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An Update of Maturity in Data for Greenland Halibut from Trawl Surveys of NAFO Subarea 0 with emphasis on Division 0A

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Abstract

Maturity information for Greenland halibut from the NAFO Subarea 0 is updated with information from surveys conducted in 2006 and 2008 and trends re-examined with emphasis on Div. 0A. L_{50} estimates for Div. 0A Greenland halibut for the two most recent years (2006 and 2008) were slightly less than that from previous years (1999 and 2004). Most estimates for Div. 0A were higher than for Div. 0B for both males and females. The most recent data show that very few fish collected in the surveys are mature (the vast majority being immature for both sexes), results that are consistent with previous information available on maturity in Div. 0A.

Introduction

Information on maturation in fishes, for example age and size at maturity and frequency of fish in spawning condition, can provide marked insights into the population dynamics of a stock. For example, maturation information may elucidate how fish stocks are responding to exploitation (Trippel, 1995; Olsen et al., 2004) and may prove valuable in specifying possible geographic areas of spawning (e.g., Jorgensen and Boje, MS 1994, Simonsen and Gunderson, 2005) or provide an indicator of stock health. Given that it is not uncommon for maturation data to vary drastically spatially and temporally (Morgan and Bowering, 1997) establishing longer time series data sets is essential for evaluating population trends. Unfortunately, however, for many species such data are drastically lacking.

Greenland halibut, *Reinhardtius hippoglossoides*, is an Arctic-boreal flatfish species distributed throughout the North Atlantic (Bowering and Nedreaas, 2000). It is an important commercial groundfish species in the area (Bowering and Brodie 1995) and as such has been the focus of a significant amount of research since the 1930s (Dyck et al., 2007 and references therein). Information on maturation in this species throughout its range is becoming more available (e.g., Junquera and Zamarro, MS 1994; Junquera and Saborido-Rey, MS 1995; Junquera et al., 2003; Morgan and Bowering, 1997; Morgan and Treble, 2006) but updating this information with more recent data is important for the re-examination and elucidation of population trends.

In this paper, we update maturity information for Greenland halibut from the NAFO Subarea 0 (see Morgan and Treble, MS 2006) and re-examine maturity trends with an additional two years of data (2006 and 2008). The previous work had shown that length at which 50% of the stock component is mature (L_{50}) was higher in Division 0A compared to 0B for both sexes, but significant interannual variation was observed (Morgan and Treble, MS 2006). These findings were mainly attributed to the potential migration of mature fish from Division 0A to spawning areas in 0B. Additionally, it was speculated that a prolonged adolescent phase or possibly that a multi-year maturation cycle, a result of environmental conditions, might explain the larger size at maturity in Division 0A fish (Morgan and Treble, MS 2006). Here we sought to extend to the growing base of maturation data in Greenland halibut for NAFO Subarea 0 with emphasis on Division 0A.

Materials and Methods

Data were collected from random trawl surveys conducted in NAFO Subarea 0A (Baffin Bay and Davis Strait) in 2006 (October 27 to November 7) and 2008 (October 8 to November 4) aboard the research vessel MV Paamiut (722 GRT stern trawler measuring 53 m in length) using Alfredo III bottom otter trawl gear. The depths covered in the surveys ranged from 400 m down to 1500 m. Tows were conducted throughout a 24 hour time period and were typically 30 minutes in duration, although were sometimes as short as 15 minutes (which were still considered to be satisfactory).

Biological information collected from all Greenland halibut included total length (± 1 cm), total weight (± 1 g), sex and stage of maturity. Additionally,
otoliths were removed for age determination on a subset, 10 per 1 cm length group per sex per stratum for both years.

To quantify female maturity data, the maturity stage of each fish was assigned as immature, early maturing, late maturing, spawning and spent and the frequency of each of the stages was calculated. Following maturity staging criteria of Riget and Boje (1989) (Table 1), stage 1 fish were considered immature, stage 2 fish were classed as early maturing, stage 3 and 4 as late maturing, stage 5 as spawning and stage 6 as spent.

