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Fecundity of Greenland halibut (*Reinhardtius hippoglossoides*) in the north east Arctic

A.C, Gundersen, O.S. Kjesbu, A. Stene, and K.H. Nedreaas.

ABSTRACT

Because of recruitment failures and a historic low spawning stock biomass, the Northeast Arctic Greenland halibut (*Reinhardtius hippoglossoides*) stock has been strongly regulated in the 1990-ies. Fecundity, which is defined as the number of vitellogenetic oocytes developing in each female prior to the spawning season, is important for understanding spawning-stock-recruitment relationships. The relation between the fecundity and length for Northeast Arctic Greenland halibut stock has not been previously established.

A total of 95 Greenland halibut ovaries, collected in September 1996 in the Norwegian and Barents Sea were analysed. The Greenland halibut were mainly in maturity stage 4, that is vitellogenic oocyte size between 2 and 4 mm in diameter. The estimated mean gonadosomatic index (GSI) was 7.5% (range 2.0-13.5%). Fecundity ranged from 6,800 to 70,500 eggs per female.

The fecundity-length (F (in 1000)-L (in cm)) relationship is:

$$F = 1.155 * 10^{-7} * L^{4.598} \quad (r^2 = 0.68).$$

The fecundity-weight (F (in 1000) –W (in g)) relationship is:

$$F = 2.539 * 10^{-4} * W^{1.439} \qquad (r^2=0.77).$$

Key words: Barents Sea – Fecundity – Gonatosomatic index – Greenland halibut

Agnes C. Gundersen, Møre Research, Section of Fisheries, P.O. Box 5075, N-6021 Ålesund, Norway. [phone +47 70 11 13 50, fax +47 70 13 89 78, e-mail: Agnes.Gundersen@hials.no]
Olav Kjesbu, Institute of Marine Research, P.O. Box 1870, Nordnes, N-5024 Bergen, Norway. [phone +47 55 23 85 00, fax +47 55 23 83 87].
Anne Stene, Ålesund College, P.O. Box 5104, 6021 Ålesund, Norway. [phone +47 70 11 12 00, fax +47 70 13 89 78].
Kjell H. Nedreaas, Institute of Marine Research, P.O. Box 1870, Nordnes, N-5024 Bergen, Norway. [phone +47 55 23 85 00, fax +47 55 23 83 87].

INTRODUCTION

Greenland halibut (*Reinhardtius hippoglossoides* Walbaum) in the Northeast Atlantic is distributed mainly on the continental slope off Norway from 62°N to the regions north of Spitsbergen. It is observed down to 1400m. In other parts of the Atlantic, Greenland halibut is observed down to 2000m (Boje & Hareide 1993). It is described as a boreal-arctic species and is found mainly at temperatures between -1° and 4°C. The population constitutes a separate management unit in the ICES management system.

During the late 80s a drop in the Greenland halibut year class indices, based on the regular 0-group and juvenile surveys, and a historic low spawning stock biomass were observed (Hylen & Nedreaas, 1995; Smirnov, 1995). Parallel to this, the importance of Greenland halibut as a commercial fish species increased. There was also a decrease in the commercial catch per unit of effort (CPUE) and this lead to strong regulations including a fishing ban north of 71°30N from 1992.

Studies of fish reproduction and stock-recruitment relations are basic issues in the work of precautionary approach, to prevent a stock collapse. Fecundity, which is defined as the number of eggs developing in a female for the following spawning season (Bagenal 1978) is important for obtaining data on population stability and year-class strength. Generally deepwater species along with Arctic and Antarctic species produce fewer and bigger eggs than related boreal species (Marshall 1953). Fecundity is usually related non-linearly to total fish length and weight. The relations are usually allometric (Bagenal 1978).

Little work has been done on Greenland halibut fecundity, particularly in the Northeast Atlantic. Millinsky (1944) estimated fecundity of two Greenland halibut females in the Barents Sea. In the Northwest Atlantic a few investigations on Greenland halibut have been conducted. Lear (1970) examined 45 females from the Newfoundland-Labrador area. Bowering (1980) examined 153 females from Southern Labrador and the Southeastern Gulf of St. Lawrence. Jensen (1935) estimated the fecundity of one female in West-Greenland waters. In East-Greenland waters a fecundity-length relationship is presented for 1996 (Rønneberg *et al.* 1998).

This paper describes the results of a fecundity study of Greenland halibut in the Norwegian and Barents Seas. The objectives were to obtain relations between fecundity and length, and fecundity and weight.

MATERIALS AND METHODS

The ovaries were collected in September 1996 from fish caught using gillnets and longlines on the continental slope west of Bear Island (*Fig. 1*). The combined sample consisted of 95 females randomly chosen from the catches. The females were maturing with egg diameters of 2-4mm (visual), which implies that spawning would have likely occurred a few months later. The ovaries were frozen at sea and preserved in 3.6% phosphate and then approximately one month later stored in buffered formaldehyde.

