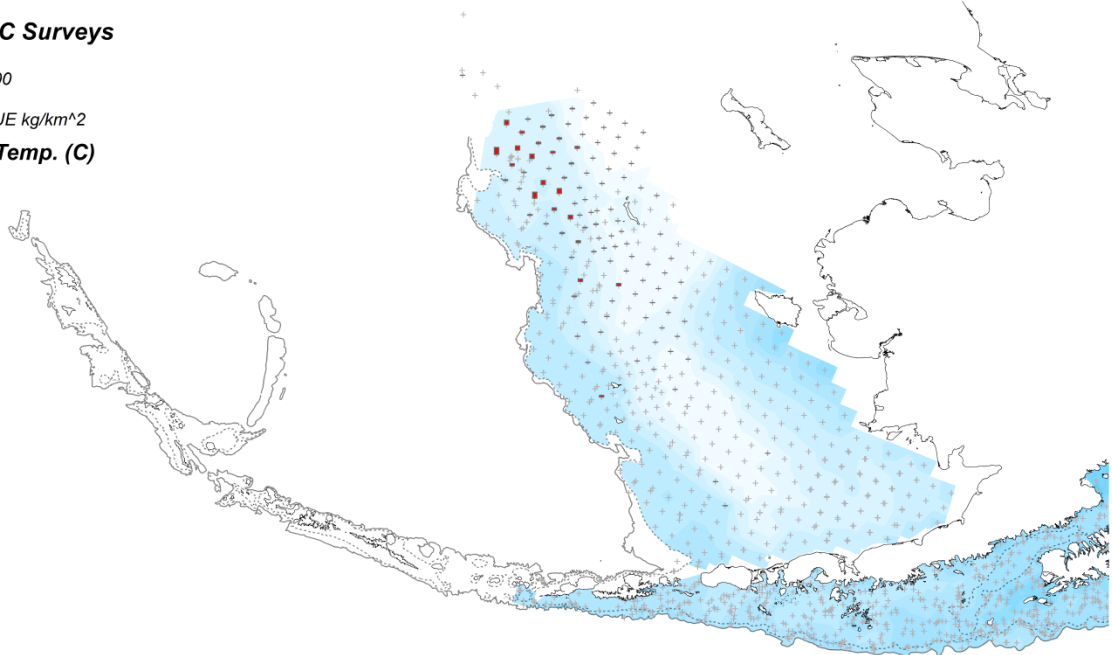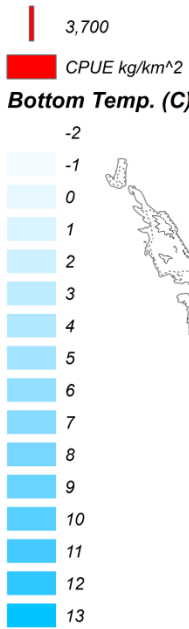
3,700

CPUE kg/km^2

Bottom Temp. (C)

-2
-1
0
1
2
3
4
5
6
7
8
9
10
11
12
13

2009 AFSC Surveys

3,700

CPUE kg/km^2

Bottom Temp. (C)

-2
-1
0
1
2
3
4
5
6
7
8
9
10
11
12
13

Figure 5.11.(cont.) Greenland turbot CPUE kg/km^2 for all Alaska Fisheries Science Center surveys combined for each year with bottom temperature in Celsius and 200m (dashed line) and 1000 m (solid gray line) isobaths. Surveyed locations are marked with gray +, while areas with turbot are marked with red bars. All CPUE bars are on the same scale for all surveys.

2010 AFSC Surveys

(red bar)	3,700
(red square)	CPUE kg/km^2

Bottom Temp. (C)

-2
-1
0
1
2
3
4
5
6
7
8
9
10
11
12
13

2011 AFSC Surveys

(red bar)	3,700
(red square)	CPUE kg/km^2

Bottom Temp. (C)

-2
-1
0
1
2
3
4
5
6
7
8
9
10
11
12
13

Figure 5.11.(cont.) Greenland turbot CPUE kg/km^2 for all Alaska Fisheries Science Center surveys combined for each year with bottom temperature in Celsius and 200m (dashed line) and 1000 m (solid gray line) isobaths. Surveyed locations are marked with gray +, while areas with turbot are marked with red bars. All CPUE bars are on the same scale for all surveys.
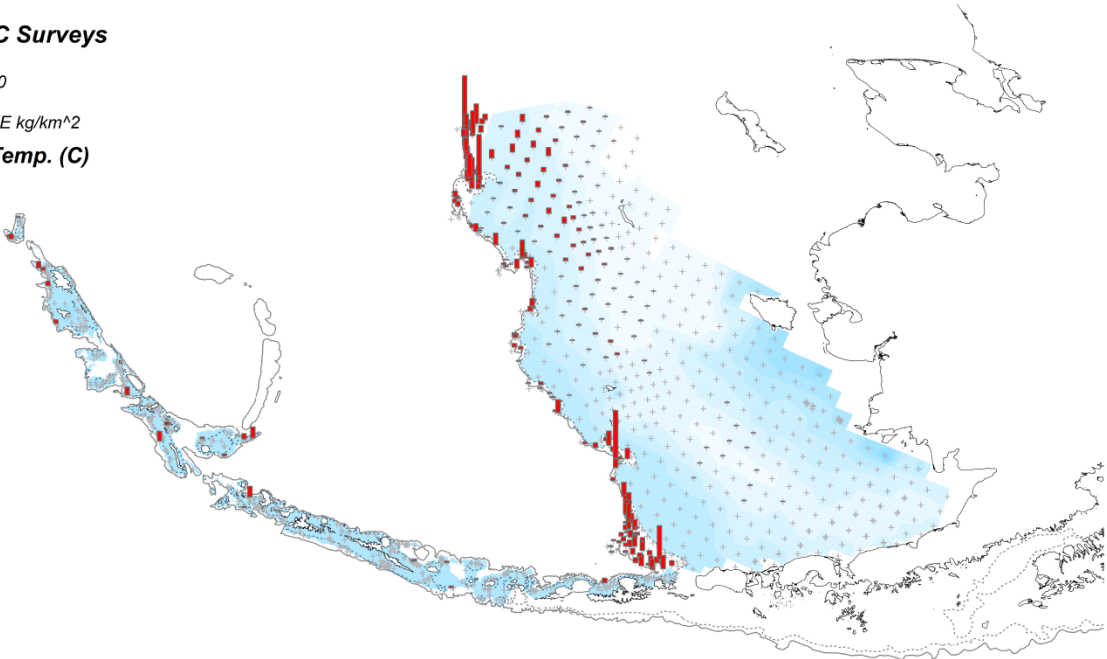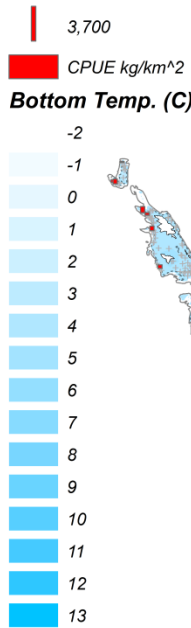
Figure 5.11.(cont.) Greenland turbot CPUE kg/km^2 for all Alaska Fisheries Science Center surveys combined for each year and 200m (dashed line) and 1000 m (solid gray line) isobaths. Bottom temperatures were not yet available for this map. Surveyed locations are marked with gray +, while areas with turbot are marked with red bars. All CPUE bars are on the same scale for all surveys.
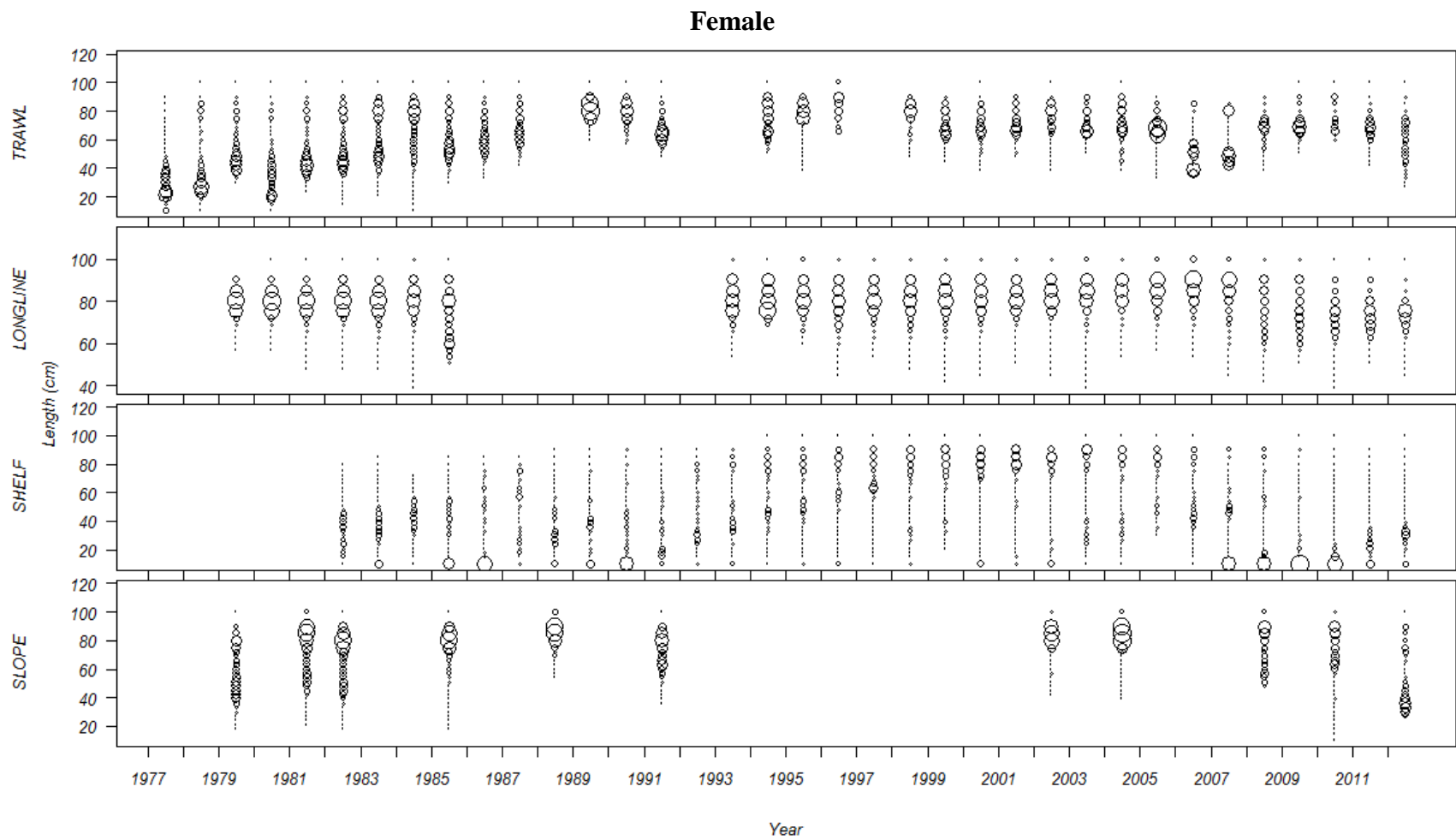
Female

Figure 5.12. Greenland turbot size composition data for females from the Trawl fishery, longline fishery, shelf survey and slope survey.

Male
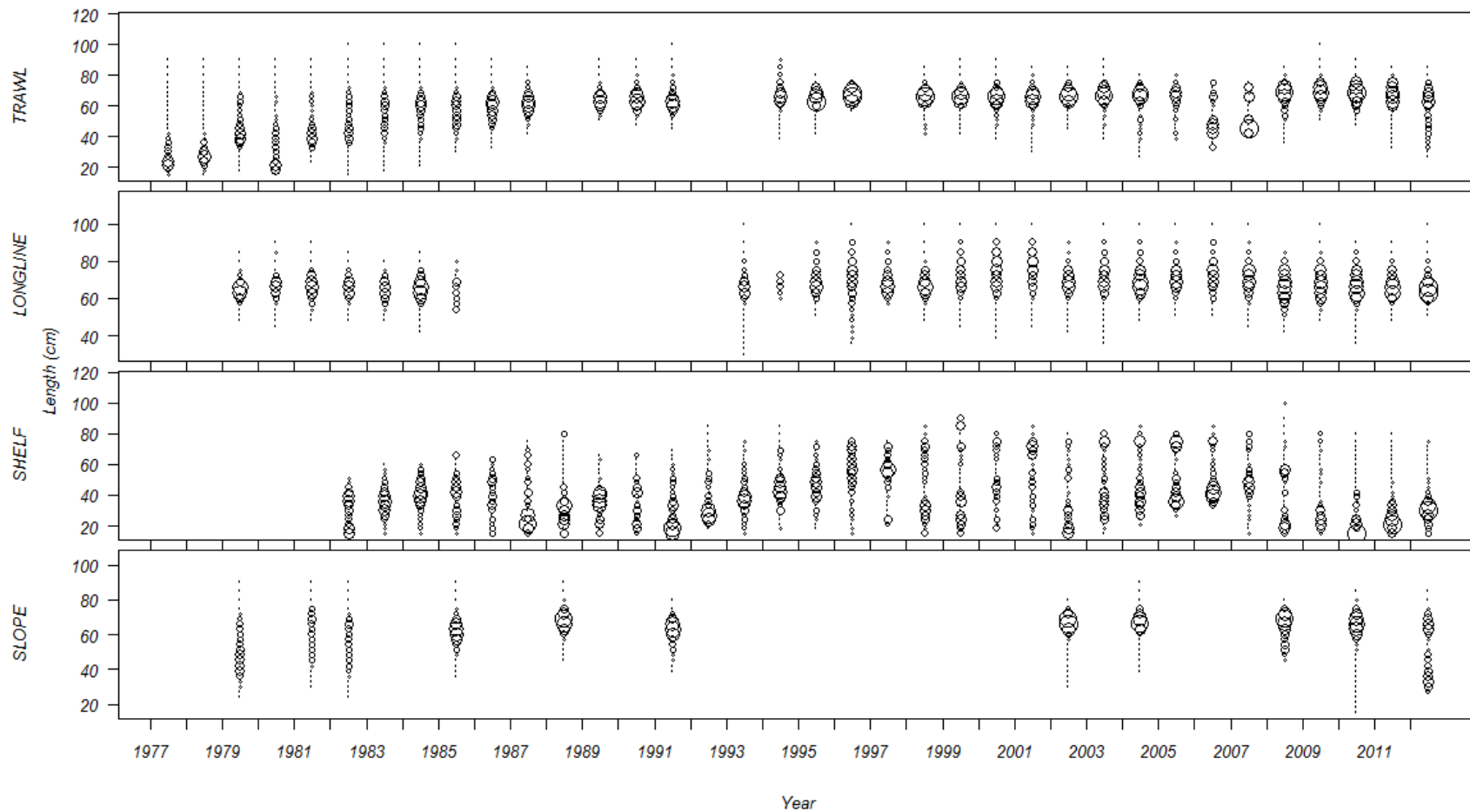
Figure 5.12. (Cont.) Greenland turbot size composition data for males from the Trawl fishery, longline fishery, shelf survey and slope survey.
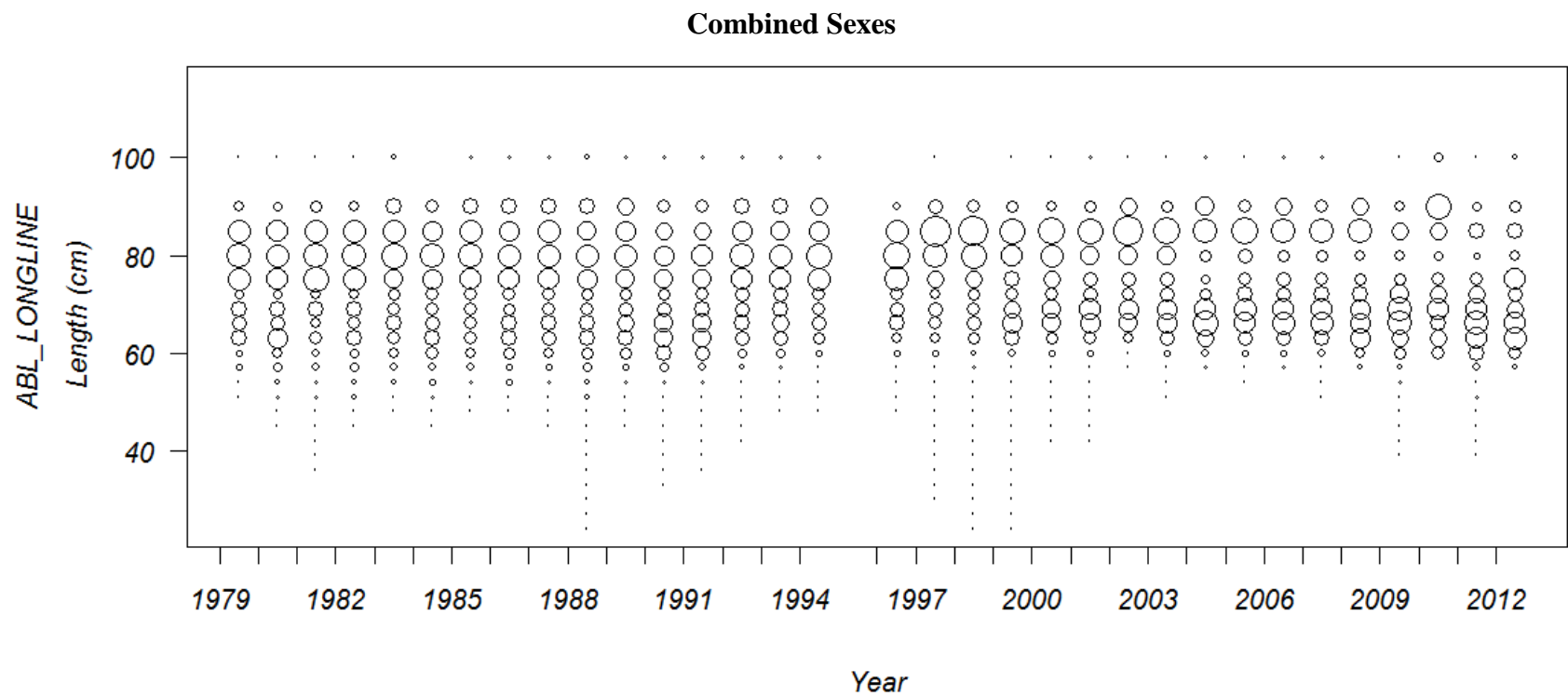
Combined Sexes

Figure 5.12. (Cont.) Greenland turbot size composition data for combined sexes from the Auke Bay Laboratory longline survey.
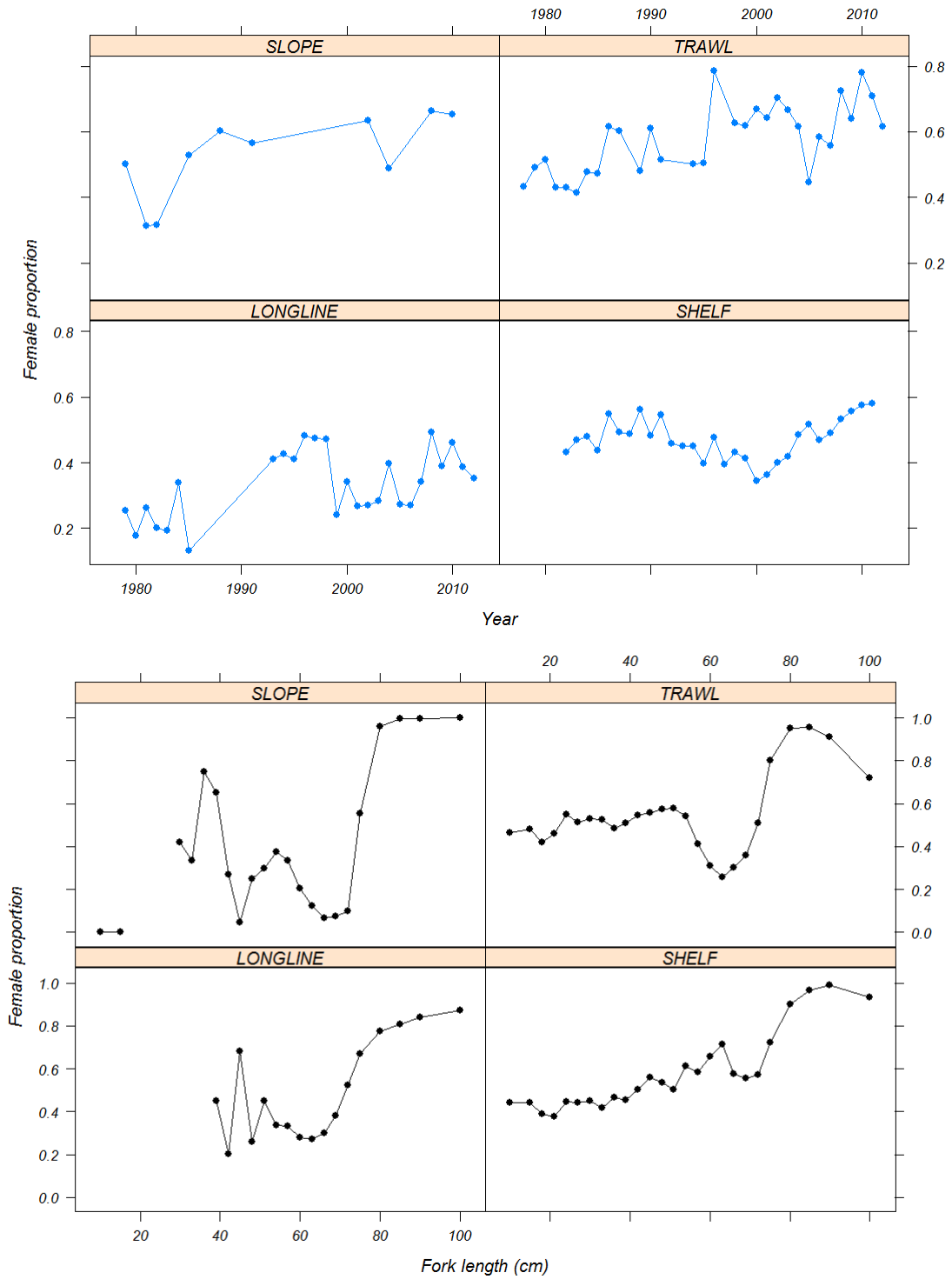
Figure 5.13.   Proportion of Females in the size composition data by fishery (Trawl and Longline) or survey (Shelf and Slope) by year (top) and by length (bottom) from the length composition data.
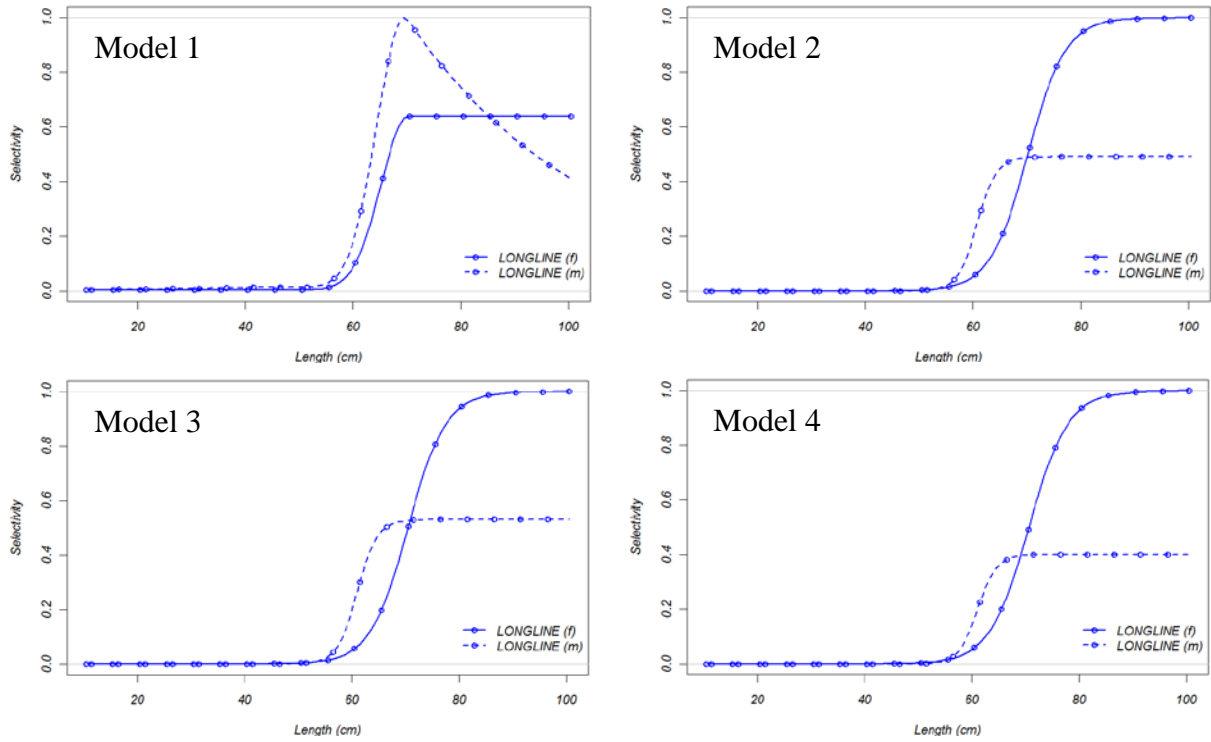
Figure 5.14. 2012 Longline fishery selectivity by sex for the four candidate models.
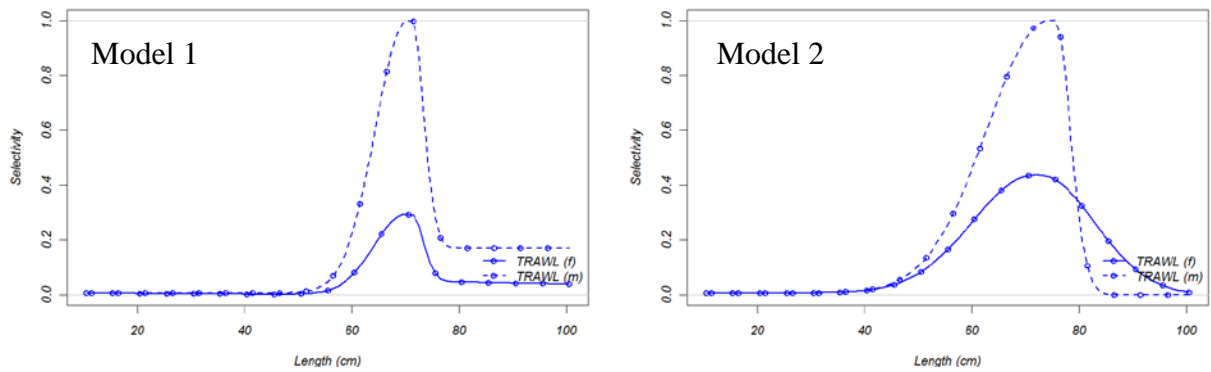
Figure 5.15. 2012 Trawl fishery selectivity by sex for Model 1 and Model 2. Please note that Models 3 and 4 have selectivity shapes similar to Model 2.
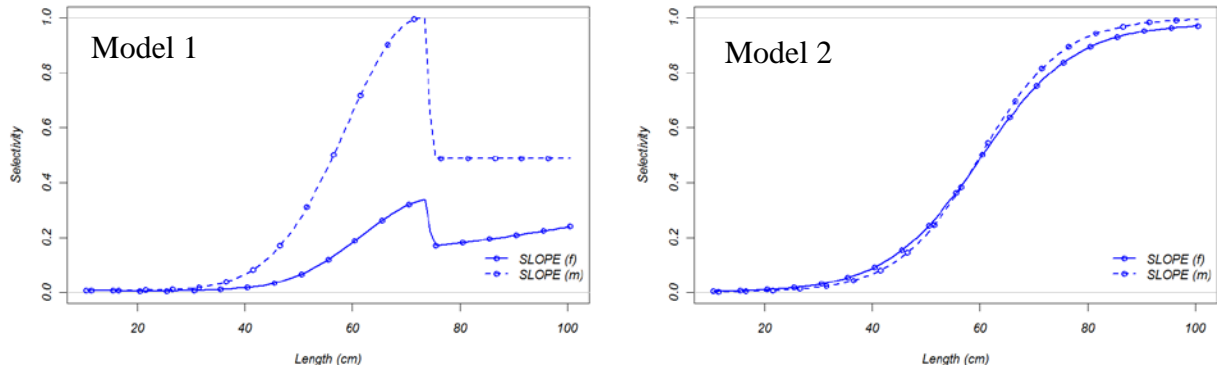
Figure 5.16. 2012 Slope survey selectivity by sex for Model 1 and Model 2. Please note that Models 3 and 4 have selectivity shapes similar to Model 2.
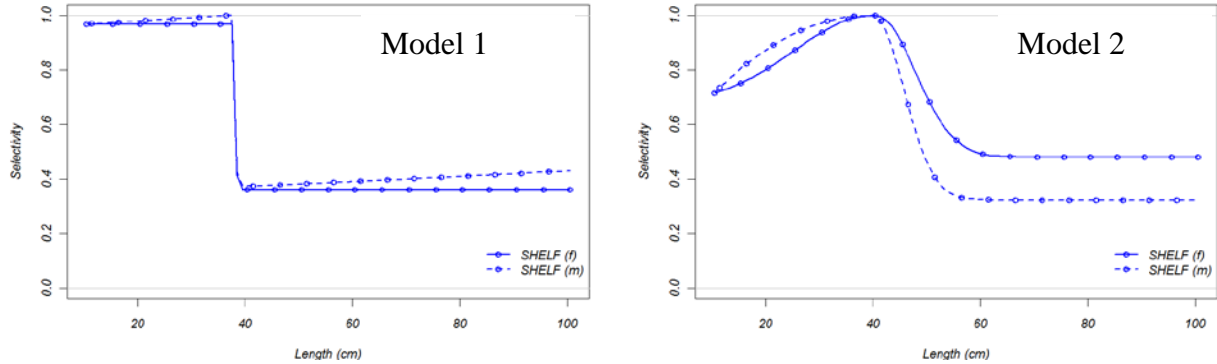
Figure 5.17. 2012 Shelf survey selectivity by sex for Model 1 and Model 2. Please note that Models 3 and 4 have selectivity shapes similar to Model 2.
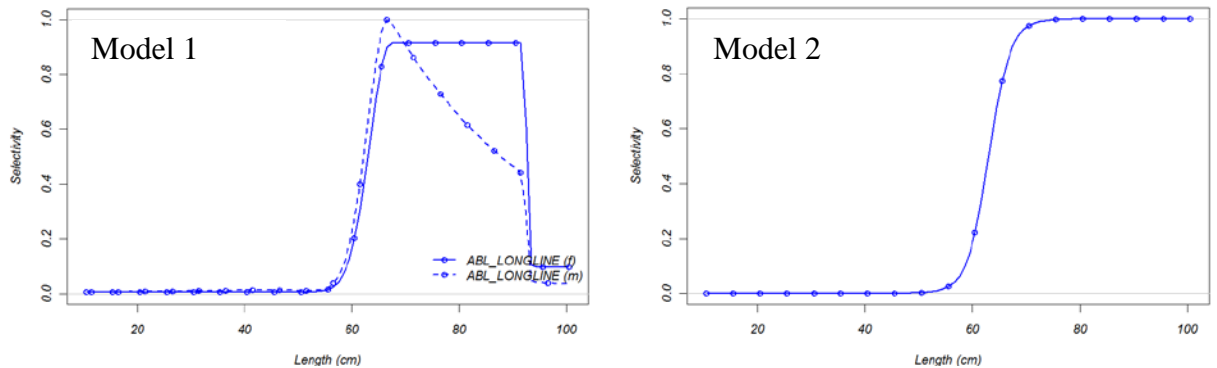
Figure 5.18. 2012 ABL longline survey selectivity by sex for Model 1 and Model 2. Please note that Models 3 and 4 have selectivity shapes similar to Model 2.
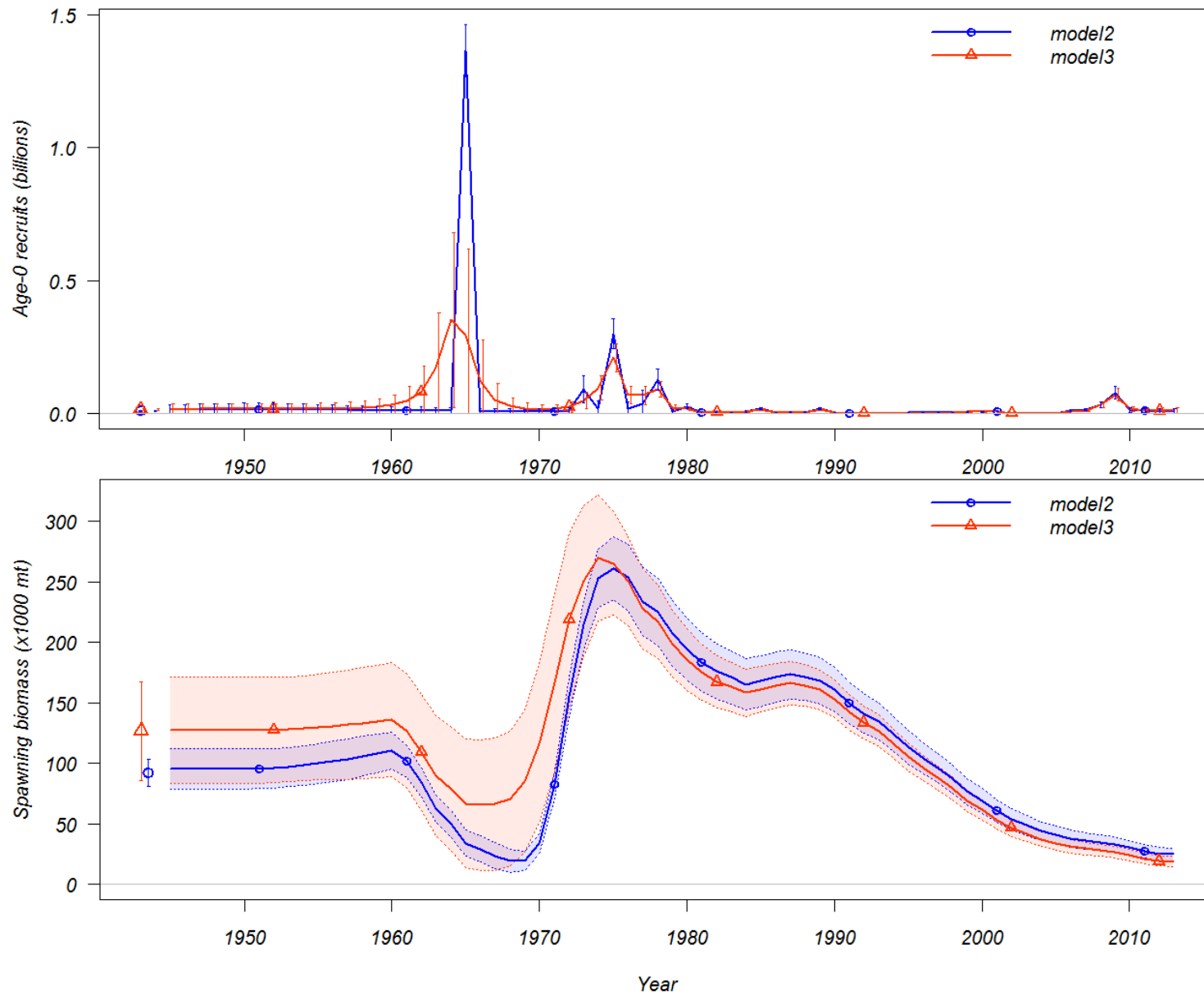
Figure 5.19.   Age-0 recruitment (top) and female spawning biomass (bottom) for Model 2 and Model 3.
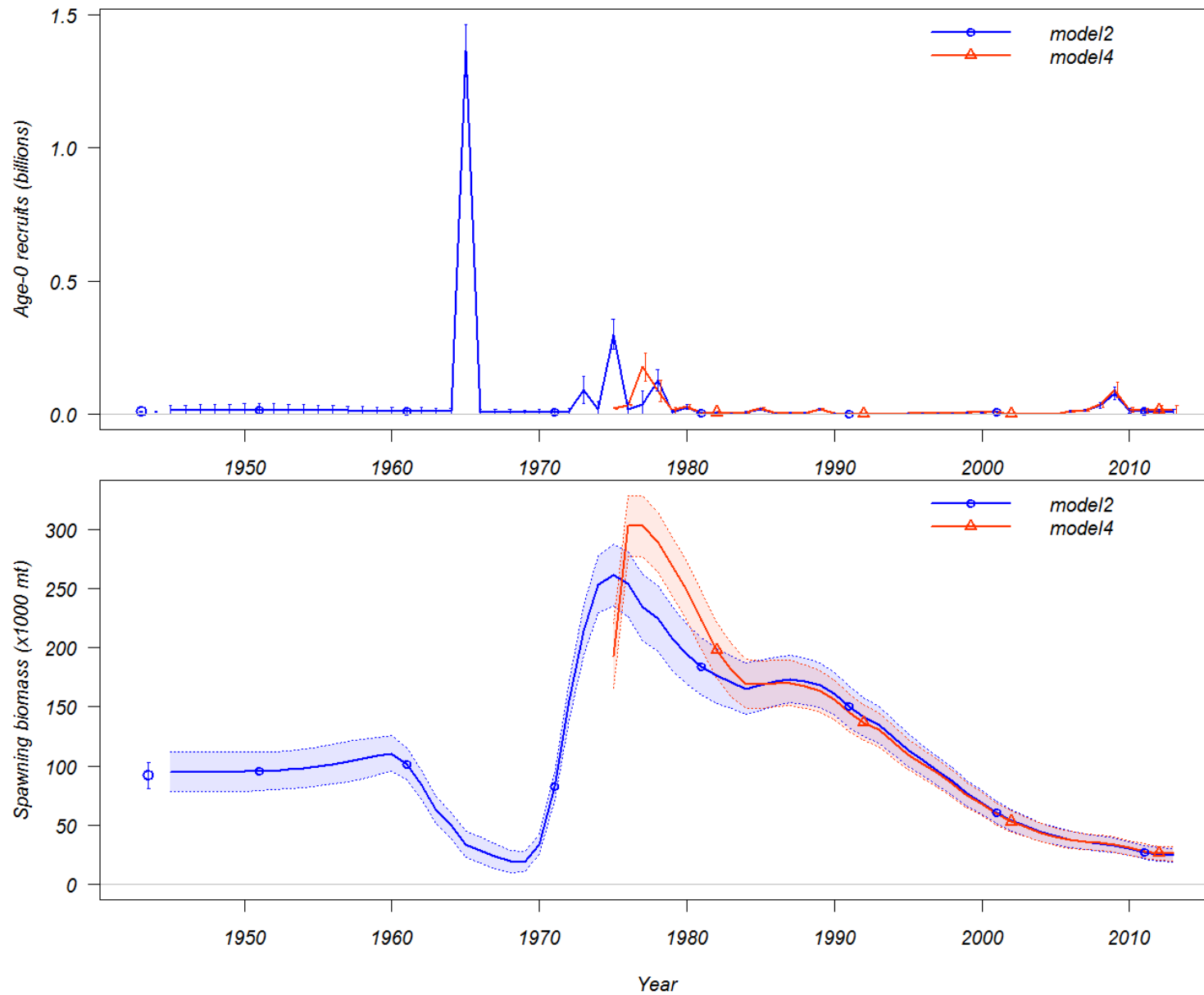
Figure 5.20.   Age-0 recruitment (top) and female spawning biomass (bottom) for Model 2 and Model 4.
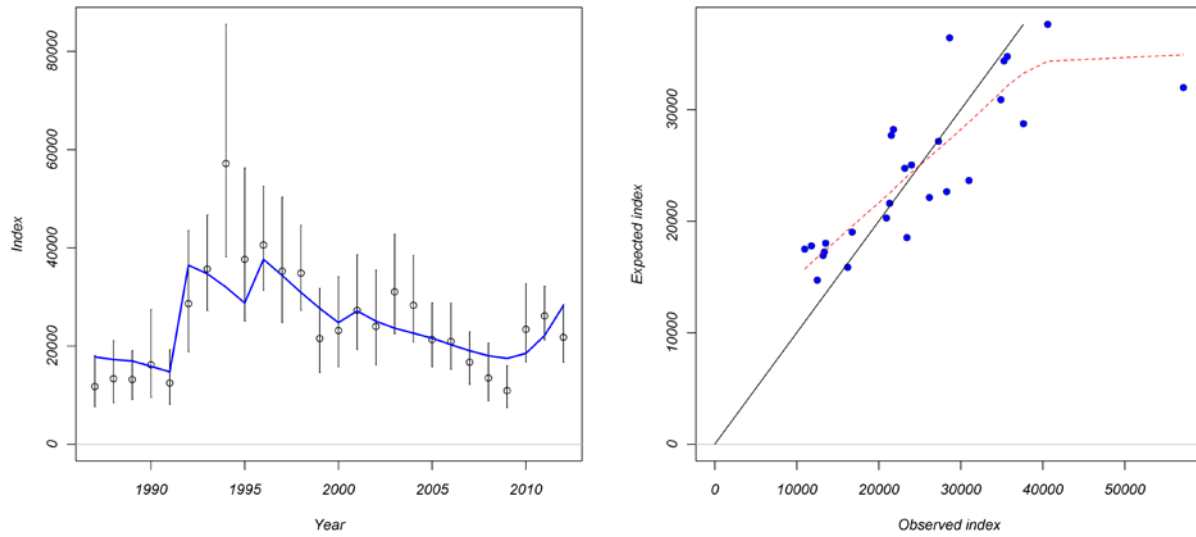
Figure 5.21.   Shelf survey index (index values are total survey biomass in tons) and model fits. Error bars are 95% confidence intervals. Black line on right is 1:1 line, red line is a loess smooth.
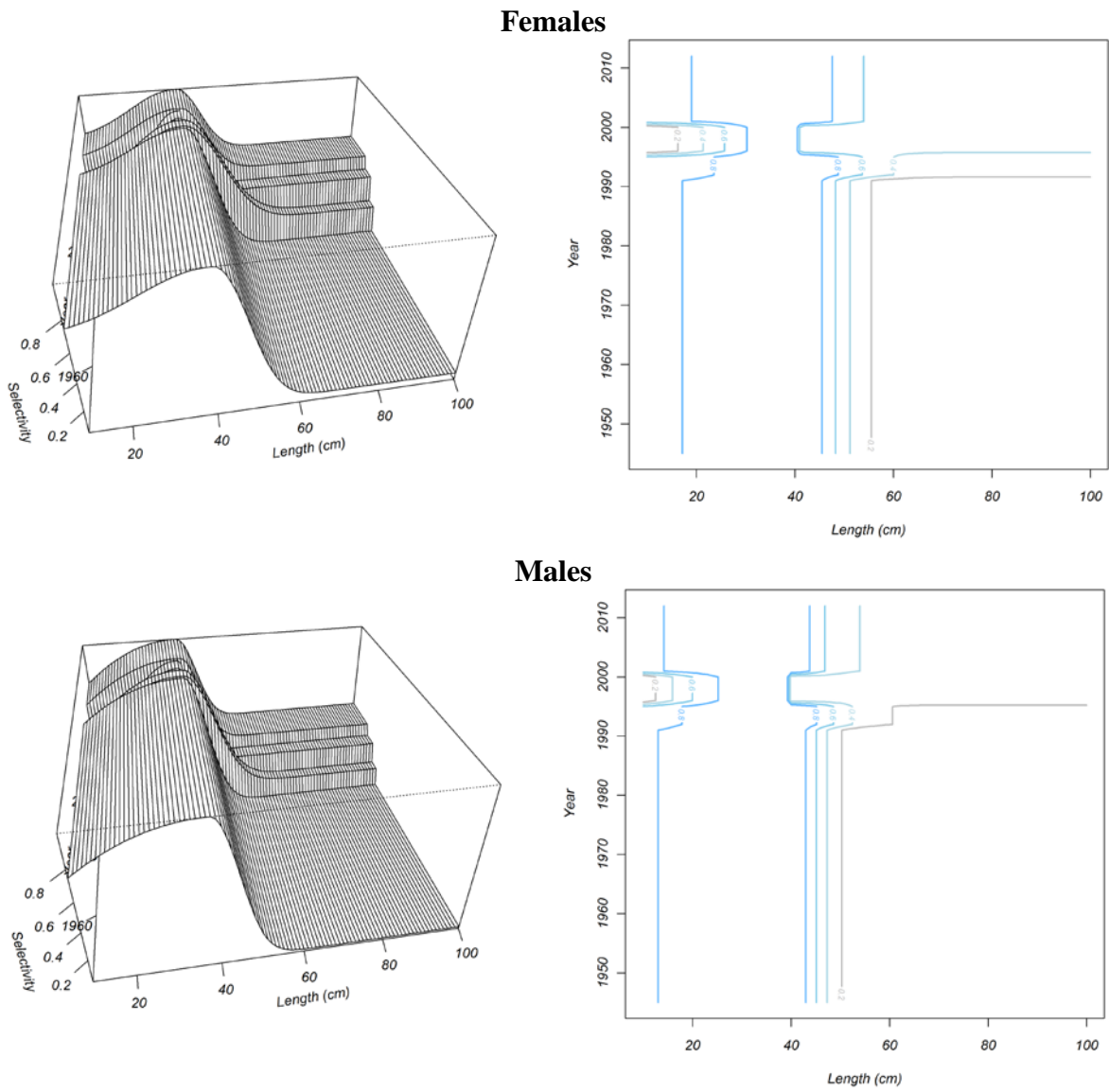
Females