Maturities were modeled according to sex using a generalized linear model (GLM) with a logit link function and binomial error (McCullagh and Nelder, 1983; SAS Institute Inc., 1993). Length was modeled as a continuous variable. For the logit link function,

$$\eta = \log\left(\frac{\mu}{1-\mu}\right)$$

and

$$\eta(\mu)^{-1} = \left(\frac{1}{1+\exp(-\mu)}\right) = \text{proportion mature}$$

where $\mu = \tau + \gamma L$, τ is an intercept, γ length effect, L the length range.

Finally, generalized linear models of the same form were used to test the significance of area and year effects, both of which were assumed to be class variables. Their significance was tested after removing the effect of length (Type 1 analysis) using the model: $x = \tau + \gamma L + \beta$ where τ is an intercept, γ length effect, L the length range, and β is the area or year effect.

Results and Discussion

For females there were some fish of at least 90 cm in length sampled in every year. L_{50} was generally higher in Div. 0A (varying between 67 and 84 cm across all years) than in 0B (62 cm and 67 cm in 2000 and 2001, respectively) (Fig. 1) and there was a significant difference in proportion mature at length between these areas (χ^2 = 123, df = 1, P <0.0001). Additionally, there was significant interannual variation in Div. 0A (χ^2 = 34 df = 3, P <0.0001). The two more recent surveys had a much lower L_{50} (67 and 73 cm in 2006 and 2008 respectively) than in the earlier surveys which both had L_{50} greater than 80 cm. Multiple comparisons showed that the first two years sampled in Div. 0A (1999 and 2004) were not significantly different from one another and that the two most recent years of sampling (2006 and 2008) were also not significantly different. When years were combined however, these two periods were different from one another with females maturing significantly larger in 1999 and 2004 than in 2006 and 2008 in

Div. 0A. The two years (2000 and 2001) for which Div. 0B was surveyed were also significantly different from one another (χ^2 = 58 df = 1, P <0.0001, Fig. 2). Most of the females surveyed were immature (Table 2). Considering only the two most recent years of data (2006 and 2008) for Div. 0A, the majority of females were immature or early maturing, with a small subset of late maturing and spent fish (Table 1). No spawning females were observed in these years.

The results for males were quite similar to those for females. L_{50} was higher in Div. 0A (over 50 cm in all years) than in 0B (39 and 43cm in 2000 and 2001 respectively) (Fig. 3). There were few length groups for males in Div. 0A where all fish were mature and many of the largest length groups had no mature fish (Fig. 3). This is despite sampling fish of a similar length range as Div. 0B. There was also a significant difference between areas for males (χ^2 = 1507, df = 1, P <0.0001) and there was significant interannual variation in Div. 0A (χ^2 = 119, d f= 3, P <0.0001). Unlike females, all comparisons between years were significantly different, indicating that the proportion mature at length was different in each area in each year (Fig. 4). The two years that were sampled for Div. 0B were also significantly different from one another (χ^2 = 543, df = 1, P <0.0001).

This update, which includes 2006 and 2008 data, extends previous findings and adds to our knowledge regarding maturation in Greenland halibut, especially in NAFO Div. 0A. Estimates of L_{50} in 2006 and 2008, for both sexes, were slightly less than that estimated in previous years in Div. 0A (1999 and 2004, Morgan and Treble, MS 2006). A decrease in size at maturity is suggestive of a decline in population size (Trippel 1995) although further work will be needed to confirm this. Additionally, now including the 2006 and 2008 data, L_{50} was still equal to or higher in all Div. 0A estimates when compared to Div. 0B for both males and females. The most recent data show that very few fish collected in the surveys are mature (the vast majority being immature for both sexes), results that are consistent with previous information available on maturity in Div. 0A (Morgan and Treble, MS 2006). Additionally, as was found in the previous study (Morgan and Treble, MS 2006), many of the larger length groups contained no mature fish although this is not uncommon (Junquera and Zamarro, 1994; Morgan and Bowering, 1997, Simonsen and Gundersen, 2005) for this species. Some Greenland halibut, regardless of size, may never enter a spawning phase (Simonsen and Gundersen, 2005) and this may be part of the reason for the lack of adult fish within this Subarea.
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The Greenland halibut maturation data updated in this report are relatively consistent with that collected in other NAFO Subareas and Divisions. Morgan and Rideout, MS (2007) report L_{50} values of 62 cm and 78 cm in Div. 2J and 3K, for males and females respectively. Length at 50% maturity for females in Divisions 3LMNO ranged between 64.5-69.5 cm from 1990-1997 (Junquera et al., 1999) and Morgan and Bowering (1997) provide an overall L_{50} estimate of 71.5 for females captured in a variety of surveys spanning 17 years across a relatively broad area (Divisions 2GHJ, 3KLM and 0B).

