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# Comparative Analyses of Greenland Halibut (*Reinhardtius hippoglossoides*) Maturation for Populations Throughout the North Atlantic

by

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## Abstract

We examined the maturation of four populations of Greenland halibut: Gulf of St. Lawrence, Labrador-eastern Newfoundland, East Greenland-Iceland-Faroe Islands and the Northeast Arctic (Svalbard and Barents Sea). We compared the maturity schedules among these populations as well as the variability in the data across the different populations. Estimates of size and age at 50% maturity were very similar except that the fish in the Labrador-eastern Newfoundland area appeared to mature at a larger size and older age. All data sets showed substantial variability with data from the Gulf of St. Lawrence during the 1996 to 2000 period being perhaps the least variable. When data collected over the entire distribution area were compared to data collected from portions of population distribution variability was found to be substantially less.

Keywords: Greenland halibut, maturation, length, age, variability

## Introduction

Greenland halibut (*Reinhardtius hippoglossoides* Walbaum) is a deep-water flatfish species that is distributed throughout the north Atlantic and is also found in the north Pacific (Hubbs and Wilimovsky, 1964; Bowering and Brodie, 1995). It has been caught as deep as 2200 m (Boje and Hareide, MS 1993; de Cardenas *et al*, MS 1996) although it is generally found in highest densities from 500 to 1200 m and in some areas to 1800 m (Bowering and Brodie, 1995). The species is fished commercially throughout its range in the north Atlantic (Vis *et al*, 1997).

There are four main populations in the north Atlantic (Figure 1). These are in the Gulf of St. Lawrence (NAFO Divisions 4RST), off eastern Canada and west Greenland (NAFO Subareas 0, 1, 2 and Divisions 3KLMNO), the east Greenland, Iceland and Faroe Islands population (ICES Subareas V and XIV) and the north east Arctic population (ICES Subareas I and II). Although considered to be a single population, the Greenland halibut off eastern Canada and west Greenland in the offshore are managed as two separate stocks: NAFO Subarea 0 and 1 and Subarea 2 + Divisions 3KLMNO.

Studies on the maturation and spawning of Greenland halibut have revealed a great deal of variability. The proportion of adult fish at size and age has been found to exhibit a high degree of geographic and temporal variation (Junquera, MS 1994; Junquera and Saborido-Rey, MS 1995a; Morgan and Bowering, MS 1999). The occurrence of immature fish at large size also appears to be common (Fedorov, 1971; Jorgensen and Boje, MS 1994; Morgan and Bowering, 1997). Greenland halibut appears to have a peak and secondary spawning period with some fish in spawning condition being found in most months (Fedorov, 1971; Junquera, MS 1994; Junquera and Zamarro, 1994). Fedorov (1971) also found that Greenland halibut (at least in the Barents Sea) might skip spawning seasons.

Consistent with other studies on maturation in Greenland halibut, Morgan and Bowering (1997) found that proportion mature-at-size and age from data collected on different portions of the Subarea 2 + Div. 3KLMNO area exhibited a great deal of spatial and temporal variability. There were no apparent trends in this variation. They hypothesized that this variation might be the result of the irregularities in the maturation process and spawning of Greenland halibut leading to variability in the distribution of adult fish. They suggested that surveys of the entire Subarea 2 + Div. 3KLMNO distributional area of Greenland halibut would be required in order to account for this variability. This idea received some support when it was found that estimates of maturity-at-size and age derived from surveys of the entire area were far less variable than those derived from only the Div. 2J3K portion of the stock area (Morgan and Bowering, MS 2001).

The purpose of this paper was to compare the estimates of maturity from the different populations of Greenland halibut in the north Atlantic. As well, we wished to examine the degree of variability in maturity-at-size (and where possible age) in other populations of Greenland halibut in the north Atlantic in comparison to the Div. 2J3K portion of the Subarea 2 + Div. 3KLMNO stock.

## Materials and Methods

Data for comparison were available from 7 sources representing the 4 main populations across the north Atlantic.

Data from Div. 4RST were available from two sources. Data were collected from 1978 to 1981 in January-February during stratified random surveys using bottom otter trawls. Information on size and age at maturity were both available. Data collected during August from 1996 to 2000 were also available. These data consisted of information on size at maturity only. The surveys were stratified random using a bottom otter trawl but sampling for purposes of estimating maturity was divided into three areas of concentration of Greenland halibut.

For Div. 2J3K, data were available at size and age from 1978 to 2000. Data were collected during stratified random surveys using a bottom otter trawl. Surveys were mainly conducted during October-December.

For Subareas V and XIV data were available from Div. XIVb and Va. Data were collected in Div. XIVb from 1995 to 1998 and in 2000 using a variety of gear types. In 1995, gillnets were used, in 1996 and 1997 data were examined from longline samples and in 1998 and 2000 data were from bottom otter trawl. Data were size based only and were collected during July-August during the commercial fishery. For Div. Va, data on maturity-at-size were available from 1996-2000. The data were collected during fixed station stratified random surveys conducted during October with bottom otter trawl.