Males

Figure 5.22.   Time-varying selectivity at size for the Shelf survey for Model 2 for females
(top) and males (bottom).
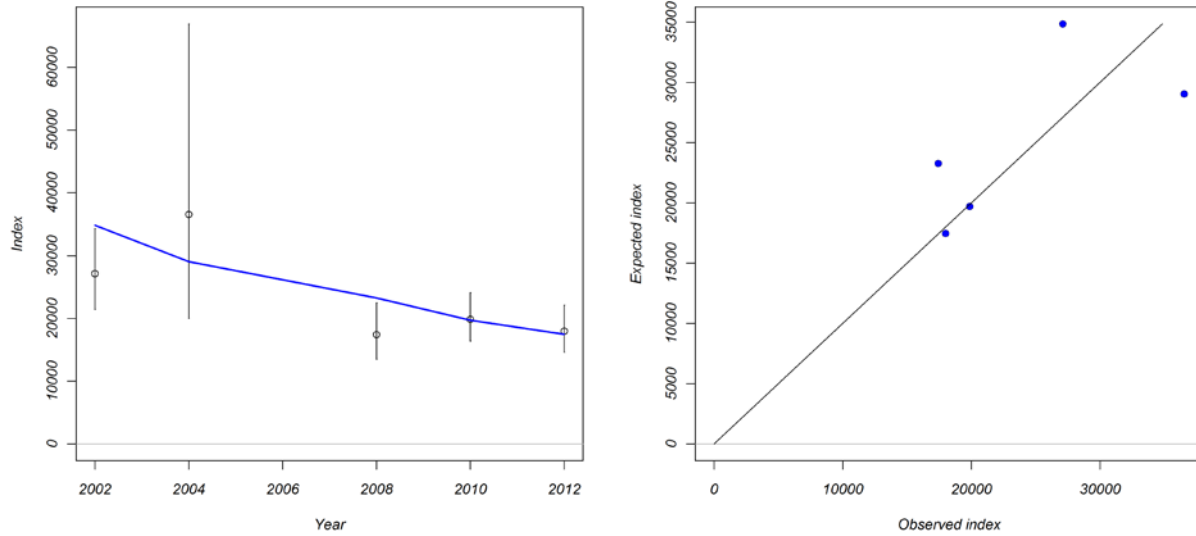
Figure 5.23.   Slope survey index (index values are total survey biomass in tons) and model fits. Error bars are 95% confidence intervals. Black line on right is 1:1 line, red line is a loess smooth.
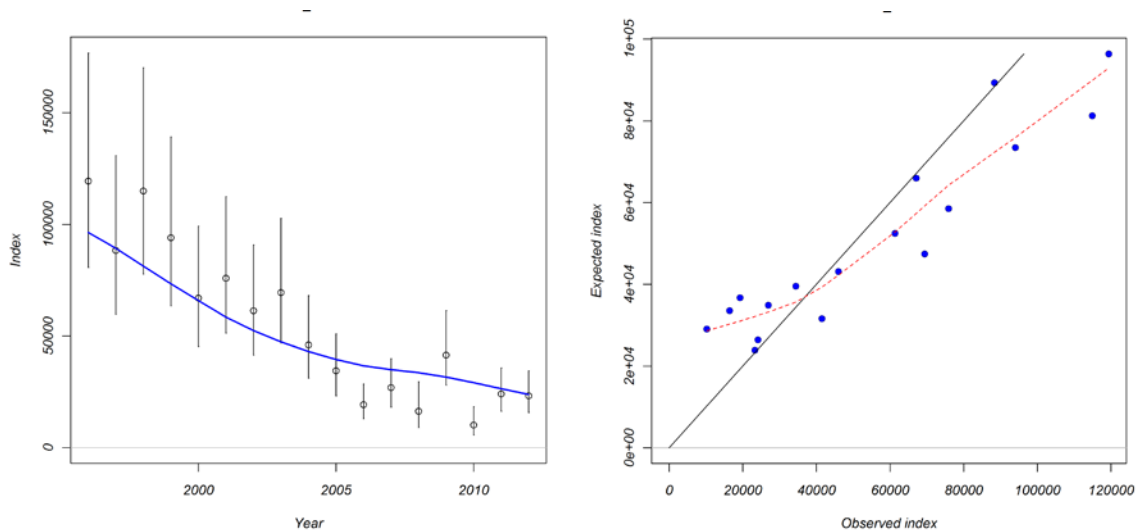
Figure 5.24.   Auke Bay Laboratory Longline survey index (index values are in Relative Population Numbers (RPN)) and model fits. Error bars are 95% confidence intervals. Black line on right is 1:1 line, red line is a loess smooth.
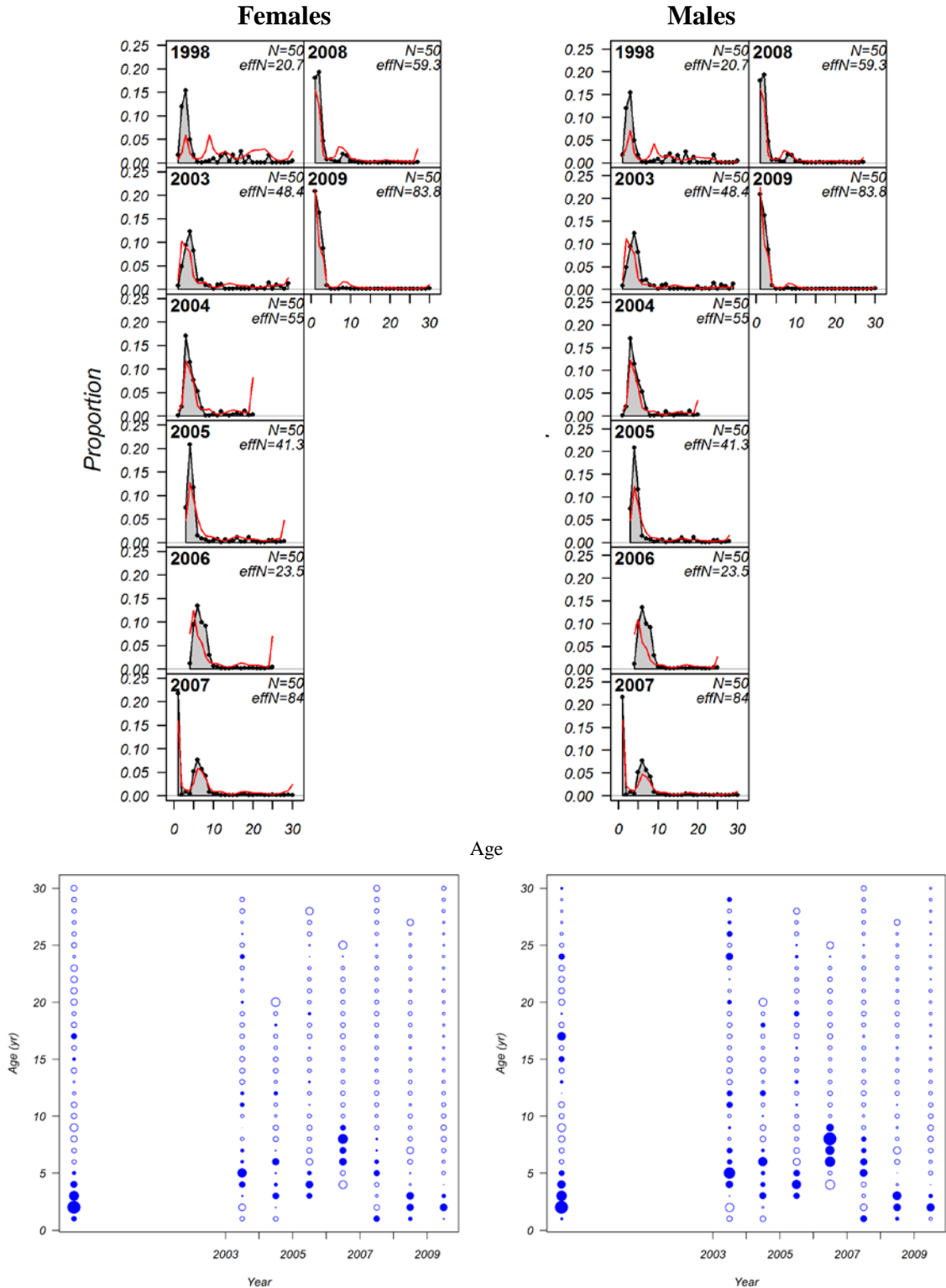
Figure 5.25.   Shelf survey age composition data and fits (red line)from Model 2 (top) for
Females and males.   (Bottom) Shelf survey age composition Pearson residuals
(Left female max = 4.84, Right male max = 3.56). Closed bubbles are positive
residuals and open bubbles are negative residuals.
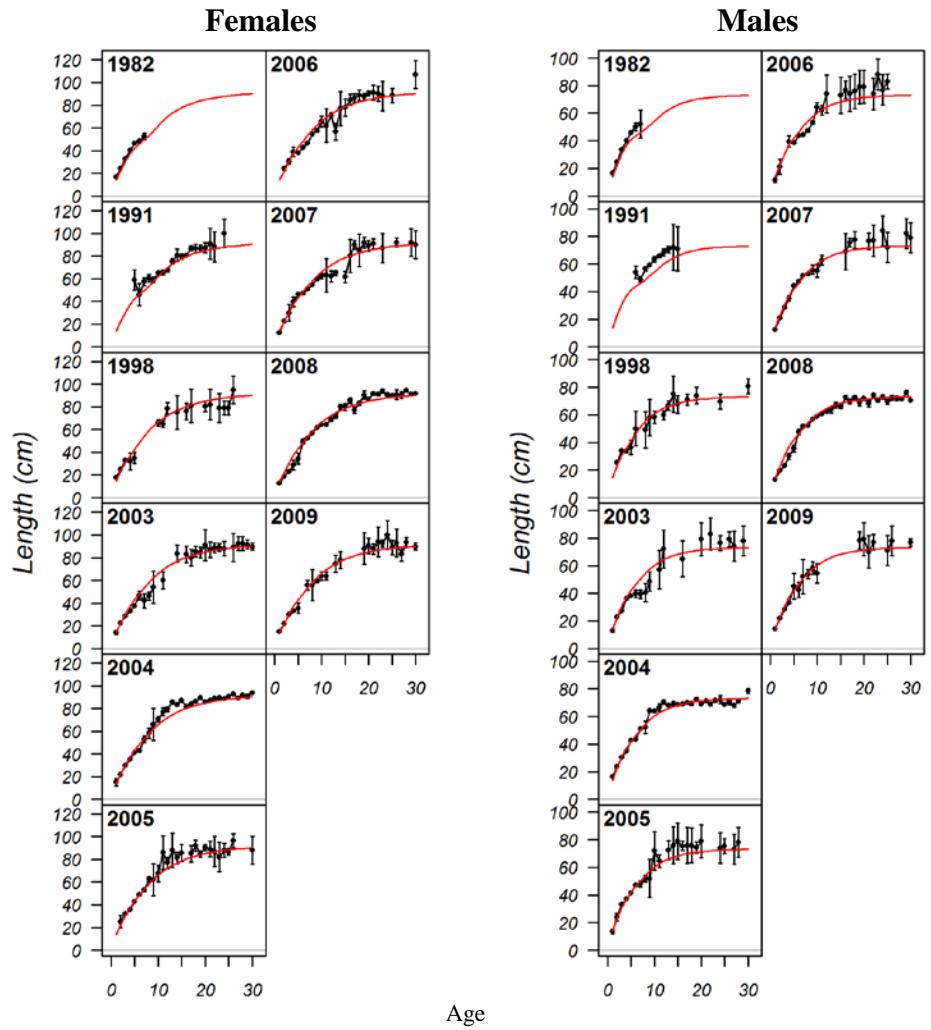
Figure 5.26.   Length at age data and fits (red line) from Model 2 for females and males.
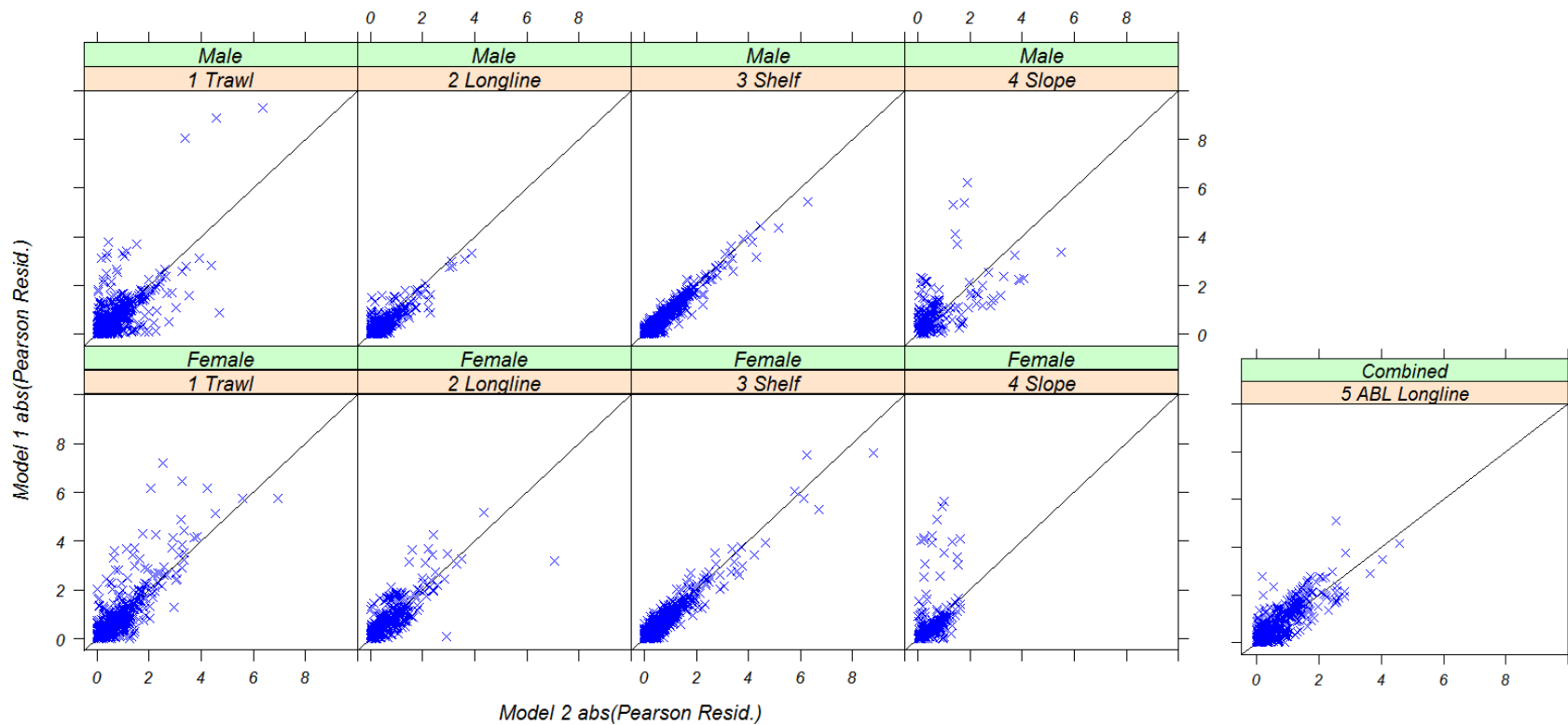
Figure 5.27.   The size composition absolute values for Pearson residuals for the 2011 Refence Model configuration (Model 1) and the 2012 authors' choice model (Model 2) by survey or fishery and sex with a 1:1 line in black. Above the 1:1 line means a tighter fit to the data for Model 2.
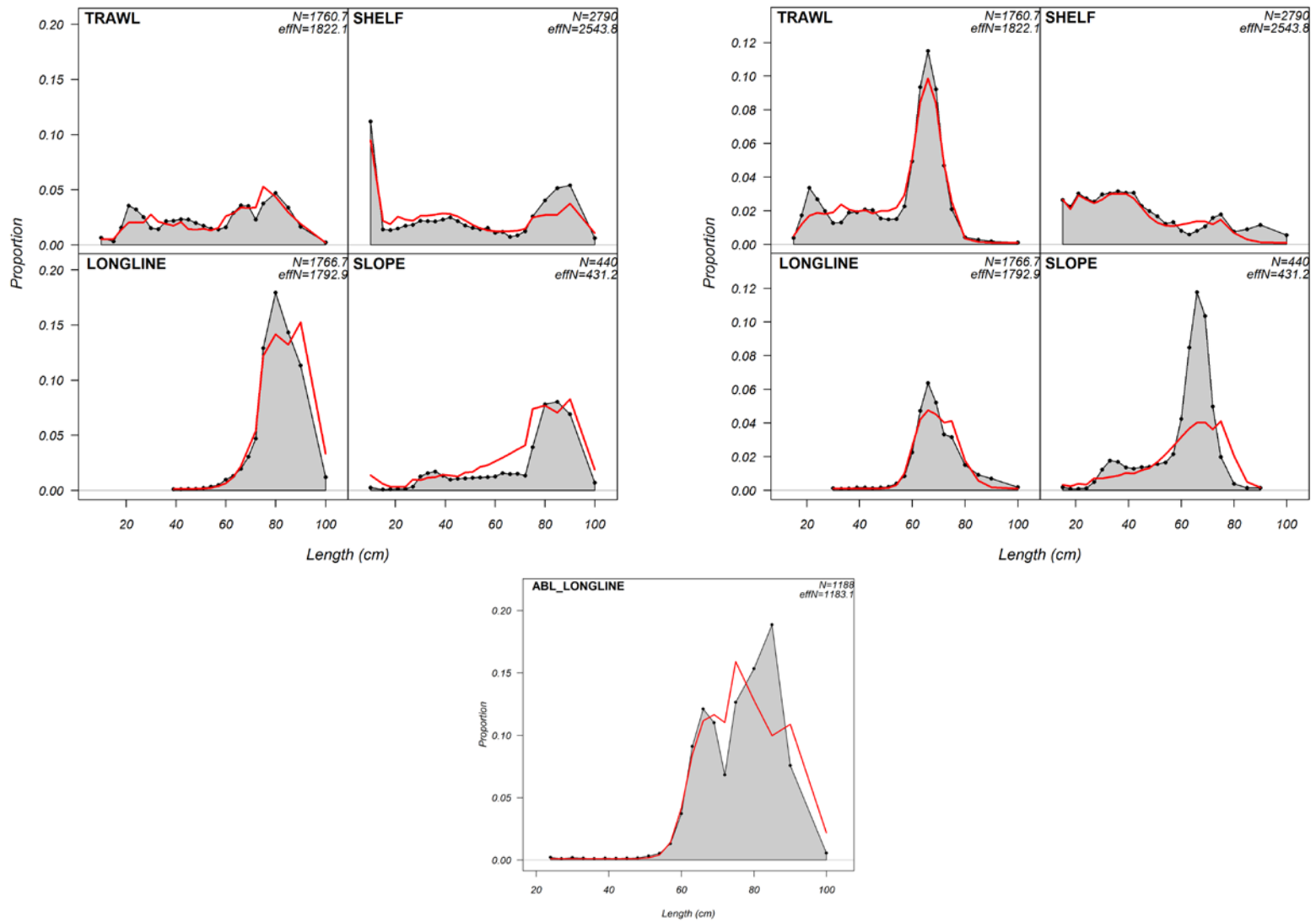
Figure 5.28.   All size composition data combined across years and fits (red line) for all fisheries and survey for Model 2. ABL longline has combined males and females.
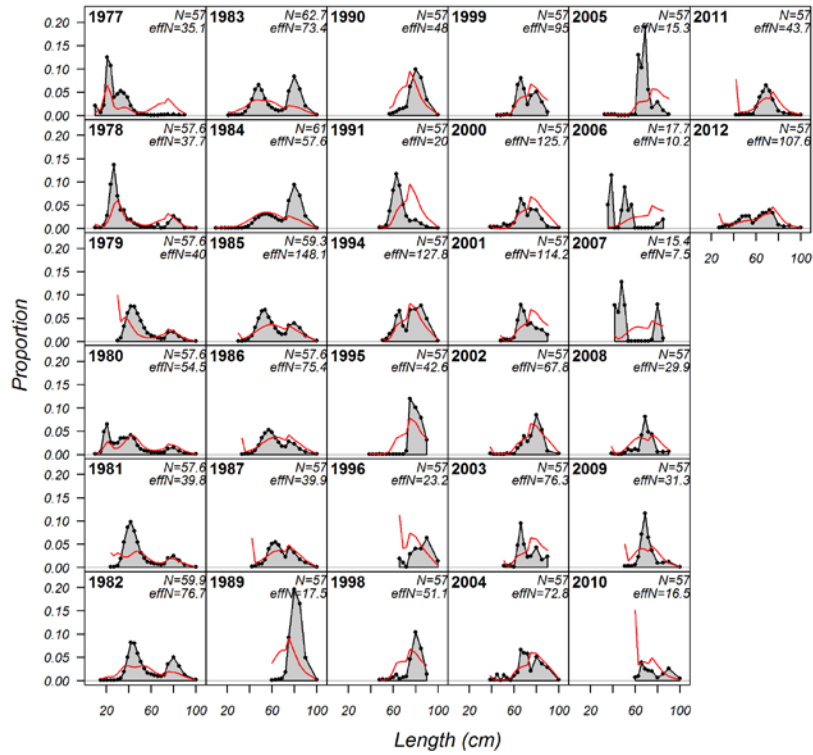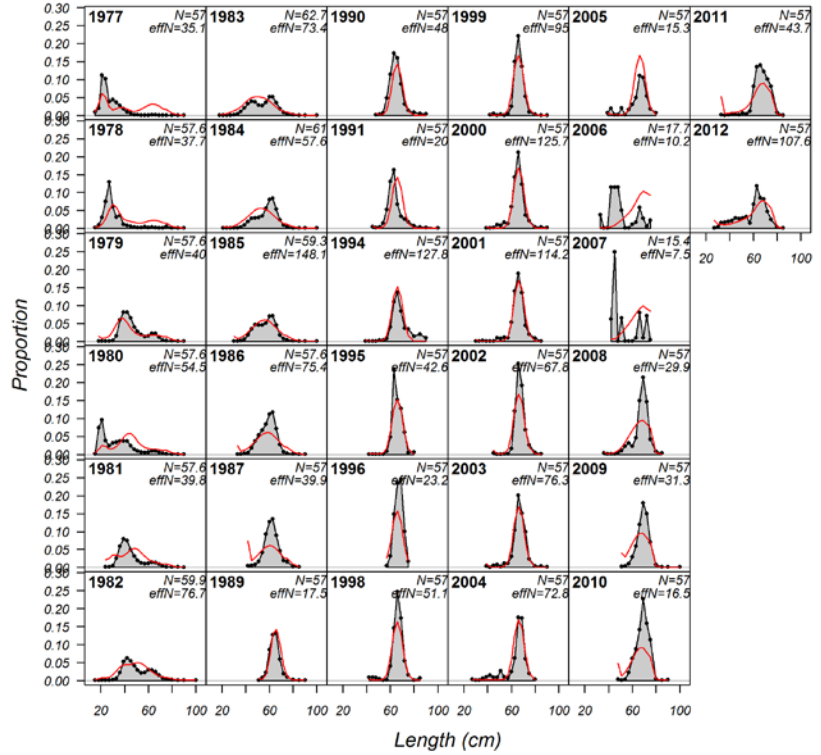
Figure 5.29.   Trawl fishery size composition data and fits (red line) from Model 2 for females and males.