Significant geographic and temporal variation in maturation indices of Greenland halibut is not uncommon (Jørgensen and Boje, MS 1994; Junquera and Zamarro, 1994; Morgan and Bowering 1997; Junquera et al., 1999; Morgan et al., 2003; Morgan and Treble. MS 2006) and the results of the present update corroborate these findings. There are several likely explanations for these marked differences, most related to the spawning behaviour of the species. First, spawning may occur sporadically in unknown locations (Jørgensen and Boje 1994) and it is suggested that this species may not be capable of spawning on an annual basis (Federov, 1971; Simonsen and Gunderson 2005). The spawning migrations of this species may vary in time (Morgan et al., 2003). Furthermore, Greenland halibut may have a main and secondary spawning period during some years (Federov, 1971; Junquera and Zamarro, 1994) as mature fish have been captured throughout the year (Morgan and Bowering 1997). Finally, it is perhaps possible that some maturity stages have been misclassified (Junquera et al., 1999) which could possibly lead to variation between areas and years.

Maturation differences between Baffin Bay (Div. 0A) and Davis Strait Div 0B), have also been found in the past (Simonsen and Gundersen, 2005; Morgan and Treble, MS 2006) and the data presented here further confirms this. Davis Strait is thought to be a spawning area for Greenland halibut (Templeman, 1973; Jørgensen 1997, Simonsen and Jørgensen 2005) and it has been suggested that mature fish from Baffin Bay may migrate to Davis Strait to spawn (Simonsen and Gundersen, 2005). This would explain the smaller L_{50} for fish from the Baffin Bay area. Jørgensen and Boje (1994) found the majority of female fish they sample in Davis Strait had developed ovaries. Additionally, there may be a prolonged adolescent stage in Baffin Bay Greenland halibut or some of these fish may never enter a spawning phase because of environmental conditions (Simonsen and Gundersen, 2005); both of which would further explain the high incidence of immature fish in Div. 0A. Further assessments of Greenland halibut maturation in Subarea 0 are still essential to confirm or refute these hypotheses.

In summary, we have provided updated information for maturity data in Subarea 0 Greenland halibut with emphasis on Div. 0A. L_{50} estimates for Div. 0A Greenland halibut for the two most recent years (2006 and 2008) were slightly less than that from previous years (1999 and 2004). Most estimates for Div. 0A were higher than for Div. 0B. These results extend previous findings and add to the current information available regarding maturation in this species. Further work is still required to fully understand the reproductive biology of this species.

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Table 1. Maturity staging criteria used in 0A survey, 2004-08 (Riget and Boje, 1989 with photos by Agnes Gundersen and Inge Fossen at Møre Research in Norway).

1 Immature *Females:* The ovaries are small, no eggs are visible to the naked eye. *Males:* Testes mostly clear and very small having a length of less than ¼ of the abdominal cavity	
2 Maturing (A) *Females:* The eggs are small, but visible to the naked eye. Egg diameter < 1 mm. *Males:* Testes opaque having a length between ¼ and ½ of the abdominal cavity	
3 Maturing (B) *Females:* Egg diameter 1-2 mm. Less than 50% of the eggs are translucent *Males:* Testes opaque having a length between ½ and ¾ of the abdominal cavity.	
4 Maturing (C)	

