Northwest Atlantic Fisheries Organization

Serial No. N5216 **NAFO SCR Doc. 06/5**

SCIENTIFIC COUNCIL MEETING – JUNE 2006

A First Look at Maturity Data for Greenland Halibut from Trawl Surveys of NAFO Subarea 0

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Abstract

Information on maturity of Greenland halibut from Subarea 0 is lacking. However, maturity data was collected on surveys conducted in the area between 1999 and 2004. This study examined maturity data and produced estimates of proportion mature at length for males and females for Divisions 0A and 0B. L_{50} was higher in Div. 0A than in Div. 0B for both males and females. There was significant interannual variation in maturity at length for both sexes. The larger size at maturity in Div. 0A than in Div. 0B is consistent with a migration of fish to Div. 0B to spawn as they become adults, but could also be due to a prolonged adolescence or a multi-year maturation cycle caused by limitations on somatic growth in the colder environment found in Div. 0A.

Keywords: maturation, Greenland halibut, Subarea 0.

Introduction

There is little information on Greenland halibut (*Reinhardtius hippoglossoides*) in the offshore regions of Subarea 0 and 1. Jørgensen and Boje (MS 1994) found that few fish matured in Div. 1A with more than half of the fish maturing in Div. 1D. This indicates that spawning may take place in the Davis Strait. The time course of gonadal development indicated that spawning would take place in the winter or early spring. A more recent study supports the Davis Strait as a spawning location (Simonsen and Gundersen, 2005).

Information on maturity of Greenland halibut from Subarea 0 is lacking. However, maturity data was collected on surveys conducted in the area between 1999 and 2004 (Treble *et al.*, MS 2000; Treble *et al.*, MS 2001; Treble, MS 2002; Treble, MS 2004). The purpose of this study was to examine this maturity data and produce estimates of proportion mature at length for males and females for Div. 0A and 0B.

Materials and Methods

Stratified random otter trawl surveys were initiated in NAFO Subarea 0 (Baffin Bay and Davis Strait) beginning in 1999. These surveys covered depths from 400 m down to 1 500 m. The timing of the surveys varied slightly from year to year but were all conducted in the autumn between the beginning of September and the end of October. The 1999 survey was conducted in southern Division 0A (Baffin Bay) from October 7 to 19, the 2000 and 2001 surveys in Div. 0B (Davis Strait) ran from October 9 to 19 and October 19 to 26, respectively, and two surveys were conducted in Div. 0A in 2004, September 4 to 12 and October 14 to 24. The research vessel MV *Paamiut* (722 GRT stern trawler measuring 53 m in length) used Alfredo III bottom otter trawl gear. Tows were 30 minutes in duration although tows down to 15 minutes in length were considered acceptable, and occurred throughout a 24 hr period. All Greenland halibut were sampled for length, weight, sex and maturity. Otoliths were removed for age determination on a subset, 10 per 1 cm length group per sex per stratum for 1999, 2000 and 2001 and per trip for 2004.

Female maturity stages were divided into immature, early maturing, late maturing, spawning and spent. The occurrence of these stages in each year was tabulated. For all data the immature class was left the same. For the first 3 years the classification of Templeman *et al.* (1978, Table 1) was used. From this the stages MatAP, SpentPMatAN and MatAN were classed as early maturing. The MatAN fish are to spawn in the next year but these were combined with those early maturing fish that were thought to be spawning in the present year because the classification used in 2004 did not have these stages (Table 2). Late maturing fish were MatBP and MatCP. Spawning fish were partly spent and spent fish were SpentP. SpentL did not occur. In 2004, stage 2 were classed as early maturing, stage 3 and 4 as late maturing, stage 5 as spawning and stage 6 as spent.

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

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

and

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

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

In addition the significance of area and year effects was tested using generalized linear models of the same form. Area and year were assumed to be class variables and there significance was tested after first removing the effect of length (Type 1 analysis) using a model of the form: $x = \tau + \gamma L + \beta$, 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 over 90 cm in length sampled in every year. L_{50} was higher in Div. 0A (over 80 cm in both years) than in Div. 0B (62 and 67 cm in 2000 and 2001, respectively) but there were few length groups in Div. 0A where all fish were mature and many of the largest length groups had no mature fish (Fig. 1). There was a significant difference in proportion mature at length between the areas (χ^2 = 242, df= 1, P <0.0001). There was also significant annual variation (χ^2 = 358, df= 3, P <0.0001). Multiple comparisons showed that 1999 and 2004 were not different from one another but that all other comparisons between years were significantly different. This means that there was no difference between the two years in which Div. 0A was surveyed but that Div. 0B was different than Div. 0A and in addition the two years (2000 and 2001) for which Div. 0B was surveyed were significantly different from one another (Fig. 2). Most of the females were immature (Table 3). Of the adult females, most were in the early maturing stage, although in 2000 a number of spent females were also found.