Females (Max = 9.33)

Males (Max = 11.22)
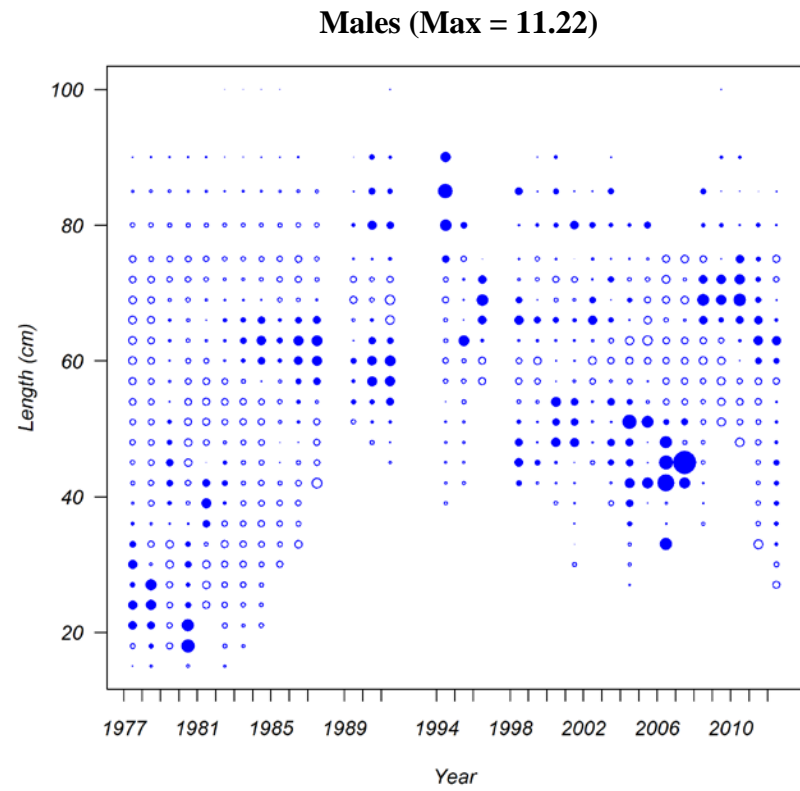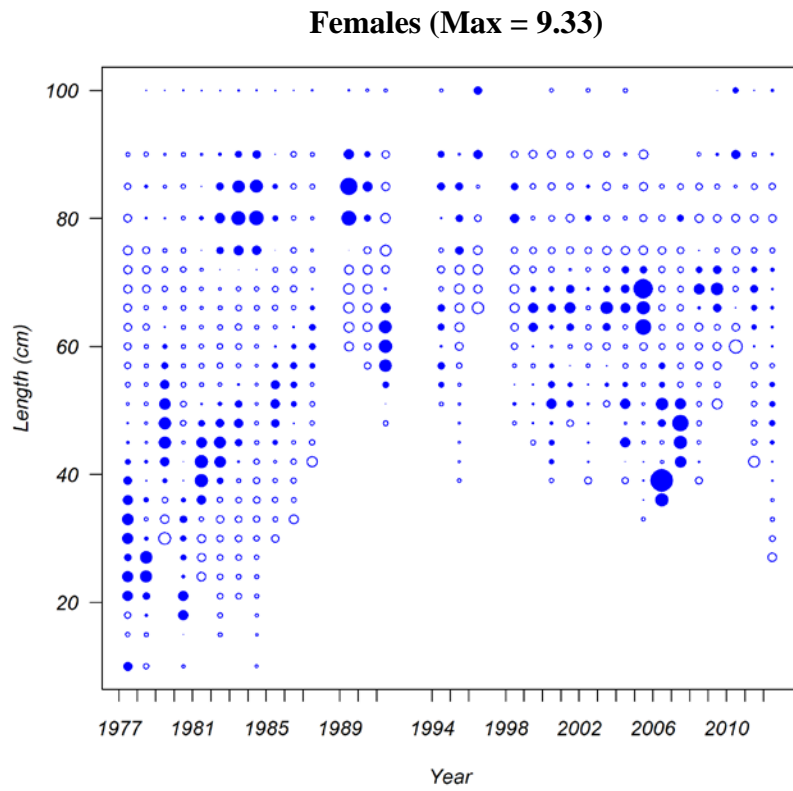
Figure 5.30. Trawl fishery size composition Pearson residuals. Closed bubbles are positive residuals and open bubbles are negative residuals.
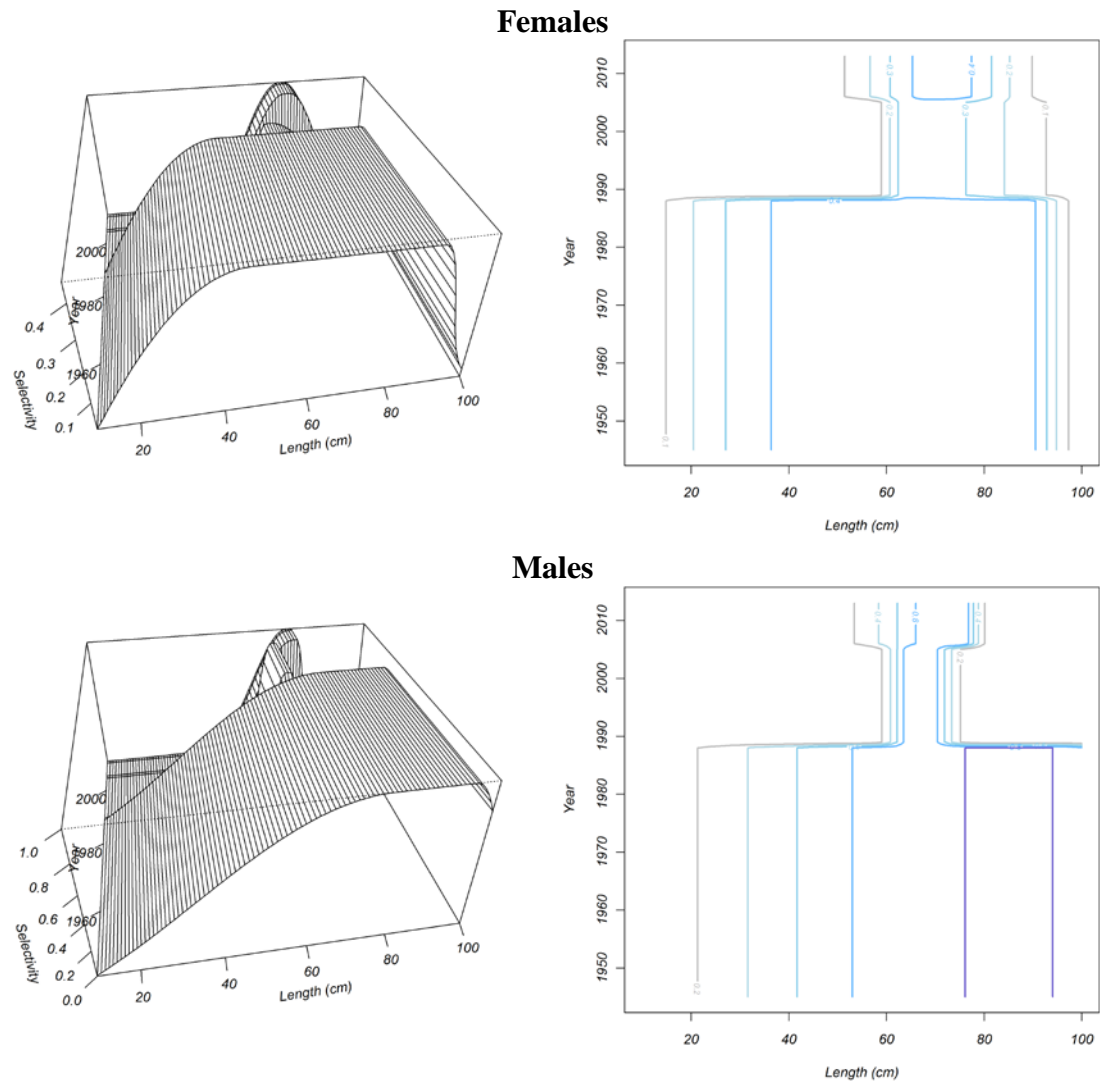
Females

Males

Figure 5.31.   Time-varying selectivity at size for the Trawl fishery for Model 2 for Females (top) and males (bottom).
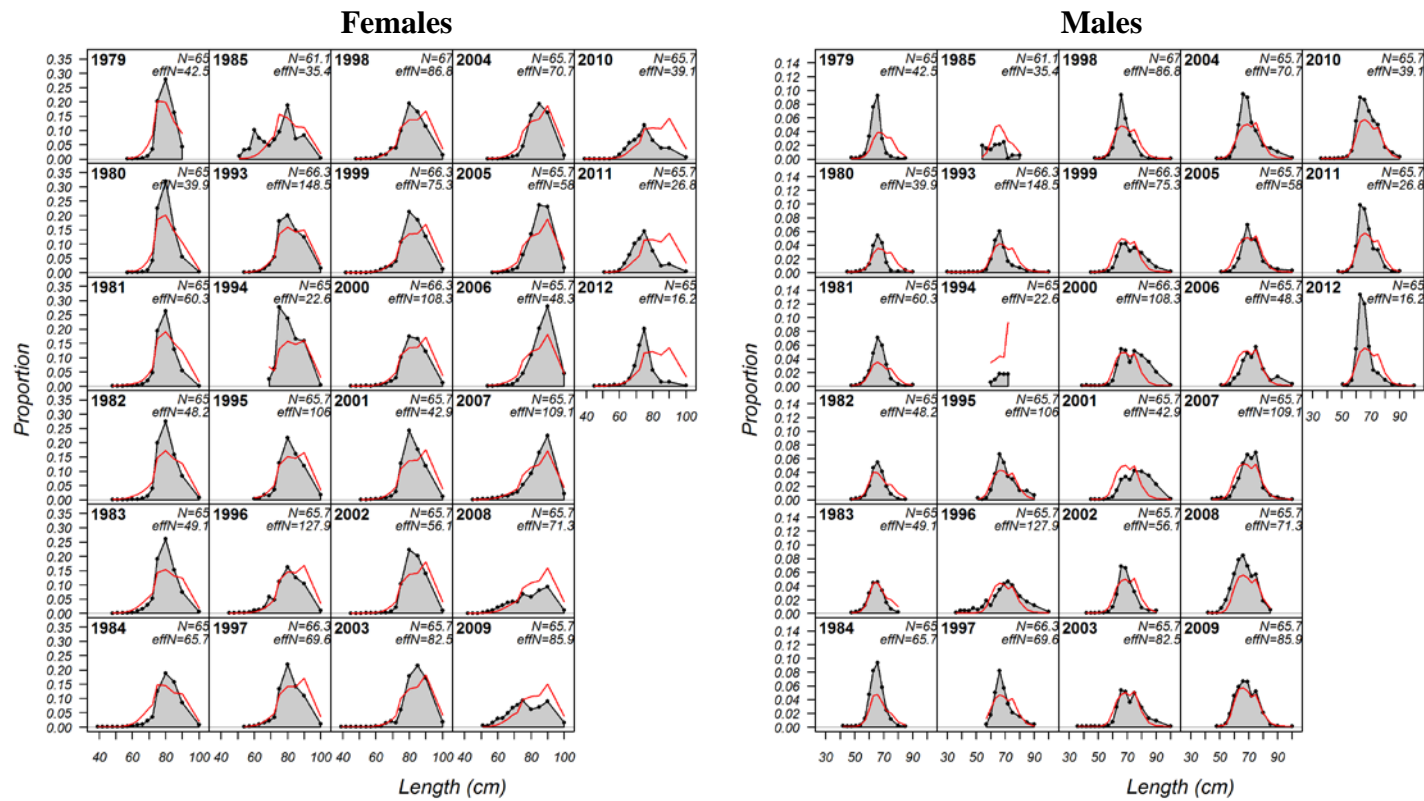
Figure 5.32.   Longline fishery size composition data and fits (red line) from Model 2 for females and males.
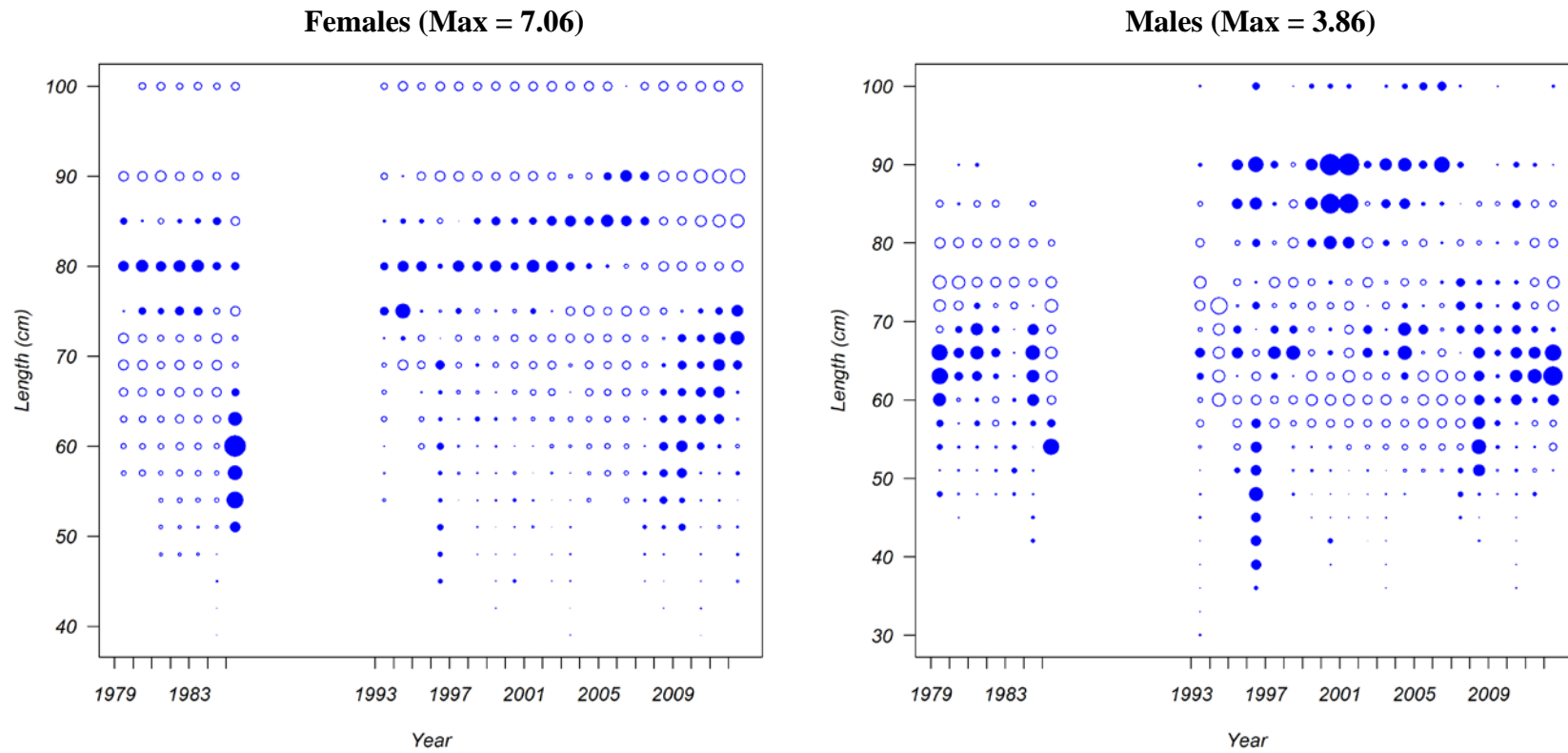
Figure 5.33. Longline fishery size composition Pearson residuals. Closed bubbles are positive residuals and open bubbles are negative residuals.
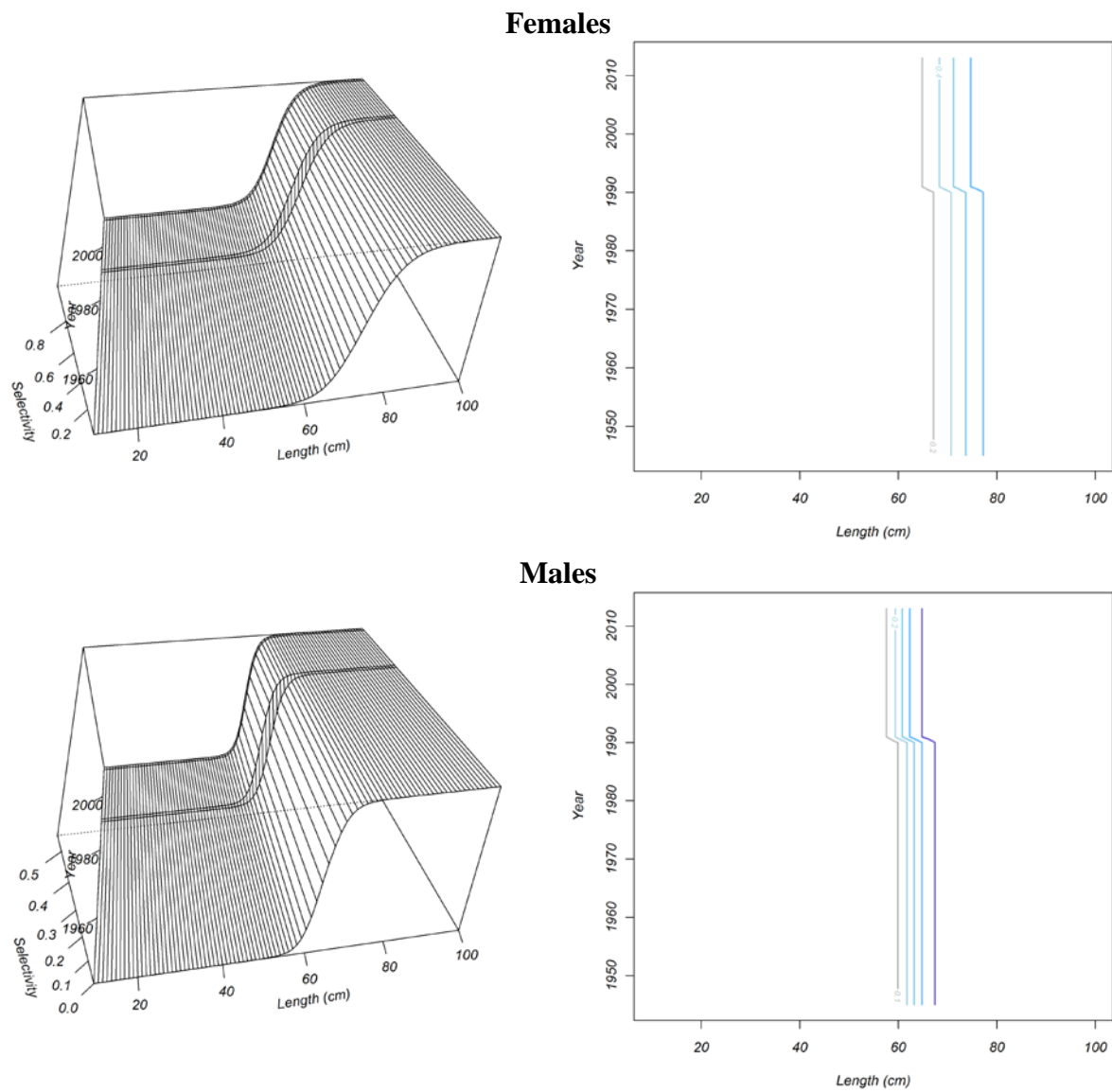
Females