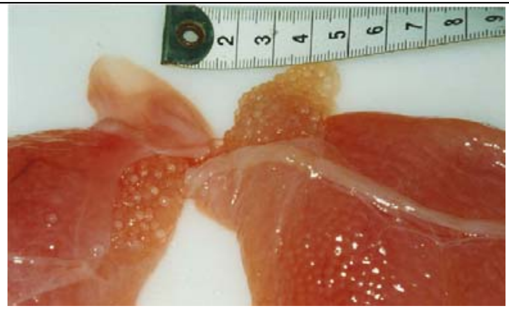
Females: Egg diameter 2-4 mm. More than 50% if the eggs are translucent and with a hint of colour. *Males:* Testes big and white in appearance having a length between ¾ and $^{1}/1$ of the abdominal cavity	
5 Spawning *Females:* Egg diameter 4-5 mm. The eggs are translucent and big. Running stage. *Males:* Running stage: sperm is running	
6 Resting *Females:* The ovaries are red and loose, often with some remaining transparent eggs. Sometimes the ovary lacks the red colour, but it is still loose and with a thick ovary wall and a hollow space transversely through the ovary. *Males:* Not possible to assess resting males.	
7 Uncertain	

Table 2. Occurrence of different female maturity stages by survey year and month. Bolded values indicate the updated data presented in the present document.

NAFO Div.	Year	Month	Total	Immature	Early Maturing	Late Maturing	Spawning	Spent
0A	1999	10	4275	4261	14	0	0	0
0B	2000	10	1616	1480	63	0	0	73
0B	2001	10	1398	1329	68	0	1	0
0A	2004	9	231	213	17	1	0	0
0A	2004	10	333	320	6	7	0	0
0A	**2006**	**10-11**	**4416**	**4375**	**16**	**4**	**0**	**21**
0A	**2008**	**10**	**5494**	**5371**	**68**	**9**	**0**	**46**