Data from Subarea I and II were available from two sources. Data were available from Russian stratified random surveys of Subarea II using bottom otter trawls conducted during September-December (1984 to 1989) or October-December (1990 to 2000). Data were available on maturation at both size and age except for 2000 when only data on size were available. This data set is referred to as II Russia. Data from Subarea II were also available from 1996 to 2000 from sampling conducted during July to September by Norway. This survey is conducted with bottom otter trawl and is a combination of stratified random and fixed stations. Data were available for both size and age and this data set will be referred to as II Norway.

In all data sets maturity was determined by macroscopic examination of the gonads. Fish were divided into juveniles and adults and any fish where this determination was considered uncertain were removed from the data sets. Data were available for both males and females in all cases.

Estimated proportion mature-at-size and age, as well as size ($L_{50}$) and age ($A_{50}$) at 50% maturity were determined using probit analyses with a binomial error structure and a logit link function (SAS Institute Inc., 1989).

Each data set was tested for significant annual variation using generalized linear models with a logit link function and binomial error structure (McCullagh and Nelder, 1983; SAS Institute Inc., 1993).

The variability of each data set was determined in a number of ways in addition to testing for significant annual variation. Each time series of $L_{50}$ and $A_{50}$ was examined to determine the range in values over the time series. As well, the largest change between two adjacent years was determined. The percentage of years where there was not a significant fit of the model to the data was determined. For each data set a single generalized linear model was fit using all of the data in the time series. Then the average of the absolute value of the standardized deviance residuals was calculated as a further measure of variability. Finally, for data sets on length at maturity, the observed and predicted proportion mature for selected years were plotted.

**Results**

Length at 50% maturity was greater for Div. 2J3K than for the other populations for both males and females (Fig. 2, Table 1). Except for Div. 2J3K, $L_{50}$ was generally less than 50cm for males and less than 65cm for females. Average $L_{50}$ was lowest for Div. 4RST 1996-2000 and for males ranged from 39 to 62 cm. For females average $L_{50}$ ranged from 48 to 79 cm. There was little indication of trends over time in any of the time series except for males in Div. 4RST 1996-2000 and females in Div. 4RST 1978-1981 which both showed a decline in $L_{50}$.

Age at 50% maturity was also greatest in Div. 2J3K (Fig. 3, Table 1). The other three data sources had $A_{50}$ that were very similar to one another. There was little indication of trends over the time periods in any of the time series except for females in Div. 4RST 1978-1981 which showed a decline in $A_{50}$. On average, $A_{50}$ ranged from about 5 to almost 10 for males and from 8 to almost 13 for females.

Despite few trends in the data, all data sets had significant annual variation in proportion mature-at-length for both males and females (Table 2). There was also significant annual variation in proportion mature-at-age for all data sets except for females from Subarea II Norway, which exhibited no significant interannual variability.

There was no clear indication from other metrics of variability as to which of the populations (if any) was the most variable (Tables 3 and 4). The largest range in $L_{50}$ for both males and females was Div. 2J3K while the largest annual change was for Div. 2J3K for females and Subarea II Russia for males. Div. XIVb had the largest percentage of years with a non-significant model fit for males for proportion mature at length. The largest average absolute value of the standardized deviance residuals was Div. XIVb for females and Div. 4RST 1978-1981 for males. The largest range in $A_{50}$ was found in Subarea II Russia for males and Div. 2J3K for females. These two data sets also had the largest difference between years in $A_{50}$. Div. 2J3K and 4RST 1978-1981 had the largest percentage of years with non-significant model fit and the largest average of the absolute value of the standardized residuals for maturity-at-age for males and females respectively. Based on these results none of the populations is clearly more variable than the others. The Div. 4RST 1996-2000 data set is perhaps the least variable with the smallest range in $L_{50}$, the smallest maximum annual change and no years in which the model did not fit the data.

Observed and predicted proportion mature-at-length are presented for selected years for males in Figure 4 and females in Figure 5. All data sources show a large degree of interannual variability. Almost all show instances where the observed proportion mature at larger sizes is less than at smaller sizes. Most show instances (particularly among males) where the estimated curve is incomplete. There were cases where very few sampled length classes had fish estimated to be 0% mature (e.g. Fig. 4 Subarea II Russia 1984) and cases where no sampled length classes were estimated to be 100% mature (e.g. Fig. 5 Div. 2J3K 2000).

**Discussion**

Estimates of age and size at 50% maturity were fairly similar across populations with the exception of Div. 2J3K which were higher. The estimates for Div. 2J3K are greater than some estimates produced for the Div. 3LMN portion of this population which at 65-70 cm are very similar to the estimates derived here for other populations (Junquera *et al*., 1999). These latter estimates were produced from data collected at a greater maximum depth than most of the Div. 2J3K time series. However, since 1995 the maximum depth of the Div. 2J3K survey has been extended to 1500 m with no appreciable decrease in estimates of $L_{50}$ and $A_{50}$. The age and size at maturity determined here for the Div. 2J3K population are not unique as estimates from Russian surveys in the 1940's and 1960's of the northeast Arctic population were very similar (Kovtsova and Nizovtsev, MS 1985).

Variability in maturity estimates appears to be a feature common to all of the data examined here with the Div. 4RST 1996-2000 data set being perhaps the least variable. Previous studies have also shown inconsistencies in the maturation of Greenland halibut with the occurrence of immature fish at large size, as well as irregularities in spawning frequency and location (Federov, 1971; Bowering, 1982; Riget et al., 1992; Junquera and Zamarro, 1994).

