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Roughhead Grenadier (*Macrourus berglax*) in the Waters off East Greenland: Distribution and Biology.

by

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Abstract

The study focuses on distribution, catch-rates and biological-stock-parameters of roughhead grenadier (*Macrourus berglax*) at East Greenland based on data from trawl surveys, long line surveys and commercial catches from the period 1993-2000. Roughhead grenadier was recorded at most fished stations at depths between 200 and 1600 m. Catch rates and length frequencies varied both with gear, areas, depth and year. The catch rates were highest at depths between 1 000 and 1 500 m in the long line survey and between 800 and 1200 m in the trawl survey. In both types of surveys the length distributions were dominated by fish around 20 cm. Sex ratio changed with depth and length of 50% maturity (L_{50}) was estimated to be at 15 and 28 cm for males and females, respectively. Estimate of potential fecundity from 25 specimens varied between 17-56 000 eggs specimens^{-1}.

Introduction

Roughhead grenadier (*Macrourus berglax*) occurs in relatively cold water (-0.5 to 5.4 °C (MS Atkinson and Power, 1987)) along the continental shelf throughout the North-Atlantic Ocean, at depths between 200 and 2000 m (Savvatimsky, 1969; Parsons, 1976; MS Murua, 2000). Roughhead grenadier is caught commercially mainly in NAFO Div. 3LMN regulatory area as by catch in the fishery for Greenland halibut (*Reinhardtius hippoglossoides*) (Anon., 2001). Based on its frequent occurrence in catches over a much wider area it might represent a potential for further commercial utilisation (Jørgensen, 1995; 1996; MS 2001; Magnússon and Magnússon, 1995; Olsen, 1995; Parsons, 1976; Savvatimsky, 1985a.)

In Greenland waters roughhead grenadier is a common by-catch both in the long line fishery for Greenland- or Atlantic-halibut, and in the trawl fishery for Greenland halibut (Jørgensen 1995, 2001). Indications of catch rates and relative abundance are given from scientific and commercial vessels from several areas in the north Atlantic and abundance seems to differ between areas and depths (Eliassen, 1983; Jørgensen, 1995; MS 2001; Magnússon and Magnússon, 1995; Olsen, 1995; Parsons, 1976).

Although knowledge about biological characteristics of roughhead grenadier is limited, a number of studies have described different aspects of its biology (Jørgensen, 1995; 1996; Katsarou and Nævdal, 2001; Murua and Motos, 2000; Swan and Gordon, 2001; Savvatimsky, 1985a). Females seem to mature at about 14 years of age (Eliassen, 1983; Muarua and Motos, 2000) and the rate of growth is relatively slow (Jørgensen, 1996; Muarua and Motos, 2000). Spawning occurs throughout the year with a peak during winter/spring (Geistdoeffer, 1979; Magnússon and Magnússon, 1995; Savvatimsky, 1984; 1985a; Eliassen and Falk-Petersen, 1985). The potential fecundity seems to vary between approximately 14 000 and 80 000 eggs individuals^{-1} (Murua and Motos, 2000).

The study summarises information about distribution patterns, catch rates and some biological stock parameters for roughhead grenadier based on data from scientific bottom trawl and long line surveys and sampling of commercial catches along the eastern coast of Greenland from 1993 to 2000.

Materials and Methods

Data were collected during long line and bottom trawl surveys conducted since 1993 along the east coast of Greenland. The bottom trawl data were collected during three surveys in 1998, 1999 and 2000. The surveys were conducted as stratified random bottom trawl surveys and covered the area from 61°30'N to 66°00'N at depths between 400 and 1 500 m. The mesh size was 140 mm with a 30 mm mesh liner in the cod end. For further information about surveys and gear see MS Jørgensen, 2001 and MS Jørgensen, 1998, respectively.

Long line data were sampled during 5 years (1993, 1994, 1996, 1997 and 2000) in the area from 60° to 64°N at depths between 300 and 1600 m. All surveys used Mustad No 12 hooks baited with mackerel or squid.

Further, sampling was carried out during 1998 and 2000 on board commercial trawlers targeting Greenland halibut in area Q2 at depths between 600-800 m (Fig. 1). The mesh size in the cod end was 140 mm.

Length distribution and catch rates were given for five sub areas (Fig. 1) and seven depth strata (200-400, 401-600, 601-800, 801-1 000, 1 001-1 200, 1 201-1 400 and 1 401-1 600 m). Effort within the different areas and strata varied both between surveys and gear.