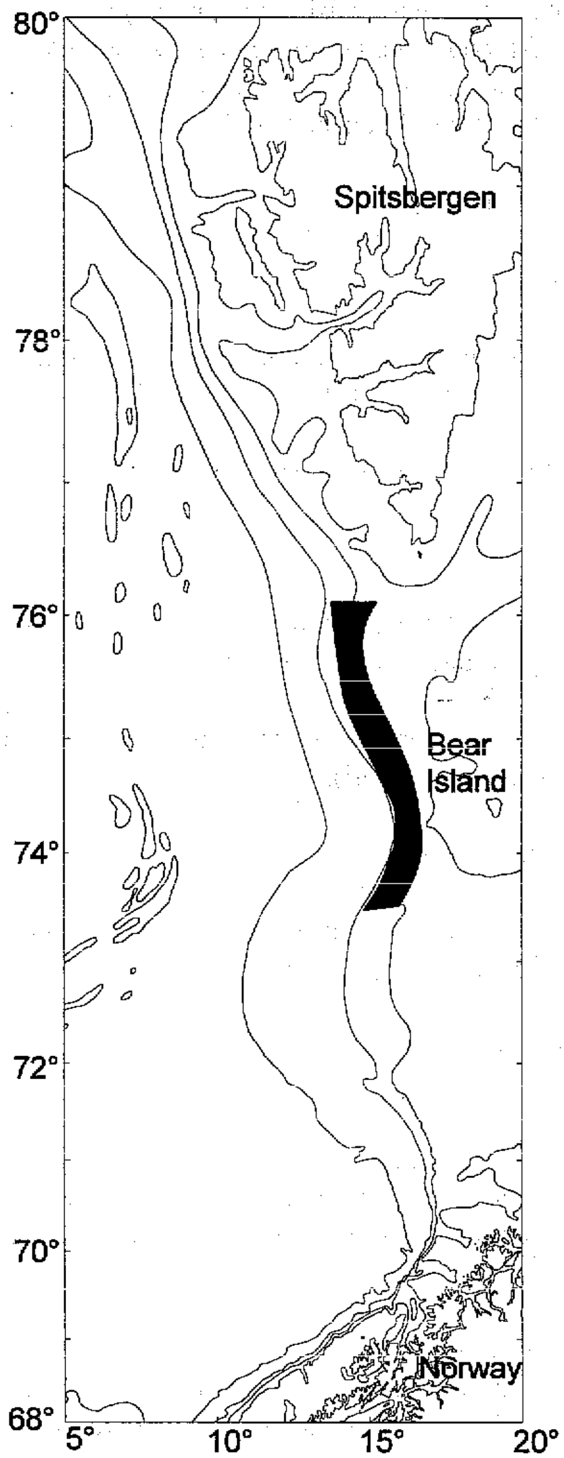


Fig. 1. *Sampling areas for Greenland halibut used in the fecundity study. Samples were taken during the Autumn Survey conducted by the Institute of Marine Research, Bergen in 1996, west of the Bear Island.*

The methods used in fecundity analyses are the same for whatever purpose fecundity estimates are needed (Bagenal 1971). For the present study, the gravimetric method described by Bagenal & Braum (1978) was used. The procedure for estimating the number of eggs in an ovary was: measure the total weight of the ovary after fixation, collect 4 subsamples, store the samples in 70% ethanol, establish a raising factor (R_{xy}) for each sample based on sample weight and ovary weight, count the number of eggs in sample 1 and 2, and estimate the total number of eggs (defined as the fecundity) in the ovary. If the coefficient of variation (CV) between the two samples (1 and 2) exceeded 5%, samples 3 and 4 were counted.

Raising factor was defined as (i):

(i) $R_{xy} = GW_x / SW_{xy}$

R_{xy} = Raising factor for ovary x and subsample y, GW_x = gonad weight after fixation of ovary x, and SW_{xy} = subsample weight of ovary x, subsample y.

Fecundity was estimated by the equation (ii):

(ii) $F_{xy} = R_{xy} * N_{xy}$

F_{xy} = fecundity of ovary x, subsample y, R_{xy} = Raising factor for ovary x and subsample y, and N = number of eggs counted ovary x, subsample y.

Gonadosomatic index (GSI) is defined as the relation between the gonad weight (GW) (g) and the total weight (W) (g) of the fish (iii).

(iii) $GSI = (GW * 100\%) / W$

Hepatosomatic index (HSI) is defined as the relation between the liver weight (LW) (g) and the total weight (W) (g) of the fish (iv).

(iv) $HSI = (LW * 100\%) / W$

Subsample size

An acceptable subsample size was established by comparing the fecundity obtained from an analysis of subsamples taken from the same ovary. Subsamples of 1.7g were used due to a coefficient of variation below 5%, corresponding to more than 200 eggs per sample.

Types of oocytes

Three types of oocytes were discovered. Vitellogenic oocytes assumed to become spawning eggs in a few months, were defined as G1. Oocytes of significant smaller diameter with yolk, were defined as G2. Small previtellogenic oocytes were defined as R (recruit group). As the ovaries had been frozen oocyte diameter was not measured. The number of G1 oocytes is the fecundity estimate for an ovary.

Homogenity

Homogenity was tested by comparing four different ovarian sections; anterior, middle and posterior section of the right lobe and the middle section of the left lobe. Five ovaries were analysed and from each section four subsamples were taken.

Data analyses
The Excel-97 was used in the data analyses.

Relations between fecundity and length and fecundity, and weight were established using log-log-transformed regression.

The coefficient of variation (CV) was used in the analyses to evaluate the fecundity estimates (v). The coefficient of variation (%) is the standard deviation (std) of the estimates divided by the mean fecundity (F_{mean}) (Sokal & Rohlf 1995).

(v) $CV = (std^{*} 100\%) / F_{mean}$

RESULTS

Homogenity
The fecundity of the 5 chosen ovaries varied from 20,000 to 35,000 eggs. A comparison of the midsections of the two lobes within each ovary, indicated a minor variability between the two lobes. No systematic trend was, however, observed (*Fig. 2*). The right midsection CV was in the range 1.3-5.5%. The CV of the left midsection was in the range 1.9-5.5%.