Estimates of maturity at size and age could be highly variable if macroscopic determination of juvenile and adult stages was difficult and/or unreliable. There have been several comparisons of macroscopically and histologically determined maturity stages (Walsh and Bowering, 1981; Junquera and Saborido-Rey, MS 1995b; Junquera et al., 1999; Morin and Bernier, MS 1999). These studies have generally indicated that the largest number of misclassifications of the juvenile stage are with the early maturing and resting stages. Although these studies concluded that estimates can be improved by histological determination of maturity, most found little difference between estimates from the two methods. A study, which compared macroscopic determination at sea with those conducted in the laboratory has found differences between the two sets (Gundersen, unpublished data). The accuracy of macroscopic determinations of maturity should be explored further, in particular examining the degree to which misclassification varies across year and cohort.

Of the surveys examined here, only the Div. 4RST 1996-2000 covers the entire distribution of the stock being examined. This may be part of the reason that this data set is the least variable. In order for lack of coverage to lead to interannual variability there would need to be spatial/temporal variation in the proportions of adult fish in the surveyed area. This could occur if there are spawning migrations, which vary in time or if there is variability in the overall juvenile or adult distribution. There is some evidence for this type of distributional variation in the Subarea 2 + Div. 3KLMNO and Subarea I and II populations (Anon. 1994; Albert et al., In Press). A time series of surveys with more extensive coverage would be required to compare to the more limited surveys in order to confirm this possibility. To date this has only been done for the Subarea 2 + Div. 3KLMNO population. Morgan and Bowering (MS 2001) found that estimates from surveys with more extensive coverage were less variable than from those covering only Div. 2J3K. Although the entire Div. 4RST distributional area of Greenland halibut is covered in the 1996-2000 surveys the data are collected based on three areas. When the data are anlayzed for each area separately there is greater varibility (wider fiducial limits and more variation across time) than for the estimates of the entire area (Fig. 6). More data sets of this sort with longer time series are required to fully explore this possibility.

One of the aims of constructing annual estimates of proportion mature is for use in the calculation of spawning stock biomass. The interannual variability exhibited by most of the data sets examined here limit their usefulness for this purpose. Averaging of data across time as well as ways to combine data from different parts of the distribution of a population will be required. The appropriate means of achieving this needs to be examined on a case-by-case basis.

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Table 1. Average length and age at 50% maturity from each data source.

| Data Source | Male | | Female | |
|---|---|---|---|---|
| | $L_{50}$ | $A_{50}$ | $L_{50}$ | $A_{50}$ |
| 4RST 1978-1981 | 42.20 | 5.34 | 58.22 | 8.23 |
| 4RST 1996-2000 | 39.23 | | 48.22 | |
| 2J3K | 62.37 | 9.78 | 78.54 | 12.78 |
| XIVb | 48.91 | | 62.79 | |
| Va | 47.24 | | 64.01 | |
| II Norway | 41.20 | 4.74 | 57.30 | 8.47 |
| II Russia | 43.29 | 4.81 | 60.61 | 8.13 |

Table 2. Results of generalized linear analyses of year effect on proportion mature-at-age and size.

| Data Source | | Length | Age |
|---|---|---|---|
| 4RST 1978-1981 | Male | insufficient data | insufficient data |
| | Female | $\chi^2$=111.9, df=3, p<0.0001 | $\chi^2$=39.7, df=3, p<0.0001 |
| 4RST 1996-2000 | Male | $\chi^2$=66.4, df=4, p<0.0001 | |
| | Female | $\chi^2$=76.3, df=4, p<0.0001 | |
| 2J3K | Male | $\chi^2$=702.4, df=20, p<0.0001 | $\chi^2$=575.3, df=20, p<0.001 |
| | Female | $\chi^2$=438.2, df=18, p<0.0001 | $\chi^2$=442.5, df=18, p<0.001 |
| XIVb | Male | $\chi^2$=135.8, df=3, p<0.0001 | |
| | Female | $\chi^2$=129.3, df=5, p<0.0001 | |
| Va | Male | $\chi^2$=123.1, df=4, p<0.0001 | |
| | Female | $\chi^2$=502.1, df=4, p<0.0001 | |
| II Norway | Male | $\chi^2$=20.6, df=4, p<0.0005 | $\chi^2$=11.9, df=4, p<0.05 |
| | Female | $\chi^2$=250.4, df=4, p<0.0001 | $\chi^2$=5.0, df=4, NS |
| II Russia | Male | $\chi^2$=496.1, df=16, p<0.0001 | $\chi^2$=78.5, df=14, p<0.0001 |
| | Female | $\chi^2$=393.8, df=16, p<0.0001 | $\chi^2$=480.9, df=14, p<0.0001 |

Table 3. Metrics of variability for proportion mature-at-length.