For all surveys, length distribution and catch rates were estimated by station. Sex, maturity and individual weight were recorded at a number of stations. In the trawl surveys catch rates were standardized to kg $(km^2)^{-1}$ swept. In the long line surveys catch rates were estimated as kg 1 000 $hooks^{-1}$.

Length was measured as pre anal length in 0.5 cm below during scientific trawl surveys and 1.0 cm below from long line and commercial catches. Length frequencies were compared both graphically and by the use of the two-sided Kolmogorov-Smirnov statistics (Zar, 1984).

Subjective determination of stage of maturity was recorded according to a general 5 stages scale, Table I (Fotland *et al*., 1997).

Length at maturity

The length were 50% of the individuals reaches maturity, L_{50}, was estimated for each sex by fitting of a logistic growth function to the proportion of mature individuals within different length-groups (I, II). Each observation was weighted to number of observations within each length-group during the fitting process. Model fitted by minimizing of the squared differences between the observed and calculated values.

Logistic growth curve: $$Y = 100 / (1 + e^{a+bX}) \quad \text{(I)}$$

Y = portion mature individuals (%).
X = length-group
a and b = estimated parameters for each sex.

L_{50} given by: $$L_{50} = -a / b \quad \text{(II)}$$

Potential fecundity

Potential fecundity for individual roughhead grenadier was estimated based on counts of eggs and total gonad weight. Samples were collected during the long line survey in 2000 and the fecundity was estimated according to Gundersen *et al*. (1999, 2001).

Results

Distribution:

Catch rates:

In the scientific trawl surveys the catch rates were generally largest in sub area Q1, within the same range in Q2 and Q5 and very low in Q3 (Q4 has not been covered due to rough bottom) (MS Jørgensen, 2001). The largest concentration, up to 0.8 tons $(km^2)^{-1}$ was found in Q1 at depths between 800 and 1000 m and in all Sub areas the highest concentrations generally were found at depths between 800 and 1200 m (Fig. 2; MS Jørgensen, 2001).

All the scientific trawl surveys covered the same geographic area. Significant differences in catch rates between years were only found for the 1400-1600 m depth stratum in sub area Q5 ($F_{2,\ 7}$ = 9.929, p = 0.028), where average catch rate during 2000 was significantly higher than during 1998 and 1999 (pair wise mean differences Bonferroni statistics, p < 0.001). In general no differences in catch rates were observed between years for any of the Sub areas (F stat., p>0.15; Fig. 2) and data were pooled to increase sample size.

Significant differences in catch rates by depths were found only in sub area Q1 ($F_{5,\ 42}$ = 4.279, p < 0.004). Here the catch rate in the 800-1 000 m stratum was significantly higher than in depth stratum 400-600 m. (pair-wise mean differences Bonferroni statistics, p = 0.001, Fig. 2).

Differences in catch rates were found between sub areas within stratum 600-800, 800-1 000 and 1 000-1 200 meters (pair-wise mean differences Bonferroni statistics, p < 0.004). In these strata catch rates in Sub area Q1 were significantly higher compared to the same strata in sub area Q3 and/or Q5 (Fig. 2).

Catch rates for long line varied between 50 and 250 kg 1 000 hooks^{-1} within most areas and depth strata. Highest catch rates were recorded in sub area Q6 (around 200 kg) while catch rates in both sub area Q3 and Q4 varied around 150 kg (Fig. 3). In sub area Q5, where most of the commercial long line fishery is taking place, average catch rates increased from 13 to 150 kg with depths between 1 000 and 1600 m (Fig. 3).

In general there was no overlap in the areas covered by the different long line surveys. The only exception was depth stratum 1200-1400 and 1400-1600 m in sub area Q5, which were covered during 1996, 1997 and 2000. A significant difference in catch rates between years was found in the 1200 to 1400 m stratum ($F_{2,\ 46}$ = 13.512, p <0.001). Here catch rates in 1997 were significantly lower than in 1996 and 2000 (pair-wise mean differences Bonferroni statistics, p < 0.001; Fig. 3). Despite this, data from different years were pooled to in order to enable a more detailed analysis of distribution by sub area and depth strata.

Only in Sub area Q5 (where catch rates increased by depth) there was found significant differences in catch rates by depth stratum ($F_{2,\ 56}$ = 21.476, p < 0.001) (Fig. 3).