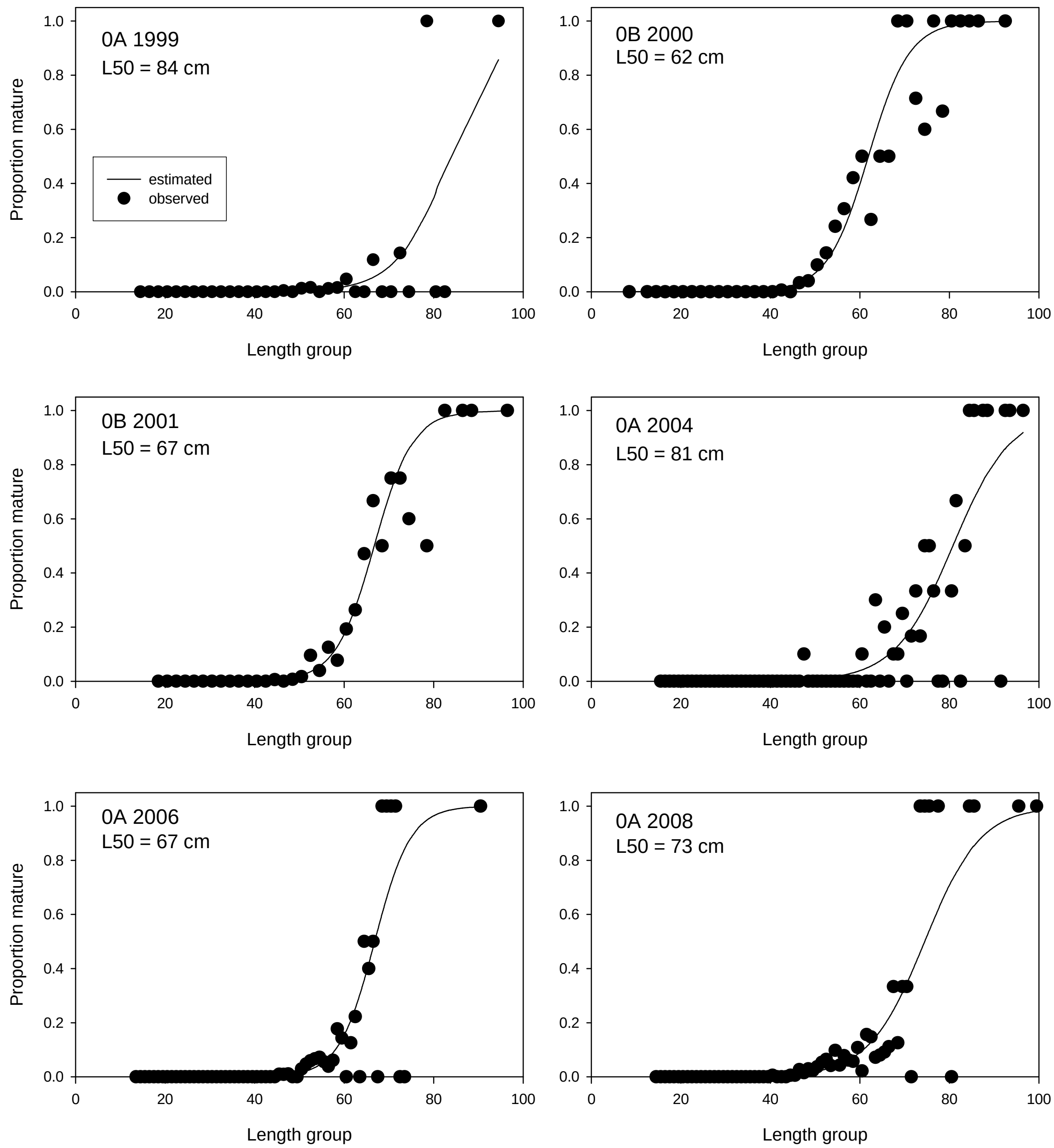


Figure 1. Estimated and observed (symbols) proportion mature at length for female Greenland halibut from Canadian surveys of NAFO Divisions 0A and Div. 0B.