| Data Source | Range in $L_{50}$ | Maximum annual change | Percent years with NS fit | Trend | Average standardized deviance residual |
|---|---|---|---|---|---|
| Male | | | | | |
| 4RST 1978-1981 | 3.73 | - | 50 | unknown | 0.769 |
| 4RST 1996-2000 | 2.30 | 1.30 | 0 | yes | 0.752 |
| 2J3K | 14.38 | 7.20 | 8.7 | no | 0.653 |
| XIVb | 7.05 | 7.06 | 20 | no | 0.767 |
| Va | 5.78 | 5.29 | 0 | no | 0.740 |
| II Norway | 2.62 | 2.17 | 0 | no | 0.724 |
| II Russia | 12.02 | 7.60 | 0 | no | 0.710 |
| | | | | | |
| Female | | | | | |
| 4RST 1978-1981 | 8.53 | 3.30 | 0 | yes | 0.661 |
| 4RST 1996-2000 | 3.40 | 2.90 | 0 | no | 0.646 |
| 2J3K | 22.60 | 12.14 | 17.4 | no | 0.677 |
| XIVb | 5.75 | 5.75 | 0 | no | 0.707 |
| Va | 7.44 | 6.89 | 0 | no | 0.661 |
| II Norway | 9.44 | 8.91 | 0 | no | 0.624 |
| II Russia | 12.26 | 7.81 | 0 | no | 0.657 |

Table 4. Metrics of variablity for proportion mature-at-age.

| Data Source | Range in $A_{50}$ | Maximum annual change | Percent years with NS fit | Trend | Average standardized deviance residual |
|---|---|---|---|---|---|
| Male | | | | | |
| 4RST 1978-1981 | 0.64 | - | 50 | unknown | 0.817 |
| 2J3K | 2.32 | 1.08 | 17.4 | no | 0.649 |
| II Norway | 0.73 | 0.44 | 0 | no | 0.749 |
| II Russia | 3.24 | 1.79 | 0 | no | 0.711 |
| | | | | | |
| Female | | | | | |
| 4RST 1978-1981 | 1.00 | 0.58 | 0 | yes | 0.611 |
| 2J3K | 3.54 | 2.14 | 17.4 | no | 0.689 |
| II Norway | 1.25 | 1.25 | 0 | no | 0.568 |
| II Russia | 2.33 | 1.58 | 0 | no | 0.626 |