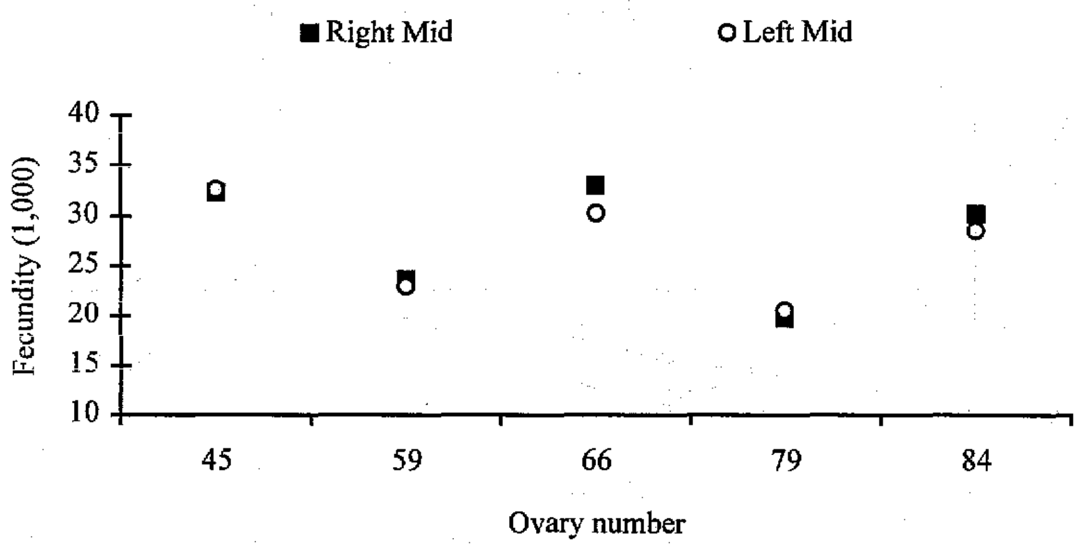
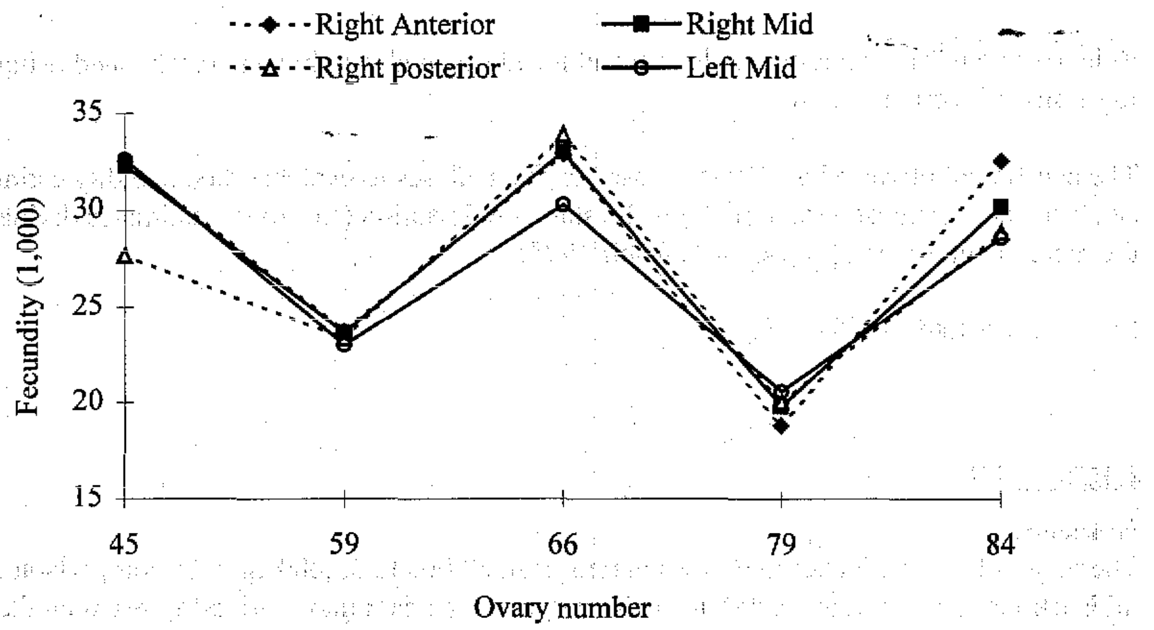


Fig. 2. *Mean fecundity (1,000) of 5 subsamples studied for homogenity of the ovary. Comparison of left and right lobe represented by samples taken in the midsection of the ovaries.*

No systematic difference in the fecundity estimates, based on samples from any of the four sections was observed (*Fig. 3*). Therefore, subsamples from the middle section of the right lobe were regarded as representative for the ovary, and the egg counts were based on subsamples taken in this section.

a)



b)