Males showed similar results. L_{50} was higher in Div. 0A (over 60 cm in both years) than in Div. 0B (39 and 43 cm in 2000 and 2001, respectively). As with females 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 = 1 056, df= 1, P <0.0001). In addition there was significant interannual variation (χ^2 = 1 777, df= 3, P <0.0001), but for males, 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).

Previous Studies on the maturation and spawning of Greenland halibut have also 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 1995; Morgan and Bowering, 1997; Morgan and Bowering, MS 1999; Morgan *et al.*, 2003). The occurrence of immature fish at large size also appears to be common (Fedorov, 1971; Jorgensen, 1997; 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). There is some evidence that this species may not spawn every year (Fedorov, 1971; Junquera *et al*., 2003; Simonsen and Gundersen, 2005)

Differences between the maturation of Greenland halibut in Baffin Bay compared to Davis Strait have also been noted in a recent study of ovary development in Greenland halibut in west Greenland waters (Simonsen and Gundersen, 2005). They found more fish in Davis Strait were in an advanced state of maturation in the autumn than in Baffin Bay, and suggest three possibilities to explain these differences: 1) Greenland halibut conduct spawning migrations to Davis Strait; 2) there is local spawning with an extended adolescent phase and/or multi-year maturation cycle that might explain the large proportion of fish classed as immature; and 3) a majority of fish in Baffin Bay never enter a spawning phase due to a lack of energy surplus caused by harsh environmental conditions (Simonsen and Gundersen, 2005).

Marked differences were observed in bottom temperatures between Baffin Bay and Davis Strait during autumn surveys conducted in 1999, 2000 and 2001. For example in 2001 a majority of stations in Baffin Bay had bottom temperatures below 1.0°C (average 0.9°C) while in Davis Strait most stations were above 3.0°C (average 3.2°C) (Treble, MS 2002). It is known that fish that inhabit colder waters grow slower and mature at a larger size and older age (Morgan and Colbourne, 1999). This may contribute to a greater occurrence of either a multi-year maturation cycle or prolonged adolescence within Baffin Bay.

The larger size at maturity in Div. 0A than in Div. 0B is consistent with a migration of fish to Div. 0B to spawn as they become adults. However this could mean that they do not make a return migration once spawning is complete. Also a longer time series might show that this relationship between the two areas is not consistent. For example, in the SA2+3K area Bowering (1983) found a clear increase from south to north in the proportion of adult fish at a given length. This was believed to be the result of a northward migration of mature fish towards the main spawning area in the Davis Strait as reported by Templeman (1973), Chumakov (1975) and Bowering (1984). This pattern was observed in data from the deep water gillnet fishery in 1993 examined by Morgan and Bowering (1997) which showed a clear progression from south to north with a higher proportion of mature fish at a smaller size in the northern areas. However, data from this fishery in the same general area during 1994 showed the opposite pattern. Also, in the 17 year research vessel survey time series, there was no consistent spatial pattern in maturation rate observed between Div. 2J and 3K.

Further research into Greenland halibut life-history (e.g. maturation and migration patterns) within SA0 is necessary before we can draw any firm conclusions as to what is causing observed differences in proportion of mature fish in Div. 0A (Baffin Bay) compared to Div. 0B (Davis Strait).

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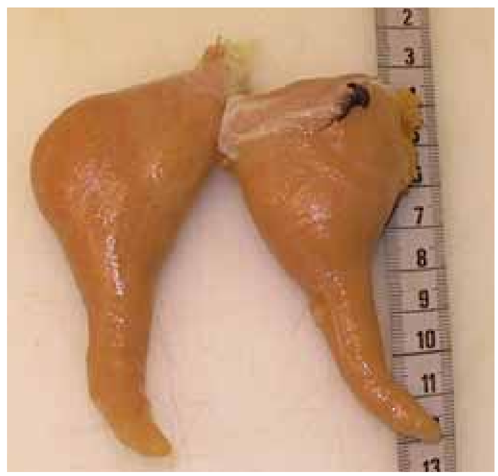
TABLE 1. Description of groundfish maturity stages used in the Newfoundland Region.