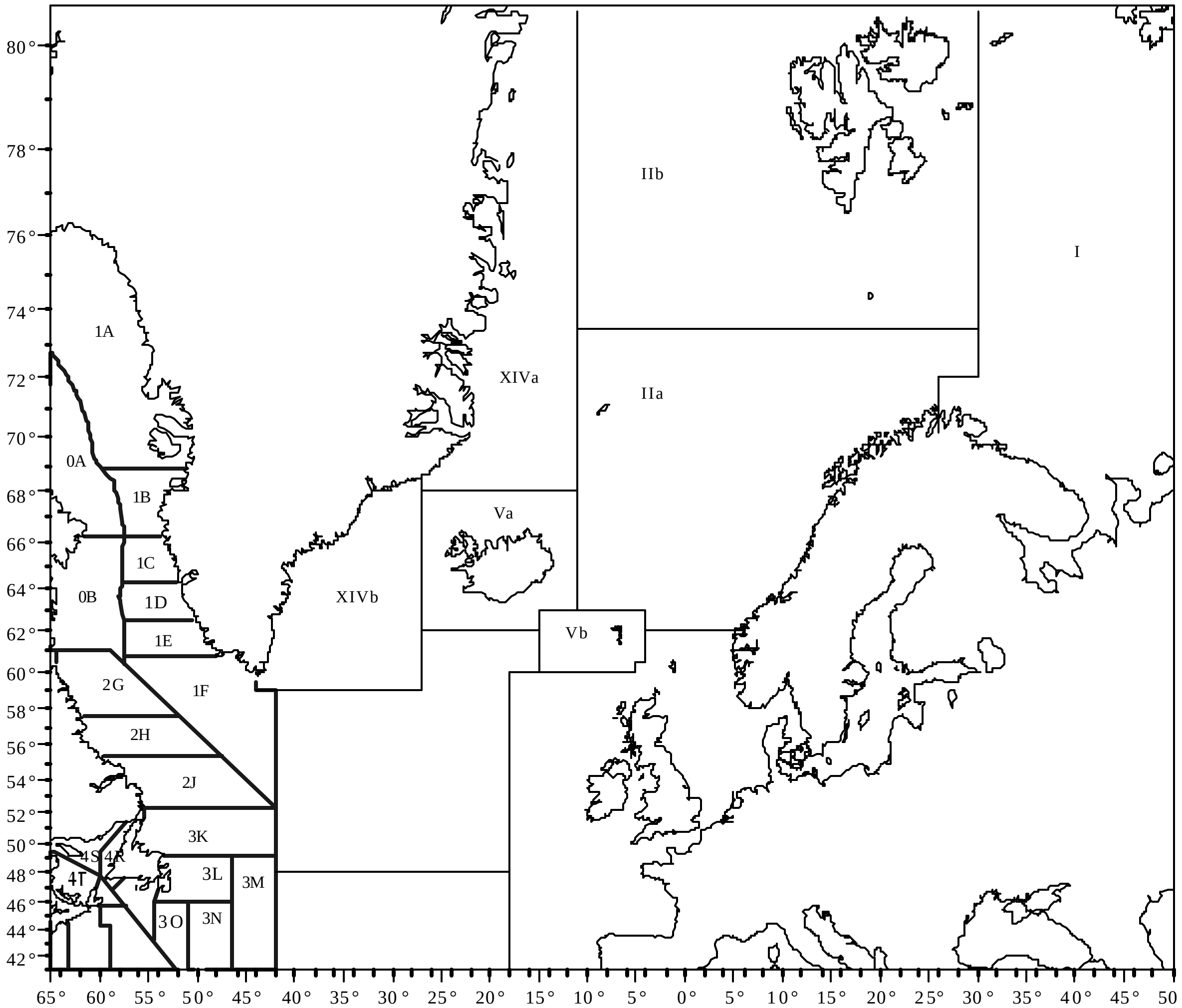


Figure 1. Map of study area.

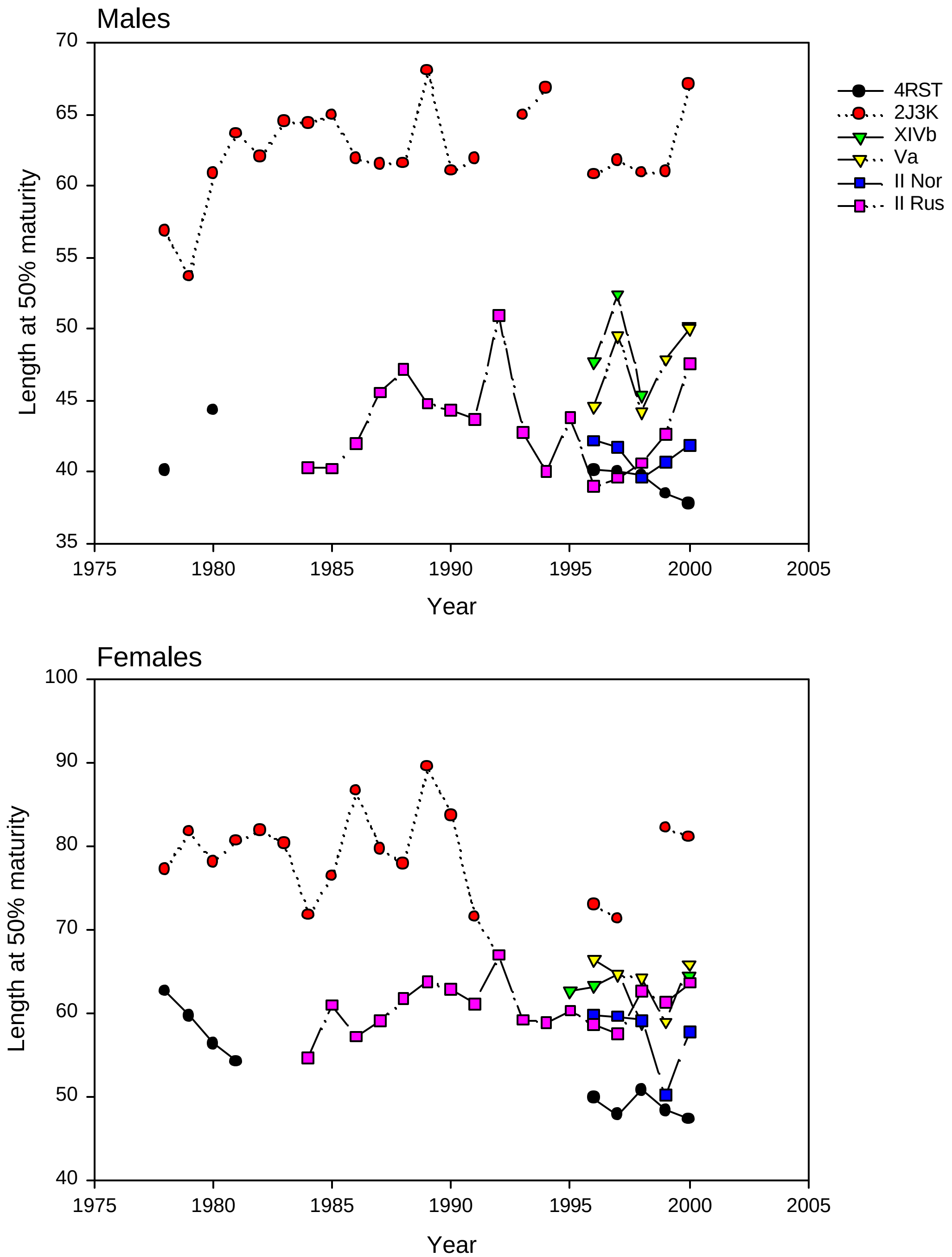


Figure 2. Length at 50% maturity for male and female Greenland halibut from different areas.