Within stratum 1 000-1 200 and 1 200-1 400 m, statistically significant differences in catch rates were found between sub areas ($F_{1,\ 8}$ = 21.263, p = 0.004 and $F_{2,\ 52}$ = 35.444, p < 0.001, respectively). In both strata catch rates in Sub area Q5 were significantly lower than catch rates in Sub areas Q4 and Q6 (Fig. 3).

Length:

Both long line and trawl catches were dominated by fish shorter than 20 cm pre anal length. A Kolmogorov-Smirnov Two Sample Test, K-S, applied to data from the scientific trawl catches, showed that there were no significant differences in length distribution between years (K-S p > 0.65; Fig. 4). Data from the scientific trawl surveys were hence pooled for further analysis.

Length frequencies from the scientific trawl surveys were pair-wise tested by sub area. Significant differences were found between all areas (K-S, p < 0.001). The difference was caused by an increasing proportion of larger fish, from Sub area Q5 to Q2 and further from Q2 to Q1 (Q3 was not included in the analysis due to few observations and Q4 was not surveyed due to rough bottom) (Fig. 4).

Similar, when length distributions were tested by depth stratum, differences were found between the 800-1000 m stratum and the 400-600, 600-800, 1 000-1 200 and 1 200-1 400 m strata (K-S, p = 0.006, 0.017, 0.005 and 0.021 respectively) (Fig. 4). A higher proportion of medium sized fish (25-31cm) in the 800-1000 m stratum seems, at least to some extent, to be causing the observed differences.

When length distributions at a certain a depth stratum were compared by sub areas, statistical significant differences were found at all depth strata. In six strata this was caused by a higher proportion of larger fish in Sub area Q1 compared to Q5 (K-S, p < 0.05) (Fig. 4).

For long line the only stratum where there has been consecutive sampling of length data was depth stratum (1 200-1 400 m) in Sub area Q5, which was sampled in 1996, 1997 and 2000. Here the length distribution from 2000 differed significantly from distributions obtained during 1996 and 1997 (KS, p < 0.001; Fig. 5). This was due to an increasing proportion of larger fish in 2000 (Fig. 5). However all data from the long line survey were pooled to test for possible differences in length distribution between sub areas and depth strata.

The length distributions by sub area were tested by a K-S test. Statistical significant differences in the length distributions were found between all areas (K-S, $p < 0.001$). The differences were due to a larger proportion of small fish in Sub area Q5 and Q6 while larger fish dominated in sub area Q4 (Fig. 6).

When length distributions were tested by depth, significant differences were found between most strata (Table II), where the highest proportion of large and small fish being found in the 800-1 000 m and 400-800 m strata, respectively (Fig. 6).

When length distributions in each of the seven depth strata (002-1 600 m) were compared between sub areas, statistical significant differences were found within all depth strata. In five strata this was caused by a higher proportion of small fish in Sub area Q5 compared to Q4 or Q6 (K-S, $p < 0.05$). In depth stratum 800-1 000 m the difference was caused by a higher frequency of large fish in Sub area Q5 compared to Q6.

The length distributions from the commercial trawlers were skew to the right with a modal peak just below 20 cm (Fig. 5). However, a significant difference was found between the two surveys (K-S two sample test, $p<0.001$), mainly due to a larger proportion of smaller specimens (<21 cm) in 2000. (Fig. 5),

Commercial trawling normally takes place within small geographic areas due to a combination of restricted distribution of commercial concentrations of Greenland halibut and difficult trawling conditions, while the scientific trawl surveys covers a much wider depth range. Figure 5 shows the length distribution by depth stratum in the scientific and commercial trawl. A clear mode around 20 cm was seen in both the trawl catches in 1998 and 2000 while the “tail” of larger fish seen in 1998 disappeared in 2000. The mode around 20 cm is also seen in the scientific catches but otherwise these length distributions are hard to interpret due to few observations.

The best coverage of both trawl and long lines was in area Q5. Here the long line sets were mainly concentrated at depths where the fishery for Greenland halibut normally takes place although sets were also made both shallower and deeper (Fig. 5). Fish between 15 and 20 cm pre anal length dominated the catches during all years, areas, gears and strata. In general maximum fish length increased by depth, but it should be noticed that length distribution differed both between gears, years and depth strata.