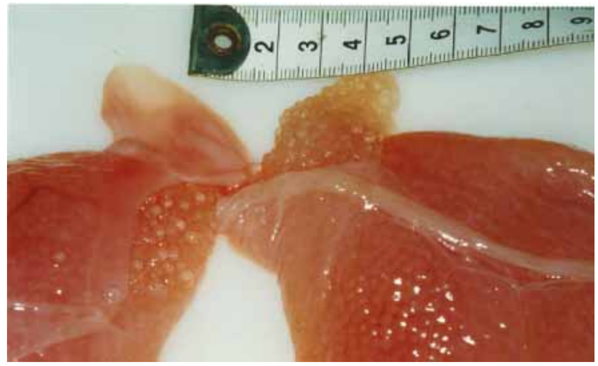
Male	Female
Immature: Testes narrow and translucent, vasa deferentia very narrow and thin walled.	**Immature**: Ovary small, grey to pink in colour; membrane thin and translucent; eggs not visible to the naked eye.
Spent L: Vasa deferentia wide and opaque, sometimes with residual milt from spawning in previous year; outer edges of testes not pinkish or greyish as in maturing fish; spent in previous (L=last) year.	**Spent L**: Ovary thick-walled with no new egss visible to the naked eye; spent in the previous (L-last) year.
Mat P: Testes relatively thick compared with immature, with outer edges pink or grey in early stage and white in later stage; early in the year some testes may show evidence of spawning in a previous year but the edges of the testes indicate recovery; maturing to spawn in present (P) year, i.e. year of capture.	**Mat A-P**: Eggs visible to naked eye in ovary itself; all eggs opaque; maturing to spawn in present year.
Partly Spent P: Some milt extruded in present year, but residual milt in testes and wasa deferentia.	**Mat B-P**: Opaque and clear eggs present with less than 50% of the volume being clear eggs; maturing to spawn in th present (P) year.
Spent P: Spawning completed in present year; recovery not sufficiently advanced for outer edges of testes to be pinkish or greyish in colour.	**Mat C-P**: 50% or more of the volume are clear eggs; this stage also includes the ripe condition where the ovarian content is almost liquid with clear eggs; to spawn or spawning in the present (P) year.
Spent P Mat N. Spawning completed in present year; outer edges of testes pink or grey or even becoming white in preparation for spawning in the next (N) year; this stage becomes Mat P in January of the next year.	**Partly Spent P**: Ovary not full as in Mat C-P; some eggs extruded but many clear eggs remaining.
Mat N: Testes developing from immature stage for spawning in the next (N) year; testes becoming thick, being pink or grey early in this stage and gradually whitening; this stage becomes Mat P in January of the next year.	**Spent P**: Spawning completed in present year but possibly a few clear eggs remaining; no new opaque eggs visible to the naked eye.
	Spent P Mat A-N: Spawning completed in present year, and new opaque eggs, for spawning in the next (N) year, visible to the naked eye; this stage becomes Mat A-P in January of the next year.
	Mat A-N: No evidence of previous spawning; but new opaque eggs, for spawning in the next (N) year, visible to the naked eye; this stage becomes Mat A-P in January of the next year.

TABLE 2. Maturity staging criteria used in northern survey in 2004 (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.	

<table>
<tr><td>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</td><td></td></tr>
<tr><td>5 Spawning

Females:
Egg diameter 4-5 mm. The eggs are translucent and big. Running stage.

Males:
Running stage: sperm is running</td><td></td></tr>
<tr><td>6 Resting

Females:
The ovaries are read and loose, often with some remaining transparent eggs. Sometimes the ovary lacks the read colour, but it is still loose and with a tick ovary wall and a hollow space transversely through the ovary.

Males:
No possible to assess resting males.</td><td></td></tr>
<tr><td>7 Uncertian</td><td></td></tr>
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TABLE 3. Occurrence of different female maturity stages by survey year and month.