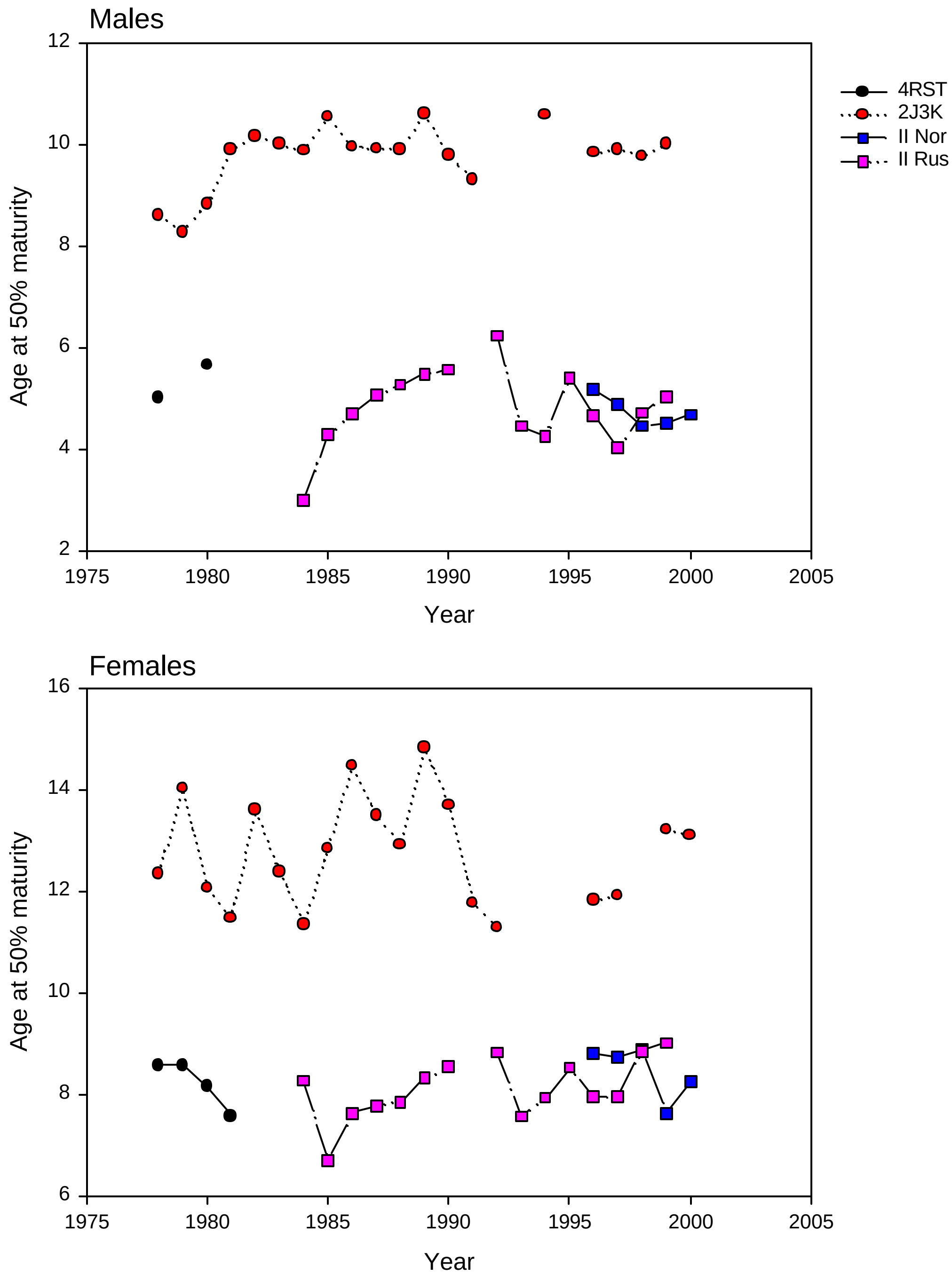


Figure 3. Age at 50% maturity for male and female Greenland halibut from different areas.