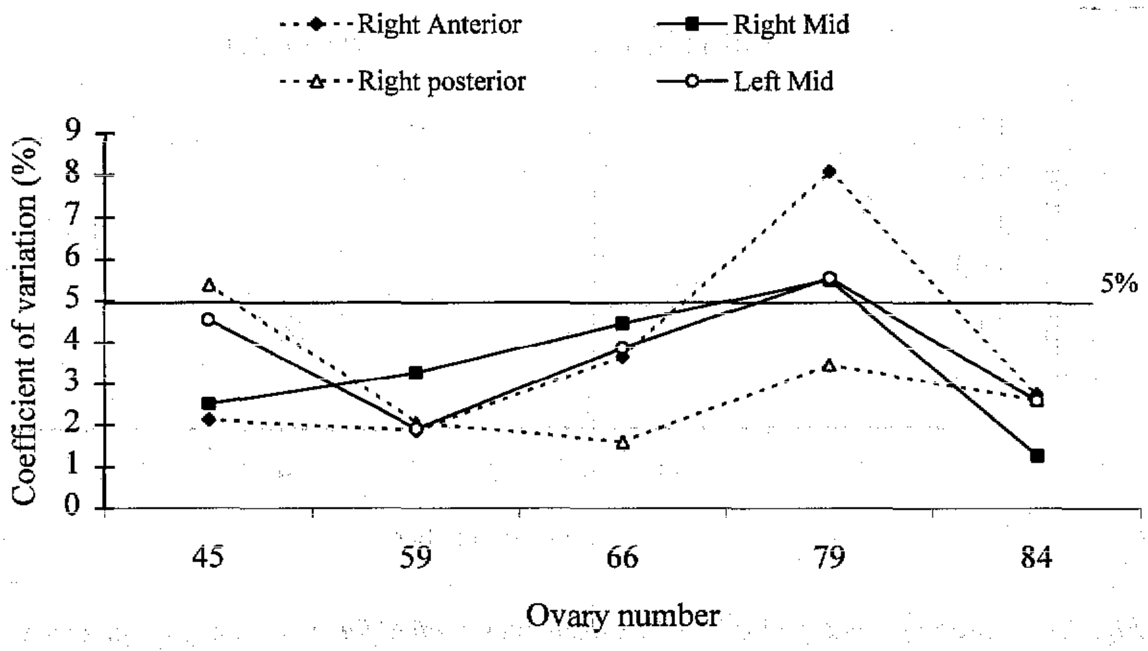


Fig. 3. *Comparison of fecundity for four subsample sections (a) of Greenland halibut and coefficient of variation (CV) of mean fecundity of the four sampling sections within each ovary (b).*

The Greenland halibut females

Total length of the Greenland halibut females sampled ranged from 48cm to 80cm (*Fig. 4*). The Greenland halibut caught by longlines were on average smaller than the Greenland halibut caught by gillnets (*Fig. 4*). The mean length of the gillnet samples was 67.6cm (std=5.1, N=45), whereas the mean length of Greenland halibut sampled from longline catches was 63.0cm (std = 6.0, N = 50). Mean length of the combined sample was 65.2cm (*Tab. 1*).

Tab. 1. Summary table for the Greenland halibut on which the fecundity studies are conducted.

Gear	Longline	Gillnets	Total
N	50	45	95
Mean length (cm)	63.0	67.6	65.2
Minimum length	48	51	48
Maximum length	80	78	80
Std	6.0	5.1	6.0
Variance	36.1	25.9	36.4

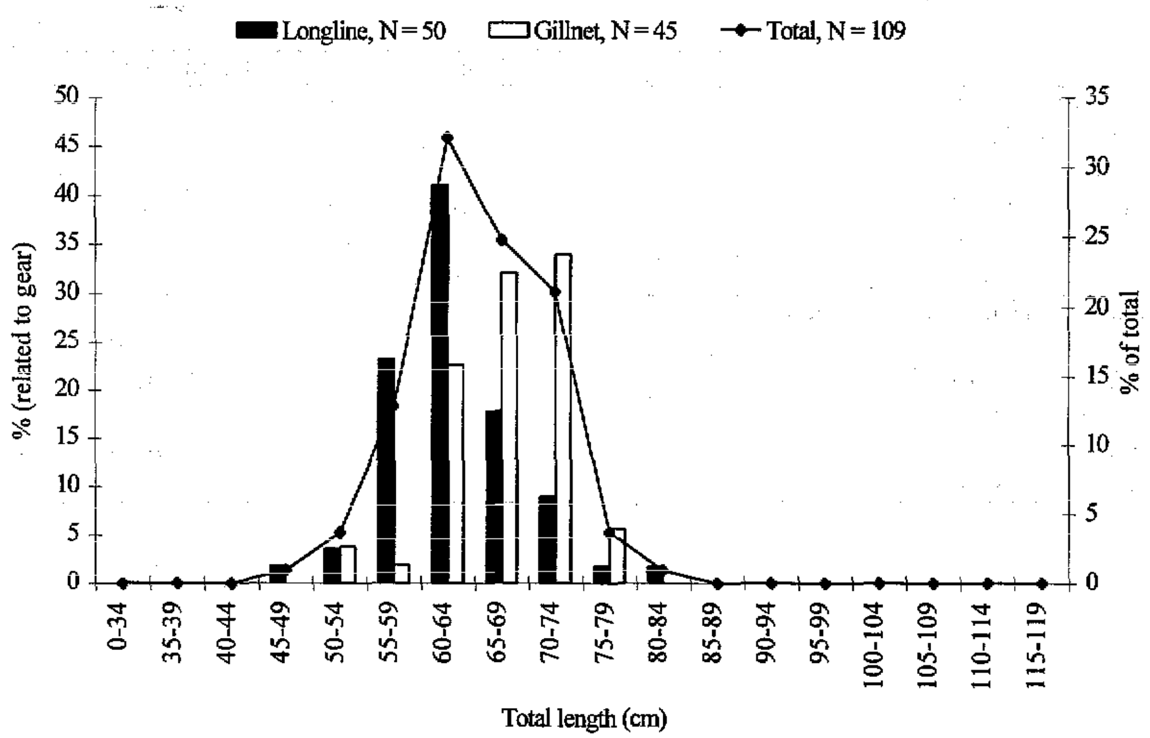


Fig. 4. Length distribution of the Greenland halibut investigated for fecundity.
indicate longline catches,
indicate gillnet catches,
——— indicate total length distribution of the combined fecundity sample.
N = number of individuals recorded.