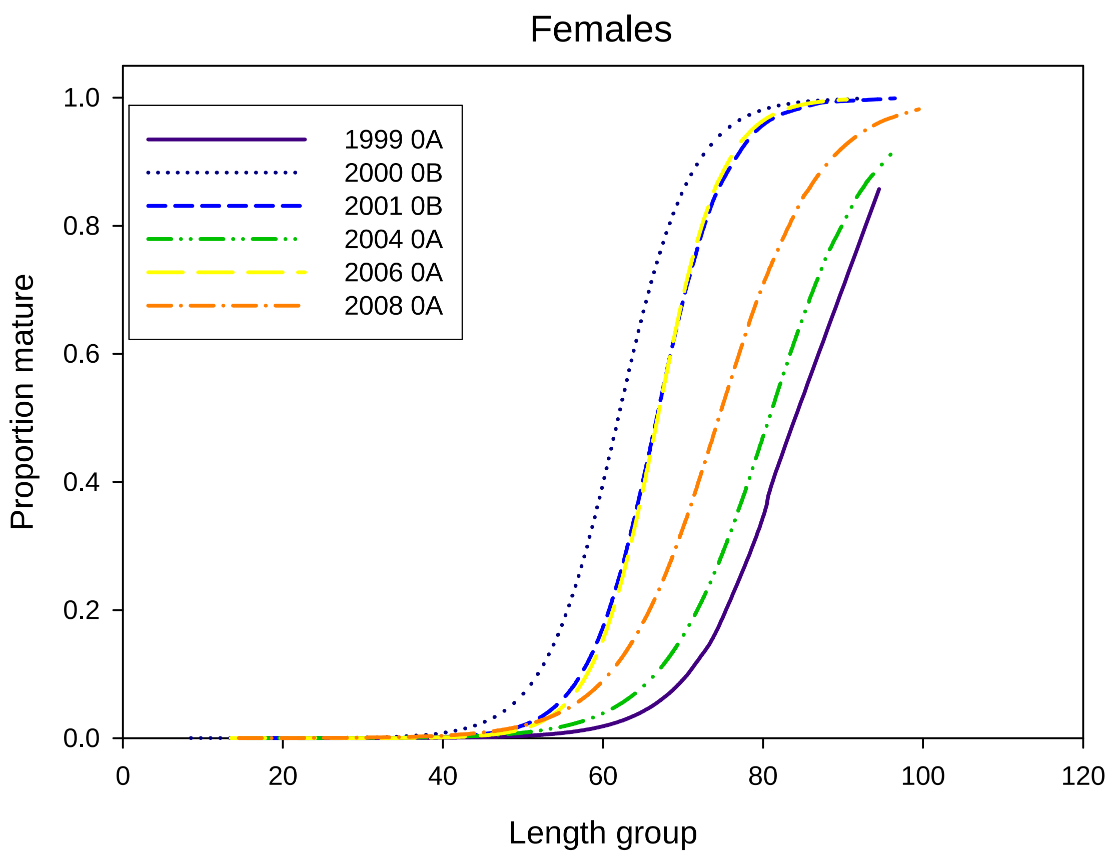


Figure 2. Estimated proportion mature for female Greenland halibut for all years and Divisions sampled.