Males

Figure 5.34.   Time-varying selectivity at size for the Longline fishery for Model 2 for females (top) and males (bottom).
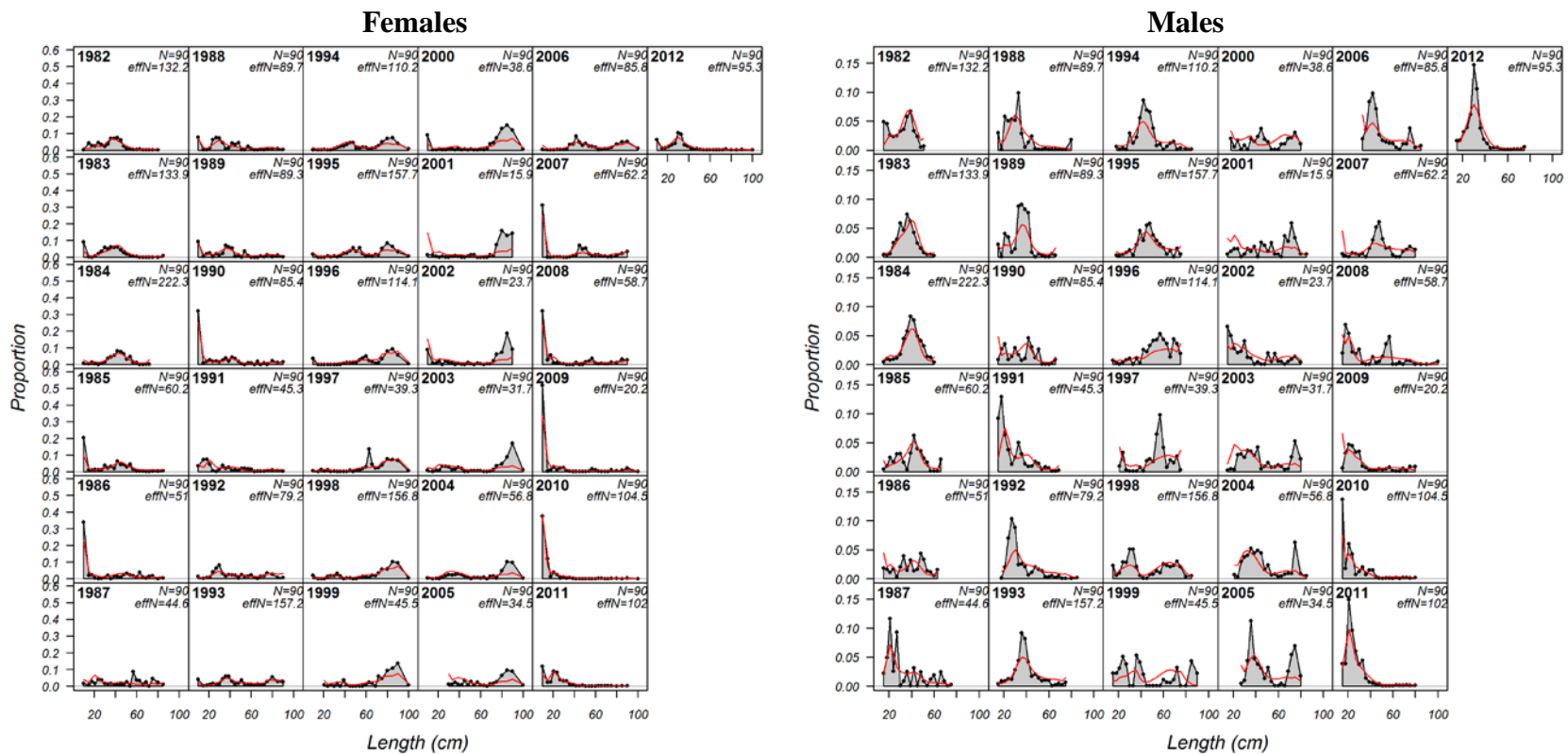
Figure 5.35.   Shelf survey size composition data and fits (red line) from Model 2 for females and males.
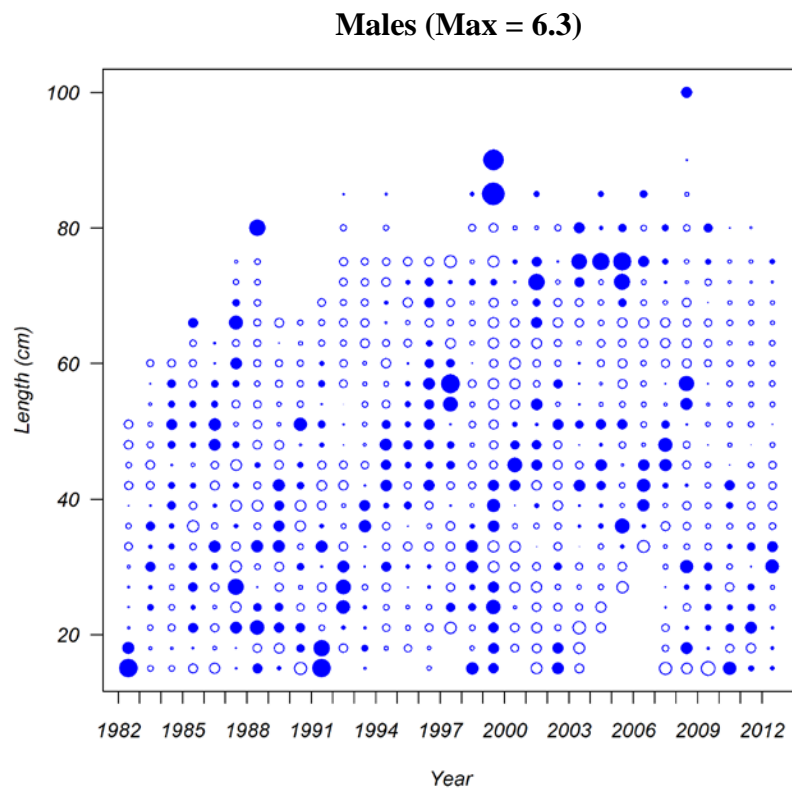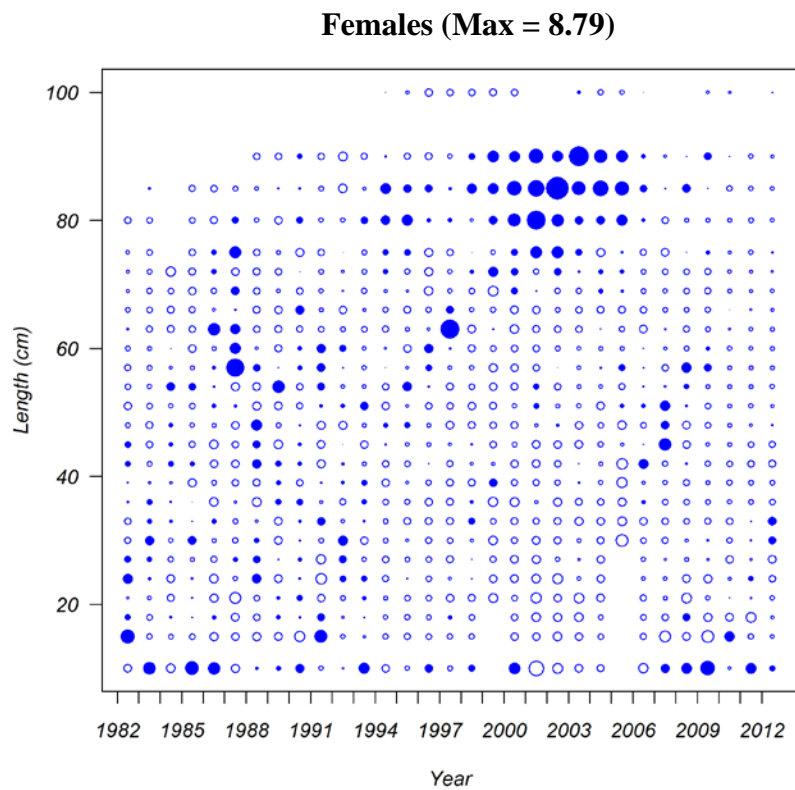
Figure 5.36.   Shelf survey size composition Pearson residuals. Closed bubbles are positive residuals and open bubbles are negative residuals.
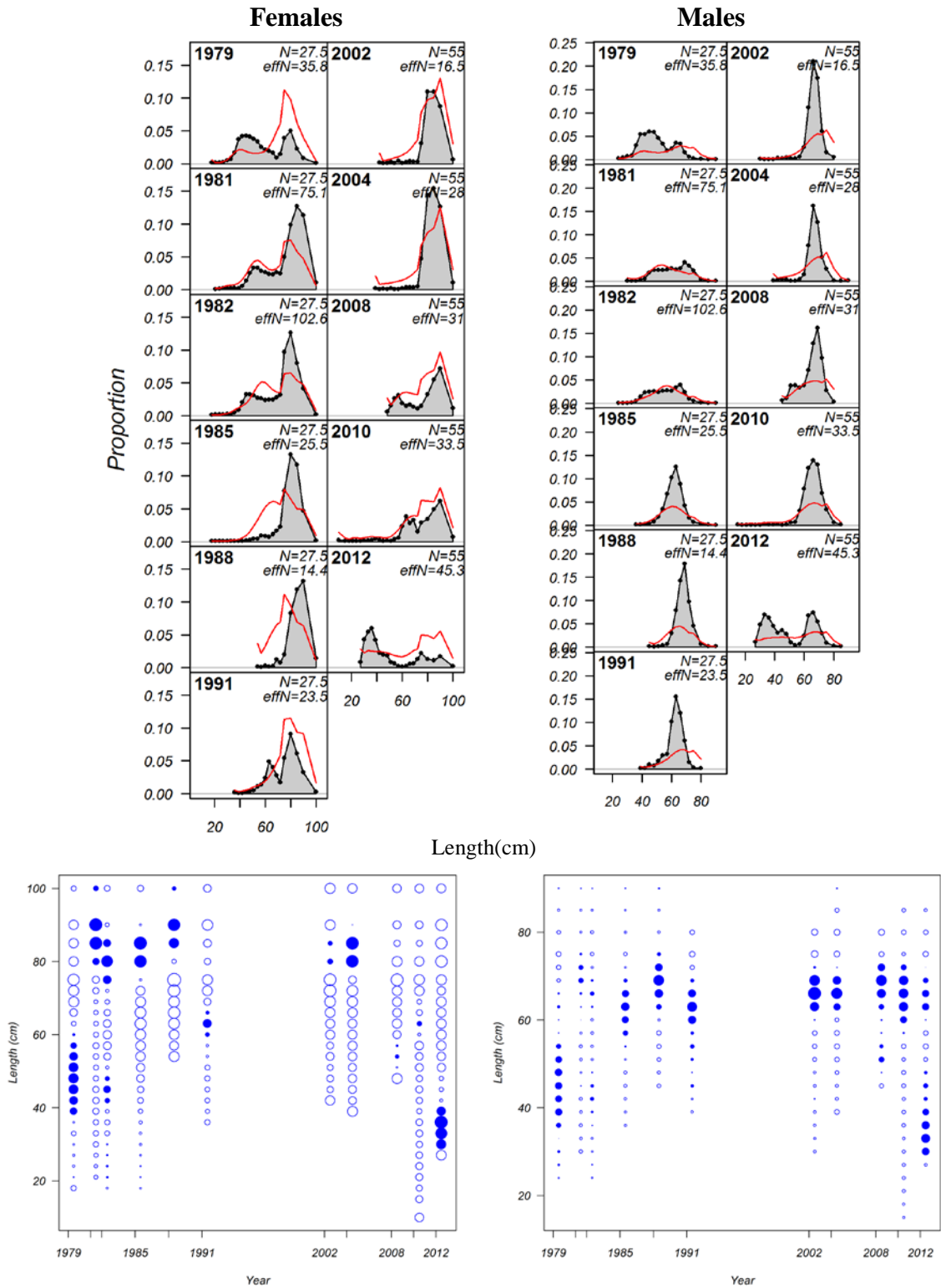
Figure 5.37. (Top) Slope survey size composition data and fits (red line)from Model 2 (top) for females and males.   (Bottom) Slope survey size composition Pearson residuals (Left female max=1.64, Right male max = 5.51). Closed bubbles are positive residuals and open bubbles are negative residuals.
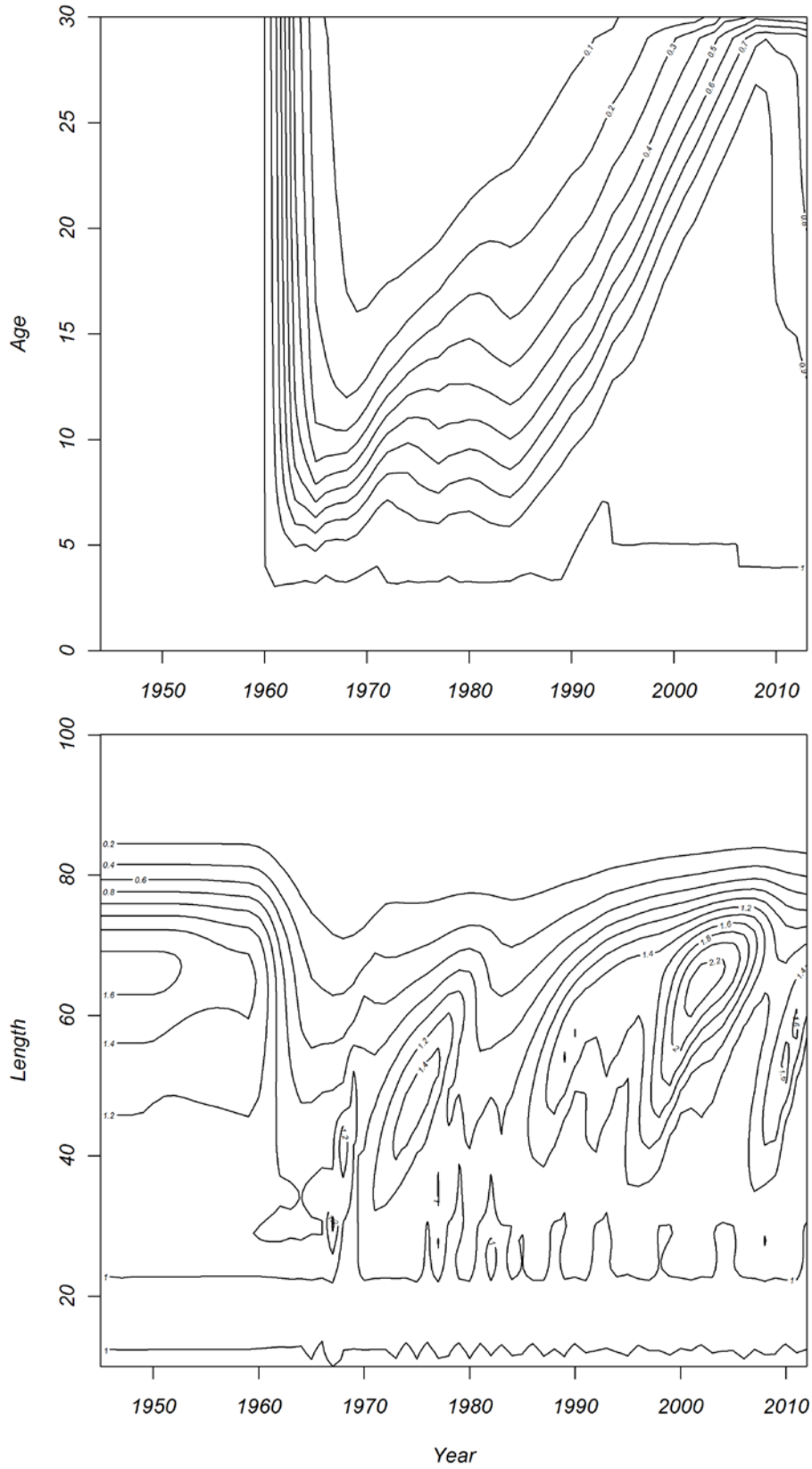
Figure 5.38.   BSAI Greenland turbot sex ratio (males:females) by age (top) and size (bottom).
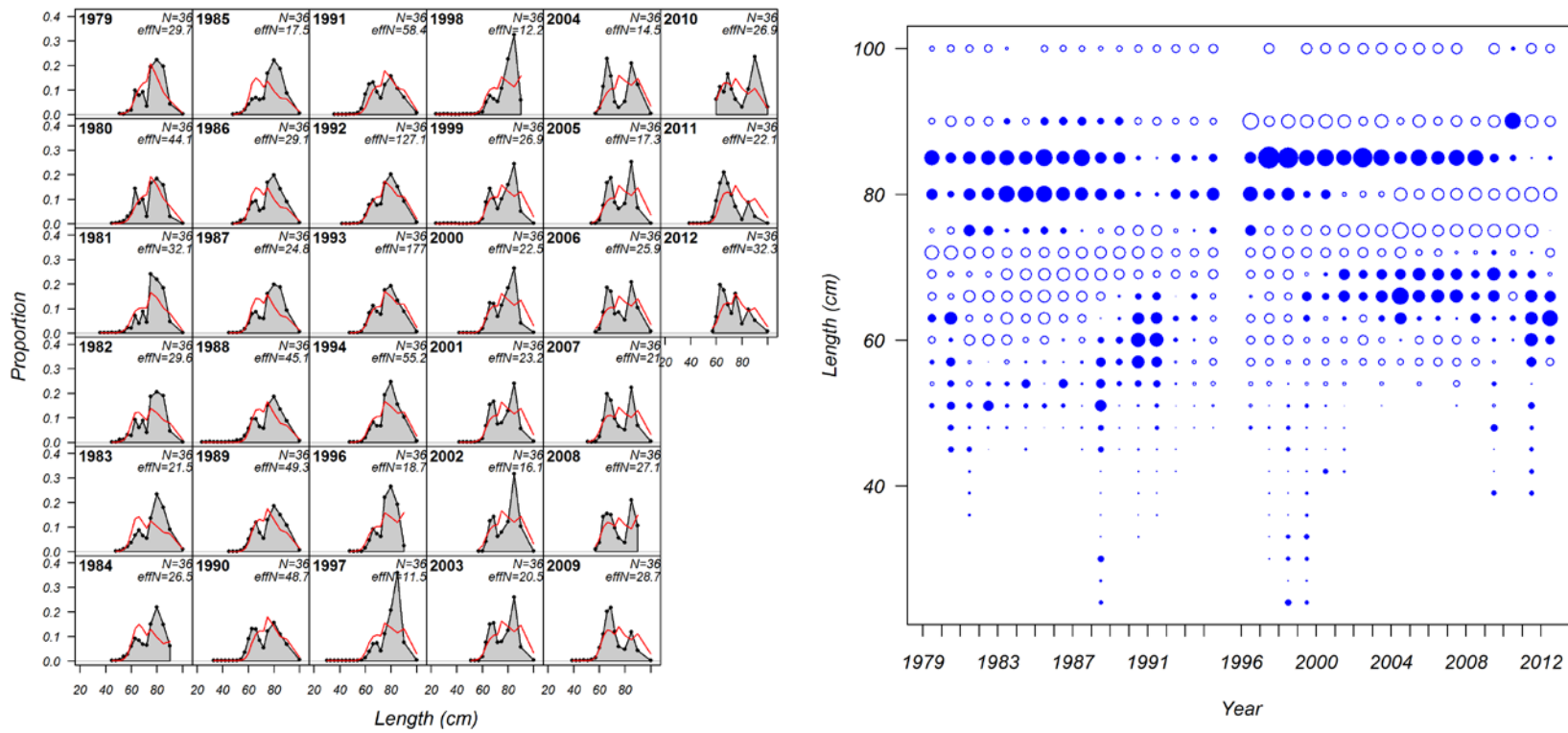
Figure 5.39.   (Left) Auke Bay Laboratory Longline survey size composition data and fits (red line)from Model 2 (top) for combined sexes.   (Right) Slope survey size composition Pearson residuals (max = 4.57). Closed bubbles are positive residuals and open bubbles are negative residuals.
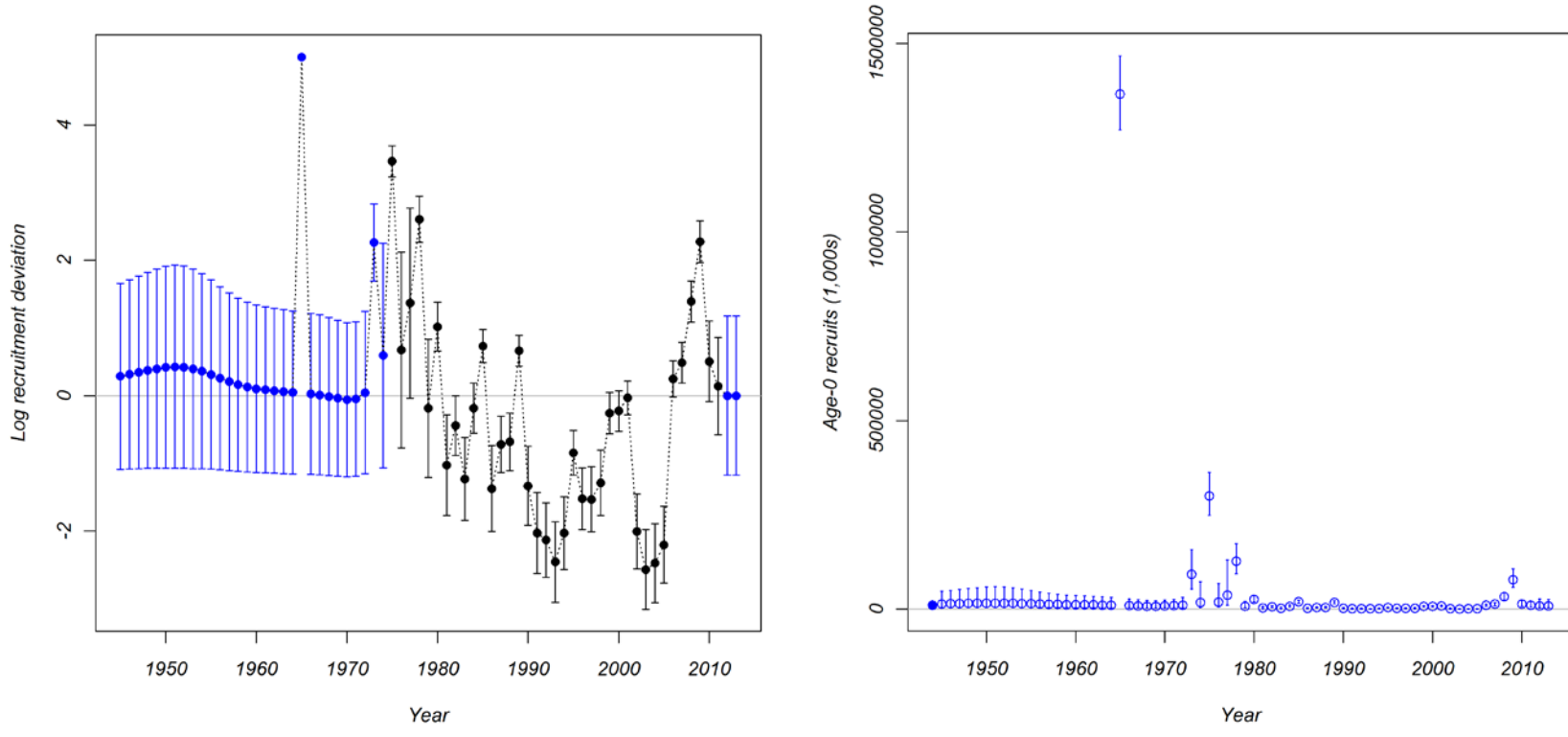
Figure 5.40.   Log recruitment deviations (left) and Age-0 recruits (right) in thousands for Model 2.
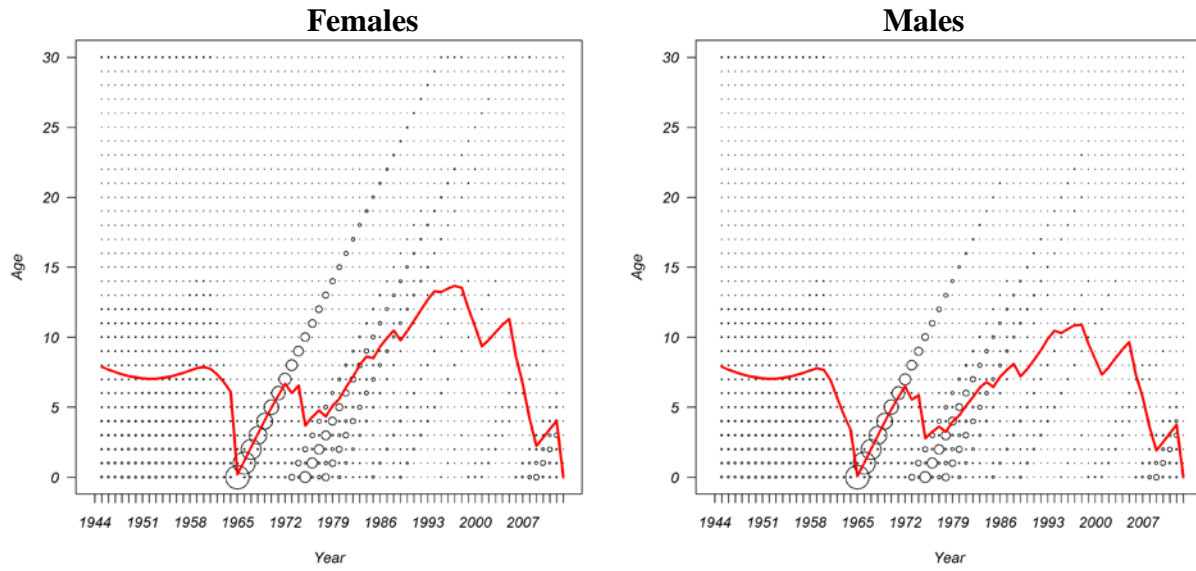
Figure 5.41.   BSAI Greenland turbot numbers at age and mean age by year (red line).
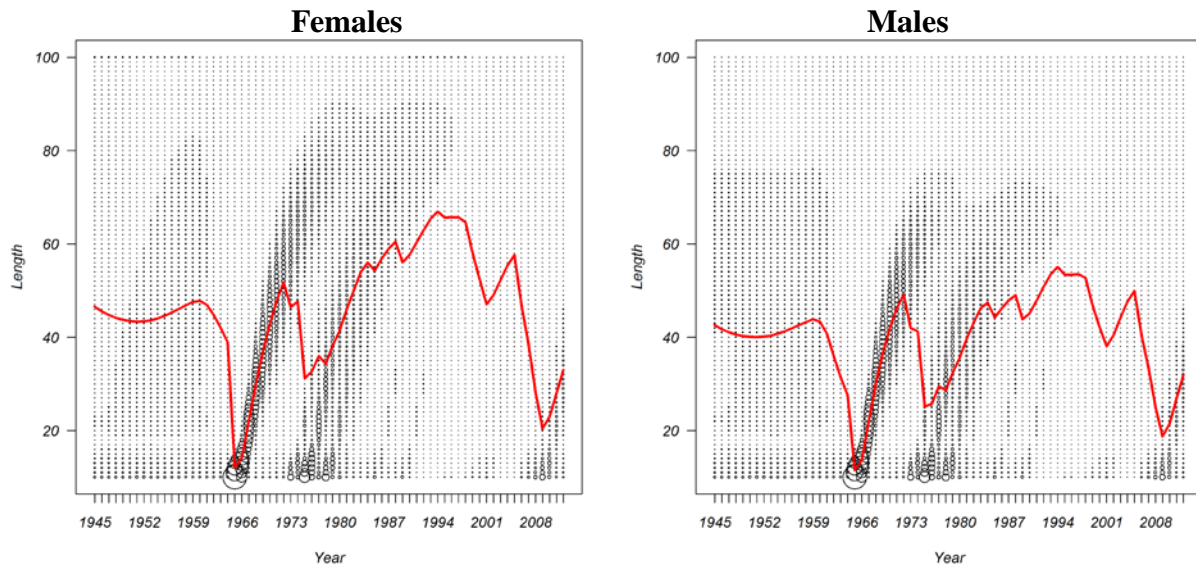
Figure 5.42.   BSAI Greenland turbot numbers at size and mean size by year (red line).
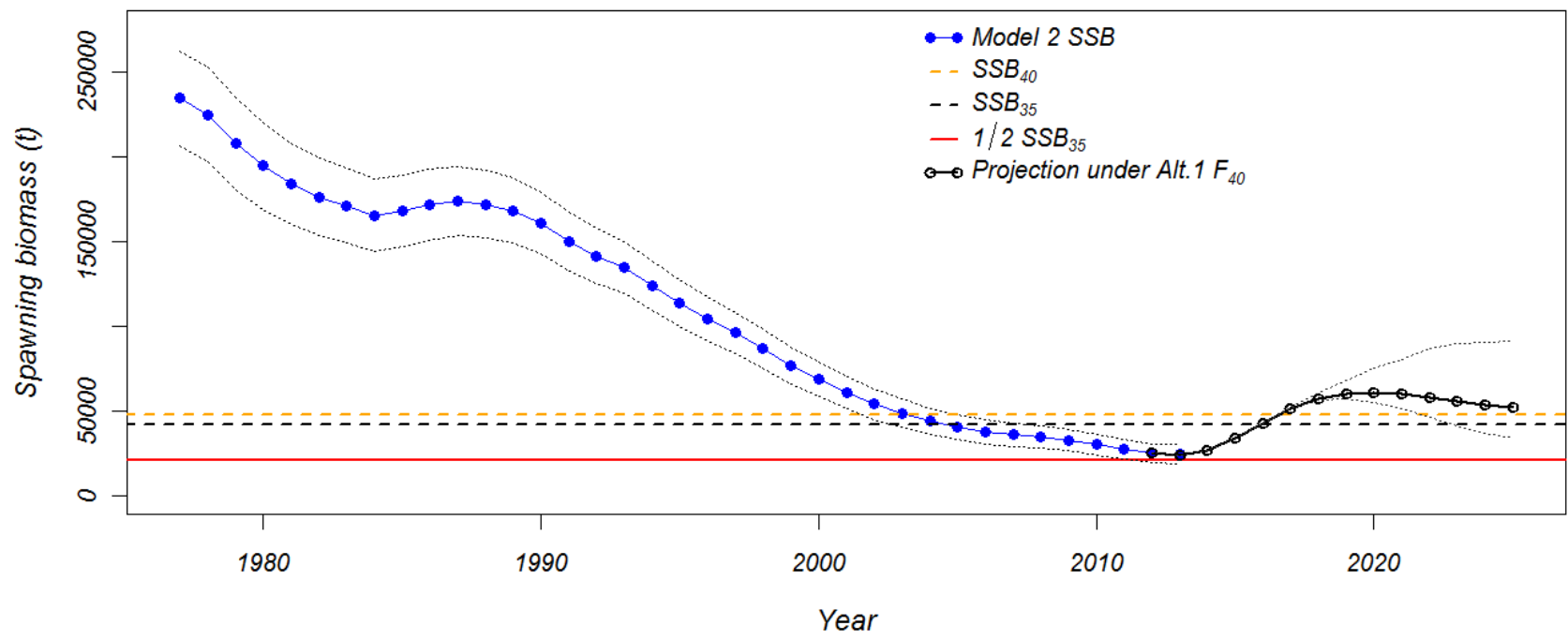
Figure 5.43. Female spawning biomass in tons for BSAI Greenland Turbot for this year's reference model (Model 2) with reference levels and projection out to 2025 from Alternative 1 F_{40} fishing levels. Model error bars are 95% confidence intervals based on the inverted Hessian, projection error bars are 95% credible intervals based on 1,000 simulations.
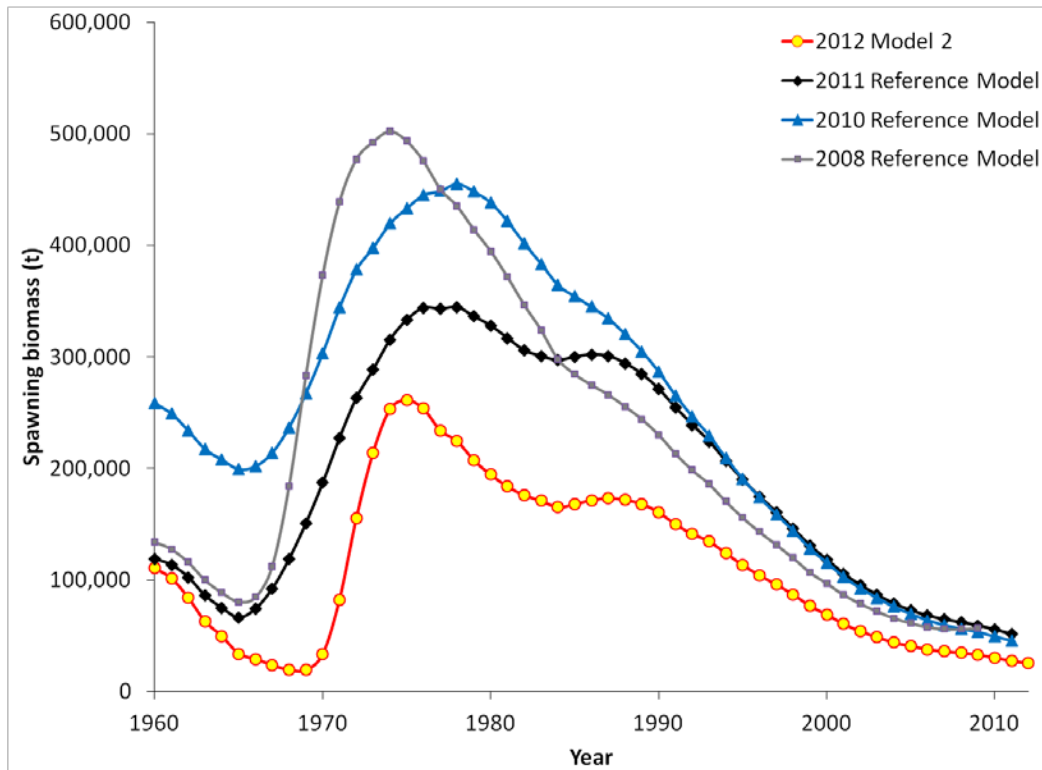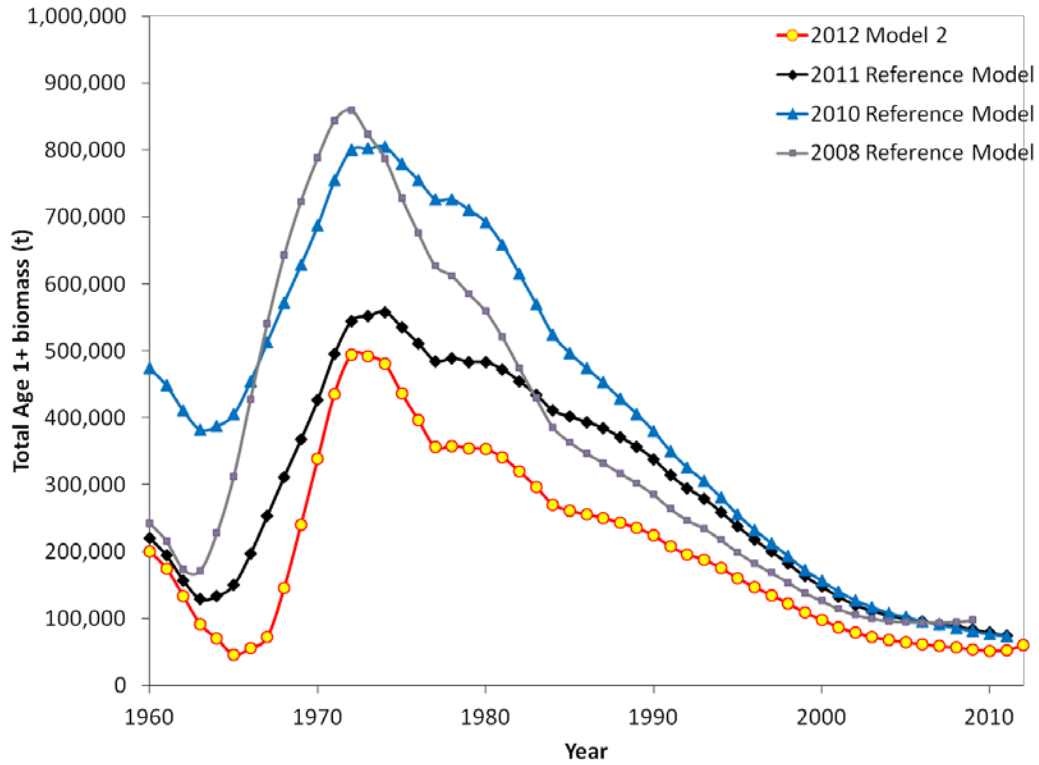
Figure 5.44.   Total age +1 biomass (t) and female spawning biomass in tons for BSAI
              Greenland Turbot for this year's reference model (Model 2) and previous years'
              stock assessments.
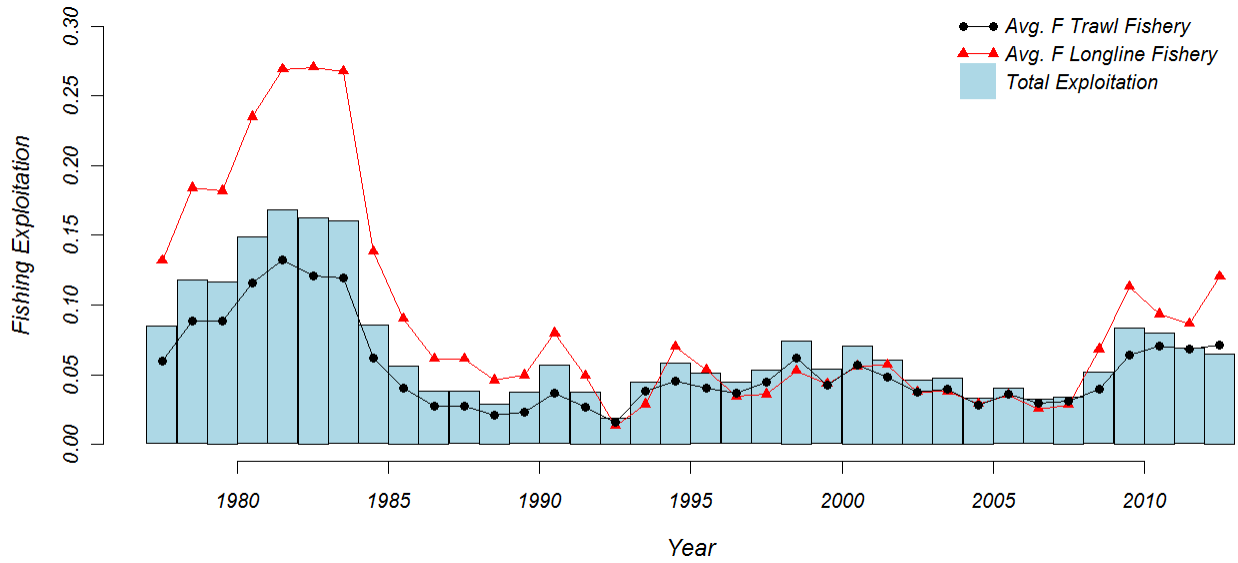
Figure 5.45.   BSAI Greenland turbot total exploitation rate (bars) and average Fs for the trawl and longline fisheries.
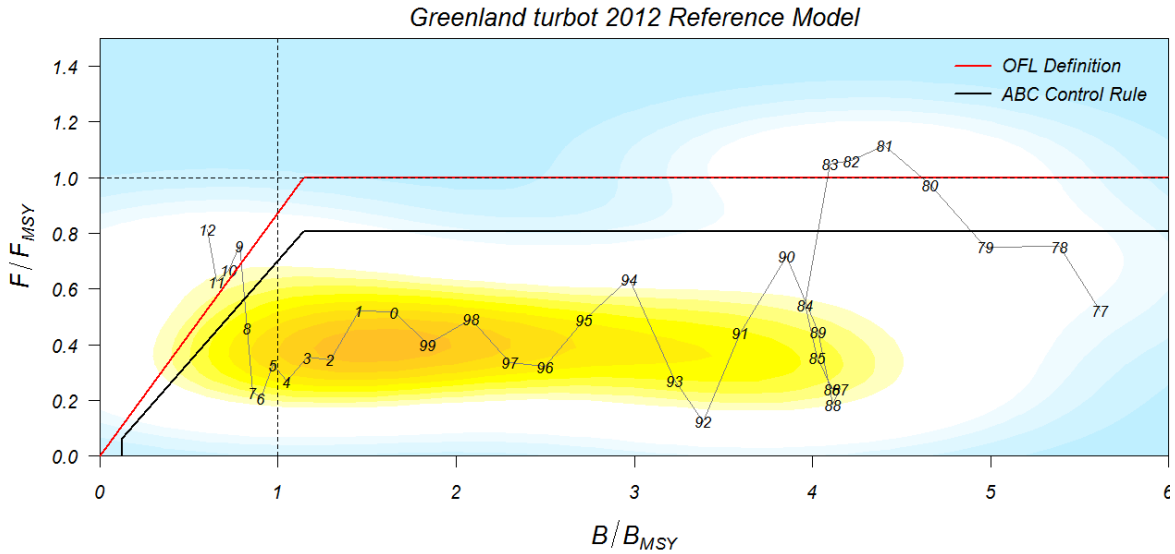
Figure 5.46.   Ratio of historical F/F_{msy} versus female spawning biomass relative to B_{msy} for BSAI Greenland turbot, 1960-2011. Note that the proxies for F_{msy} and B_{msy} are $F_{35\%}$ and $B_{35\%}$, respectively.
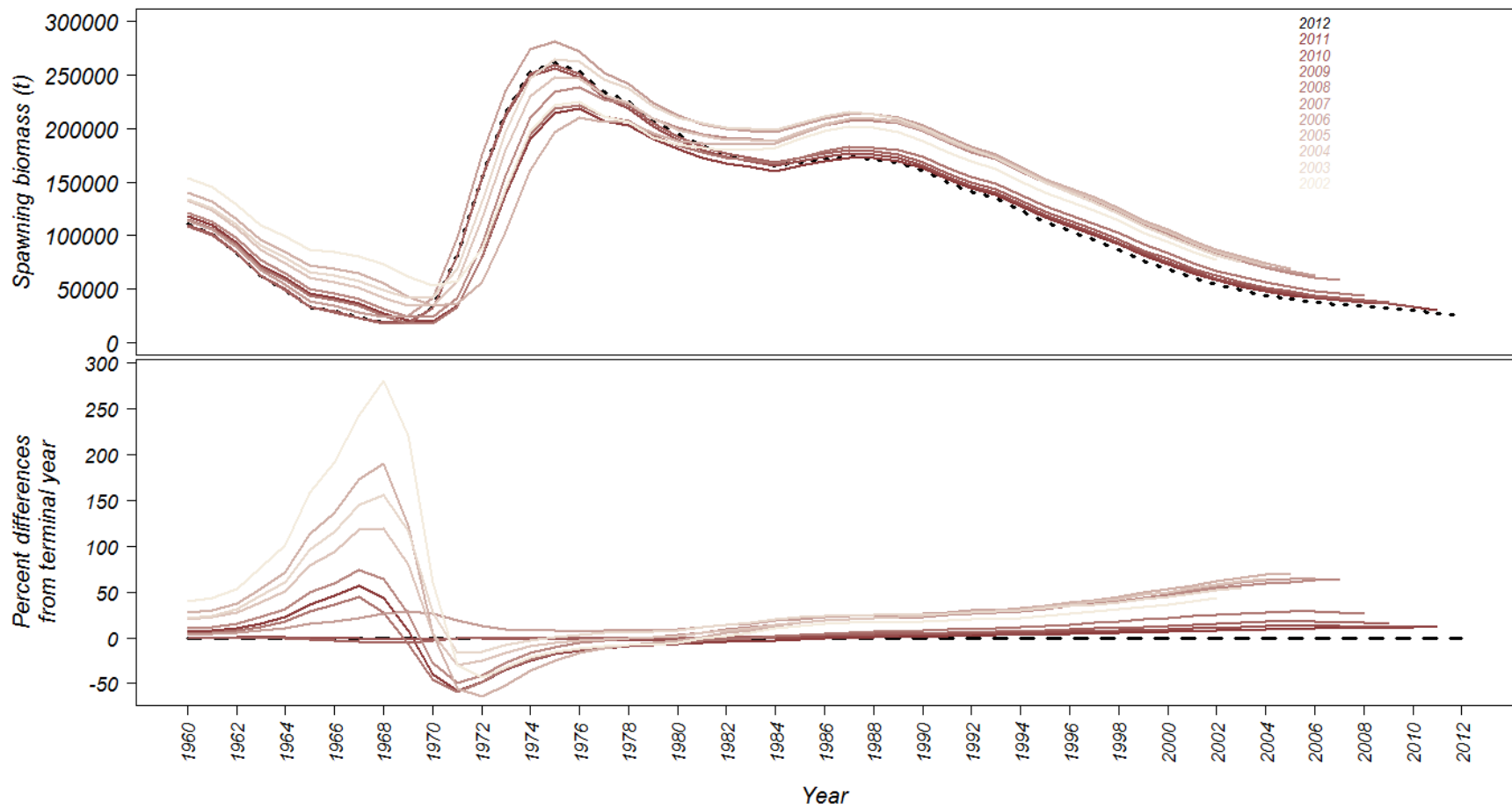
Figure 5.47.   Retrospective analysis plot of spawning biomass (top) and change in spawning biomass per year for the retrospective runs (bottom).
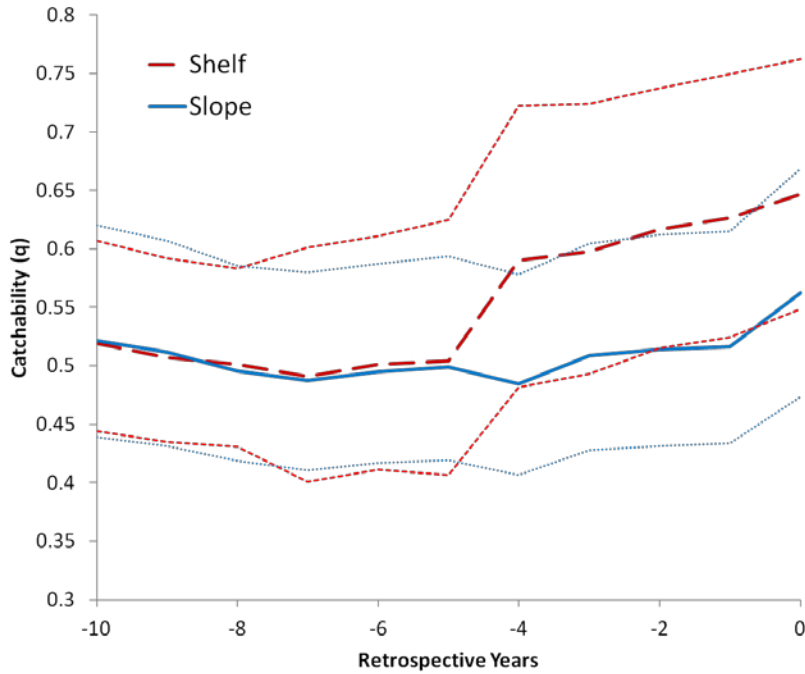
Figure 5.48.   Retrospective analysis plot of Shelf and Slope Survey catchability (q) estimates.
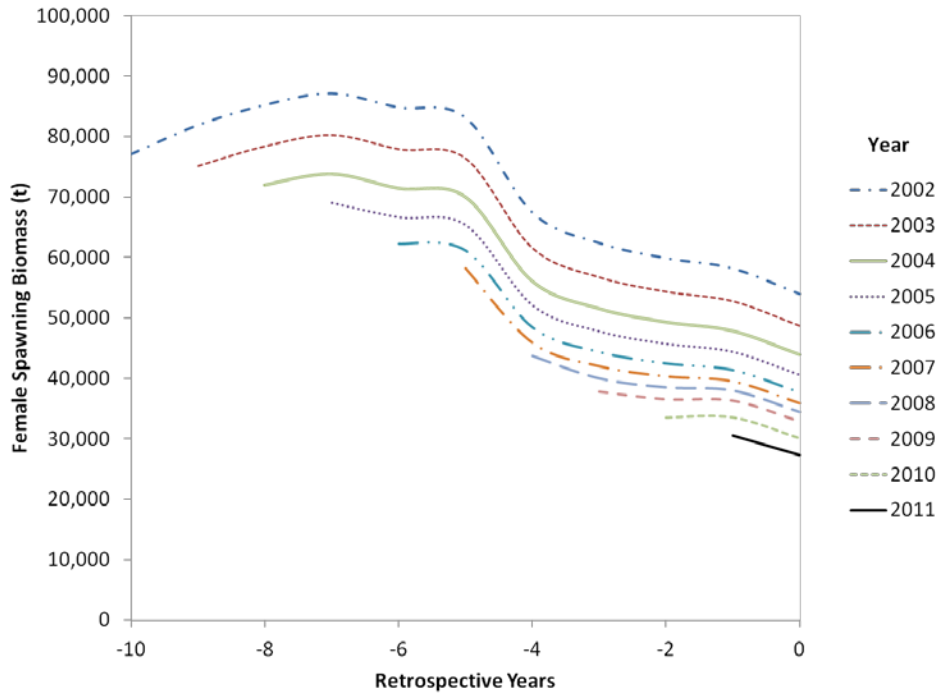
Figure 5.49.   Retrospective analysis plot of female spawning biomass. Each line is the female spawning biomass estimated for a specific year when data from 0 to 10 years were removed.
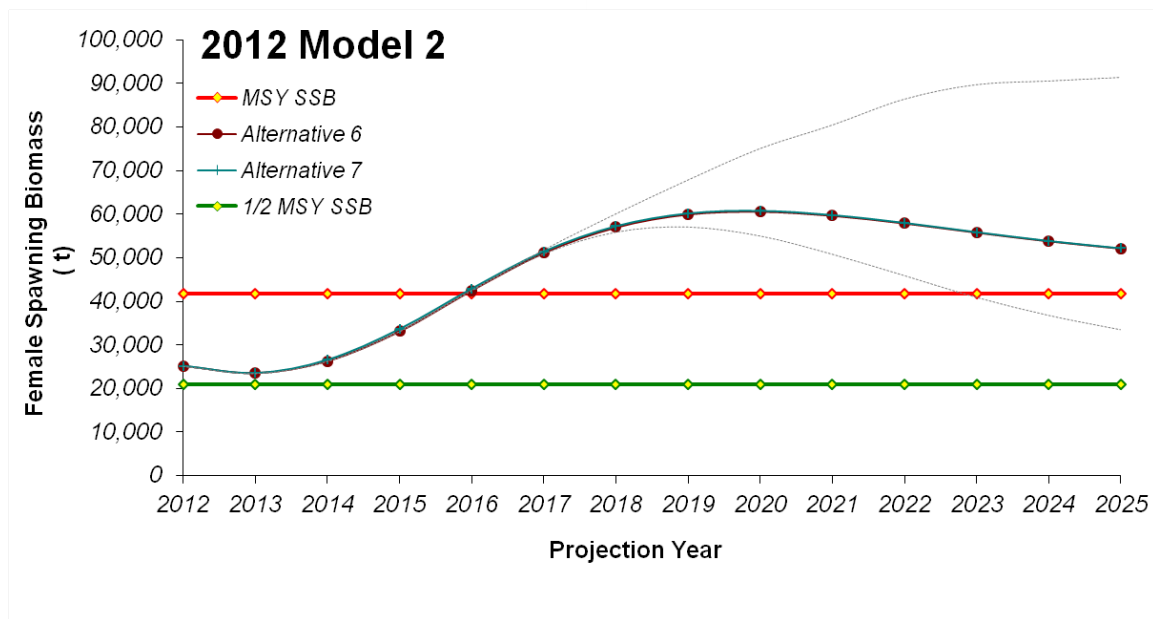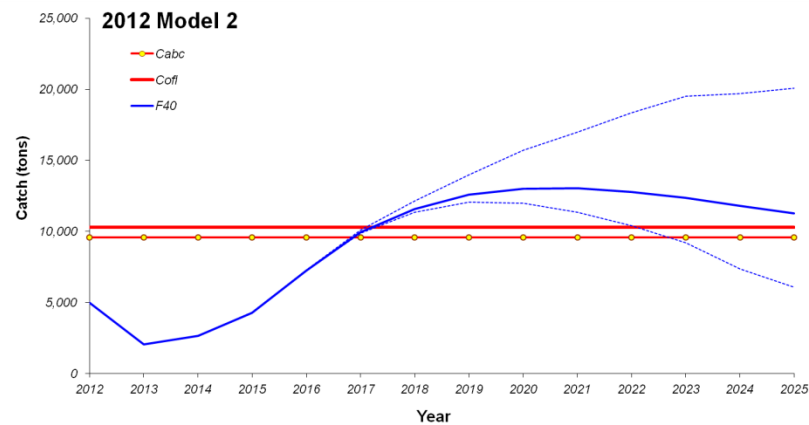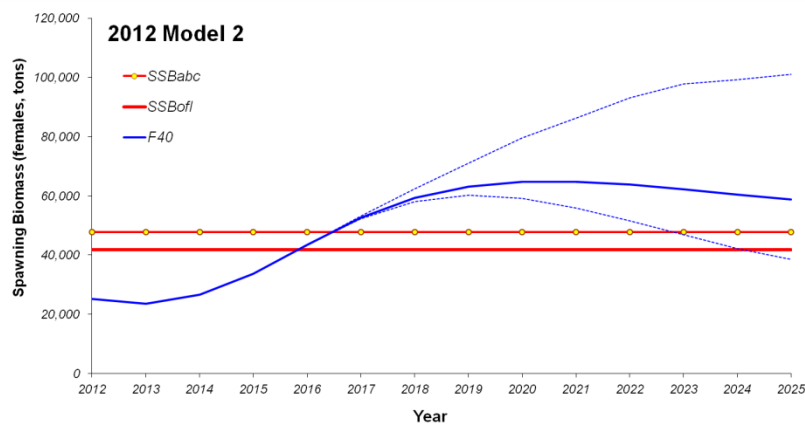
Figure 5.50.   Alternative 1 projected (upper left) female spawning stock biomass and (upper right) catch at F_{40} fishing with long-term expected OFL and ABC reference levels, and (bottom) projected female spawning stock biomass under Alternatives 6 and 7 with SSB_{MSY} and ½ SSB_{MSY} reference levels. $SSB_{35\%}$ is our proxy for SSB_{MSY}.

Appendix 5.1 September report to the NPFMC SSC Plan Team concerning changes in the 2012 Stock Assessment for the BSAI Greenland turbot (*Reinhardtius hippoglossoides*)
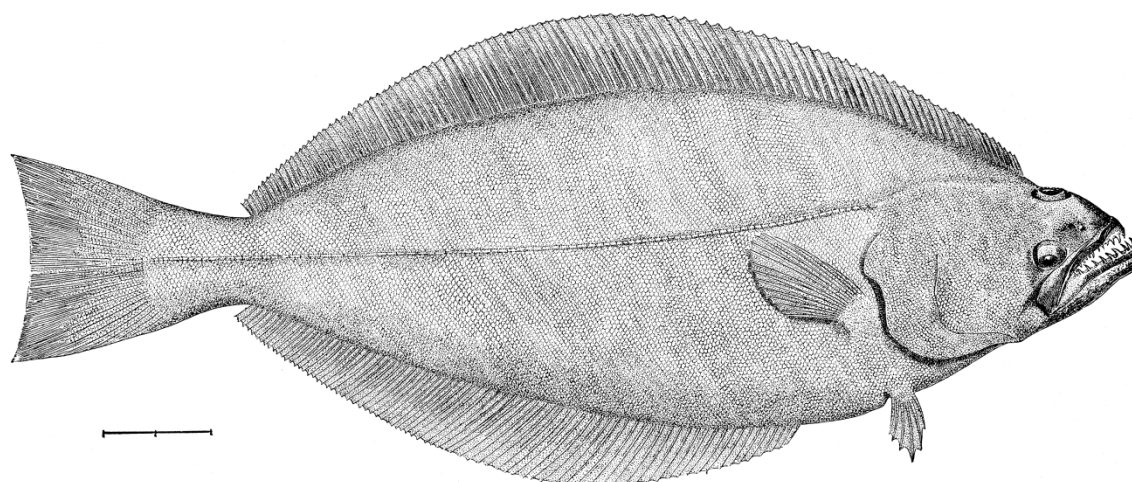
By Steven J. Barbeaux and James Ianelli

Introduction

This year the BSAI Greenland turbot (*Reinhardtius hippoglossoides*) stock assessment will be lead by Dr. Steven Barbeaux. Although the stock will continue to be modeled using the same software as previous assessments (Stock Synthesis 3), there are a number of changes within the model. This paper is meant to guide you through changes in the Greenland turbot assessment dataset and model and identify the effects of these changes on model fit and results and relies heavily on the reader's understanding of the 2011 Greenland turbot stock assessment (Ianelli et al. 2011). **This paper is not meant as a final stock assessment and all results are preliminary and will change prior to the November plan team meeting.** The changes to the data and the assessment model are an attempt to better capture the complex population dynamics of this species due its unique life history and distribution across two geopolitical boundaries (the US-Russian EEZ and the Northern extent of the AFSC surveys).

Change in weight at length relationship

The 2011 Greenland turbot stock assessment model used the same weight at length relationship for males and females ($w = 2.44 \times 10^{-6} \, L^{3.34694}$, where L = length in cm, and w = weight in kilograms). Given the high degree of sexual dimorphism observed in this species it was thought that having separate weight at length relationships for males and females would

better capture the diversity in this stock. A new weight at length relationship has been developed using the combined weight and length data from all bottom trawl surveys conducted by the Alaska Fisheries Science Center in the Bering Sea and Aleutian Islands from 1983 to 2011. There were a total of 2,861 animals measured, 1,380 females, 1,383 males and 98 unidentified used in the analysis. A linear model was fit to the log transform of length and weight as $\log(L) = \alpha S_1(\log(w)) + \beta S_2$, where L is the fork length in centimeters, w is the weight in kilograms α is the slope for females and β is the intercept for females, S_1 is the effect of sex on the slope and S_2 is the effect of sex on the intercept. Results of the linear model are shown in Table 1. The model fit was highly significant with an R^2 of 0.997 and a P-value of less than 2×10^{-16}.

Table 1 Results from linear model on the weight to length relationship for Greenland Turbot.