Fecundity

Fecundity estimates ranged from 6,800 to 70,500 eggs per female. The estimated mean fecundity was 28,100 eggs (std = 13.7, N = 95) (*Tab. 2*). The fecundity estimates for Greenland halibut caught on gillnets were slightly higher than fecundity of Greenland halibut caught on longlines (*Tab. 2*).

The relationship between fecundity (F) and length (L) (*Fig. 5*) of the combined sample is:

$$F = 1.155 * 10^{-7} * L^{4.598} \quad (r^2 = 0.68, p < 0.005).$$

The fecundity is expressed as 1,000 and the length is given as total length in cm.

The relationship between fecundity (F) and weight (W) (*Fig. 6*) of the combined sample is given by:

$$F = 2.539 * 10^{-4} * W^{1.439} \quad (r^2 = 0.77, p < 0.005).$$

The fecundity is expressed as 1,000 and the total weight is in grams.

Tab. 2. Summary table for Northeast Arctic Greenland halibut fecundity. Fecundity expressed in ,1000 eggs.

	Longlines	Gillnets	Total	Output values	
Number registrations	50	45	95		
Mean fecundity (1,000)	22.4	34.5	28.1		
Minimum fecundity (1,000)	6.8	7.8	6.8		
Maximum fecundity (1,000)	67.5	70.5	70.5		
Standard deviation	12.6	12	13.7		
Variance	146.4	144			
Expected deviation between means	0				
z				-4.88	p ~ 0
P(Z<=z) one-sided				5.43E-07	
Z-Critical, one-sided				1.64	
P(Z<=z) two-sided				1.09E-06	
Z-Critical, two-sided				1.96	

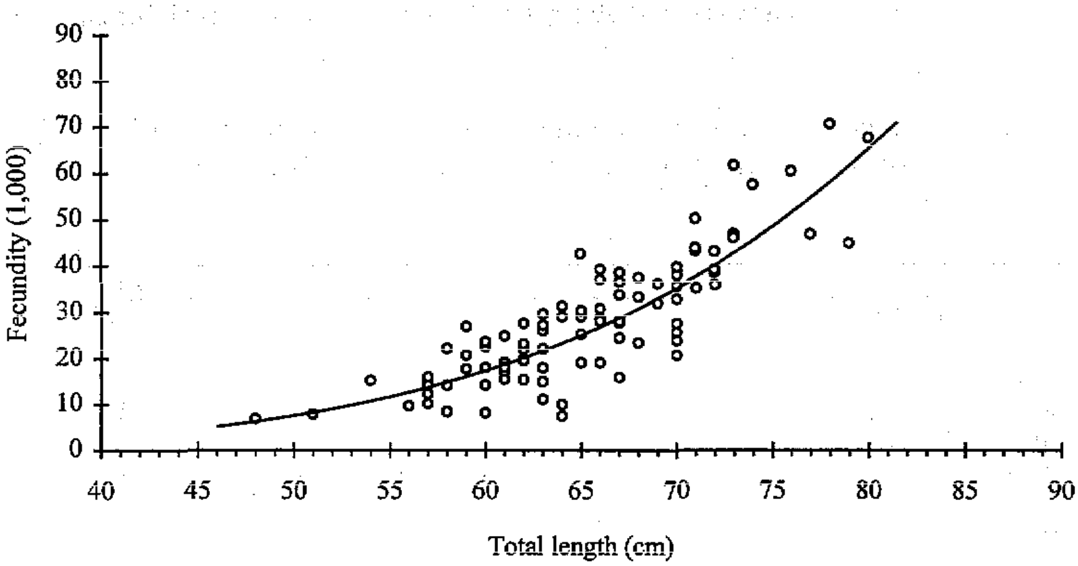


Fig. 5. *Fecundity (1,000) of Northeast Arctic Greenland halibut related to total length.* $F = 1.155 * 10^{-7} * L^{4.598}$ $(r^2 = 0.68)$.

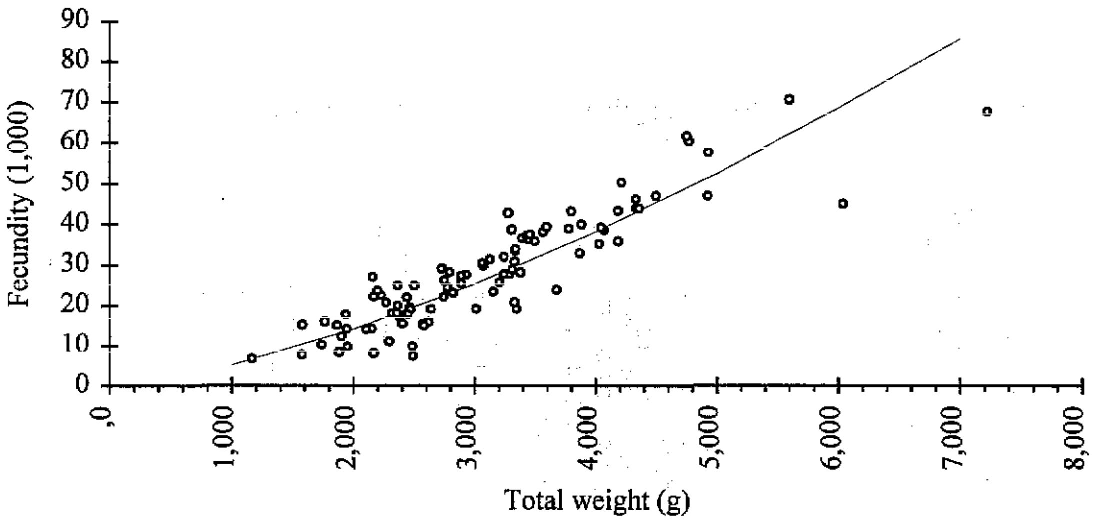


Fig. 6. *Fecundity (1,000) of Northeast Arctic Greenland halibut related to total weight (g).* $F = 2.539 * 10^{-4} * W^{1.439}$ $(r2=0.77)$.