Biological-stock-parameters

Length:

A Kolmogorov-Smirnov Two Sample Test, applied to data from both the combined scientific trawl surveys and the long line survey in 2000 showed a significant (K-S, $p<0.0001$) difference in the length distribution between males and females for both data set (Fig. 7). Males were between 6 and 32 cm and 13 and 24 cm in the trawl and long line survey, respectively, while females ranged from 5 to 50 cm and 11 to 45 cm, respectively (Fig. 7). This corresponds well to observations made during other surveys. Males were much more dominant in the over all trawl catches compared to the long line catches (Fig.7).

Sex composition by depth

In the scientific trawl data females significantly dominated the catches in the 600-800 m depth stratum while males dominated both shallower and deeper (Table III; Fig. 8). In the long line material males and females occurred with equal frequencies in the depth strata from 400 to 800 m. Females dominated catches in the 800-1 000 m depth stratum while the male dominance increased with depth from 1200-1600 m. (Table III, Fig. 8).

Maturation

During several of the surveys subjective determinations of stage of maturity were carried out. Although there seems to be good agreement between years regarding length at sexual maturation, only data collected during the long line survey in area Q3 and Q5 during August/September 2000 are presented to illustrate length at maturity. Apart from being geographically separated the samples were also taken from different depth strata within the two sub areas, 800-1 000 m in Q3 and 1 200-1 400 in Q5. Of the 301 examined females 108 were mature and further 3 were spawning. Of the 368 examined males 339 were mature. The proportion of mature females was higher in Q5 compared to Q3 (47.5 % and 24.5 %) while the opposite was observed among males (89.75 % and 96.8 %).

The pre anal length were 50 % of the females had reached maturation, L_{50}, was estimated to be 27.8 cm in area Q5 and 28.0 cm in Q3, respectively. Males reached maturity at a smaller size and L_{50} was estimated at 15.1 cm in area Q5. L_{50} was estimated at 14.8 cm in Q3, but the latter estimation was based on few observations only (Fig. 9).

Potential fecundity

Based on examination of 25 specimens in the length range 28-45 cm, sampled during the long line survey in 2000, the potential fecundity was found to wary between 17 000 to 56 000 eggs. It was further observed that the fecundity increased with fish size (Fig. 10).

Discussion

Distribution:

In the scientific trawl surveys the catch rates were generally highest in Q1 and very low in Q3 (Fig. 2) (MS Jørgensen, 2001). In the long line survey no clear patterns could be seen although catch rates seemed lower in Sub area Q5, where most of the commercial fishery occurs (Fig. 3). The observed pattern indicates differences in distribution between areas. These differences are probably due to a natural distribution pattern, but the commercial fishery might also affect the abundance in areas exposed to intensive fishing (see below). Between area variation in catch rate has previously been reported from several other areas (Eliassen, 1983; Jørgensen, 1996; Magnússon & Magnússon, 1995; Parsons, 1976).

In general catch rates were stable between years in the trawl surveys, except in the deepest strata in sub area Q5 where catch rates increased in 2000. This tendency was also seen in the long line survey were catch rates in the 1 200-1 400 m stratum were higher in 2000 compared to 1997 but at the same level as in 1996. The result indicates a change in abundance, which might be caused by changes in the population's distribution pattern. The long line data showed an increased proportion of larger fish in the 1 200-1 400 m stratum from 1997 to 2000, and hence the increased catch rates are not likely to be caused by an increase in recruitment, but rather in a redistribution of the fish.

In general catch rates were stable with regards to depth within most sub areas for both scientific trawl and long line. The exceptions were found in area Q1 and Q5 for trawl and long line, respectively, and might be influenced by the commercial fishery in these areas. In the scientific trawl surveys catch rates seemed to peak between 800 and 1 200 m (MS Jørgensen, 2001) witch is also the depth with the highest catch rates at West Greenland (Jørgensen, 1996).

In East Greenland waters catch rates peaked at greater depths compared to what was observed in Norwegian (Eliassen, 1983) and Canadian waters (Parsons, 1976). This is believed to be due to higher temperatures in deeper water at East Greenland due to the Irminger current.

Fish shorter than 20 cm pre anal length dominated catches for all gear types (Fig. 4, 5). The very few small specimens, <10 cm, observed in the trawl surveys, despite the 30 mm mesh liner in the cod end, could indicate that small roughhead grenadier are found outside the range of the survey area or the depths covered (400-1 500 m).