Coefficient	Estimate	Std. Error	T-value	Pr(>|t|)
α_{Female}	-12.592	0.023	-549.804	$< 2 \times 10^{-16}$
β_{Female}	3.219	0.006	536.719	$< 2 \times 10^{-16}$
S_{1Male}	-0.334	0.032	-10.303	$< 2 \times 10^{-16}$
$S_{1Unident.}$	0.579	0.173	3.349	0.000823
S_{2Male}	0.106	0.008	12.866	$< 2 \times 10^{-16}$
$S_{2Unident.}$	-0.253	0.071	-3.582	0.000347
	$R^2 = 0.997$		P-value $= < 2 \times 10^{-16}$	

This year's model proposes to use $w = 2.43 \times 10^{-6} L^{3.325}$ for females and $w = 3.40 \times 10^{-6} L^{3.2189}$ for males (Fig 1), the conversion of the analysis results out of log space. This relationship is similar to the weight at length relationship observed by Ianelli et al. (1993) and used in the Greenland turbot stock assessment prior to 2002 (Fig. 2).

Male Greenland turbot

$$Barbeaux(2012)= 3.4 \times 10^{-6} L^{3.2189}$$
$$Ianelli\ et\ al.(2011)= 2.44 \times 10^{-6} L^{3.34694}$$

Female Greenland turbot

$$Barbeaux(2012)= 2.43 \times 10^{-6} L^{3.325}$$
$$Ianelli\ et\ al.(2011)= 2.44 \times 10^{-6} L^{3.334694}$$
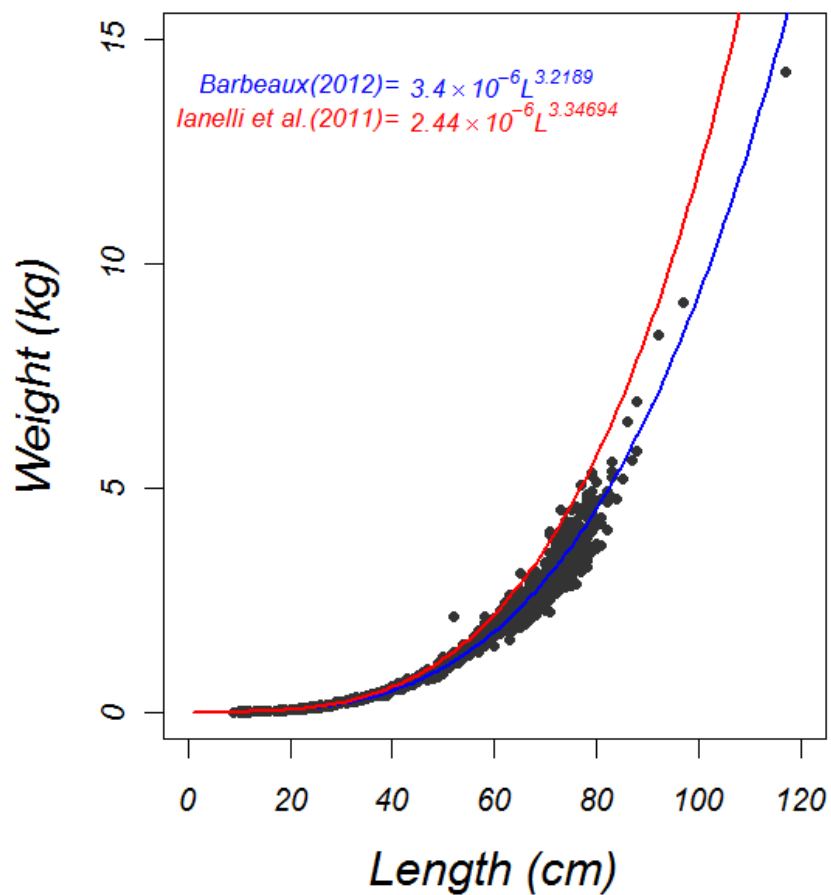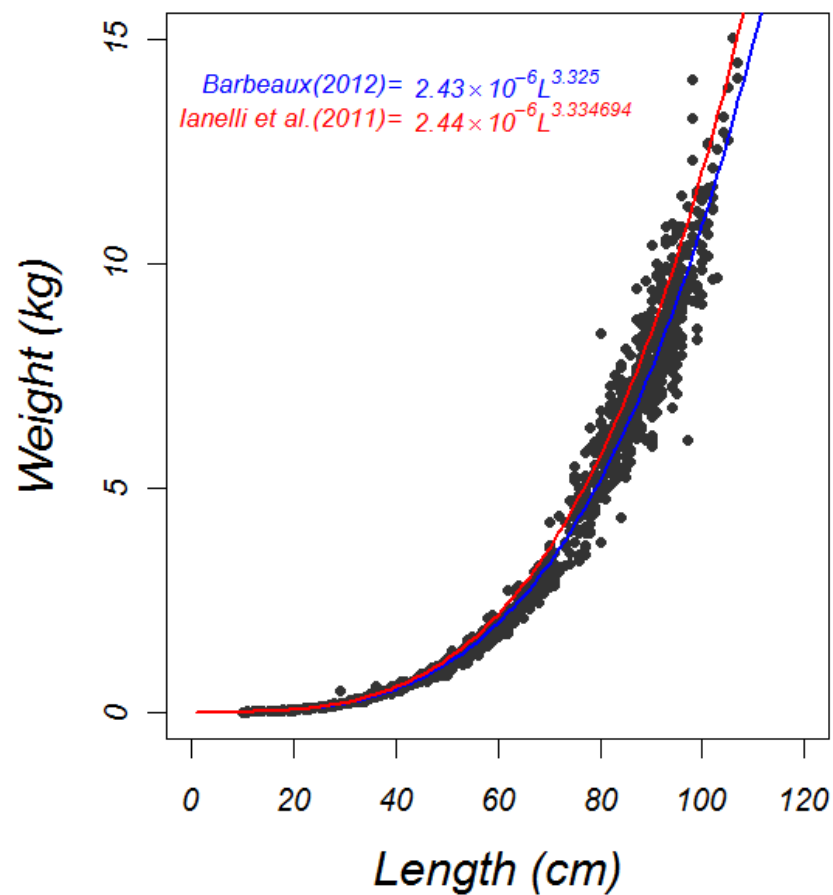
Figure 1   Comparison of weight at length relationship used in 2011 Reference model and proposed relationship. Data are compiled from all Bering Sea and Aleutian Islands trawl surveys 1983- 2011.
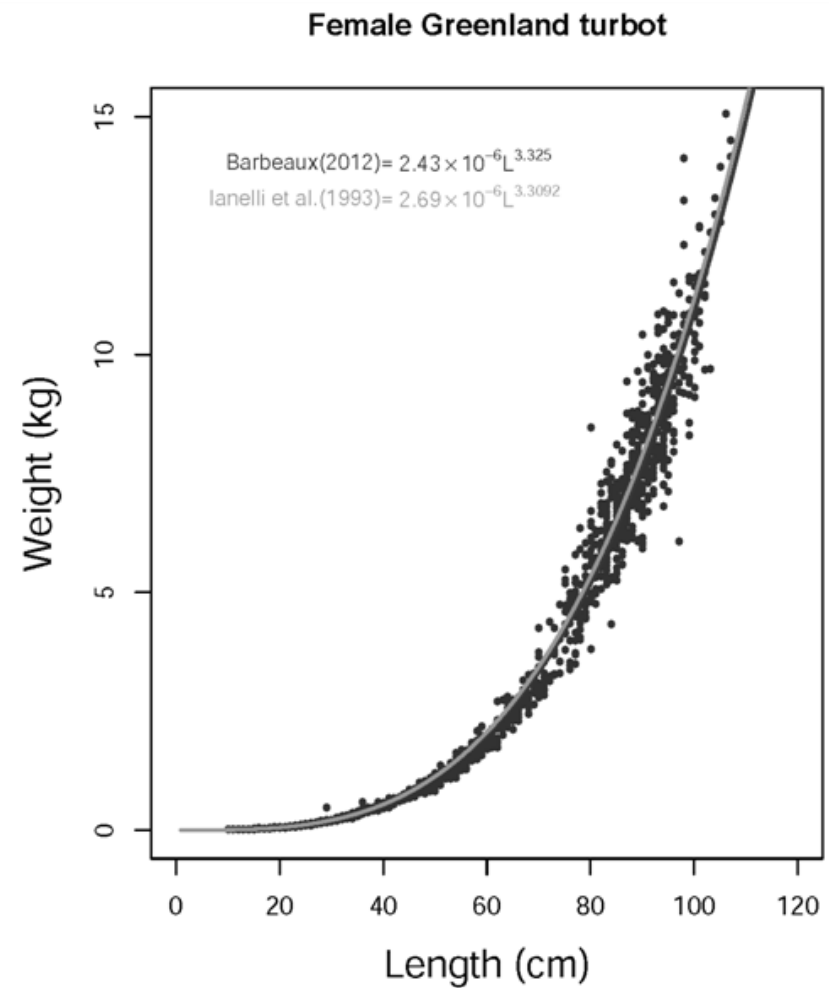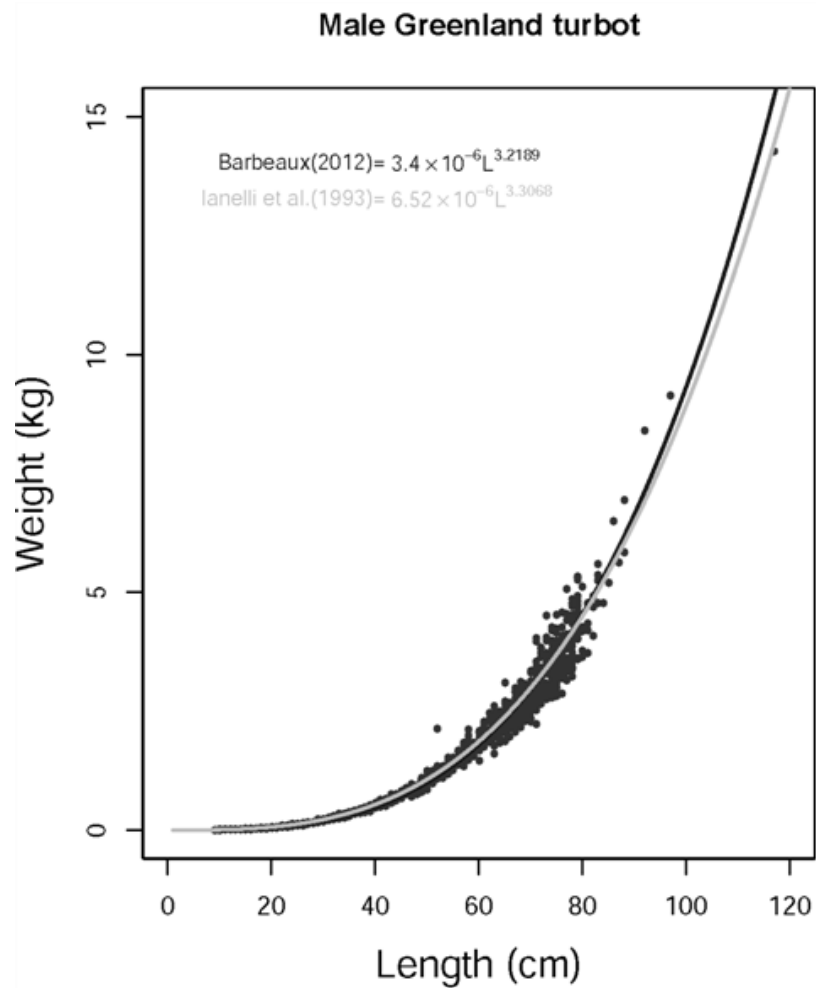
Figure 2   Comparison of weight at length relationship from Ianelli et al. (1993) and proposed relationship derived from fit to all Bering Sea and Aleutian Islands trawl survey data 1983-2010.

Effects of weight length relationship change

       The 2011 reference model was run with the improved weight at length relationship to identify effects to assessment results. The model fit was improved in the new configuration with a lower negative log likelihood overall (LL; Table 2). Most of the improvement was in the fit to size at age (-514 LL) and length composition data (-43 LL). There was slight decrease in goodness of fit to the survey abundance index data (+3.5 LL). The change in weight at length resulted in lighter Greenland turbot at age than in the 2011 stock assessment (Fig. 3). As expected the change also resulted in smaller total and spawning stock biomass estimates (Fig. 4). Further, the change in weight at length resulted in differences in estimated recruitment, particularly for the 1978 year class and early recruitment from 1960 to 1970 (Fig. 4).
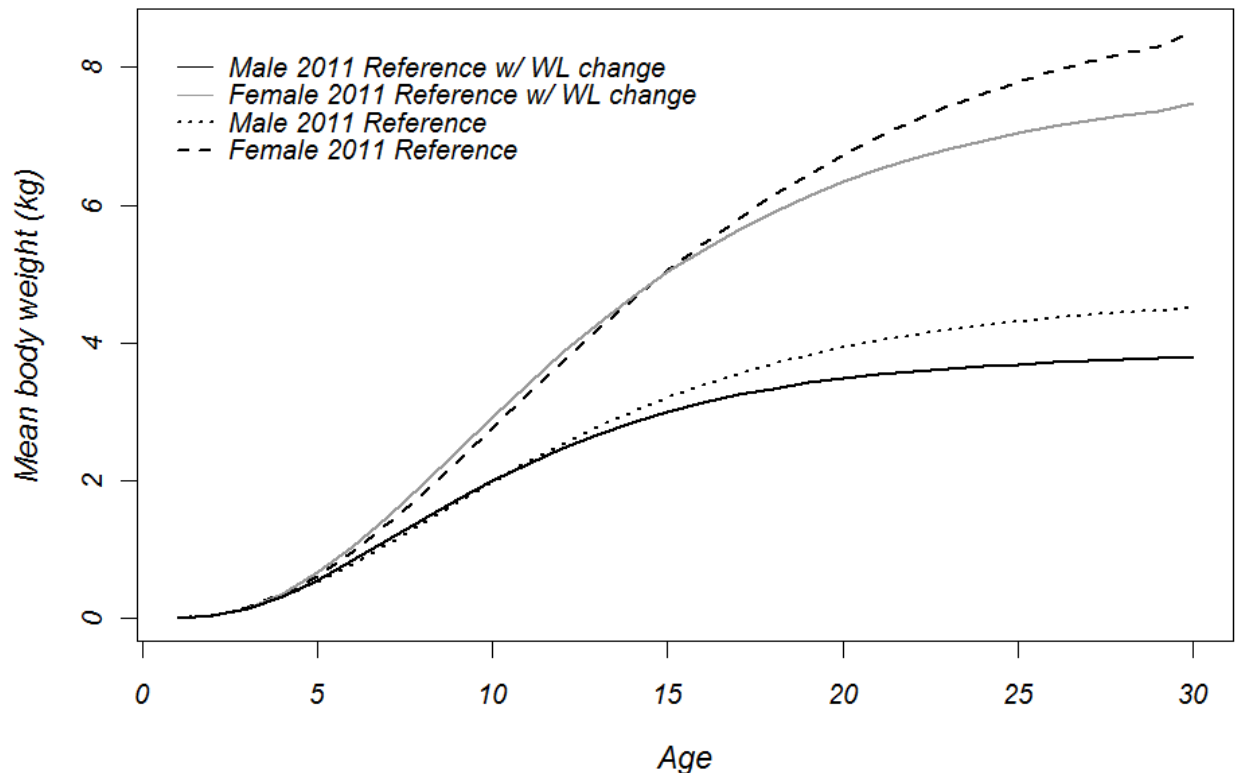
Figure 3   Difference in weight at age due to changing to the improved weight at length relationship.
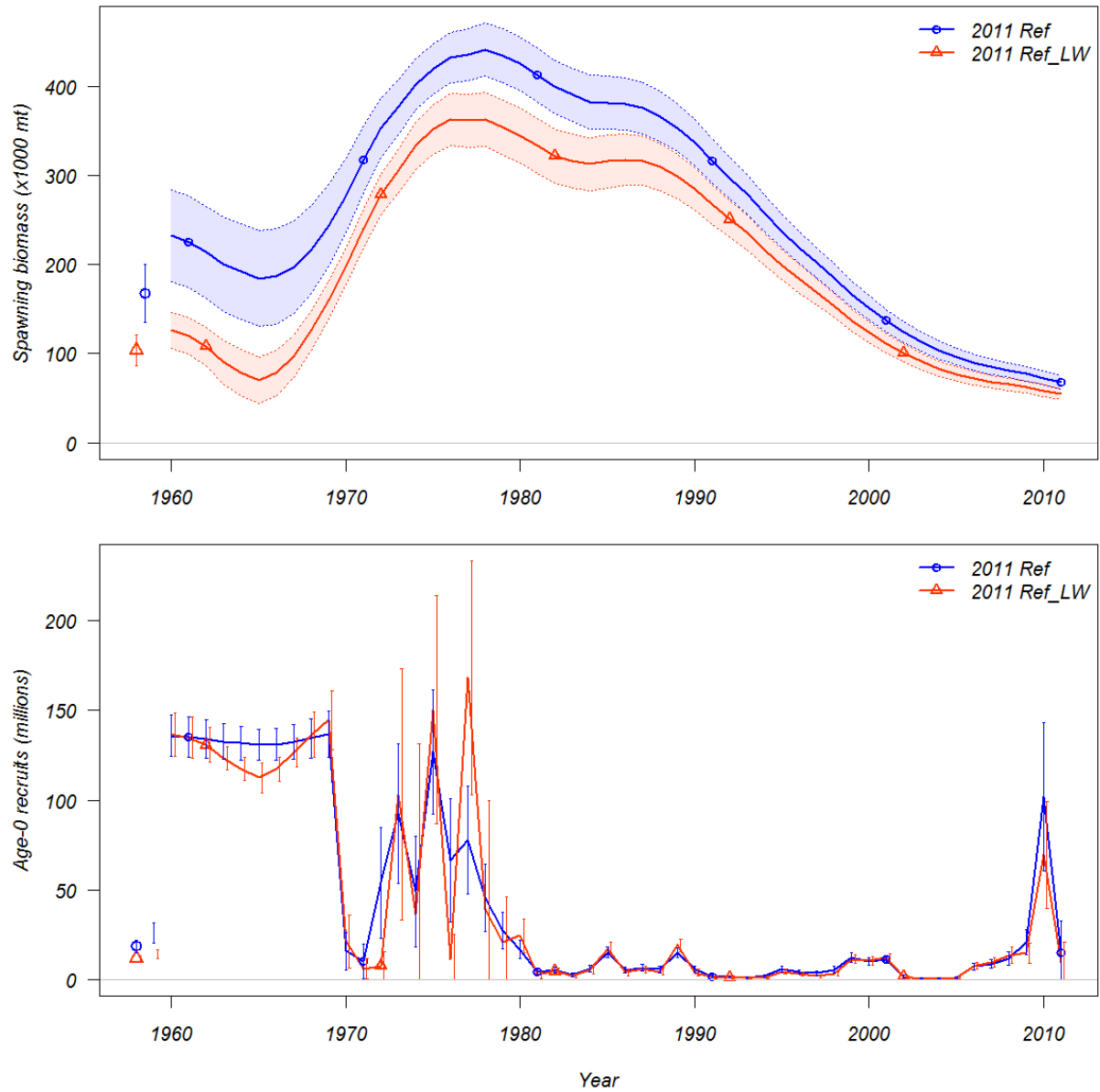
Figure 4 Change in spawning biomass estimates and age-0 recruitment from the 2011 Reference model (2011 Ref) and the 2011 Reference model with the improved weight at length relationship (2011 Ref_LW).

Table 2 Fit to the 2011 Reference model and 2011 Reference model with changes to the improved weight at length relationship (Ref_LW) , with changes to indices (Ref_Ind), changes to size and age composition data (Ref_Comp), and all three sets of data changes combined in the reference model (Ref_All). Shaded values are those where the underlying data have been changed and likelihoods should not be compared with the reference model.

		2011 Ref	Ref_LW	Ref_Ind	Ref_Comp	Ref_All
Likelihoods						
	Total	3879.21	3309.35	3834.43	4321.07	3570.63
	Survey	-30.19	-26.64	-34.20	-30.55	-31.33
	Length Composition	2219.61	2176.56	2179.42	2287.26	2322.36
	Age Composition	215.64	210.01	215.32	238.34	236.8
	Parameter priors	3.44	5.06	3.53	4.93	6.96
	Size at Age	1347.63	833.18	1347.42	1719.87	940.56
	Recruitment	123.09	111.18	122.94	101.23	95.28
Key Parameters						
	LN(R_0)	9.83	9.38	9.82	9.58	9.20
	Q for Shelf Survey	0.73	1.00	0.73	0.51	0.64
	L at Amax Fem	87.31	87.20	87.31	87.31	87.83
	L at Amax Mal	72.93	74.31	72.93	72.93	72.63
	VonBert K Fem	0.12	0.14	0.12	0.12	0.13
	VonBert K Mal	0.10	0.10	0.10	0.10	0.18
Recruits 1960-1969						
Age-0 (1×10^6)	Mean	133.50	128.06	132.55	158.66	147.19
	Median	133.39	128.68	132.46	158.77	149.21
	CV	0.02	0.08	0.02	0.06	0.19
Spawning stock biomass						
(1,000 t)	1978	441.27	358.99	434.27	406.42	327.83
	2011	67.58	57.21	67.85	55.58	46.12

Changes in the Dataset

To ensure that all aspects of the assessment could be replicated and that all corrections made to the data in the database were carried forward in the model, all data used in the model (Fig. 5) were queried anew from their respective databases (see Ianelli et al. 2011). In addition, there are some improvements to how the size composition data are processed prior to inclusion in the proposed 2012 model configuration. All data queries and data processing were conducted in R. The differences in the 2012 Candidate dataset are discussed below and effects to the 2011 Reference model results due to each change are highlighted separately.
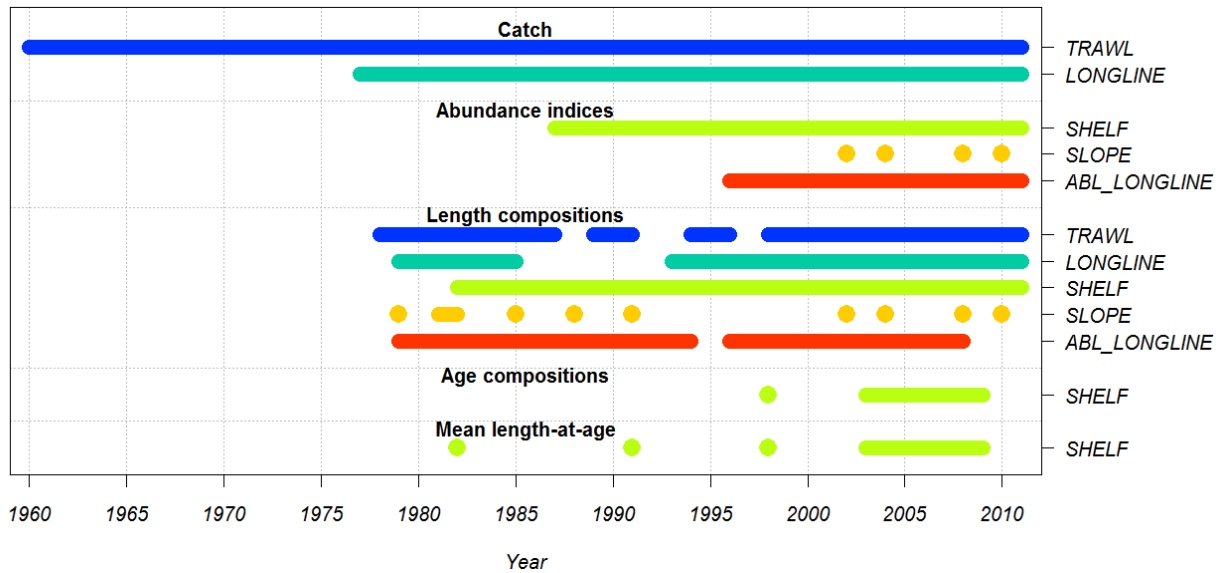
Figure 5 Data sources for the 2012 Greenland turbot stock assessment by type and year. From top to bottom, trawl fishery (Trawl) catch, longline fishery (Longline) catch, Bering sea Shelf trawl survey (Shelf) index, Bering Sea slope trawl survey (Slope) index, Auke Bay longline survey (ABL Longline) index, Trawl length composition data, Longline length composition data, Shelf length composition data, Slope length composition data, Shelf age composition data, and Shelf mean length at age data.

Catch and survey index estimates

Catch estimates were queried directly from the North Pacific Catch Accounting System (CAS) database maintained at the Alaska Fisheries Science Center by Terry Hyatt. There were differences in the most recent (post-2003) catch estimates from the 2011 Reference dataset (Fig. 6). The largest difference was in the 2010 Longline catch estimate, with an increase of 185 tons. The authors do not know why the estimates differ.
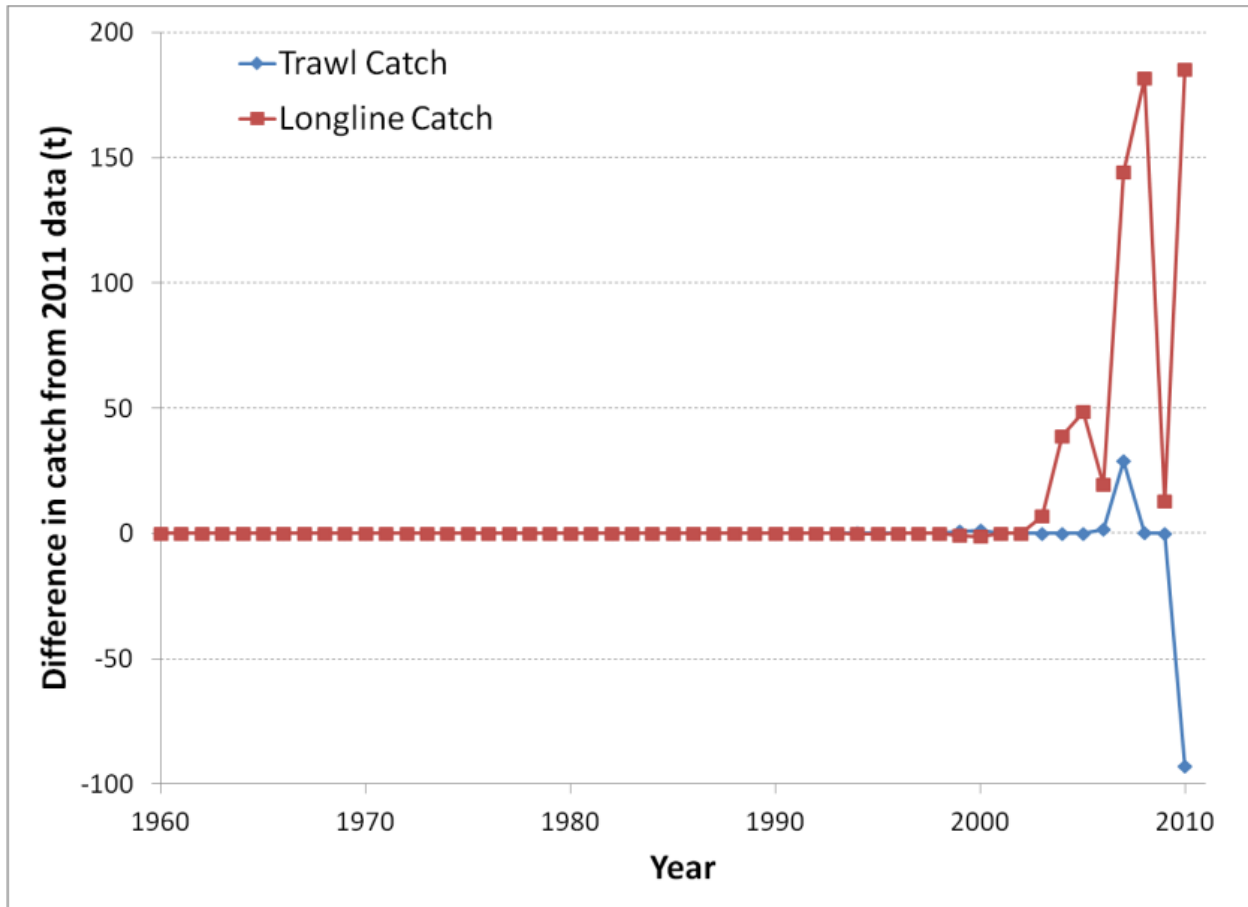
Figure 6   Difference between the 2012 candidate dataset and 2011 Reference dataset for Trawl and Longline catch estimates in tons.

The most substantial change to the assessment survey index dataset was the removal of the six Slope survey abundance index values for surveys conducted prior to 2002. These data were removed after discussions with Dr. Jerry Hoff, the current Slope survey Chief Scientist. Dr. Hoff stated that the older Slope survey data are not comparable to the most recent surveys, and may have not been conducted consistently enough in the early years to be considered a time series. The surveys differed in vessel power, in gear used, and in the ability of the surveyors to determine whether the gear was in contact with the bottom. There were only minor differences (±3%) in index values from the 2011 Reference dataset for the other two survey index values used in the 2012 Candidate dataset.

Effects of changes to indices of abundance and catch estimates on the assessment

Removal of the early Bering Sea slope survey index values and differences in the catch estimates and other survey index values made little impact on the fit or results of the 2011 Reference model (Table 1 and Fig. 7). The slight improvement (-4 LL) to the survey index likelihood can be attributed to fewer data points in the model.
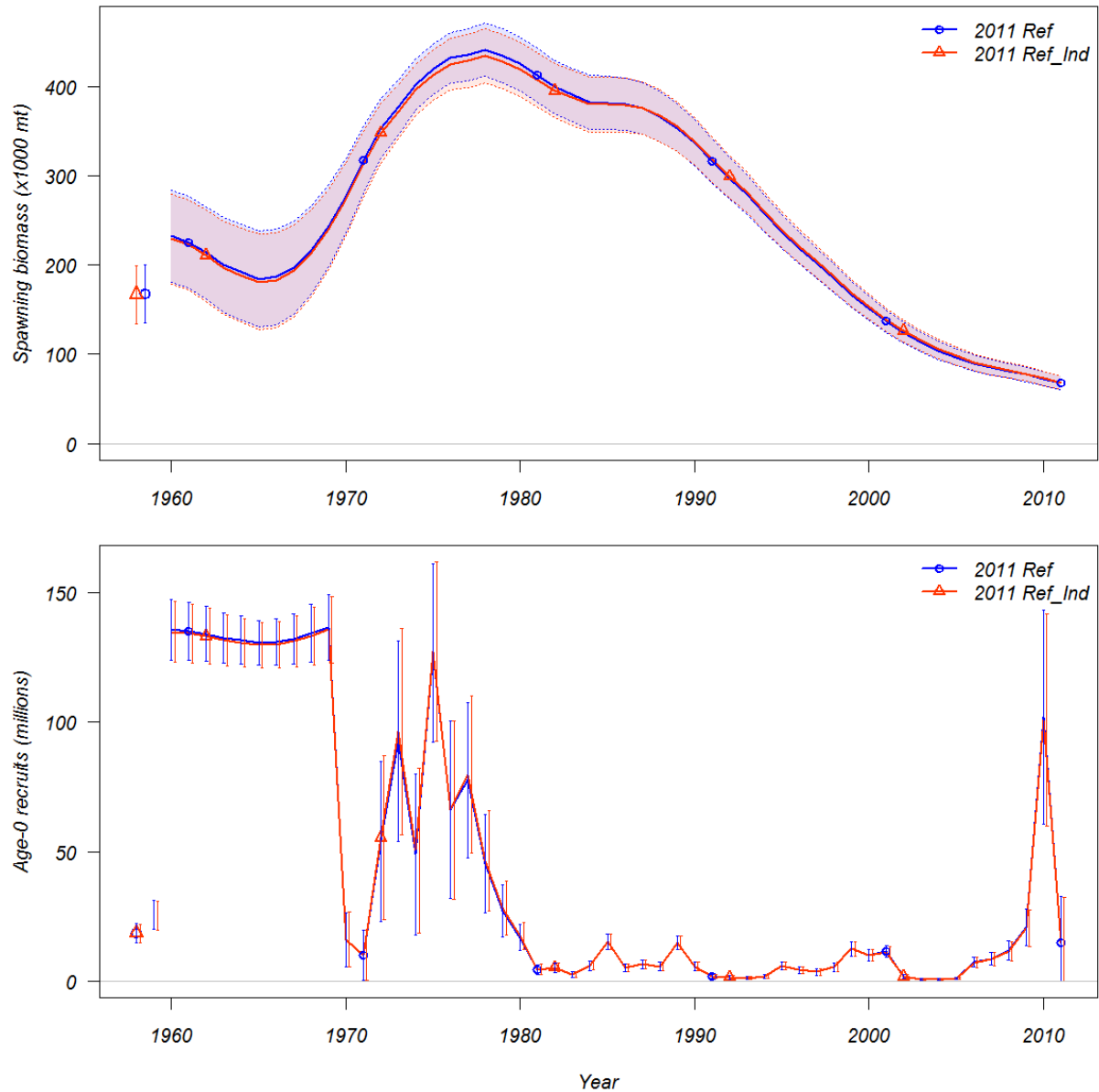
Figure 7 Spawning biomass and age-0 recruitment for 2011 reference model (2011 Ref) and 2011 Reference model with new index and catch estimates and removal of early Bering Sea slope data (2011 Ref_Ind).