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

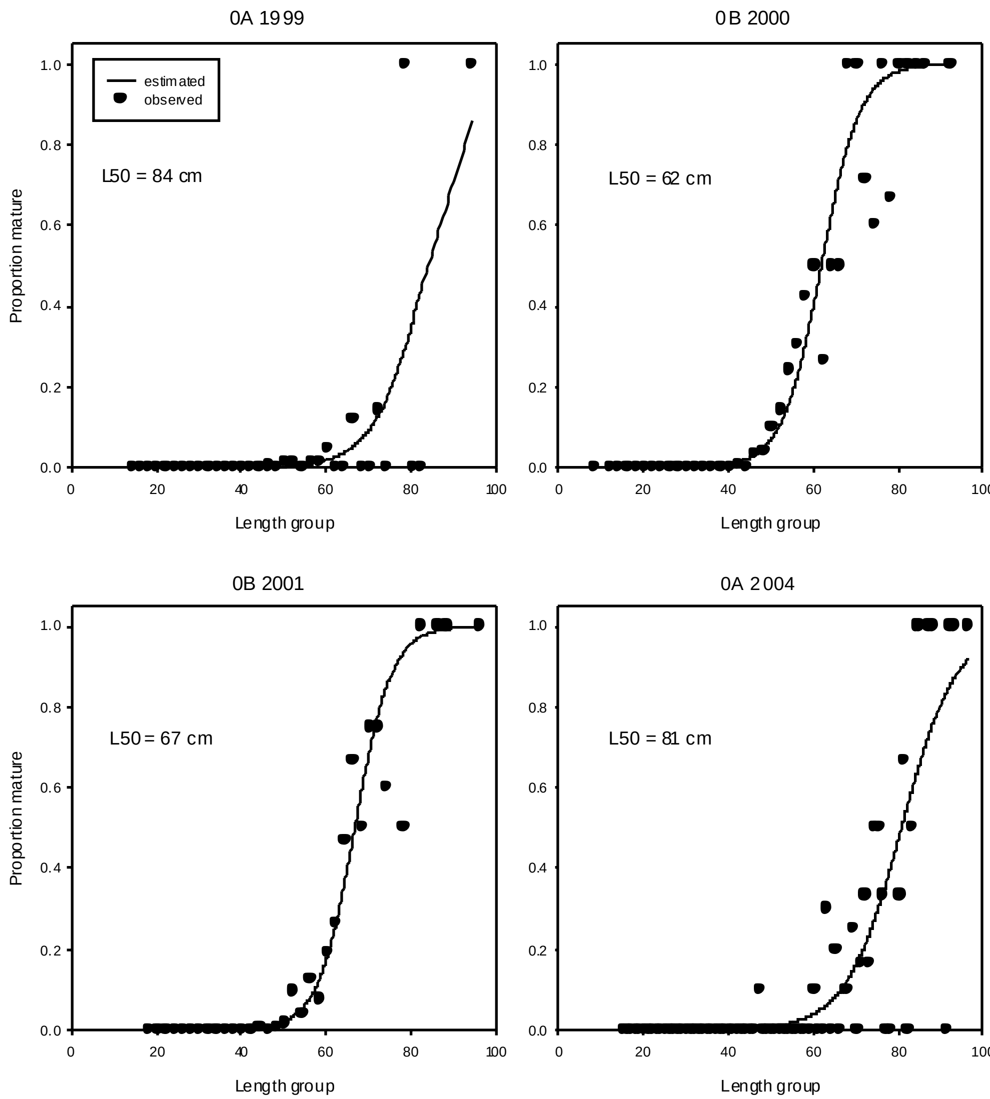

Fig. 1. Estimated and observed (symbols) proportion mature at length for female Greenland halibut from Canadian surveys of Div. 0A and Div. 0B.

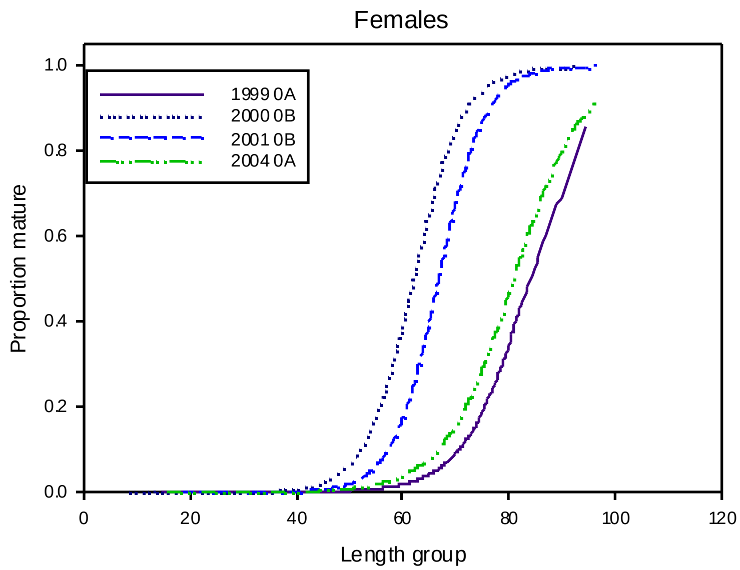

Fig. 2. Estimated proportion mature for female Greenland halibut for all years and Divisions sampled.