Gonadosomatic index (GSI

Gonadosomatic index (GSI) is defined as the relative portion of which the ovaries constitute of the total weight. For the combined sample, GSI was in the range 1.9-13.5%. Mean GSI was 7.5% (std = 2.2, N = 95) (*Tab. 3*). A weak increasing trend of GSI related to length was observed (*Fig. 7*). The GSI of Greenland halibut caught by gillnets was slightly higher than the GSI for the Greenland halibut sampled from the longline catches (*Tab. 3*). Fecundity showed an increasing trend with increasing GSI (*Fig. 8*). The coefficient of correlation of the log-log transformed data was $r^2 = 0.50$ (df = 94). The correlation was significant ($p<0.005$).

Tab.3. *Summary table of gonad weight (GW) and gonadosomatic index (GSI) for Greenland halibut used in the fecundity study. The results are related to fishing gear.*

	Longlines	Gillnets	Total
Number registrations	50	45	95
Gonad weight, GW			
Mean GW (g)	207	286	244
Minimum GW (g)	36	70	36
Maksimum GW (g)	738	640	738
Gonadosomatic index, GSI			
Mean GSI (%)	7.0	8.0	7.5
Minimum GSI (%)	1.9	4.4	1.9
Maximum GSI (%)	13.5	12.3	13.5
Standard deviation	2.4	1.7	2.2

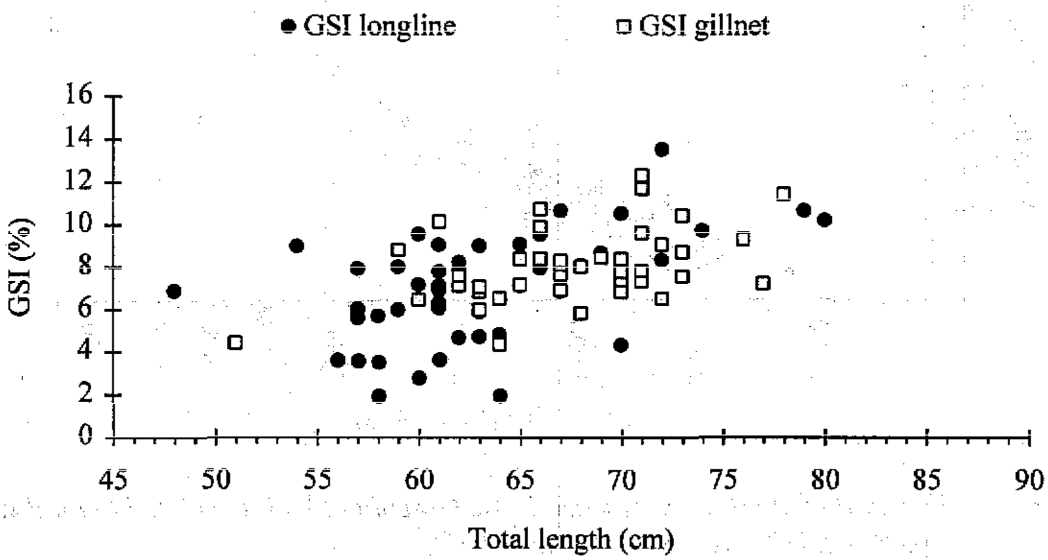


Fig. 7. *Gonadosomatic index (GSI) of Greenland halibut related to total fish length.*
● refers to the Greenland halibut caught by longlines (N = 50).
□ refers to the Greenland halibut caught by gillnets (N = 45).

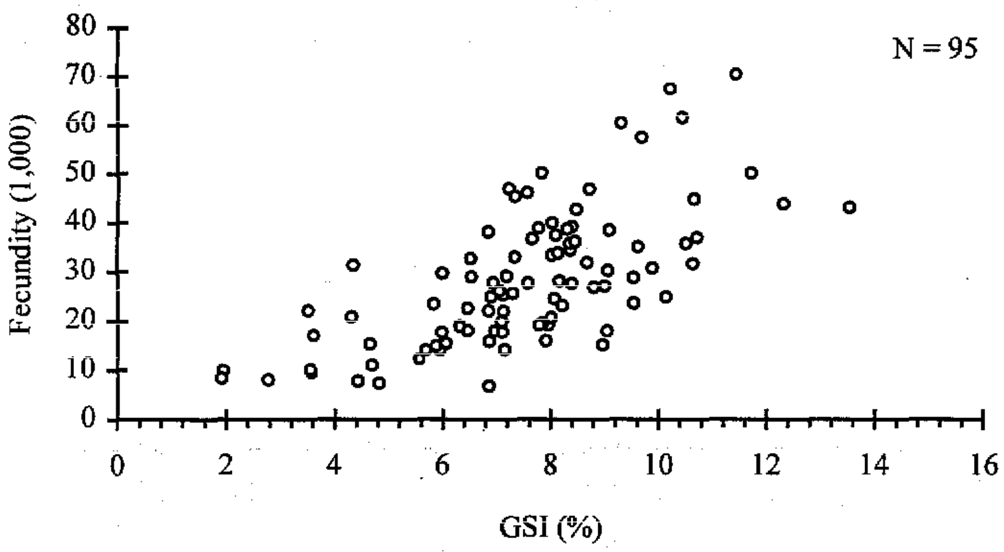


Fig. 8. *Fecundity (1,000) for the combined sample of Greenland halibut related to GSI (gonadosomatic index,%).*

Hepatosomatic index (HSI)

Hepatosomatic index (HSI) describes the relative portion of liver in each female relative to total body weight. HSI was in the range 0.3 – 4.6% (*Tab. 4*). No clear trend between HSI and total fish length was observed (*Fig. 9*).