Both data from the scientific trawl and long line surveys showed a significant difference both in over all length distribution and in the length distribution in the individual depth strata between different sub areas. In general differences were due to an increasing proportion of larger fish when moving from south to north. This could be caused by natural distribution or by the long line fishery in the southern sub areas, mainly Q5, that tend to take relatively larger fish, or a combination of both.

In catches maximum pre anal length usually increased with depth. Although the statistical significant difference in length distribution between depths strata, observed in both gears, generally was caused by a high proportion of large fish (>24 cm) in the 8-1 000 m depth stratum compared to other strata. This separation of length groups might be caused by intraspecific competition for food between length groups or preferences for a certain environment (temperature) (Eliassen, 1983) but might also be caused by migration maybe in relation to spawning. Different patterns were mean-length has increased (Cardenas, *et al*., 1996; Eliassen, 1983) or decreases (Parsons, 1976) with depth have been described for roughhead grenadier in a number of areas. This study shows that the length distribution in relation to depth is not that straightforward and is probably caused by a change in sex rate by depth (See below).

Due to selectivity a marked difference in length distribution was observed between gears. Long lines did not take fish smaller than 15 cm. Jørgensen (1995) also noted the lack of small fish in the long line catches at West Greenland. Generally long lines take larger specimens than trawl. This is particular pronounced for example Greenland halibut. This tendency is, however, not that clear for roughhead grenadier neither in this study (Fig. 7) nor at West Greenland (Jørgensen, 1995). This is probably because roughhead grenadier is a slow swimming species unable to avoid a trawl.

The length dis tributions in the commercial and the scientific trawl catches were somewhat similar, especially in 2000, with modes around 17-21 cm, despite the difference in mesh size (30 mm and 140 mm in the scientific and commercial codends, respectively) (Fig. 5).

Biological parameters

A significant difference in length distribution between sexes was observed in both gears, where females become larger than males (Fig. 7). This is probably caused by higher mortality rate amongst males while the growth rate is almost similar for the two sexes (Savvatimsky, 1994; Jørgensen, 1996; Murua, 2000). Catches were, however, dominated by males, which could have simple biological reasons or, indicate that either are sexes not equal available to the gears or sampling is not representative. Savvatimsky (1985 b) suggest that the reason why females are less frequent in long line catches is because of reduced food intake due to spawning. The dominance of males is, however, also seen in the trawl catches so this can only be part of the exp lanation.

Sex composition varied markedly between depth strata (Fig. 8). While females dominated between 600-800 m in trawl catches and 800-1000 m in long line catches males dominated both shallower (trawl) and deeper (trawl and long line). Such marked differences might indicate a strong degree of intraspecific competition where the larger females dominate the most favourable depth, while smaller fish are displaced to less favourable areas (Wootton, 1990). Migrations, for instance in relation to spawning, might also induce similar patterns. Based on the indications from length frequencies and stage of maturity, however, the female dominance within these strata might be partly due to an aggregation of large immature females.

L_{50} for males were about 15 cm (Fig. 9). Very few males < 15 cm were taken on the long lines hence most males caught were sexually mature (> 90 %). L_{50} for females was estimated to 28 cm. By the use of a convertion factor (Pre anal length = -5.2589 + 0.4853 * Total length, n = 191, $r^2 = 0.976$ (Møre Research unpublished data)) estimated value for females could be compared to previous estimates. The estimated value in this study (28 cm) were slightly higher than previous estimates reported both by Eliassen and Falk-Petersen (1985), 65 cm total length – 26.3 cm pre anal length, and Murua and Motos (2000), 66.7 cm total length – 27.1 cm pre anal length. The observed differences are however small and might be within the variability range of the estimates. According to these authors the corresponding age at 50 % maturity was 13.5 (Murua and Motos, 2000) and 15 years (Eliassen and Falk-Petersen, 1985).

The fecundity increased by fish size (Fig. 10). The number of eggs in this study varied between 17 000 and 56 000 per gonad. This is in good agreement with (Murua and Motos, 2000) who reported that the number of eggs to be between approximately 14 000 and 80 000 individuals $^{-1}$.

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Table I. Maturity scale used for roughhead grenadier (after Fotland *et al.*, 1997).