Changes in length and age composition data

Fishery length composition data were treated differently this year than in previous years. The raw Trawl and Longline length composition data were proportioned to catch numbers by haul to obtain a more accurate representation of the catch composition. The proportion (P) of fish for a particular length bin (l) and year (y) was calculated as $P_{yl} = \dfrac{\sum\left(\frac{n_{ylh}}{n_{yh}} \times N_{yh}\right)}{\sum N_{yh}}$, where n is the number of fish in a length bin (l) for an individual year (y) and haul sample (h) and N is the total number of fish in a haul (h) for year (y) for each fleet. This assumes that the length composition samples

were representative of the length composition of each sampled haul and that observer haul samples were representative of overall effort in the fleet. Previous assessments assumed that the summed raw fishery length composition samples were representative of the fleet-wide catch length composition. The largest change was in the early trawl female length composition data. In the new dataset the larger females compose a much smaller proportion of the trawl catch for 1977 through 1980 (Fig. 8A). Although there were a large number of length samples taken from the directed trawl fishery in deeper waters where these large female fish were caught, the total number of Greenland turbot observed caught in deeper waters was small in comparison with the observed number of Greenland turbot caught in shallower waters. That is, although fewer samples were taken in the shallower waters, the shallower trawl hauls contained a larger number of smaller fish. The sexed length composition data from 1990 to 2004 in both the trawl and longline fisheries were combined as unsexed in the 2011 Reference dataset, but remained differentiated in the new dataset (Fig. 8a, Fig. 8b, and Fig. 8c). The catch at age composition data were proportioned to catch in the same manner as the length composition data, but there was little difference between the 2011 Reference dataset and the 2012 Candidate dataset (Fig. 9).
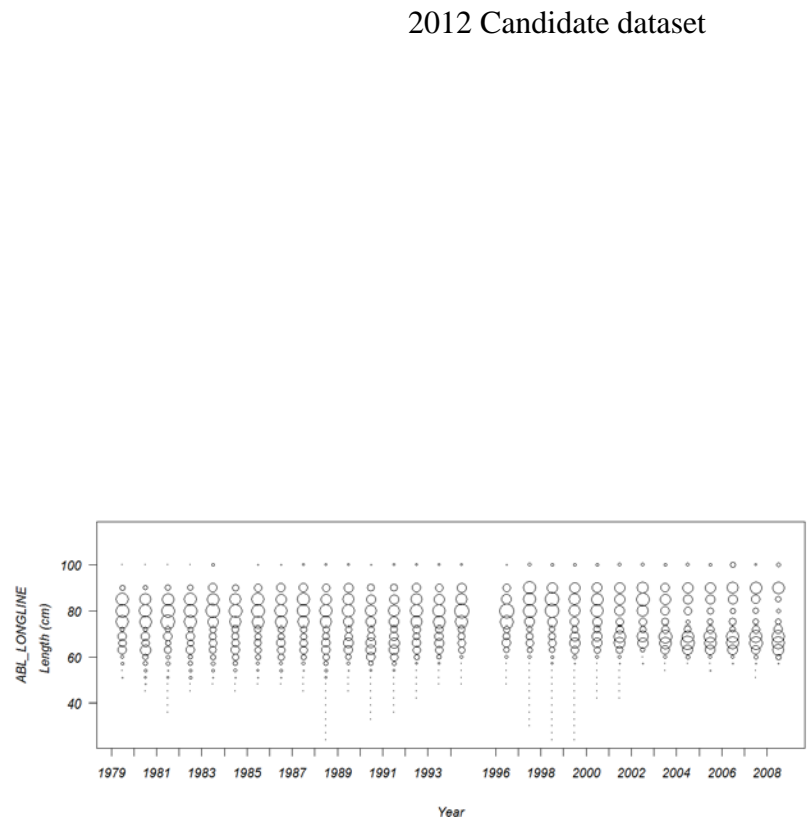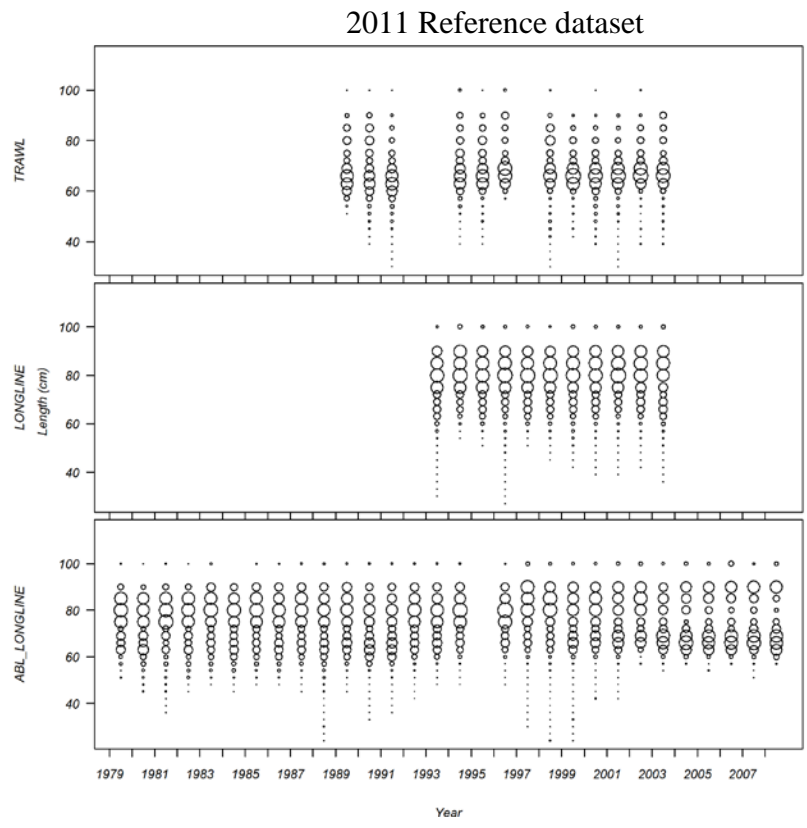
Figure 8a Length composition data from the 2011 Reference dataset (left) and the 2012 Candidate dataset (right) for sexes combined.
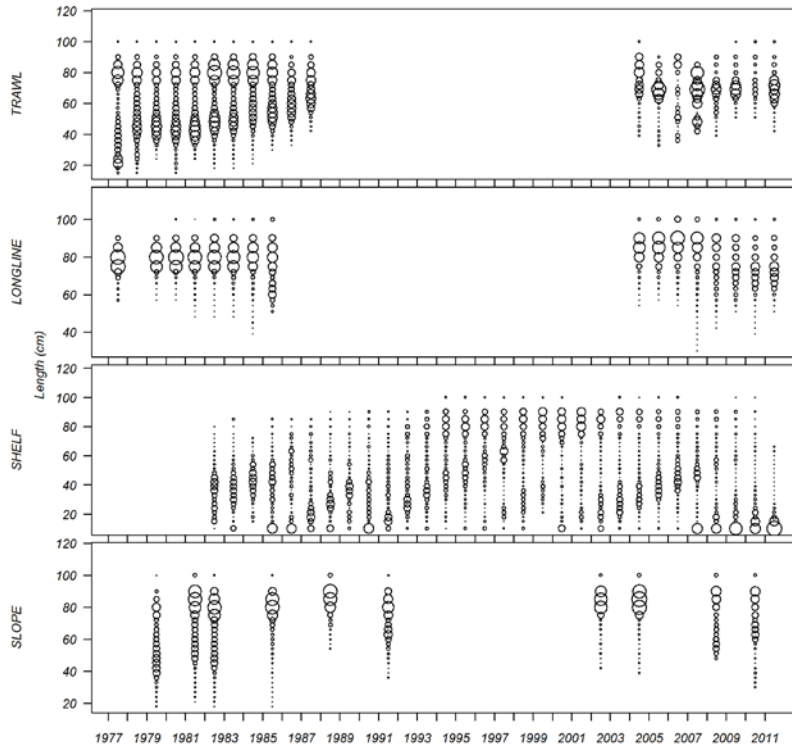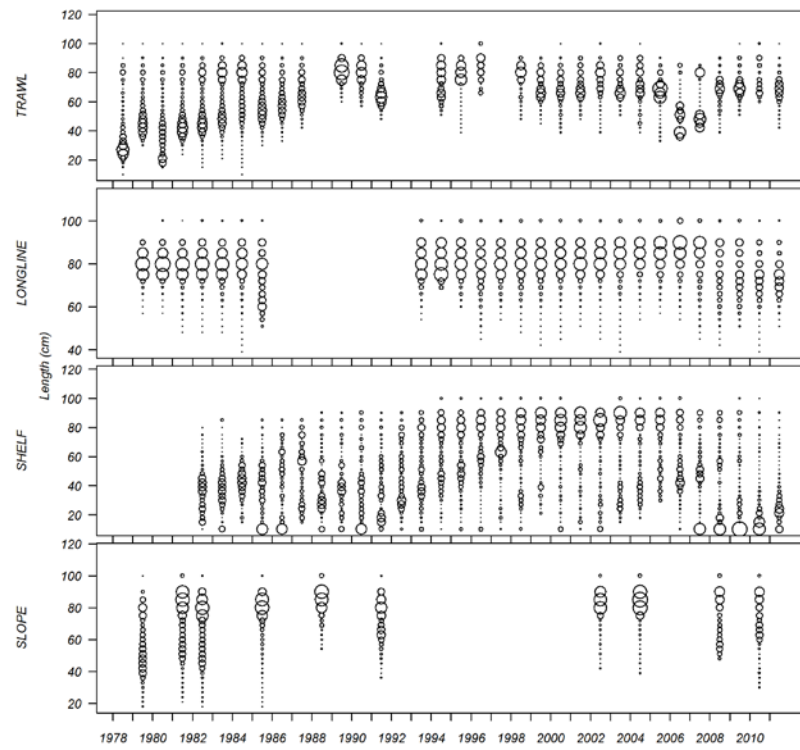
Figure 8b Length composition data from the 2011 Reference dataset and the 2012 Candidate dataset for females.
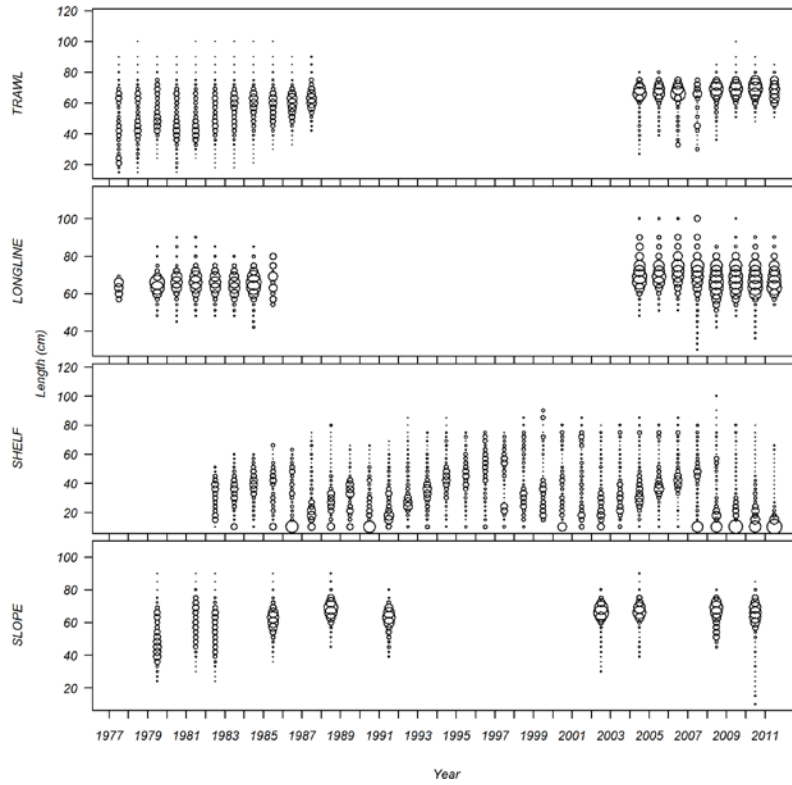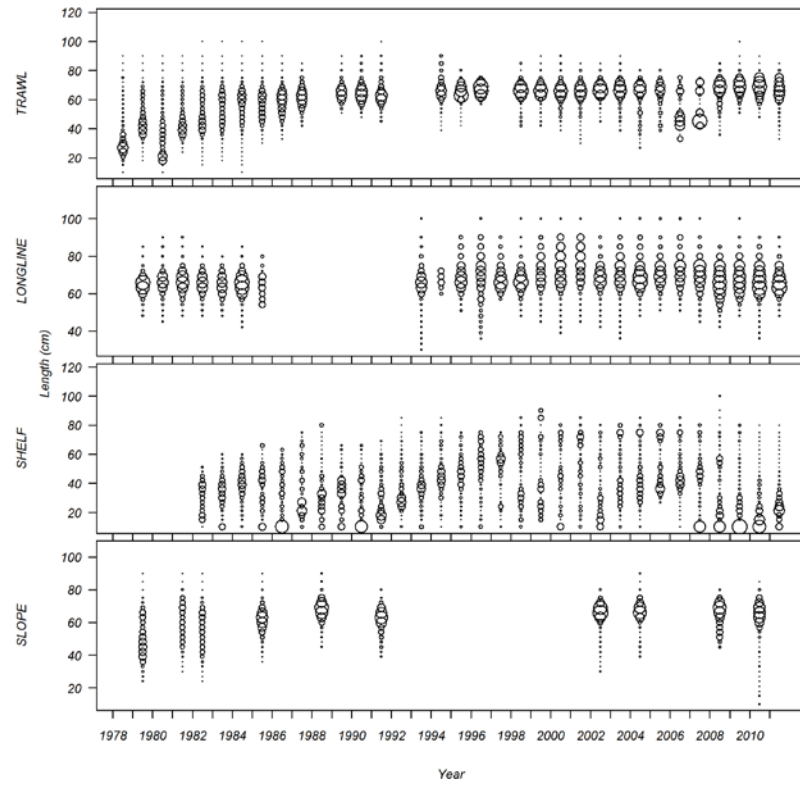
Figure 8c Length composition data from the 2011 Reference dataset and the 2012 Candidate dataset for males.
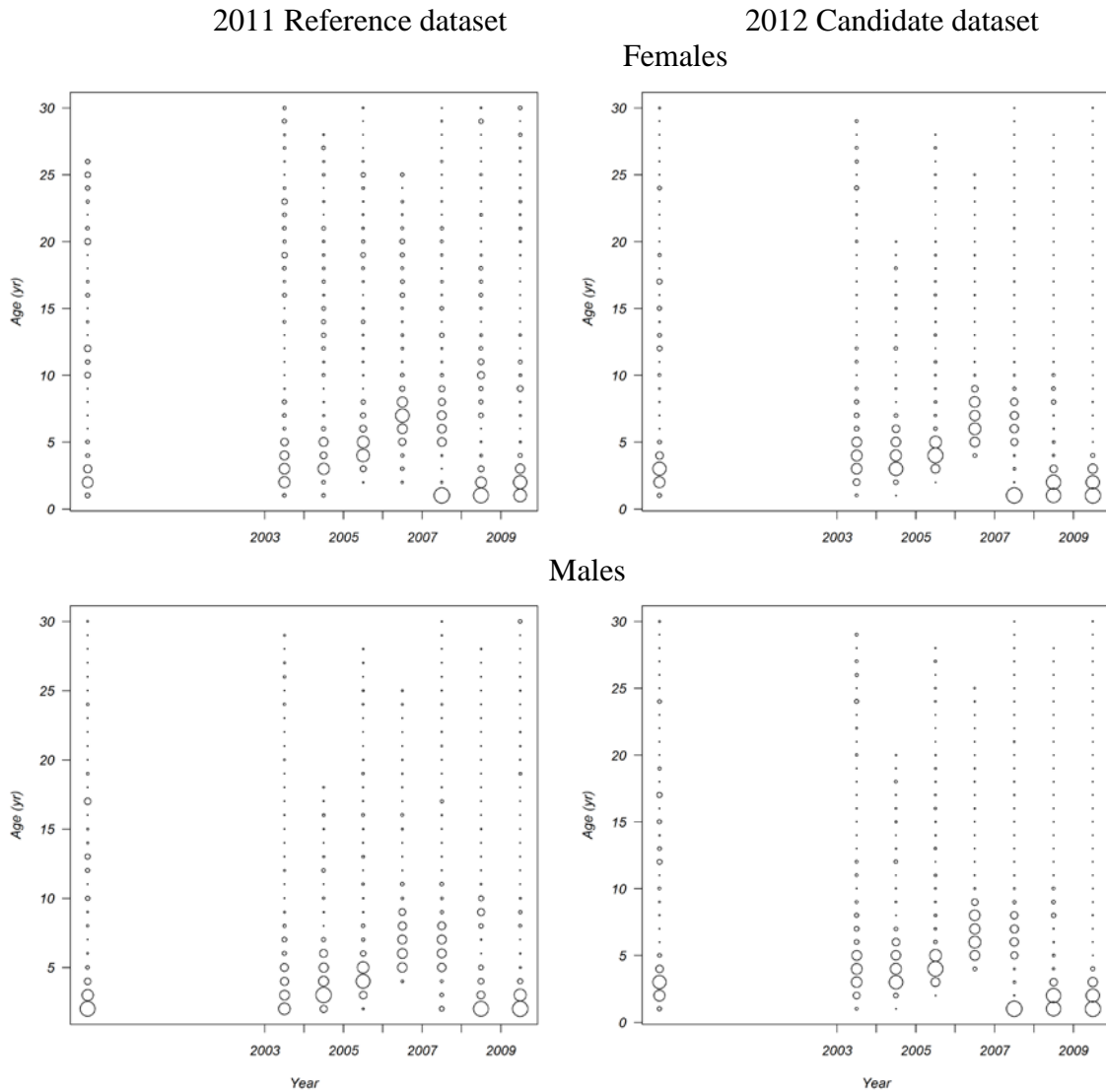
Figure 9 Bering Sea shelf trawl survey age composition data from the 2011 Reference dataset (left) and the 2012 Candidate dataset (right) for females (top) and males (bottom).

For the 2012 assessment we also propose tuning the size composition sample sizes to the output effective sample sizes. Initial sample sizes for the two fisheries for each year was determined as the minimum of 100 + (number of hauls sampled/mean number of hauls sampled/100) or the number of hauls sampled. This schema was meant to reduce the influence of within sample and across haul autocorrelation in very large, single year, sample sizes on model fit. The largest differences in sample size are in the longline fishery (Fig. 10). The maximum sample size in the 2011 Reference dataset was 500 in the 1999 and 2000 longline fishery. The mean sample size in the 2011 Reference dataset for the longline and trawl fisheries was 251 and 114. In the 2012 Candidate dataset the means were 96 and 92 for the longline and trawl fisheries, respectively. The initial annual size composition sample sizes for the surveys were set at the same values as those used in the 2011 Reference dataset. The shelf trawl survey sample sizes were set at 100,

the 2002 through 2010 slope survey sample sizes were set at 50, while those prior to 2000 were set at 25. The ABL longline sample sizes in the 2012 Candidate dataset were set at 60 following prior assessments. The age composition sample sizes in the 2012 Candidate dataset were set at 100, following prior assessments.
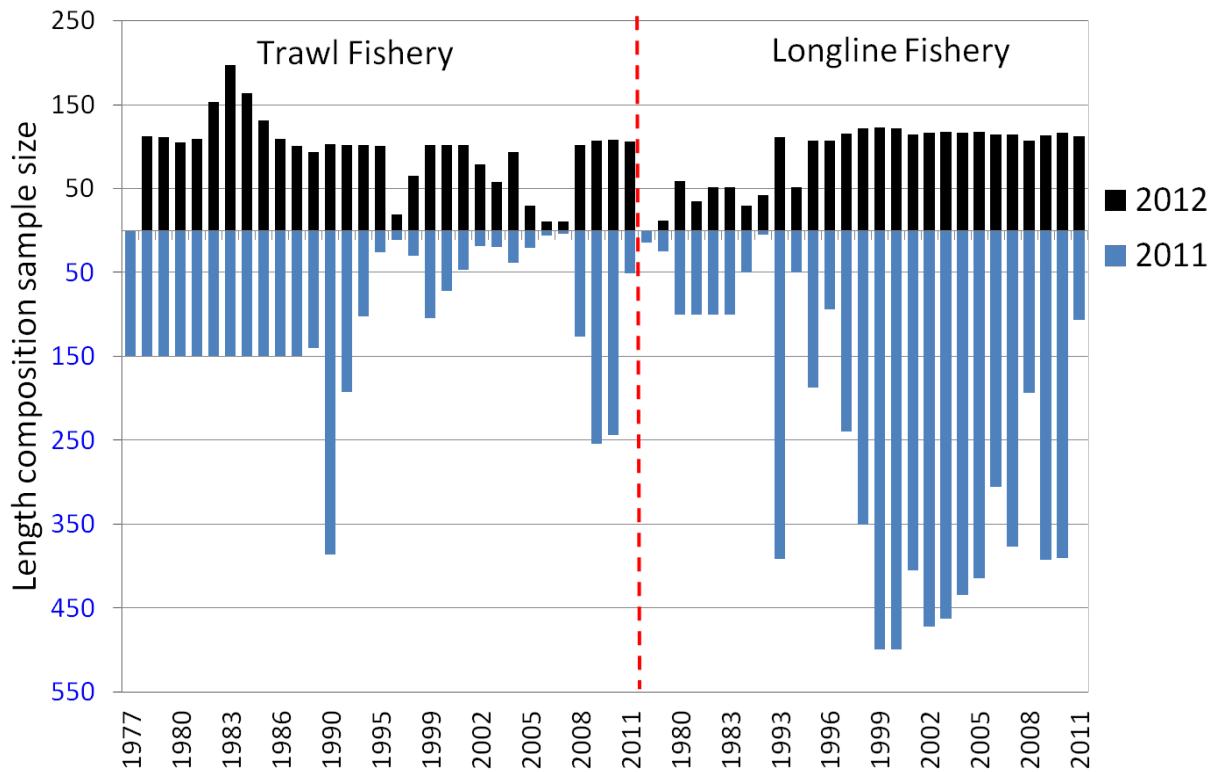
Figure 10 Initial length composition sample sizes for the trawl and longline fisheries in the 2011 Reference dataset (bottom) and the proposed 2012 Candidate dataset (top).

Effects of changes to length and age composition data and input sample sizes

The 2011 Reference model was run with only changes made to the length and age composition data to identify their effects on model results. Because we changed both the underlying data and the multinomial sample size, likelihoods between the 2011 Reference model fit to the old dataset and the model fit to the new dataset are not comparable (Table 2). The largest effect of these data changes was to reduce the estimated spawning biomass (Fig. 11) in spite of a reduction in the Shelf survey catchability (q) estimate from 0.73 to 0.51. Catchability for the Shelf trawl survey in the 2011 reference model was fit with a log uniform, non-informative prior with bounds at -2 and 2. Estimated recruitment in the early period (1960 - 1970) increased due to the smaller proportion of larger, older, females in the 1977 through 1980 trawl fishery length composition data which reduced the estimated 1972 and 1973 year class strength. In addition, the lower estimate of small fish for the 2011 survey in the proposed dataset compared to the 2011 reference dataset greatly reduced the estimate of the 2010 year class strength in the model.
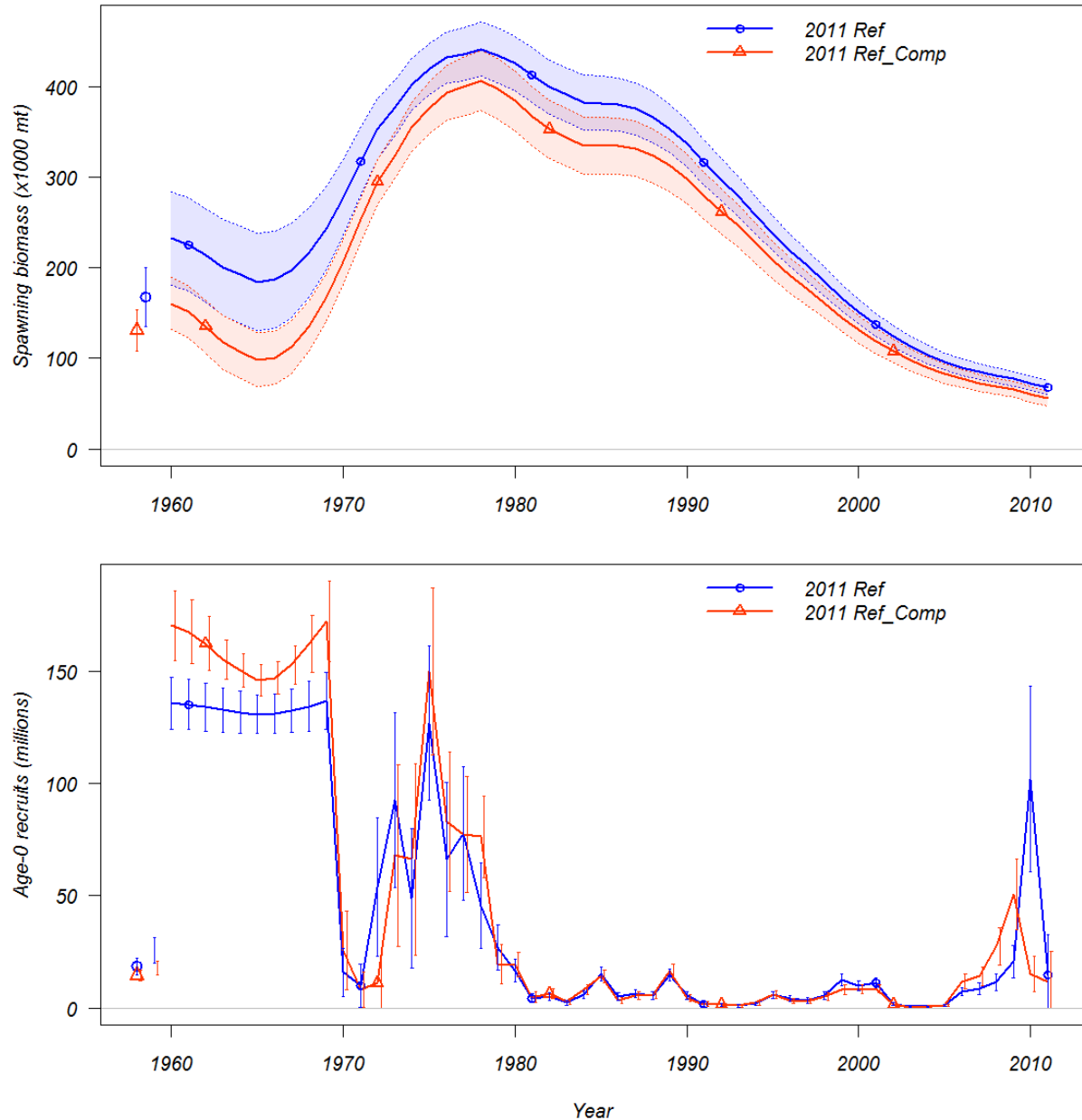
Figure 11 Spawning biomass (top) and age-0 recruitment (bottom) for 2011 Reference model and 2011 Reference
model with new size and age composition data and estimated multinomial sample sizes (2011 Ref_Comp).

Cumulative effects of all data changes to model results

The cumulative effects of all the changes to the 2011 Reference dataset to the model
results show an overall reduction in the estimated spawning biomass in spite of a reduction in
estimated catchability for the shelf survey from 0.73 to 0.64, due to the change in the weight at
length relationship (Table 2 and Fig. 12). The large 1977 year class in the 2011 Reference model
is shifted to 1978. Recruitment in the 1972-1974 year classes is greatly reduced, but the 1975 and
1978 year classes are larger to account for the large Greenland turbot in the 1980's fisheries and
surveys. Assessment of the model fit to these new data is not really relevant at this point. Model

changes to accommodate these new data and better selectivity curves for these new data will be addressed below.
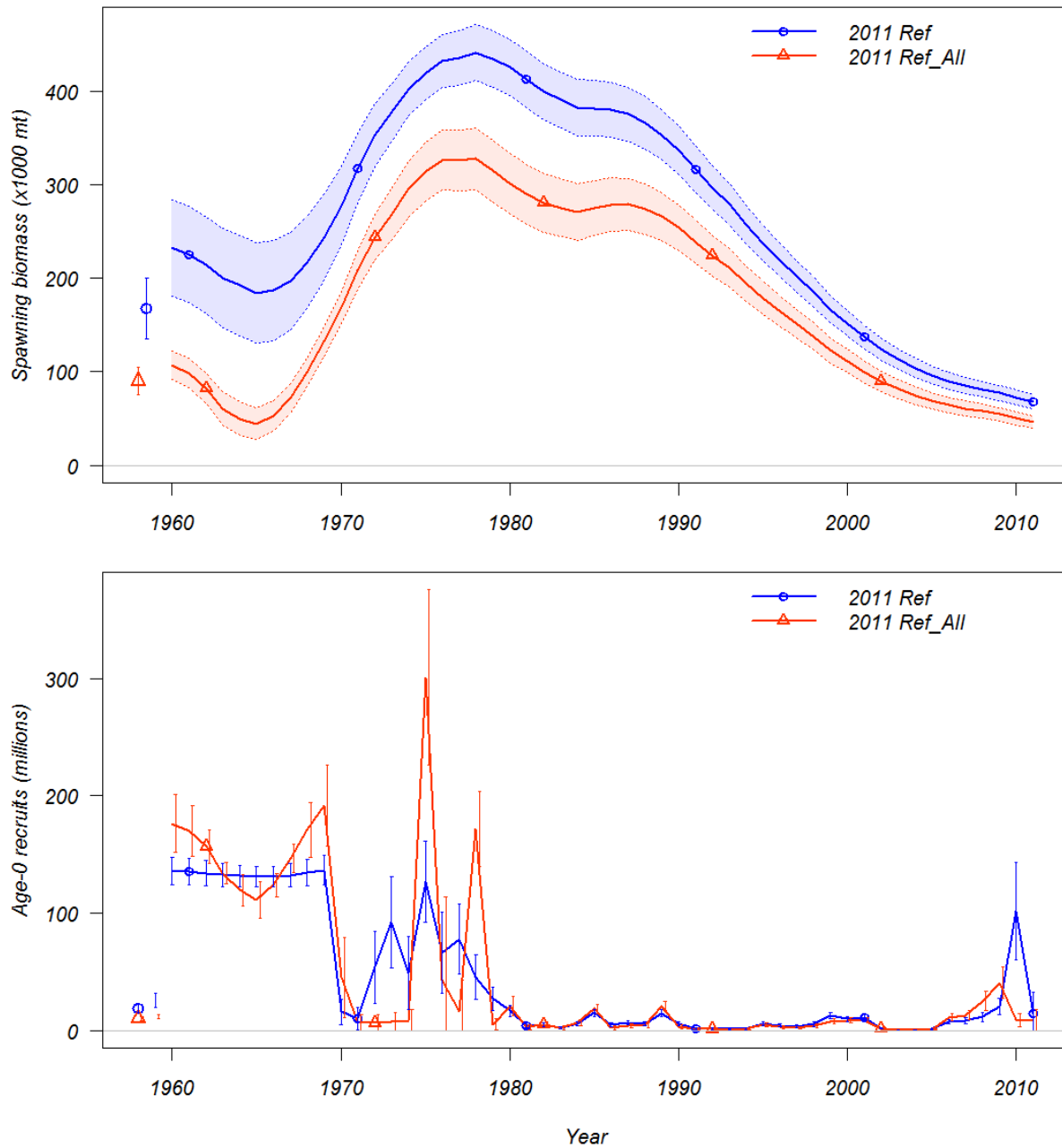
Figure 12 Spawning biomass (top) and age-0 recruitment (bottom) for 2011 Reference model and 2011 Reference model fit to the 2012 Candidate dataset with changes to the weight at length relationship, catch and index values, and length and age composition data applied.

Effects of tuning the length composition sample size

Once the 2011 Reference model was fit to the new data we proportionally reduced the sample size for each fishery or survey until the mean input sample size was close to the mean

effective sample size. Candidate models were not precisely tuned as these are preliminary proposed models and more effort was placed on ensuring the models had the proper structure. More effort in precisely tuning the models will be expended for the final models presented in November. Table 3, Figure 13, and Figure 14 show the adjustment done to the 2011 Reference model with all changes (2011 Ref_All), the tuned version of this model (2011 T_Ref_All), and one of the 2012 Candidate models (2012 RS_1Q) and their effects on spawning biomass and recruitment.   Comparing fits to the length composition data between the 2011 Reference model with all data changes and the tuned version is not possible using likelihood as the overall weighting of the data is changed. Residual patterns in the length and age composition data remain similar and there appears to be little difference in the fit. As the weighting was reduced for the length composition data, the fit (Table 2 and Table 4) to all other data was slightly improved (-41 LL; -4%), mostly in the fit to the size at age data (-28 LL; -3%) and some improvement to the fit to the survey indices (-3 LL; -10%).

Table 3 Mean effective and adjusted input sample sizes and the sample size adjustment factor for three model configurations.

	TRAWL	LONGLINE	SHELF	SLOPE	ABL_LONGLINE
2011_Ref_ALL					
Mean Effective N	53	58	85	48	65
Mean adjusted input	96	92	100	35	60
Adjustment	1.00	1.00	1.00	1.00	1.00
2011 T_Ref_All					
Mean Effective N	55	57	80	55	67
Mean adjusted input	48	74	72	35	40
Adjustment	0.50	0.80	0.72	1.00	0.66
2012 RS_1Q					
Mean Effective N	57	70	80	40	49
Mean adjusted input	48	74	72	35	40
Adjustment	0.50	0.80	0.72	1.00	0.66
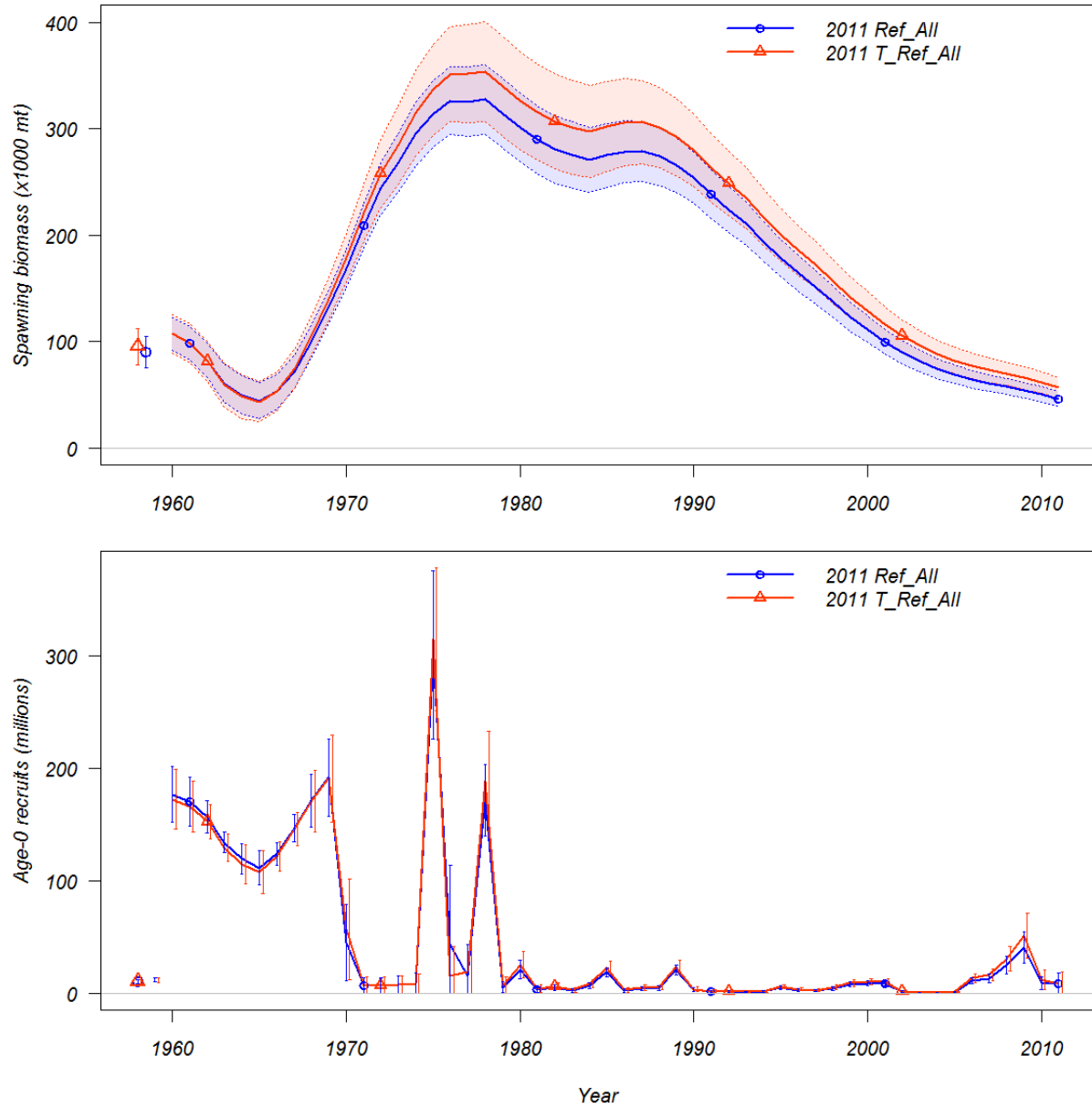
Figure 13 Spawning biomass (top) and age-0 recruitment (bottom) for 2011 Reference model fit to the 2012 Candidate dataset with changes to the weight at length relationship, catch and index values, and length and age composition data applied (2011 Ref_All) and this model tuned (2011 T_Ref_All).

	2011 Ref_All	2011 T_Ref_All	2012 RS$_1$Q

Trawl Fishery Females

Trawl Fishery Males

Longline Fishery Females

Longline Fishery Males
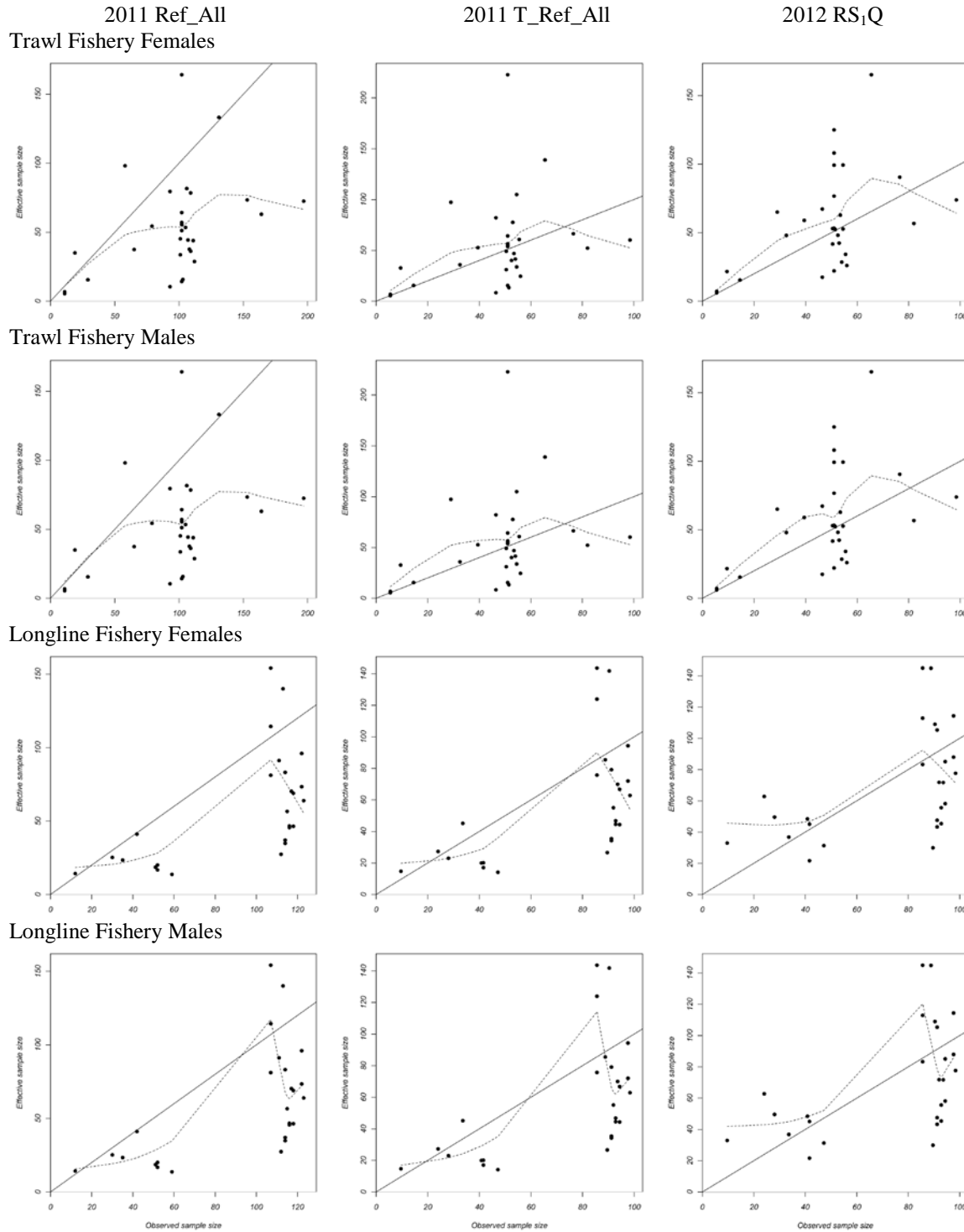
Figure 14 Expected sample size for the 2011 Reference model with all data changes (2011 Ref_All), the 2011 Reference model with all data changes and tuned sample size (2011 T_Ref_All) and one of the 2012 Candidate models with changes to recruitment, catchability, and selectivity (2012 RS$_1$Q). The solid line is the 1:1 line while the dotted line is a loess smoother fit.