Fecundity showed a weak, but increasing trend with increasing HSI (*Fig. 10*). Like for the GSI-fecundity plot (*Fig. 8*) the scatter was wide. No significant relation between fecundity and HSI was observed. The correlation coefficient for the log-log transformed data was r^2=0.10 (N = 37, p>0.05).

Tab. 4. *Summary table for liver weight and hepatosomatic index of the Greenland halibut fecundity sample. The results are related to fishing gear.*

	Longlines	Gillnets	Total
Liver weight (LW)			
Mean LW (g)	104	85	88
Minimum LW (g)	54	2	2
Maximum LW (g)	218	204	218
Hepatosomatic index, HSI			
Mean HSI (%)	2.7	2.3	2.4
Number registrations	5	32	37
Minimum HSI (%)	1.9	0.3	0.3
Maximum HSI (%)	3.4	4.6	4.6
Standard deviation	0.6	1.1	1.1

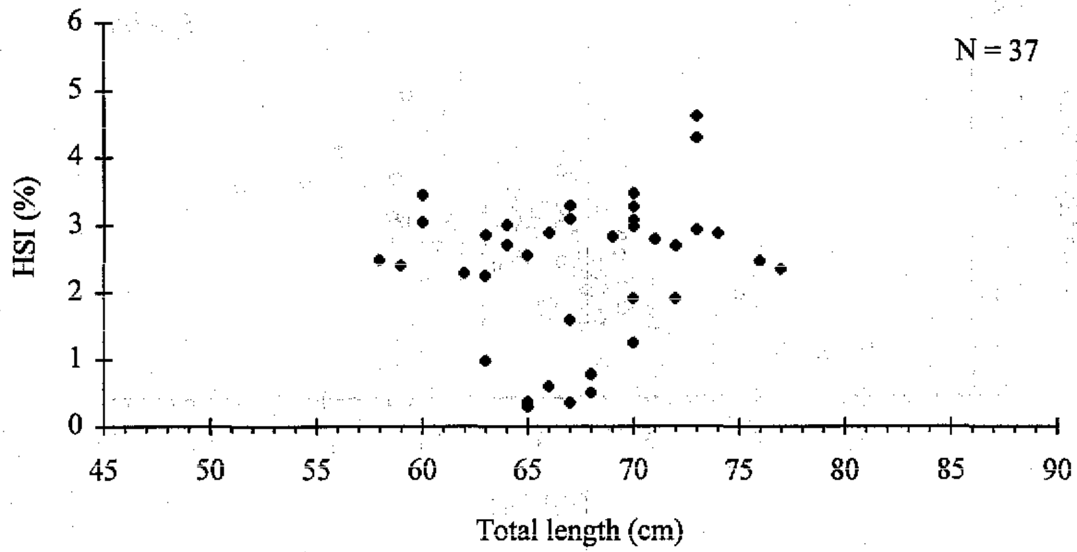


Fig. 9. Hepatosomatic index (%) of Greenland halibut related to total fish length.

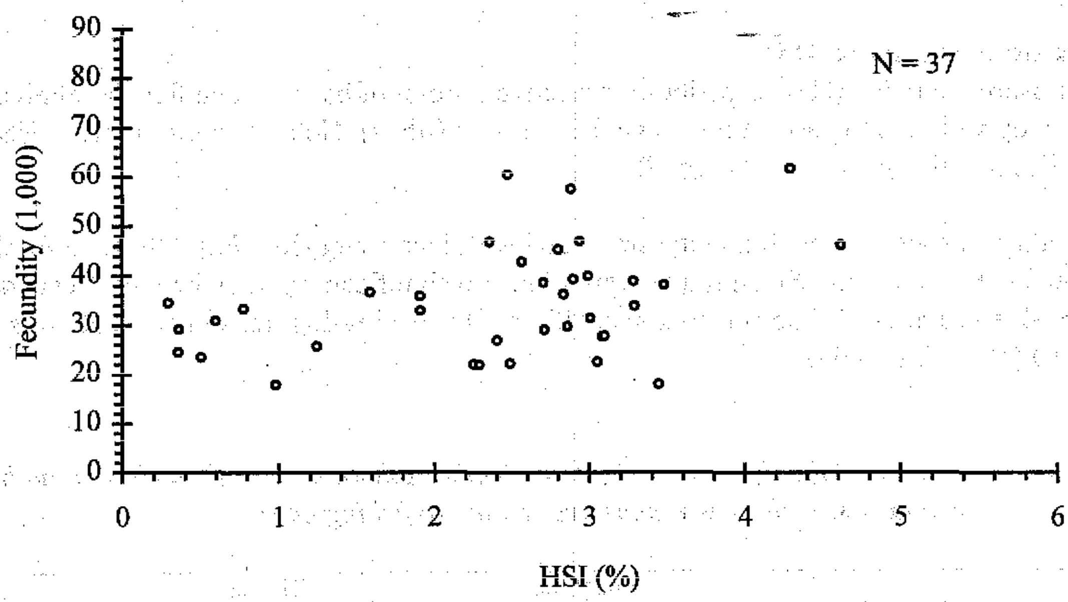


Fig.10. Fecundity (1,000) of Northeast Arctic Greenland halibut related to HSI (hepatosomatic index, %).