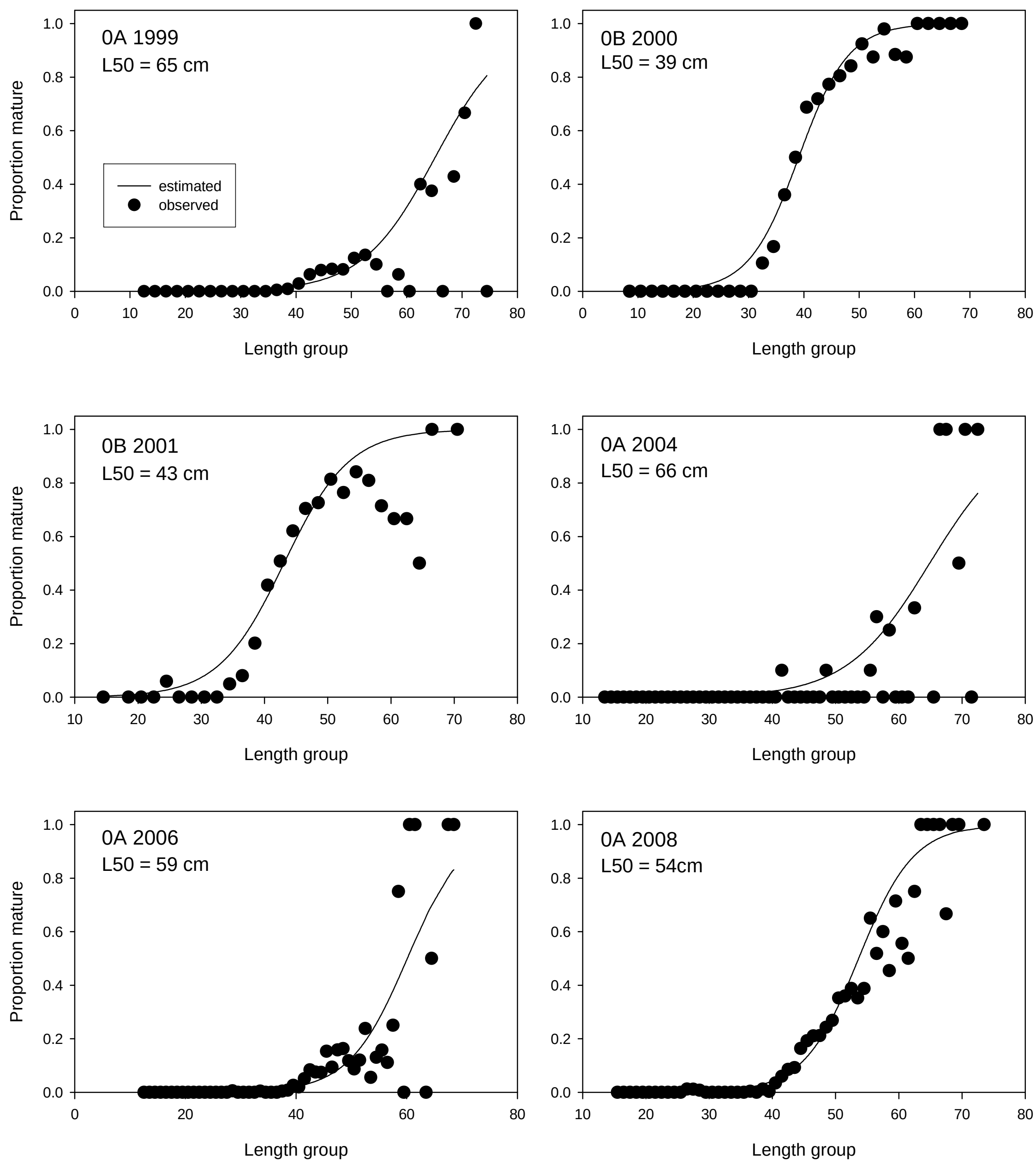


Figure 3. Estimated and observed (symbols) proportion mature at length for male Greenland halibut from Canadian surveys of NAFO Divisions 0A and Div. 0B.

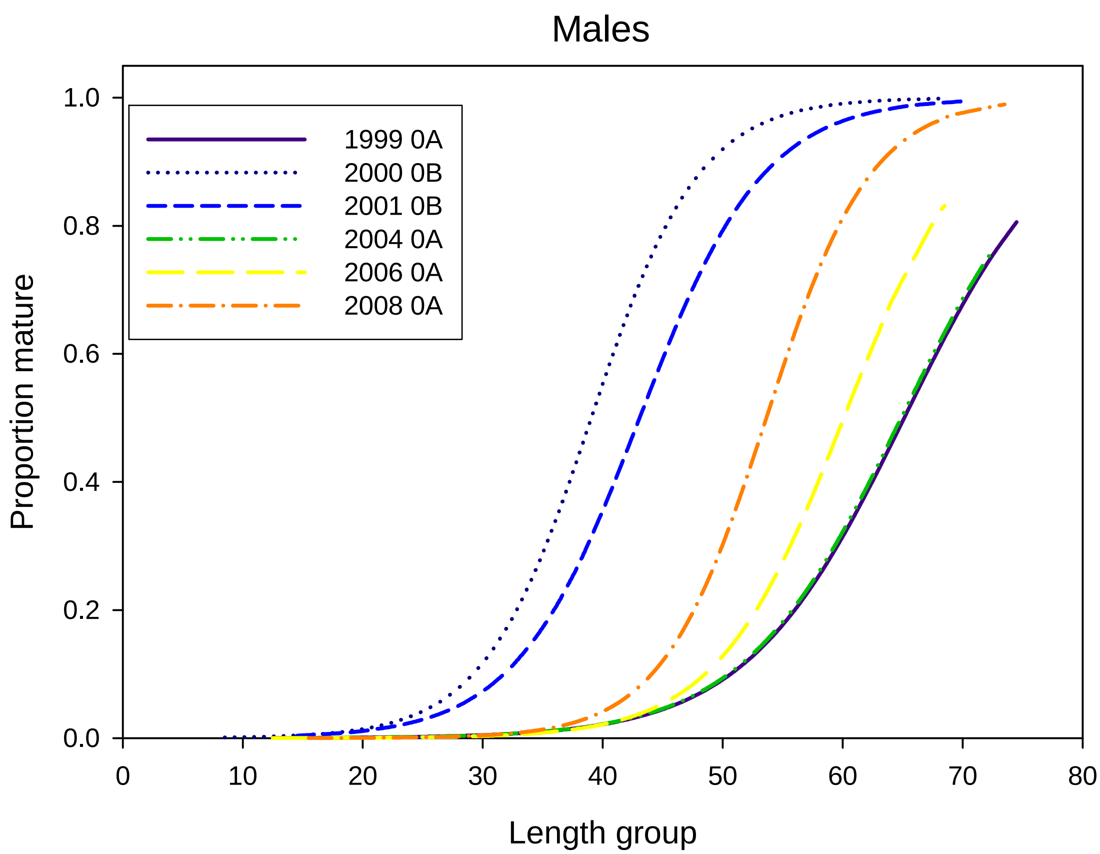


Figure 4. Estimated proportion mature for female Greenland halibut for all years and Divisions sampled.