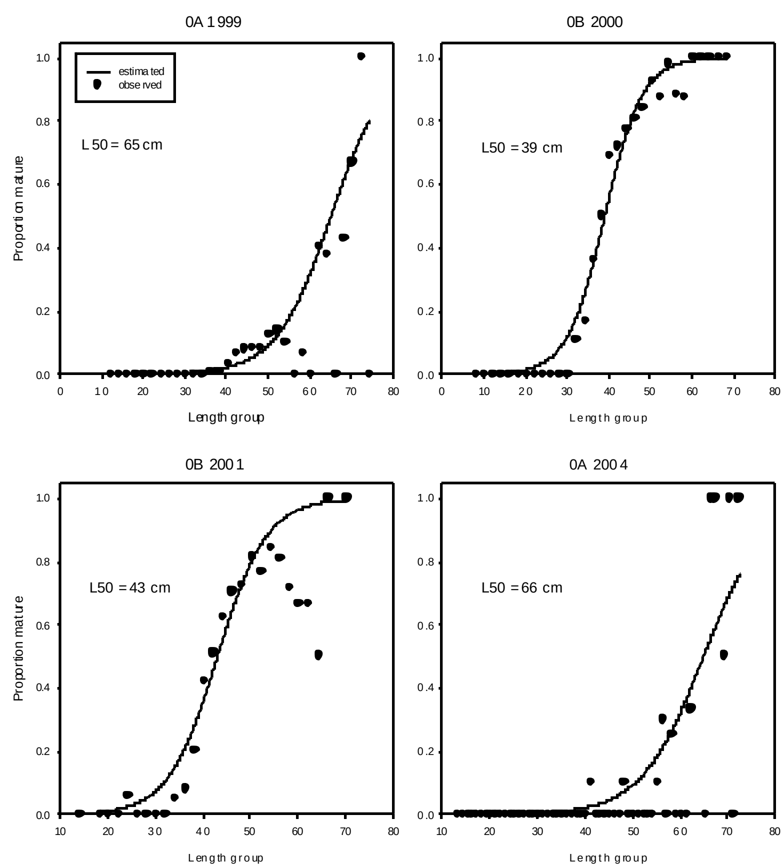

Fig. 3. Estimated and observed (symbols) proportion mature at length for male Greenland halibut from Canadian surveys of Div. 0A and Div. 0B.

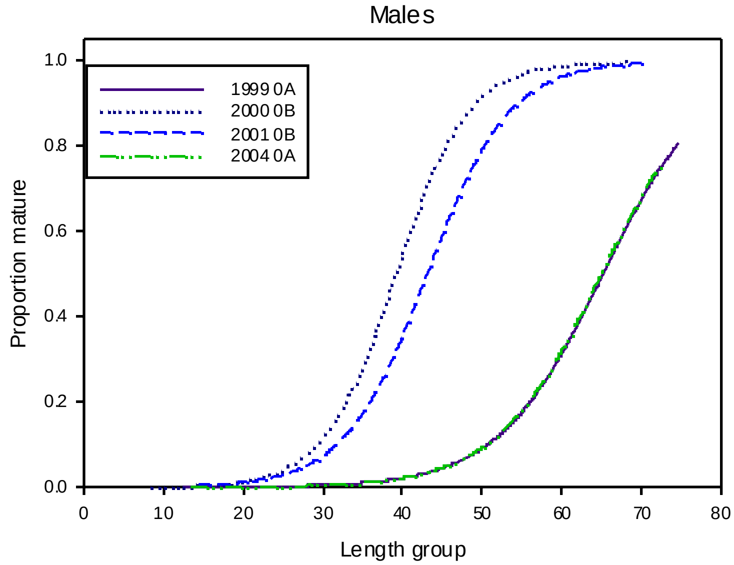

Fig. 4. Estimated proportion mature for female Greenland halibut for all years and Divisions sampled.