Changes in the Assessment model

Recruitment and generating initial conditions

Because there was a large fishery on this stock prior to there being size or age composition data available (1960 – 1979; Fig.15), assumptions need to be made on the composition of the population for these early years if the early catches are to be included in the model. In the past when selecting the most parsimonious model in SS3 using maximum likelihood, a size/age distribution with a single, seemingly random, large recruitment event is selected. This was not deemed satisfactory by the previous stock assessment author. Recruitment in the 2011 Reference model was assumed to follow a Beverton-Holt stock recruitment curve with steepness at 0.9 and sigma R at 0.6. In order to generate a more diverse size/age structure in the population at the time data become available and to support the early fishery, the 2011 Reference model was fit with a higher R_0 in the years 1960 through 1969 than in following years. Recruitment pre-1970 was assumed to follow a spawner-recruit curve with no deviation. Recruitment deviations post-1970 were assumed to be simple lognormal deviations bounded between -7 and 7. The 2011 Reference model therefore assumed a higher productivity prior to 1970 and different recruitment relationships for years 1960 through 1969 than years 1970 through 2010 (Fig.16).
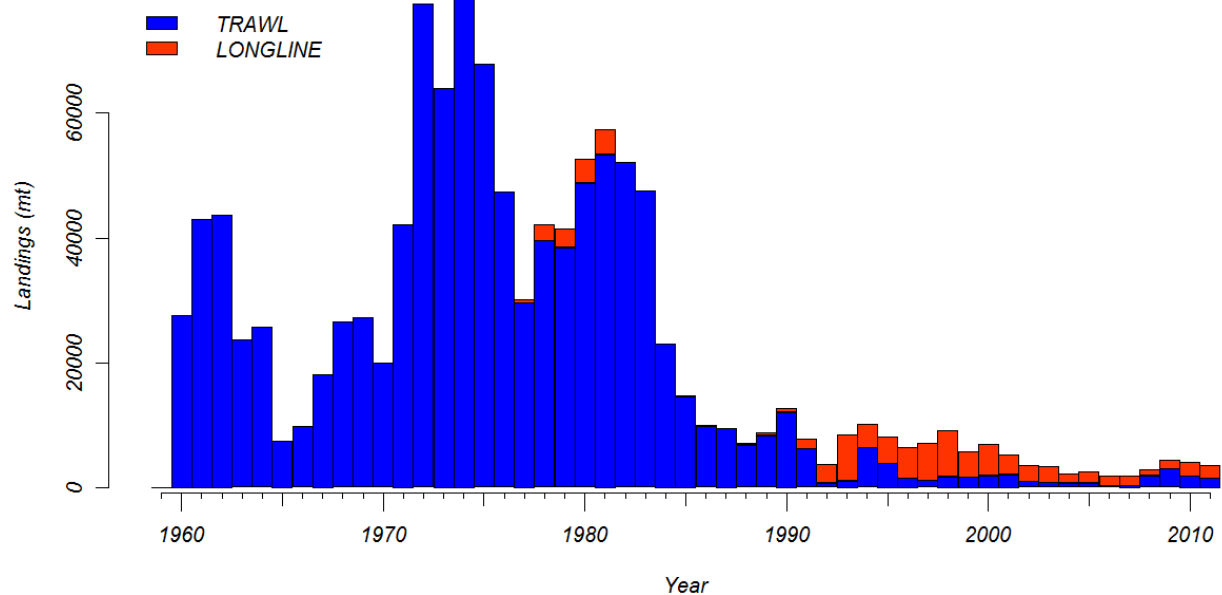
Figure 15 Greenland turbot Longline and Trawl catch in the Bering Sea and Aleutian Islands area from 1960 through 2011. This data includes targeted catch and bycatch.
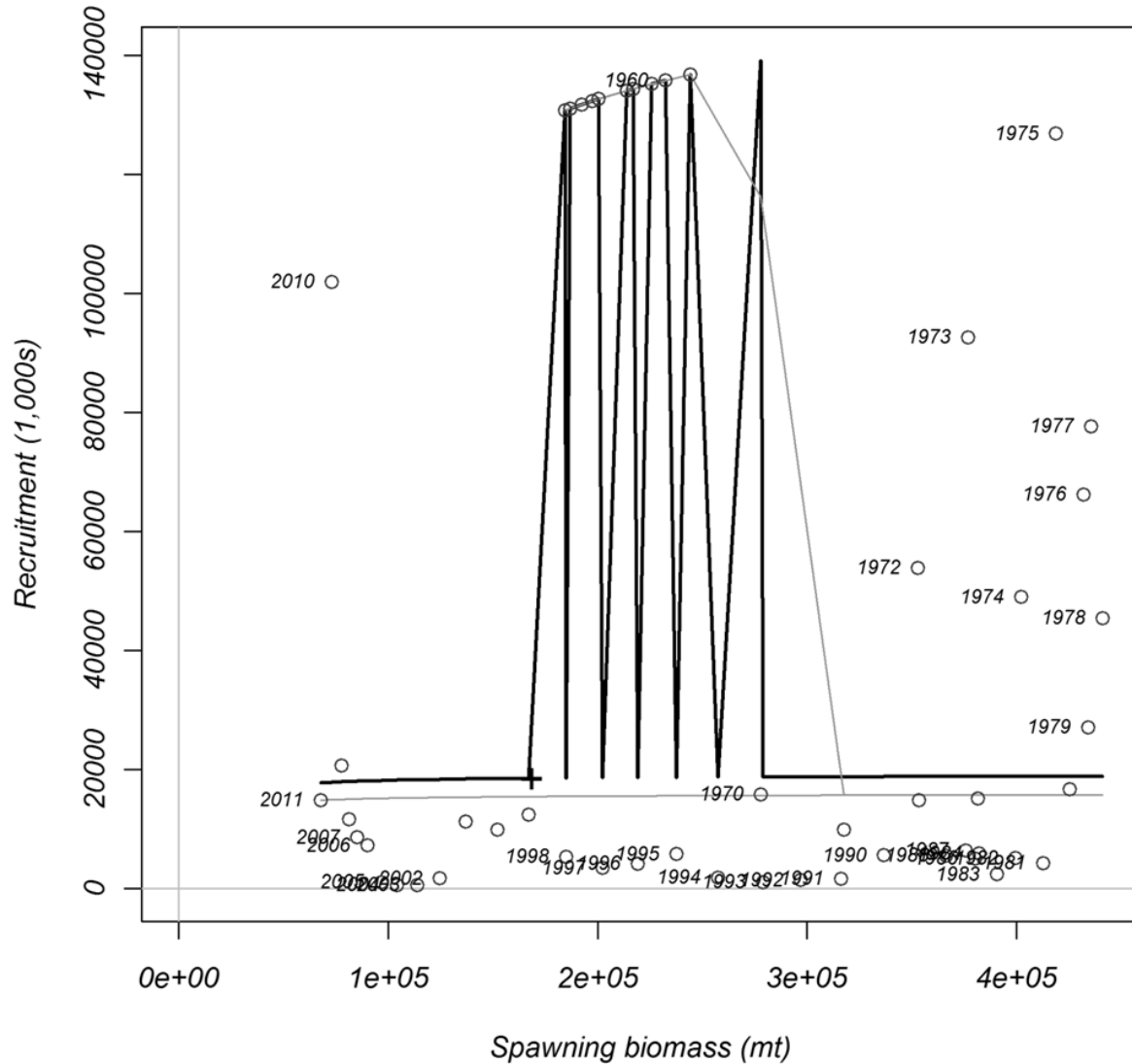
Figure 16 Combined early and late period stock recruitment relationship for 2011 Reference model showing the two different Beverton-Holt recruitment curves combined (grey line) and higher assumed productivity in the years 1960 -1970 than in later years.

In the 2012 Candidate models a single R_0 is assumed for all years. The models are fit to Beverton-Holt stock recruitment curve with a steepness (h) of 0.79 consistent with values found for Greenland turbot stocks in the North Atlantic and Arctic Ocean (Mertz and Myers 1996, Myers et al. 1999) An autocorrelation parameter was also investigated where the prior component due to stock-recruitment residuals (ε_i) is $\pi_R = \dfrac{\varepsilon_1^2}{2\sigma_R^2} + \sum_{i=2}^{n} \dfrac{\left(\varepsilon_i - \rho\varepsilon_{i-1}\right)^2}{2\sigma_R^2\left(1-\rho^2\right)}$, where ρ is the autocorrelation coefficient, and σ_R^2 is the assumed stock recruitment variance term. Although different ρ-values were explored, ρ was fixed at 0.7 for all models presented in this document. The starting year in all models was pushed back from 1960 to 1945 to allow the model more time to build a diverse population size distribution as expected from a species with an assumed natural

mortality of 0.112 (Fig. 17). Recruitment deviations for 1945 through 2011 were assumed to be simple lognormal deviations bounded between -5 and 5.
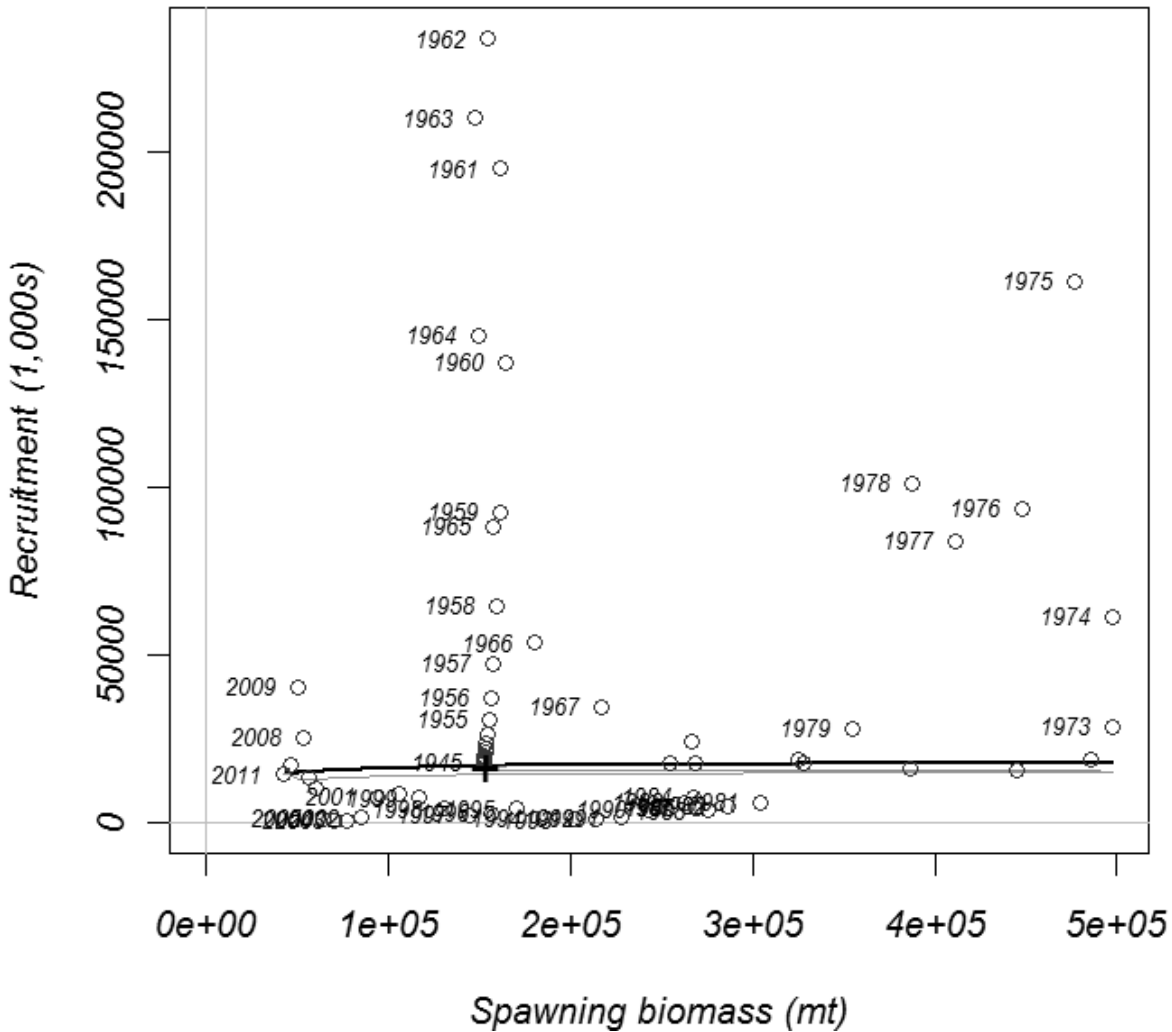
Figure 17 Stock recruitment assumed in the 2012 Candidate model 2012 R which is the 2011 T_Ref_All model with changes to recruitment. Higher productivity in the 1960s to account for high early catches is modeled as deviations from a single stock recruitment curve (grey line).

Effects of changes to recruitment and initial conditions

The changes to recruitment improved overall model performance (Table 4) with a lower negative log likelihood (- 42 LL, -2%). This improvement was made in fitting both the survey indices (-1.5; -5%) and the length composition (-58.7; -4%) with some slight degradation in fit to the size at age (+6.4; 1%) and an increase in the penalty on the priors (+18.4, +275%). The 2011 tuned reference model fit to the new data (2011 T_Ref_All) had a mean recruitment for 1960 through 1970 of 147 million age-0 fish and a coefficient of variation (CV) of 0.19. The estimates the 2012 Candidate model with only a change in recruitment (2012 R) are much lower

(mean 114 million age-0 fish), but with a much higher CV (0.71). The result of the change in how the early recruitments are handled is a smooth curve of recruitment peaking in 1962 with a large degree of uncertainty around the estimates compare to the nearly flat and highly certain recruitment assumed in the 2011 Reference model (Fig. 18). The lack of uncertainty in the 2011 Reference model early recruitment translates into overconfident estimates of early biomass and current stock status (Fig. 18). The 2012 Candidate recruitment model more accurately reflects the degree of uncertainty in these early estimates and better reflects uncertainty in the early estimates of biomass and current stock status.

Table 4 Fit to the 2011 Reference model with and all three sets of data changes combined (2011 Ref_All), Ref All with tuned composition data (2011 T_Ref_All) and 2012 models with changes in early recruitment (R), alternative selectivity curves (S_1 and S_2), changes in catchability assumptions (Q), and an alternative assumption on Sigma R (V) .

		2011 T_Ref_All	2012 R	2012 RS$_1$	2012 RS$_2$	2012 RS$_1$Q	2012 RS$_2$Q	2012 RS$_1$QV	2012 RS$_2$QV
Likelihoods									
	Total	2799.53	2757.43	2713.68	2660.87	2708.83	2653.99	2664.90	2609.93
	Survey	-28.30	-29.81	-25.11	-24.88	-25.67	-27.12	-26.75	-27.86
	Length Composition	1606.11	1547.42	1439.42	1386.66	1442.19	1389.24	1424.02	1370.61
	Age Composition	221.47	221.77	215.34	216.79	215.02	216.42	212.81	214.24
	Parameter priors	6.69	25.12	34.39	33.99	33.82	34.39	34.08	34.43
	Size at Age	912.10	918.51	972.78	971.14	968.63	966.12	970.33	967.91
	Recruitment	81.46	74.41	76.87	77.17	74.84	74.95	50.41	50.60
Key Parameters									
	SR_LN(R0)	9.24	9.73	9.68		9.73	9.73	9.70	9.71
	H – steepness	0.9	0.79	0.79	0.79	0.79	0.79	0.79	0.79
	Sigma R	0.6	0.6	0.6	0.6	0.6	0.6	0.9	0.9
	ρ - autocorrelation	0	0.7	0.7	0.7	0.7	0.7	0.7	0.7
	Q for Shelf Survey	0.57	0.70	0.78	0.77	0.70	0.68	0.73	0.70
	Q for Slope Survey	0.75	0.75	0.75	0.75	0.58	0.55	0.60	0.56
	L_at_Amax_Fem	87.99	87.87	88.54	88.57	88.50	88.51	88.50	88.51
	L_at_Amax_Mal	73.76	72.48	72.63	72.77	72.61	72.77	72.59	72.74
	VonBert_K_Fem	0.14	0.13	0.12	0.12	0.13	0.12	0.12	0.12
	VonBert_K_Mal	0.18	0.19	0.18	0.18	0.18	0.18	0.18	0.18
Recruits 1960-1969									
Age-0 (1 × 10^9)	Mean	147.20	114.09	104.78	101.31	104.57	103.02	113.18	112.47
	Median	149.21	112.75	88.45	83.93	88.75	84.12	81.32	74.60
	CV	0.19	0.71	0.60	0.62	0.59	0.61	0.79	0.82
Spawning Stock Biomass									
(1,000 t)	1978	353.92	387.18	197.87	174.62	206.03	182.45	206.36	183.22
	2011	56.75	42.86	19.73	20.02	25.39	27.25	24.00	25.79
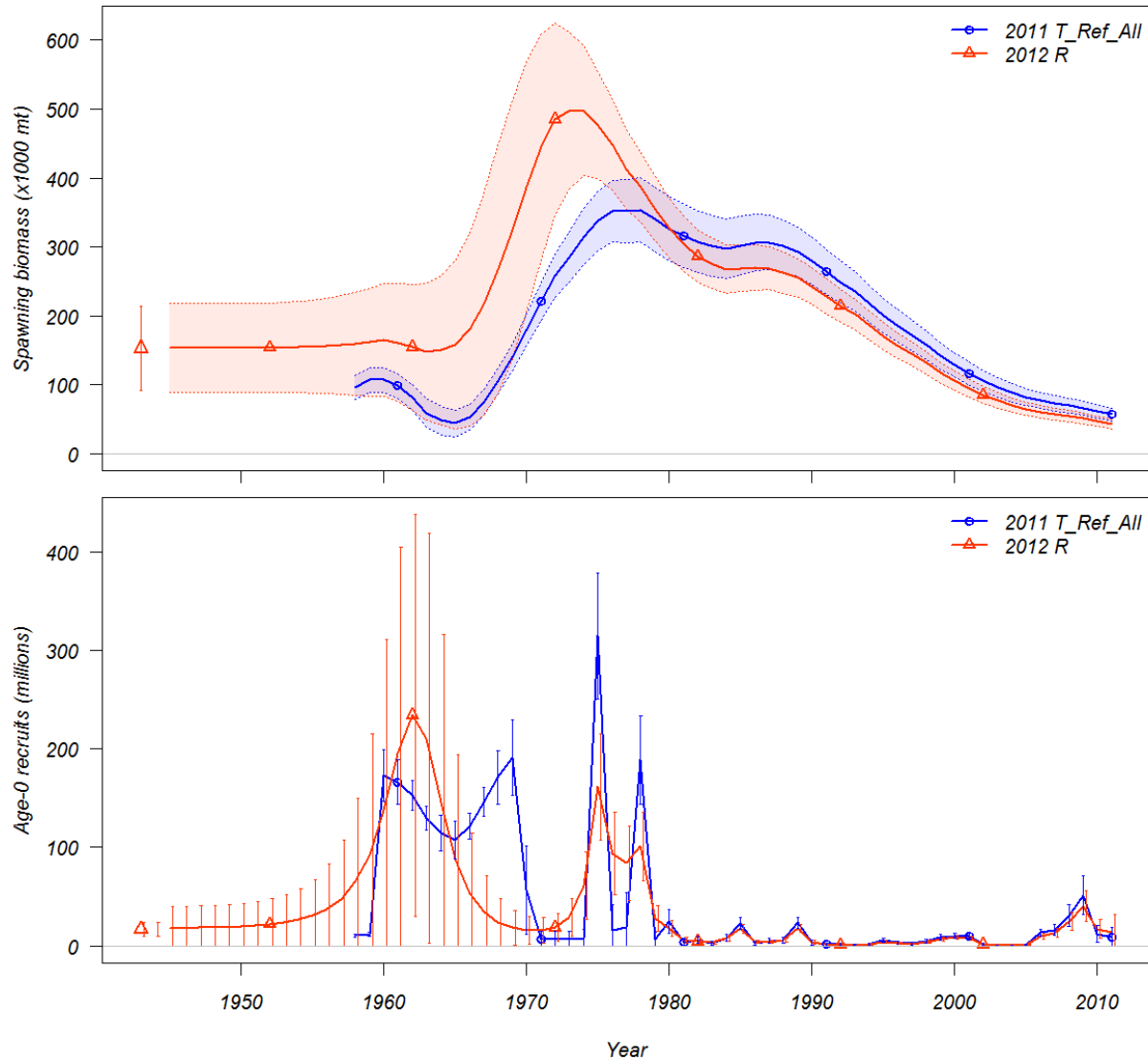
Figure 18 Spawning biomass (top) and age-0 recruitment (bottom) for 2011 tuned reference model with all proposed data changes (2011 T_Ref_All) and 2012 candidate model with alternative early recruitment assumptions (2012 R).

Selectivity

There was a lot of effort expended on exploring appropriate selectivity curves for the 2012 assessment. In this document we present two options for the 2012 Candidate model (S_1 and S_2). The only difference between the two selectivity options is in the selectivity curve chosen for the ABL longline survey.

- In S_1 the ABL Longline length composition data are fit with logistic curve.
- In S_2 the ABL Longline length composition data are fit with a four node spline. All other selectivity curves are the same between the two options.

The main difference between the 2011 Reference model selectivity and the 2012 Candidate selectivity is in how the male and female selectivity curves are allowed to differ. A new method for fitting curves that differ between male and females was implemented in the latest version of SS3 (V 2.24). In previous SS3 versions the male and female selectivity curves took the same underlying shape, but the curve could be altered between males and females using four parameters :

      P1 – size at which a dogleg occurs
      P2 – log(relative selectivity) at the minimum size
      P3 – log(relative selectivity) at the dogleg
      P4 – log(relative selectivity) at maximum size

These options do not allow the model to fit curves in which, for example, the male selectivity is higher than females in smaller fish, but lower than females in larger fish. This is the case for Greenland turbot in which males are much smaller than females reaching maturity at a smaller size, where both migrate to deeper waters as they mature, and where the fisheries and surveys are spatially distinct, targeting or encountering different parts of the population.

This problem was addressed in the latest version of SS3 (3.24) in which more flexibility in fitting the selectivity curves of the opposite sex is available. If the size selectivity pattern is logistic, then SS3 requires 3 parameters to differentiate the curve from the opposite sex:
      p1 is added to the first selectivity parm (inflection)
      p2 is added to the second selectivity parm (width of curve)
      p3 is the asymptotic selectivity
If the size selectivity pattern is the double normal, then five parameters are needed to differentiate from the opposite sex:
      p1 is added to the first selectivity parameter (peak)
      p2 is added to the third selectivity parameter (width of ascending side)
      p3 is added to the fourth selectivity parameter (width of descending side)
      p4 is added to the sixth selectivity parameter (selectivity at final size bin)
      p5 is the apical selectivity
This new method was explored for all fisheries and surveys with separate sex data. In addition, the longline and slope survey selectivity was simplified to a single logistic curve since the curve fit in last year's assessment, although fit as a double normal, was in effect a simple logistic curve (Fig. 19).

The ABL longline catch at size data is somewhat difficult to fit since the data are from combined sexes and appear to have a bimodal distribution, one for males and another mode for females. Although a simple logistic model can be fit to the data, patterns in the residuals suggest some deficiencies in the fit. For this reason we explored fitting a four node spline in the S_2 selectivity option presented here. The four node selectivity spline may better take into account the odd shape expected from the combined sex data (Methot 2011).
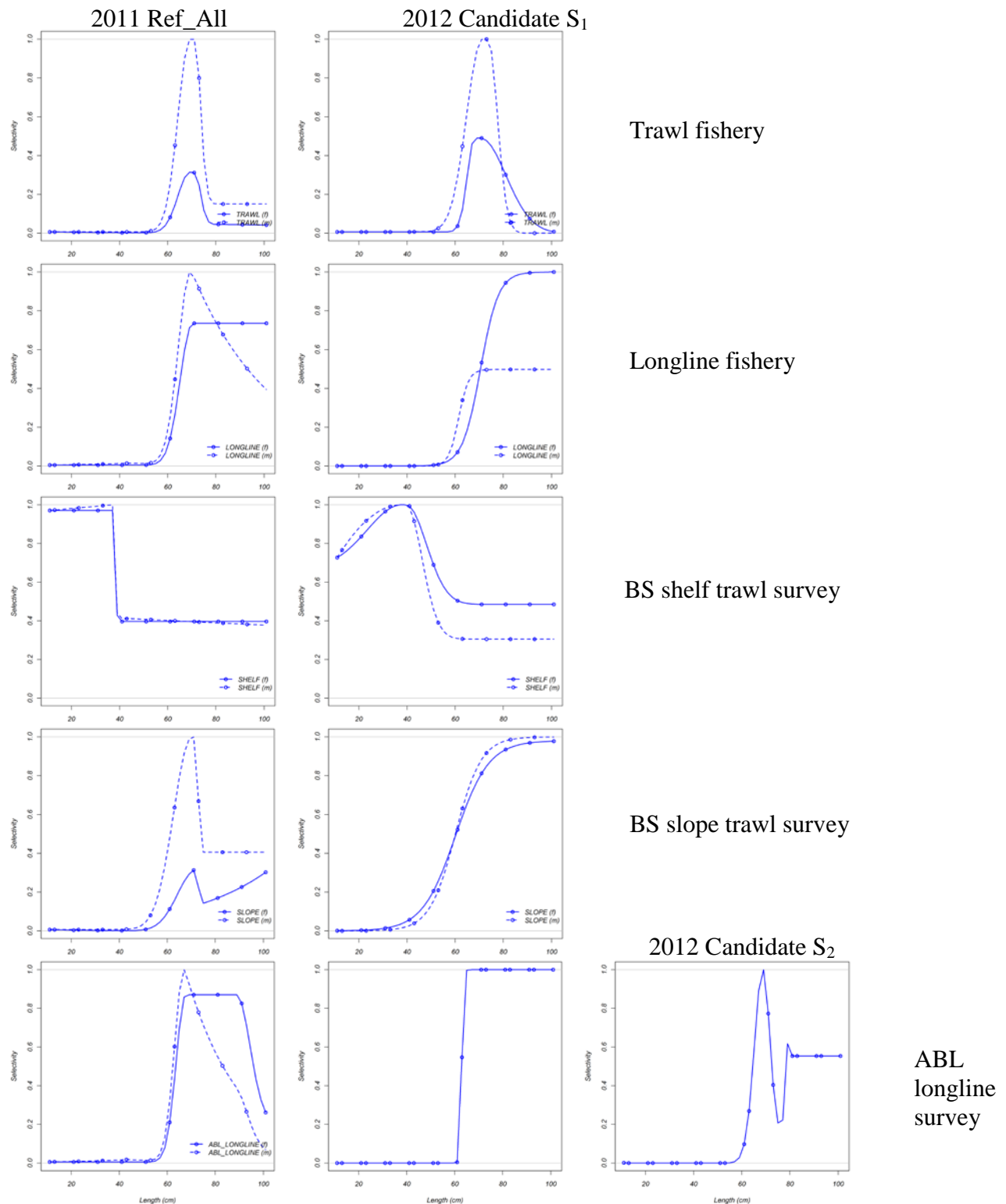
Figure 19. 2011 selectivity for 2011 Reference model and 2012 Candidate models for both male (solid) and female selectivity (dashed). Note only the ABL Longline survey selectivity changes between S_1 and S_2 models.

Effects of changes to selectivity curves

The changes in selectivity curves from the 2011 Reference model to the S_1 candidate selectivity provided some improvement to the overall model fit (Table 4) and residual pattern in the longline fishery (Fig. 20). The greatest improvement was in the fit to the size composition data (-166.69 LL; -10%) with better fits in both fisheries and all three surveys. The fit was most improved in the longline and trawl fisheries (-80 and -60.5 LL, respectively; -27% and -14%). The fit to the two trawl survey abundance indices was degraded (Shelf +5 LL or +20% and Slope +3.6 LL or +69%), while the fit to the ABL longline survey index was much improved (-5 LL; -320%). The fit to the size at age was degraded with an overall increase of +60 LL (+7%). The fit to the Shelf age composition data was slightly improved with a decrease in negative loglikelihood of -6 or -3%. The 2012 S_2 candidate selectivity option improved the model fit primarily to the ABL longline length composition data (Fig 21). The fit to the ABL Longline length composition data was improved by -50.3 LL or -39% from the S_2 over the S_1 configuration, with an overall improvement to the total model fit of -52.7 LL (-2%). Fits to all other data components in the model were changed individually by less than ±2 LL.

Even with the additional flexibility in fitting the two sexes in the latest version of SS3 there remains patterns in the residuals that are problematic in the early years of the trawl length data (1979-1989). The trawl fishery length composition data are pooled from the directed fishery and from fish caught in other fisheries. The directed fishery targeted the larger fish (predominantly females) on the slope, while the bycatch fishery mostly caught smaller fish (predominantly males) on the shelf, resulting in very different expected selectivity patterns for the two sexes. Currently SS3 can't handle such a large difference in selectivity patterns between sexes for the same fishery. In the future the authors would like to try to separate out the bycatch trawl data from the targeted trawl fishery data to see if the patterns in the size composition data for these early years can be rectified and perhaps present the results as a competing model in November. Since target is not included in these older data, this task may be difficult to accomplish.

The greatest changes in the model results (Table 4) from the 2011 Reference model selectivity configuration in the 2012 R Candidate model to the 2012 S_1 selectivity or 2012 S_2 configuration are a change in the Shelf survey catchability from 0.70 to 0.78 for S_1 and 0.77 for S_2 and a shift in the peak of the early period (1945-1974) recruitments from 1962 in the 2011 reference configuration to a slightly smaller peak in 1965 (Fig. 22) in both the S_1 and S_2 configurations (from 233.9 to 207.1 and 203.9 billion (1×10^9) age-0 fish, respectively). There is also a reduction in the point estimate of recruitment for the 1977 and 1978 age-0 recruitment in both the S_1 and S_2 configurations compared to the 2011 Reference configuration from 83.8 and 101.2 billion (1×10^9) fish to 77.65 and 88.25 billion fish for S_1 and 80.12 and 85.46 billion fish for S_2. Mean recruitment across all years (1945-2011) dropped from 36 billion age-0 fish using the 2011 reference selectivity to 32 billion age-0 fish for both the S_1 and S_2 selectivity options. The reduction in mean recruitment and increases in Shelf survey catchability resulted in smaller

spawning and total biomass estimates for all years using either of the candidate selectivity options. The 1978 spawning biomass point estimate drops from 387 thousand tons using the 2011 Reference selectivity configuration to 198 and 175 thousand tons using the S_1 and S_2 configurations. The 2011 spawning biomass point estimate drops from 43 thousand tons using the 2011 Reference configuration to 20 thousand tons for both S_1 and S_2.
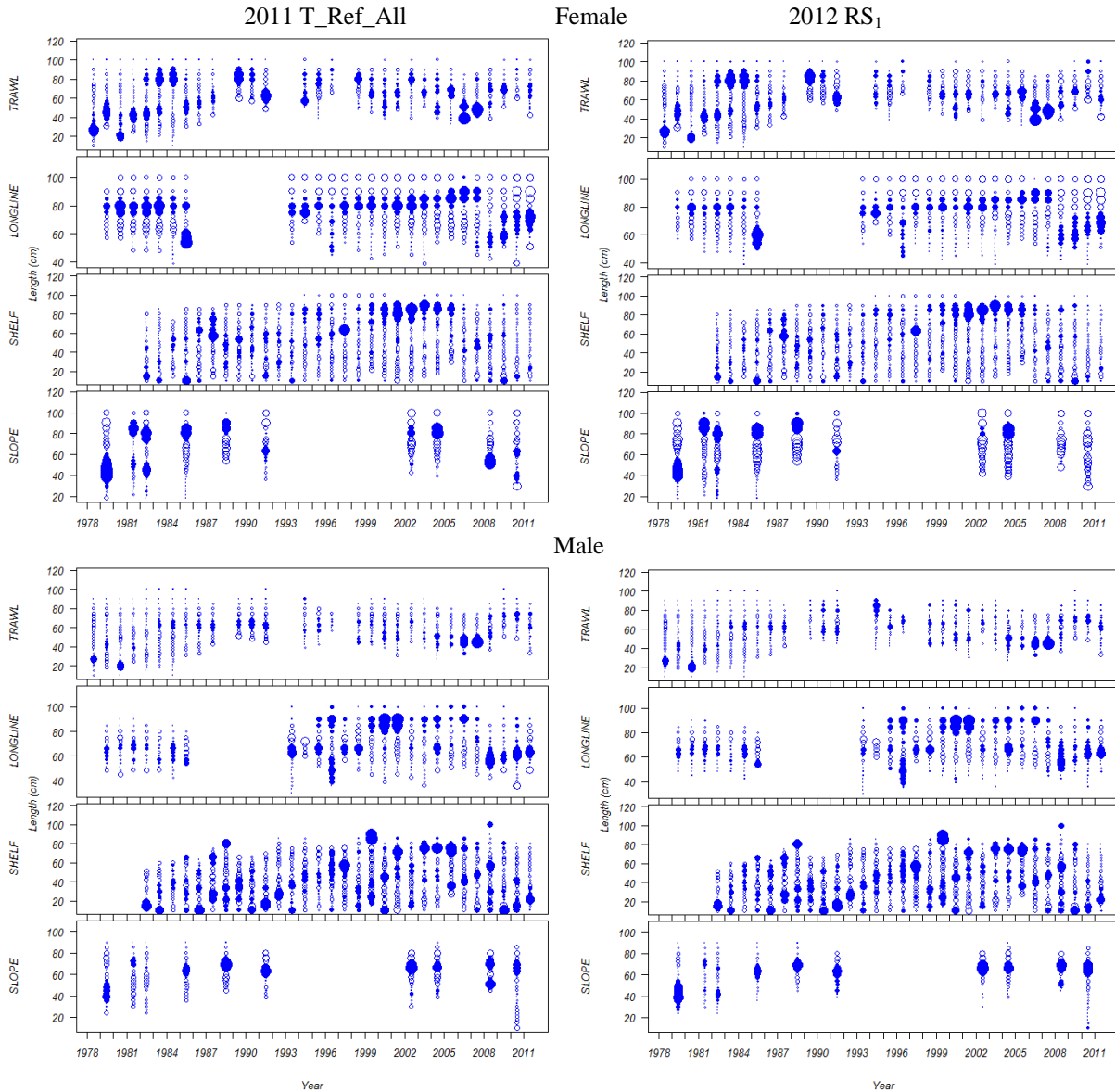