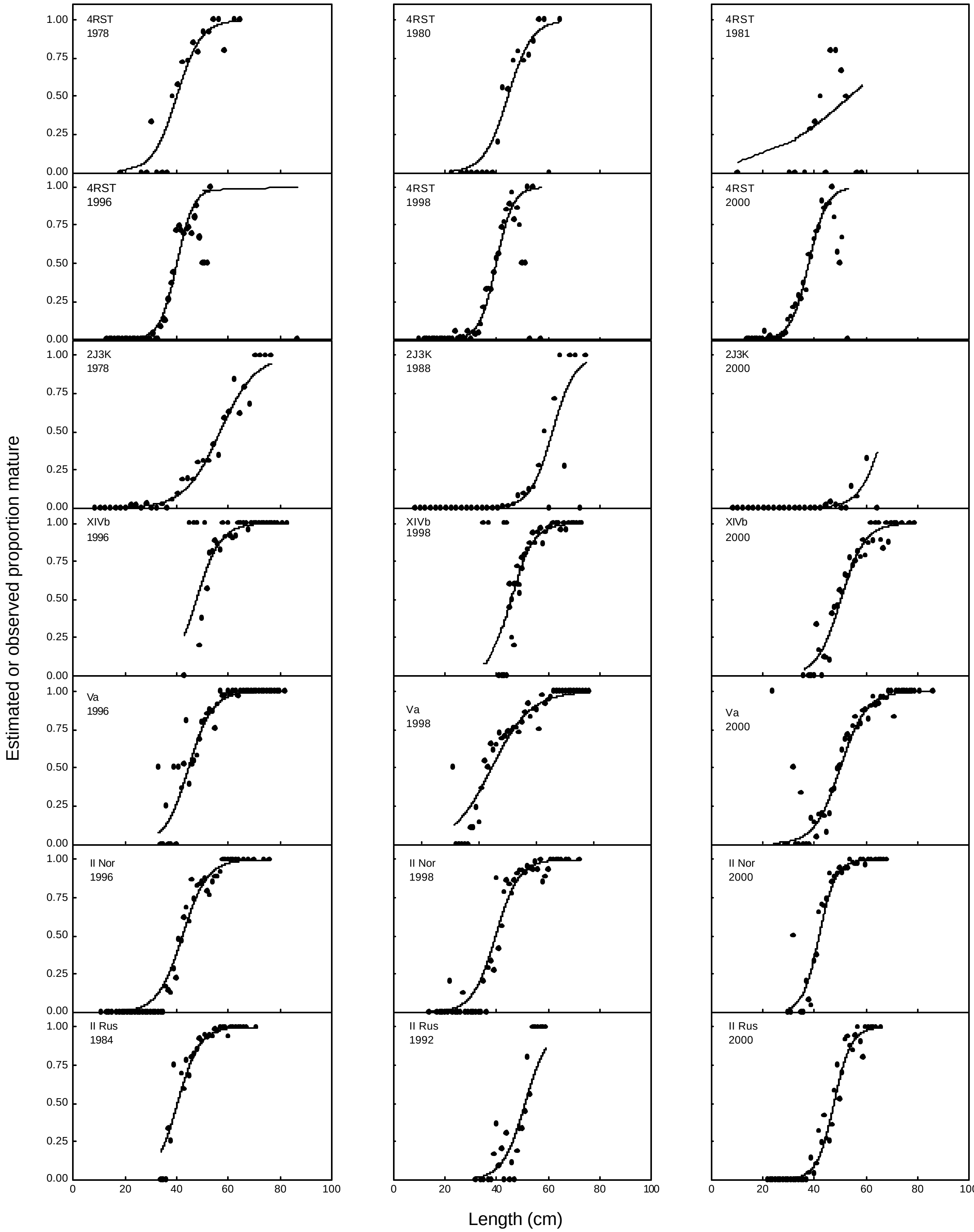


Figure 4. Estimated and observed proportion mature at length for male Greenland halibut from different areas. Only selected years are shown.