DISCUSSION

Greenland halibut included in the fecundity study were sampled in mid September 1996. The ovaries were mainly in maturity stage 4, which is, by definition, eggs with a diameter of 2-4mm (Nielsen & Boje 1995). Spawning had not started but was expected to occur within a few months time. This is in accordance to egg development and results from investigations carried out in the same area in 1996 and 1997, describing the spawning of Greenland halibut

(Albert *et al.* 1998; Stene *et al.* 1998). The eggs were easily classified and counted, as the difference between G1 and G2 was obvious.

Gonadosomatic indices (GSI) ranged 2.0-13.5. Fedorov (1968) assumed that Greenland halibut prior to spawning undergo an increase in gonad weight, the GSI reaching 15-18% as spawning is likely to occur. In West Greenland waters GSI for Greenland halibut is reported to increase from 1-3% in April-July to *ca.* 10% in October (Jørgensen & Akimoto 1990). A study conducted in East Greenland waters in 1997 (Rønneberg *et al.* 1998) reported GSI in the range 1-5% in July.

In the Barents Sea the GSI is observed to increase from a minimum in February-April towards spawning in November-January (Gundersen and others in prep.(a)). This verifies that the maturity process is in progress in the period of sampling, however, not overlapping with the time of spawning.

The fecundity of Greenland halibut showed a slightly better relationship to weight than to length, however, both relations were significant ($p<0.005$). In the fecundity-length-relationship the exponent b was estimated to 4.598. Bagenal (1978) stated that the exponent may range from *ca.* 2.3 to 5.3, most often seen a little above 3. The exponent b is therefor in the interval described by Bagenal (1978).

Sampling of the ovaries was random. The sampling was conducted from one longline setting and one gillnet setting. The samples were taken during a multigear survey in September 1996, and so the sampling has been conducted over a relatively short period of time. The samples taken from the longline catches originated from smaller females than the gillnet samples. This reflects the actual catch performance of the gears due to selectivity, described by Nedreaas *et al.* (1996). No systematic difference in the relation between fecundity and total length for fish of the same length was observed when comparing the two gears. However, the mean fecundity of the Greenland halibut sampled from the gillnet catches was significantly higher than the mean fecundity of the Greenland halibut sampled from the longline catches (*Tab. 2*). This is explained by the different length range of the two samples.

Prior to the study described in this paper, only a few egg counts have been conducted for Greenland halibut in the Northeast Arctic. Millinsky (1944) estimated a fecundity of 28,000 and 33,000 for two Greenland halibut females in the Barents Sea. This is within the same range as the results of the present study. Further analyses on the fecundity of the Greenland halibut in the Northeast Arctic are in progress (Gundersen and others in prep. (b)).

In the Northwest Atlantic a few investigations on the fecundity of Greenland halibut have been conducted. In the Newfoundland-Labrador area, the fecundity was in the range 15,000 to 215,000 (Lear 1970). A curved relationship based on 45 females collected over the period 1967-1969, was established. Bowering (1980) compared the results obtained by Lear (1970) to fecundity samples collected in the Southern Labrador and the South-eastern Gulf of St. Lawrence in 1976-1978. The equation presented by Lear (1970) indicated a higher fecundity for Greenland halibut bigger than 80cm than the equation presented by Bowering (1980). The period of sampling for the two studies may bias the results as Lear (1970) sampled the ovaries over the period March-October, whereas the results presented by Bowering (1980) was based on samples collected over a shorter time period; October-November. The great time span in season for the samples taken in 1967-1969, and the relatively few samples collected over three years may give considerable variation in estimates both due to growth during the year and annual fluctuations in fecundity.

Using the relationship between fecundity and length presented in this paper a 70cm female Greenland halibut in the Barents Sea is likely to produce 35,000 eggs on average. In the Labrador area, the fecundity–length–relationship indicated that a 70cm long female produced 30,000 eggs on average, while a 90 cm female produced 66 000 eggs. In the Gulf of St. Lawrence a 70cm female produced 50,000 eggs on average (Bowering 1980). This indicates a geographic variation in fecundity. Further studies concerning this comparative aspect should be conducted.

Jensen (1935) estimated the fecundity of one female (101cm) in West-Greenland waters to 300,000 eggs. In East Greenland waters fecundity was estimated to be in the range 32,000 – 277,000 eggs (Rønneberg *et al.* 1998). This is a considerably wider range of fecundity than observed for the present study in the Barents Sea. However, the fecundity estimates presented for East-Greenland waters (Rønneberg *et al.* 1998), and Southern Labrador (Lear 1970) are based on Greenland halibut in a wider length range, including larger fish than in the present study.

In Icelandic waters ovaries from 5 Greenland halibut females were analysed for fecundity in March 1977 (Magnusson 1997). The fecundity was in the range 17,500 (66cm) to 42,200 (74cm). The largest Greenland halibut was 96cm, showing a fecundity of 37,600. The egg diameter of the ovaries was in the range 2-4mm, which corresponds to the present study.

Fecundity for Northeast Arctic Greenland halibut showed an increasing trend with increasing GSI ($r^2 = 0.50$, $p<0.005$). The scatter of the fecundity-GSI plot was wide. The same was also observed for Greenland halibut in East Greenland waters, but a correlation coefficient was not presented (Rønneberg *et al.* 1998). A significant relation between fecundity and HSI was not observed. The scatter was wide, corresponding to the results from Greenland halibut in East Greenland waters (Rønneberg *et al.* 1998). A more comprehensive study regarding the effects of length, weight, gonad weight, GSI, liver weight and HSI on fecundity is in progress (Gundersen and others in prep (b)).

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