Figure 20 Residuals from length composition data fits for Model R which employs the 2011 reference model selectivity configuration and for Model RS_1. **Note that the scales for all of the plots differ. These plots are meant to help in examining possible patterns in the residuals and not the exact fits.** In each plot the maximum value for that data type is the same size across all data types.
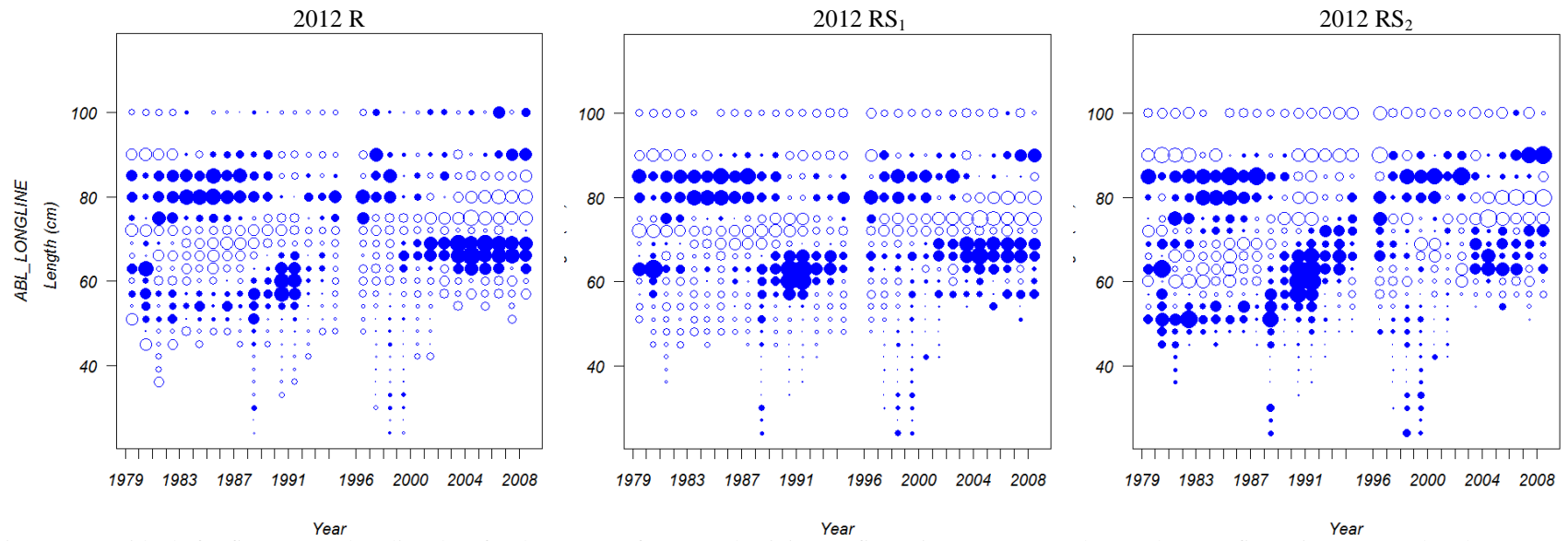
Figure 21 Residuals for fits to ABL longline data for the 2011 Reference selectivity configuration (2012 R) and S1 and S2 configurations. Note that the max value for the three plots differ (max 2012 R =3.07, 2012 RS1=3.04, and 2012 RS2 = 2.02)
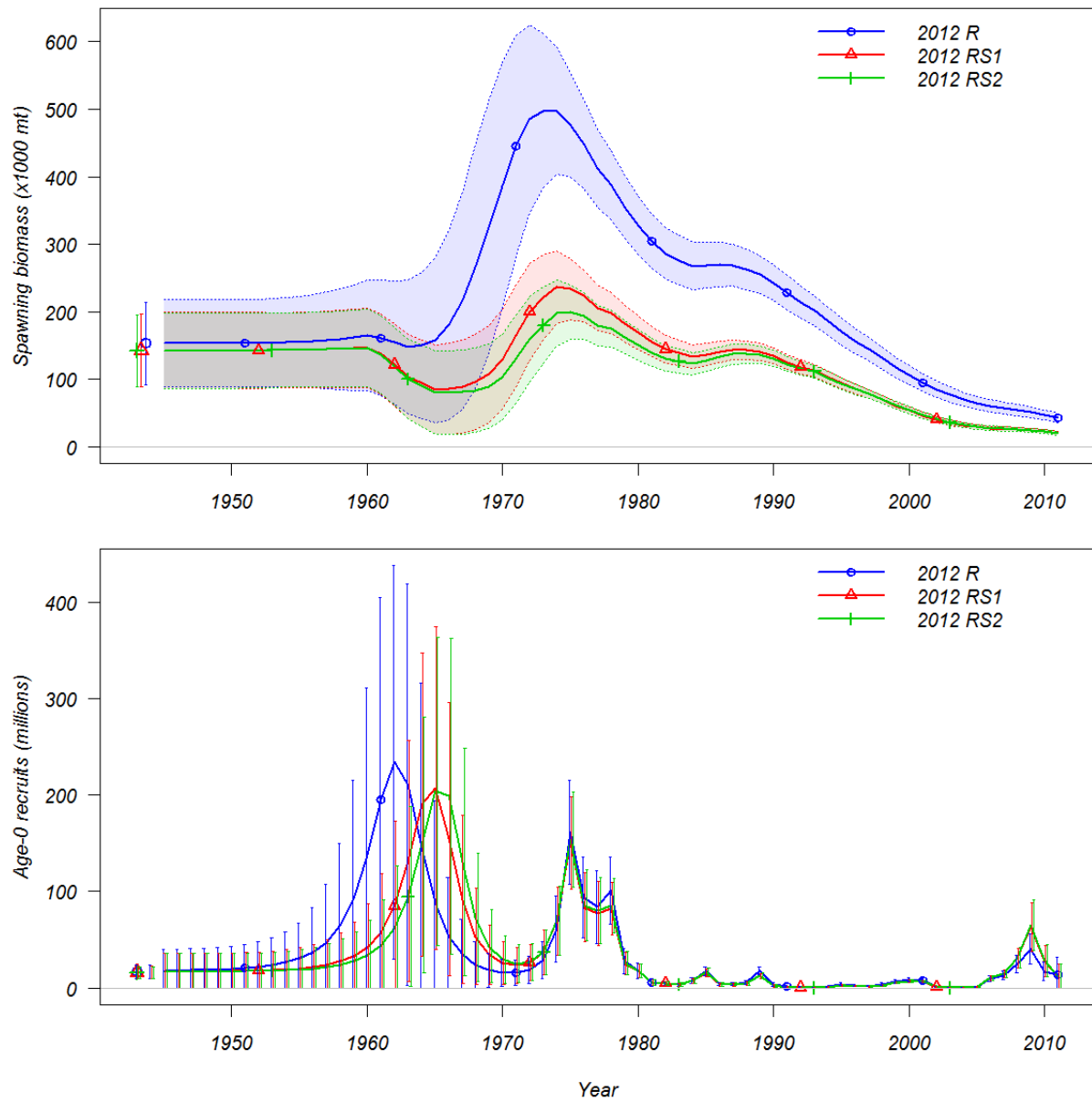
Figure 22 Spawning biomass (top) and age-0 recruitment (bottom) for 2012 Candidate model with changes to recruitment from the 2011 Reference model, with catchability fitted for both the Bering Sea slope and shelf trawl surveys using informative lognormal priors and sigma R at 0.6 (2012 RS1Q) and the same model with a four node spline fit for the Auke Bay Laboratory longline survey (2012 RS2Q).

Catchability in the Slope Survey

The 2011 Reference model assumes a fixed catchability for the slope trawl survey (q_{Slope}) of 0.75 and estimates catchability for the Bering Sea shelf survey (q_{Shelf}) with a log uniform, non-informative prior bounded between -2 and 2. There is no strong evidence to support the assumption that q_{slope} is exactly 0.75. Models were explored loosening this assumption with both the slope and shelf trawl survey catchability estimated using informative, lognormal priors [$\log(q_{slope}) \sim \mathbb{N}(-0.28768, 0.1)$ and $\log(q_{shelf}) \sim \mathbb{N}(-0.69385, 0.1)$].

Effects of loosening assumptions on Bering Sea slope trawl survey catchability

When assumptions on q_{Slope} are loosened and an informative prior distribution is place on q_{Shelf}, lower estimates of q for both the Bering Sea slope and shelf trawl surveys are obtained (Table 4 and Fig. 23). Shelf survey catchability changes from 0.78 to 0.7 while the Slope survey catchability changes from a fixed value of 0.75 to 0.68. Only marginally better fits to the survey indices (< -1 LL) and marginally poorer fits to the length composition data (>+3) are achieved in the alternative Q configuration. The changes do improve the fit to the shelf survey size at age data fit to a small degree amount (-4 LL). None of these changes to the model fit are substantial, but the change to the model estimates of spawning stock biomass is noticeable (Fig.24). The 2011 estimate of spawning stock biomass in the fixed q_{Slope} model (2012 RS_1) is 19.7 thousand tons while the spawning stock biomass estimate in the model where q_{Slope} is fit with an in formative prior (2012 RS_1Q) is 25.4 thousand tons, a 29% increase in the estimate. Similarly in the S_2 models the estimate changes from 20.0 thousand tons (2012 RS_2) to 27.2 thousand tons (2012 RS_2Q) when the assumptions on q_{Slope} are loosened. Although the variance on the MLE estimates are quite small the change to the overall likelihood is small and suggests that catchability is not well defined in the available data. This is likely due to the problem of this stock straddling the US-Russia border, migration of the stock between areas, and the surveys not consistently covering the same proportion of the stock each year.
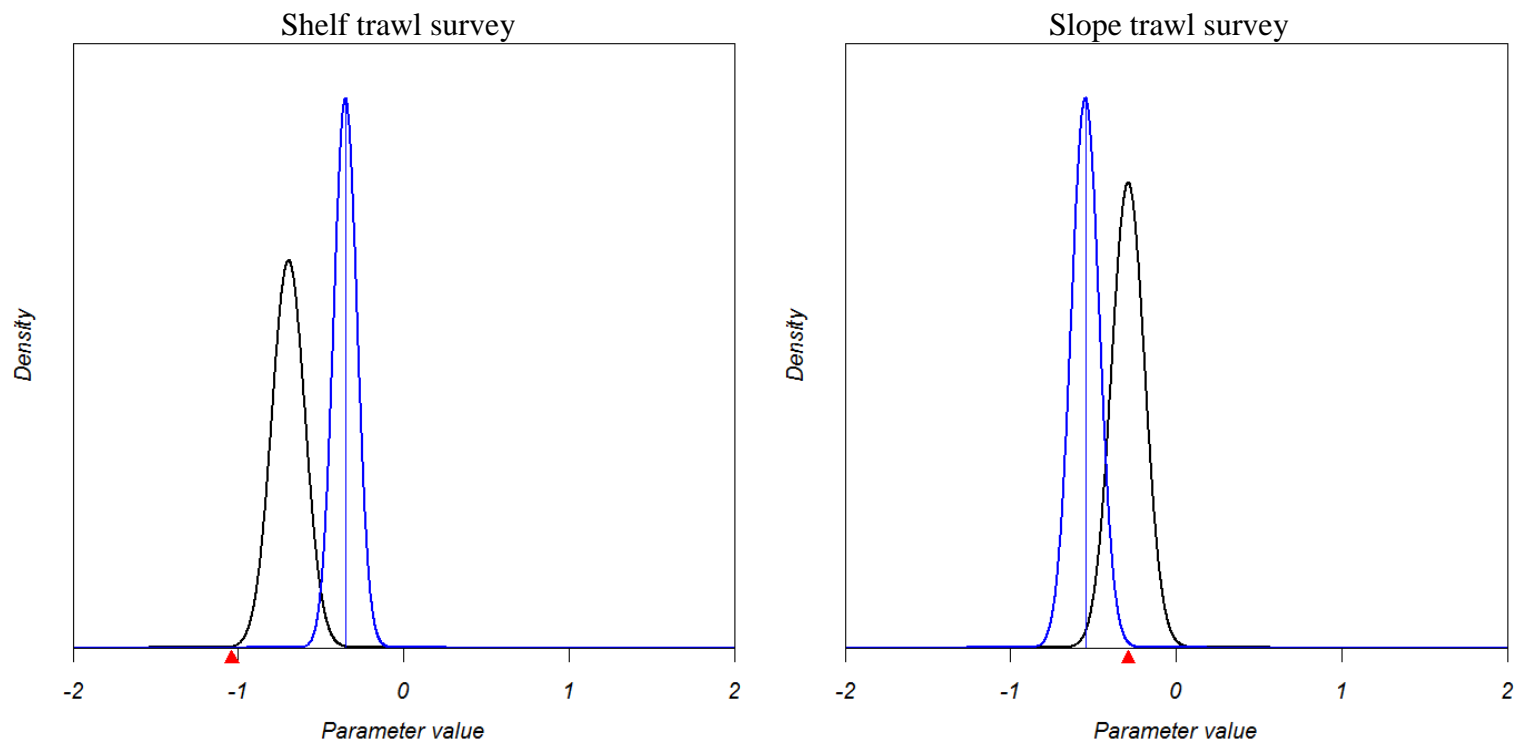
Figure 23 Prior distribution (black lines), initial value (red arrow), and MLE estimate with asymptotic variance estimate (blue lines) for Shelf trawl survey (left) and Slope trawl survey (right) catchability in the 2012 RS$_1$Q candidate model.
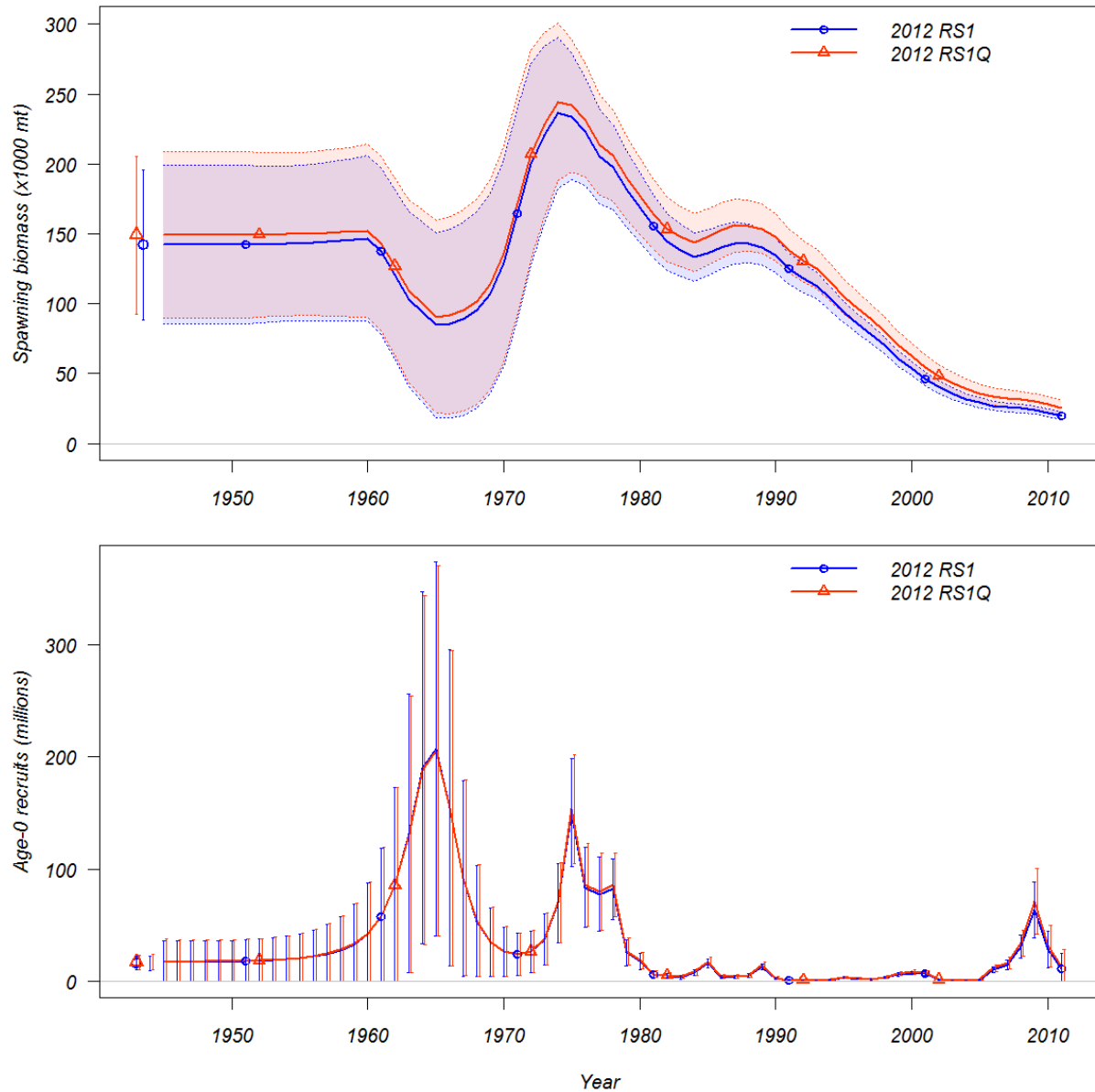
Figure 24 Spawning biomass (top) and age-0 recruitment (bottom) for 2012 Candidate model with only changes to recruitment (2012 RS1) and the 2012 Candidate model with changes to recruitment and catchability fitted for both the Bering Sea slope and shelf trawl surveys (2012 RS1Q) using informative lognormal priors.

Sigma R – Recruitment variability

The 2011 Reference model set recruitment variability (sigma R) of the Beverton-Holt stock recruitment curve to 0.6. Values for sigma R range from 0.15 to 1.0 for stock assessments of this species in the North Atlantic and Arctic Oceans (Myers et al. 1999). We tested the sensitivity of the model to changes in Sigma R with values ranging from 0.6 to 1.69.

Effects of varying sigma R

Increasing Sigma R improved model fit in all categories except size at age (Table 5). A Sigma R of 1.69 would be selected as the most parsimonious using likelihood as a goodness of fit criterion. This value is unreasonably high compared to assessments of this species in other areas and similar species. This high Sigma R is only selected due to the model attempting to create a single large recruitment event (log recruitment deviation > 5) in the 1960's to account for the early catch and large fish in the earliest length composition data where there is no data to direct the model.

Increasing Sigma R causes the model to fit a higher mean recruitment, to compensate for the higher recruitment the model fits a higher catchability for the shelf and slope surveys (Fig. 25). Post-1978 this increase in recruitment and increase in catchability results in nearly the same values for the spawning stock biomass (Table 5). The total difference in estimated spawning biomass for 1978 from the Sigma R = 0.5 to 1.69 is +1,200 t or a decrease of < 1%. The total difference in spawning biomass for 2011 from the Sigma R = 0.5 to 1.69 is -3,300 t or a decrease of 12%. Although a single extreme recruitment event may be the most parsimonious model, it is not biologically reasonable. In the author's judgment a value of 0.6 would be most reasonable and consistent with recruitment variability observed in other species with similar life history characteristics.

From Methot (2011), "for each year in the total time series the contribution of that year to the LL is equal to: $dev^2/(2sigmaR^2)+offset*log(sigmaR)$; where dev is the recruitment deviation from the expected for that year and where offset is the magnitude of the adjustment between the arithmetic and geometric mean of expected recruitment for that year. With this approach, years with a zero or small offset value do not contribute to the second component." Because of how the recruitment deviation likelihood is specified in SS3, where there are no data to inform the model, the likelihood will always be lower with many small recruitment deviations and a single or a few very large deviation, which equates to a high Sigma R (>1.0), rather than several mid-range deviations with the same mean recruitment and a lower sigma R (<1.0). Therefore for the Greenland turbot model where there are no early data to inform the model on Sigma R, for the early recruitment the model will select the highest Sigma R it can while changing the two survey catchability parameter estimates to keep the biomass estimates consistent with the available data in the later years.
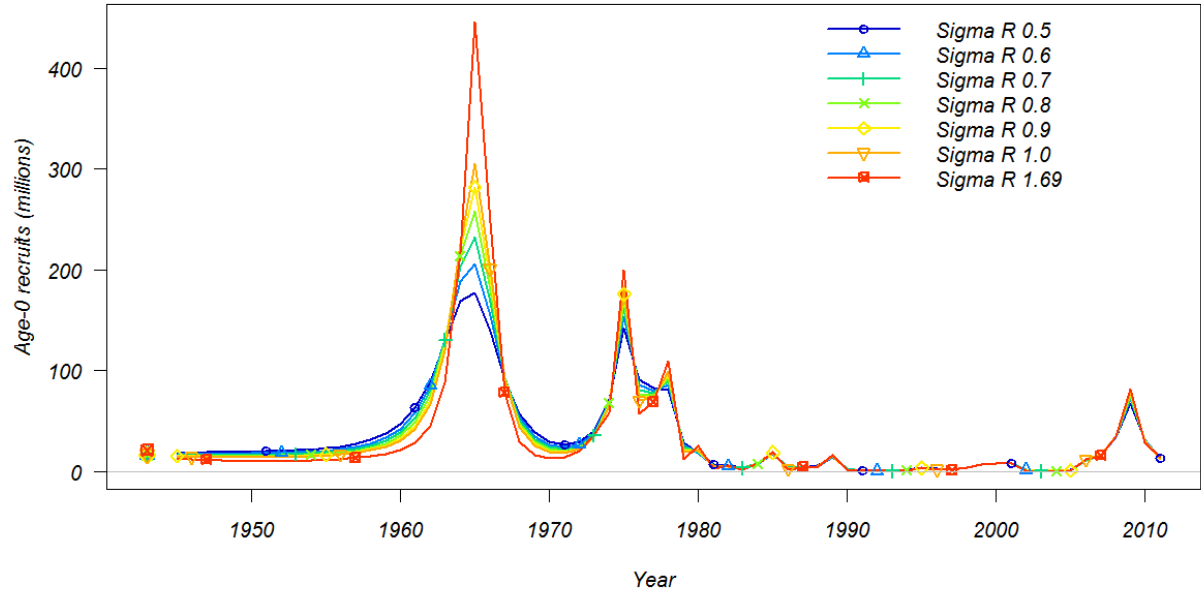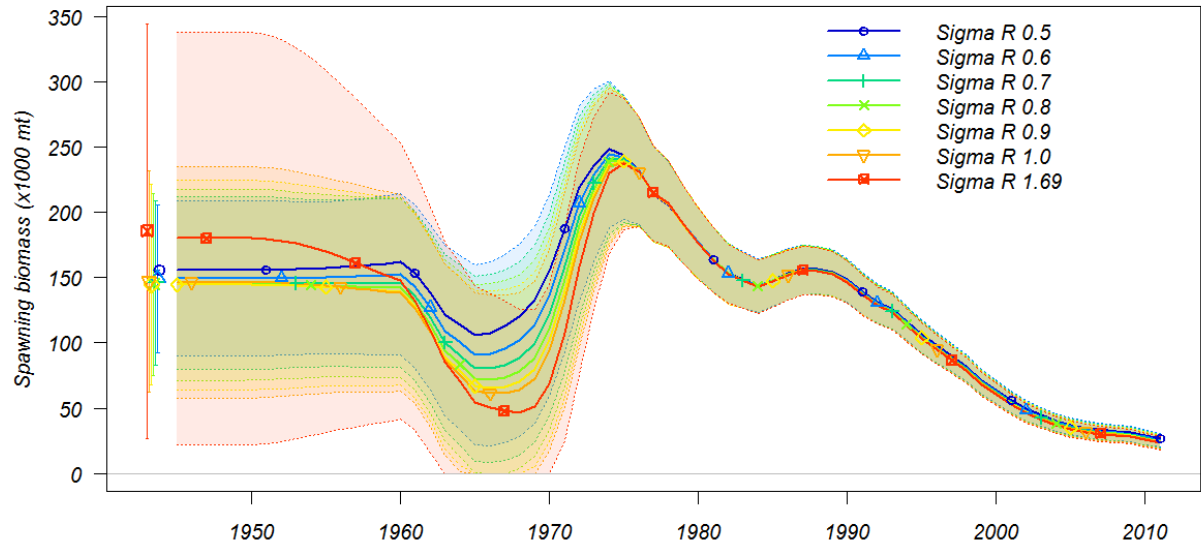
Figure 25 Effects of changing Sigma R on Age-0 recruitment in 2012 candidate model with changes to recruitment and fitting Bering Sea shelf and slope survey catchability (2012 RS$_1$Q).

Table 5 Effects of changing Sigma R in 2012 Candidate model with changes to recruitment and fitting Bering Sea shelf and slope survey catchability (2012 RS$_1$Q). The models here with sigma R = 0.6 and sigma R = 0.9 are the same as models 2012 RS$_1$Q and 2012 RS$_1$QV in Table 3.

Sigma R		0.5	0.6	0.7	0.8	0.9	0.999	1.69
Likelihoods								
Total		2740.95	2708.83	2688.16	2674.39	2664.90	2658.55	2645.68
Survey		-24.70	-25.67	-26.22	-26.54	-26.75	-26.89	-27.31
Length Composition		1455.35	1442.19	1433.66	1428.05	1424.02	1421.09	1411.70
Age Composition		217.13	215.02	213.94	213.23	212.81	212.54	212.04
Parameter priors		33.80	33.82	33.88	33.98	34.08	34.14	34.35
Size at Age		967.35	968.63	969.42	969.96	970.33	970.64	971.56
Recruitment		92.02	74.84	63.49	55.71	50.41	47.03	43.34
Key Parameters								
SR_LN(R0)		9.77	9.73	9.70	9.70	9.70	9.71	9.94
Q for Shelf Survey		0.69	0.70	0.71	0.72	0.73	0.73	0.74
Q for Slope Survey		0.57	0.58	0.59	0.59	0.60	0.60	0.61
L_at_Amax_Fem		88.50	88.50	88.50	88.50	88.50	88.50	88.51
L_at_Amax_Mal		72.63	72.61	72.60	72.59	72.59	72.58	72.57
VonBert_K_Fem		0.13	0.13	0.13	0.12	0.12	0.12	0.12
VonBert_K_Mal		0.18	0.18	0.18	0.18	0.18	0.18	0.18
Recruits 1960-1969								
Age-0 (1×10^6)	Mean	99.97	104.57	108.11	110.88	113.18	115.11	121.49
	Median	90.04	88.75	86.55	83.95	81.32	78.73	61.07
	CV	0.51	0.59	0.66	0.73	0.79	0.84	1.16
Recruits 1975-2011								
Age-0 (1×10^6)	Mean	19.97	20.11	20.24	20.33	20.41	20.48	20.71
	Median	6.09	5.61	5.32	5.10	4.93	4.88	4.94
	CV	1.62	1.67	1.71	1.75	1.78	1.81	1.92
Spawning Stock Biomass								
(1,000 t)	1978	205.65	206.03	206.20	206.35	206.36	206.46	206.81
	2011	26.53	25.39	24.71	24.29	24.00	23.81	23.24

Authors' note to the NPFMC Groundfish Plan Team

There are two areas where the author's are seeking guidance from the Plan Team for the 2012 Greenland turbot stock assessment. First the authors are seeking the acknowledgment by the plan team that they understand and accept the changes to the underlying data and the effects of these changes on the results of the 2011 Reference model. These include:

1) the new weight to length relationship developed for the 2012 Candidate models,
2) the differences between catch and survey indices in 2011 Stock assessment and those queried for 2012,
3) the difference in how the fishery length composition data were proportioned to haul catch numbers for use in the 2012 assessment as opposed to using the raw composition data,
4) the new method for calculating the sample size for fishery length composition data,
5) the method for tuning the sample size to effective sample size for length composition data.

The changes to the dataset used in the model make substantial changes to the results of the stock assessment (Fig. 26).

Second, the authors' are seeking guidance on the exploration of alternative model configurations and on what models the Plan Team would like to see in November.

1) The change in how early recruitments are handled in the proposed 2012 Candidate models is considered by the authors to be an improvement over last year because it does not presuppose a change in productivity in the stock and provides a more accurate representation of the high degree of uncertainty in these early recruitment values. The authors' are seeking suggestions by the Plan team for possible alternatives to the recruitment model assessed here.
2) Both selectivity configurations proposed for 2012 provide a better fit to the data than the 2011 Reference model configuration and better capture the differences in selectivity between males and females in the fisheries and surveys. The author's would propose presenting models with both the S_1 and S_2 selectivity configurations for the final stock assessment review in November.
3) Fitting the Slope survey catchability in the Greenland turbot model is problematic as there is little difference in the likelihood for very large differences in catchability. Fixing the values is also problematic because there is no data on how much of the stock is represented by each of the surveys and it likely varies with oceanic conditions and stock size. The stock likely straddles the US-Russian EEZs and the northernmost boundary of the Bering Sea Shelf Survey. The Authors would like to obtain feedback from the plan team on whether they want to see models with fitted catchability given the issues with these fits and if so, whether they believe using a constrained prior is appropriate.
4) Sigma R cannot be fit in the model, should the authors consider alternative values (other than 0.6) for Sigma R in model configurations for November?

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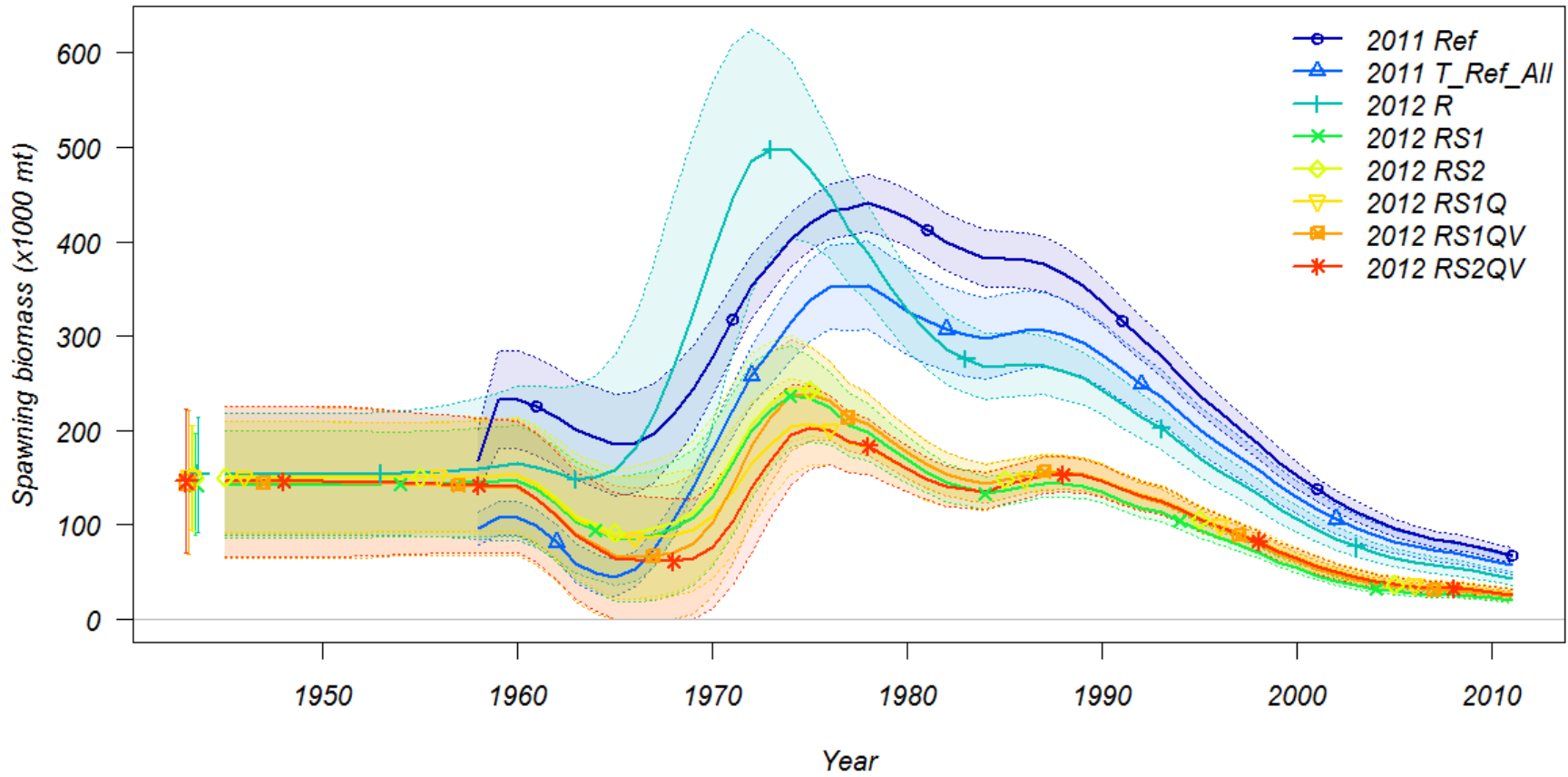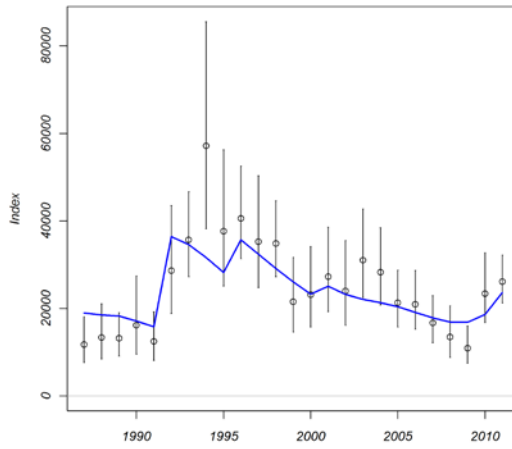
Figure 26 Spawning biomass estimates for the 2011 Reference models and selected 2012 Candidate models.
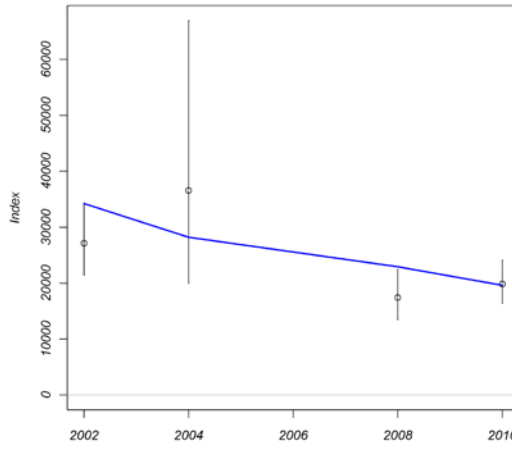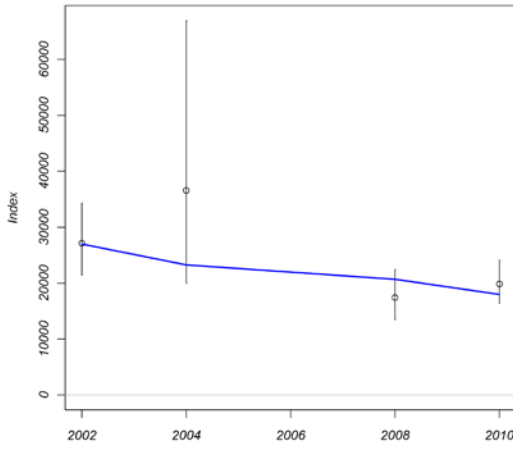
2011 T_Ref_All   2012 RS$_2$QV
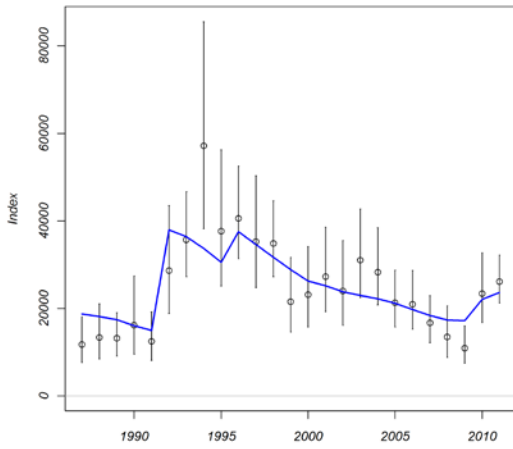
Bering Sea Shelf Trawl Survey
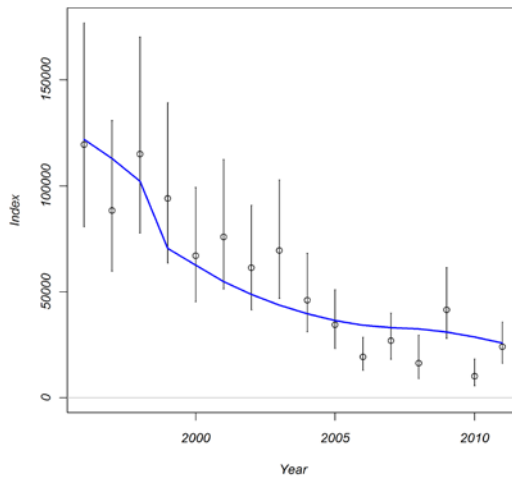

Bering Sea Slope Trawl Survey

Auke Bay Longline Survey

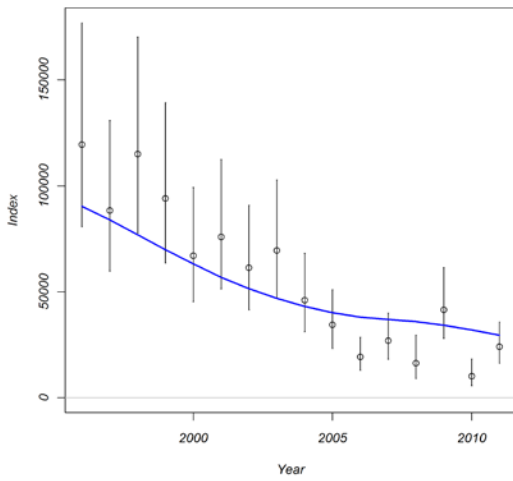

Figure (not referenced in the document) Index surveys and fits for 2011 Reference model with all data changes (2011 T_Ref_All, left) and 2012 RS$_2$QV candidate model (right).

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