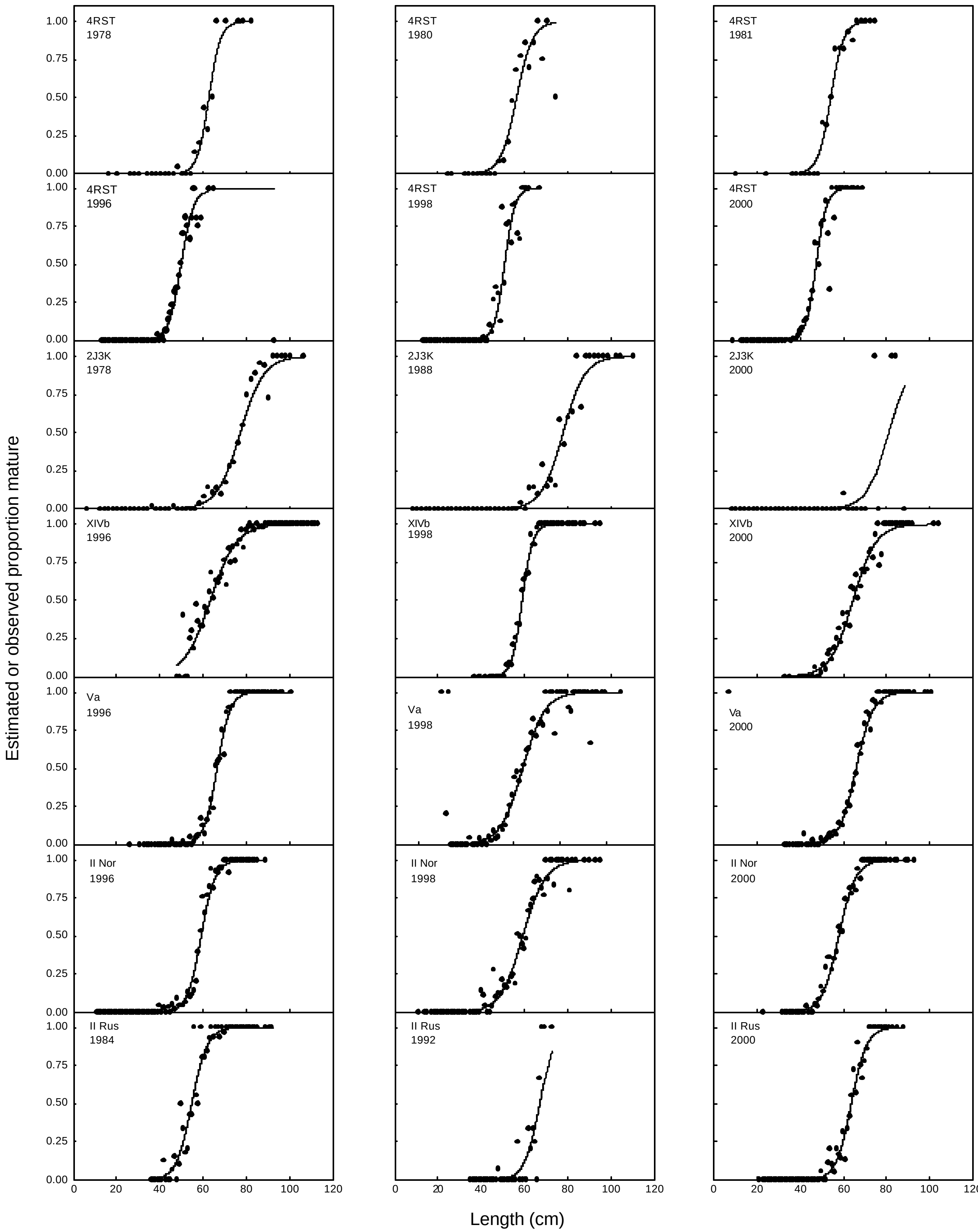


Figure 5. Estimated and observed proportion mature at length for female Greenland halibut from different areas. Only selected years are shown.

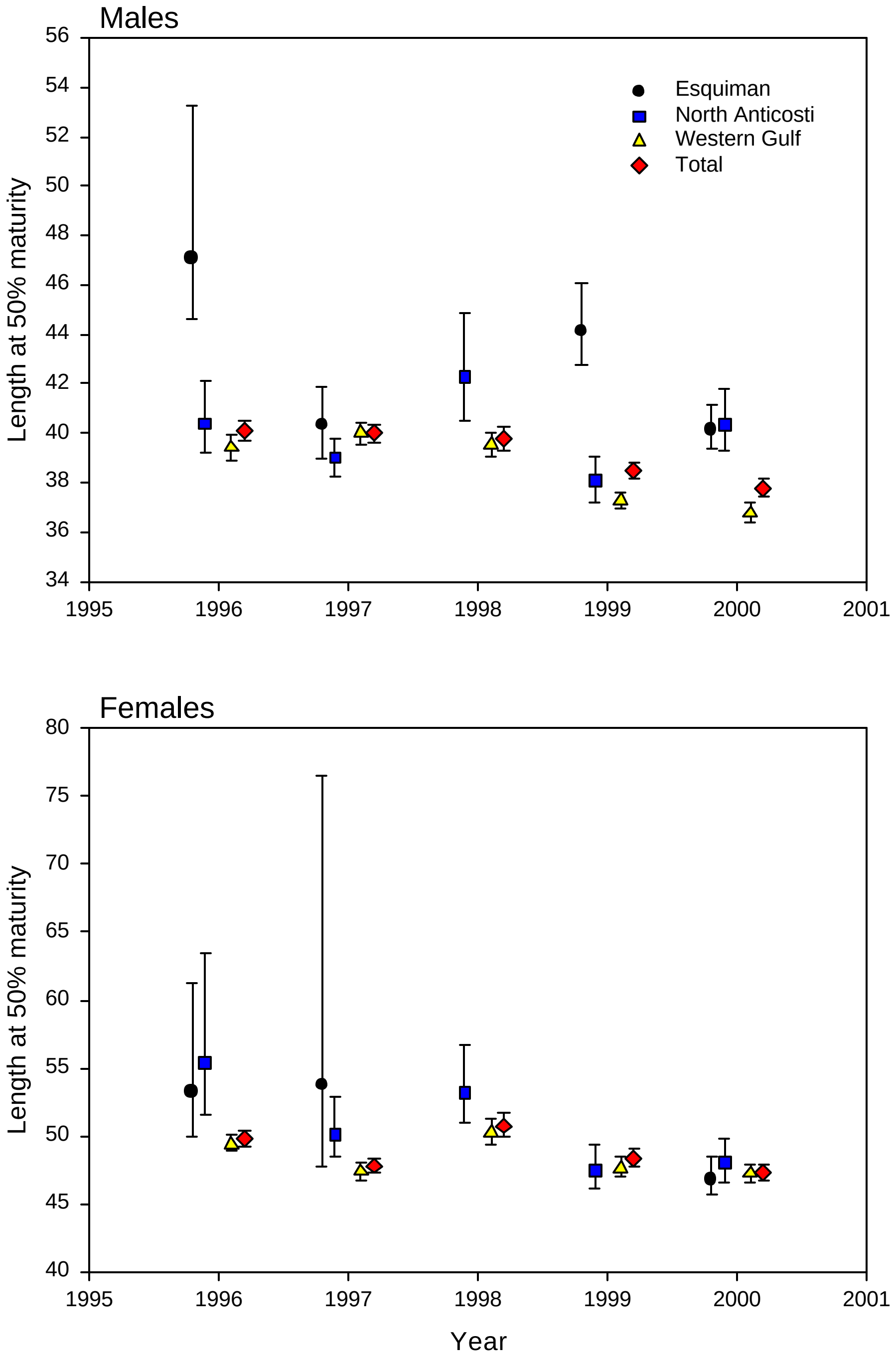


Figure 6. Length at 50% maturity (± 95% fiducial limits) for male and female Greenland halibut from NAFO Div. 4RST as a whole (total) and from 3 subareas.