Stage	*Description*
1	***Juvenile / immature:*** *Gonads are small, eggs or milt not visible to naked eye.*
2	***Maturing:*** *Gonads are developing (maturing). Eggs and milt visible to naked eye but not running.*
3	***Running:*** *Ovaries and testes are in running condition.*
4	***Spent:*** *Shortly after spawning. Gonads are usually loose and reddish. eggs or milt not visible to naked eye*
5	***Uncertain:*** *Not possible to distinguish between immature and mature.*

Table II. Probabilities for pre anal length distributions of roughhead grenadier, from different depth strata, being sampled from the same population. Pooled data from long line surveys. Two-sided Kolmogorov-Smirnov statistics.

Depth (m)	**2-400**	**4-600**	**6-800**	**8-1000**	**10-1200**	**12-1400**
4-600	0.002					
6-800	0.007	< 0.001				
8-1000	0.058	< 0.001	< 0.001			
10-1200	0.006	< 0.001	0.159	< 0.001		
12-1400	0.004	< 0.001	0.005	< 0.001	0.346	
14- 1600	0.004	< 0.001	< 0.001	< 0.001	< 0.001	< 0.001

Table III. Probabilities for males and females occurring with equal frequency in samples within different depth strata. Pearson Chi-square.

Depth	4-600	6-800	8-1000	10-1200	12-1400	14-1600
Sci. trawl	0.003	< 0.001		< 0.001	< 0.001	< 0.001
Long line	0.668	0.237	< 0.001		< 0.001	< 0.001

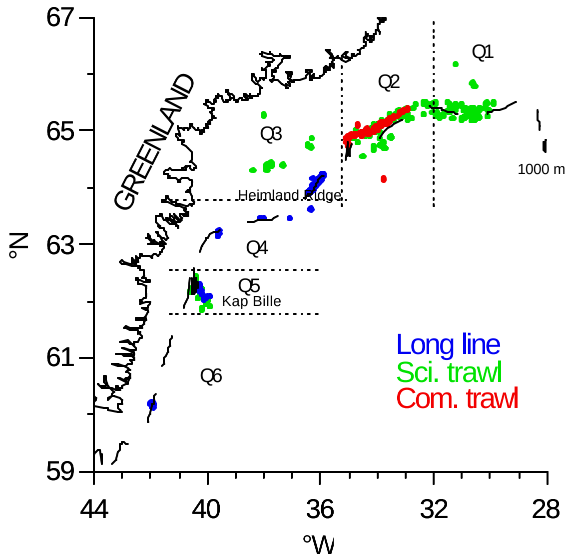

Fig. 1. Map – Survey area divided in sub areas (Q1-Q6) and location of stations with records of roughhead grenadier by gear. Further, the 1000 m depth contour line and locations mentioned in the text are indicated.

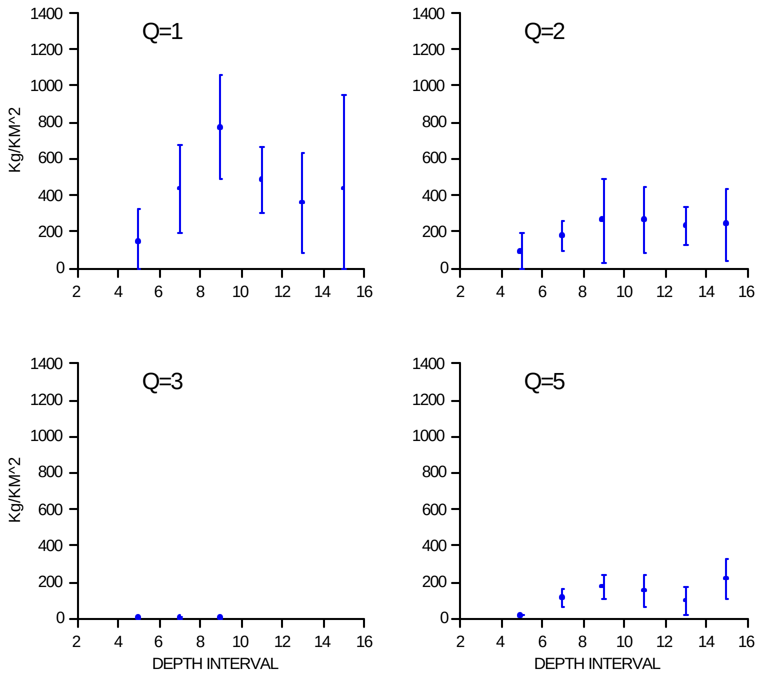

Fig. 2. Catch rates (kg /km^2) of roughhead grenadier in scientific trawl surveys by depth stratum and area (± 1 SD). All years combined.

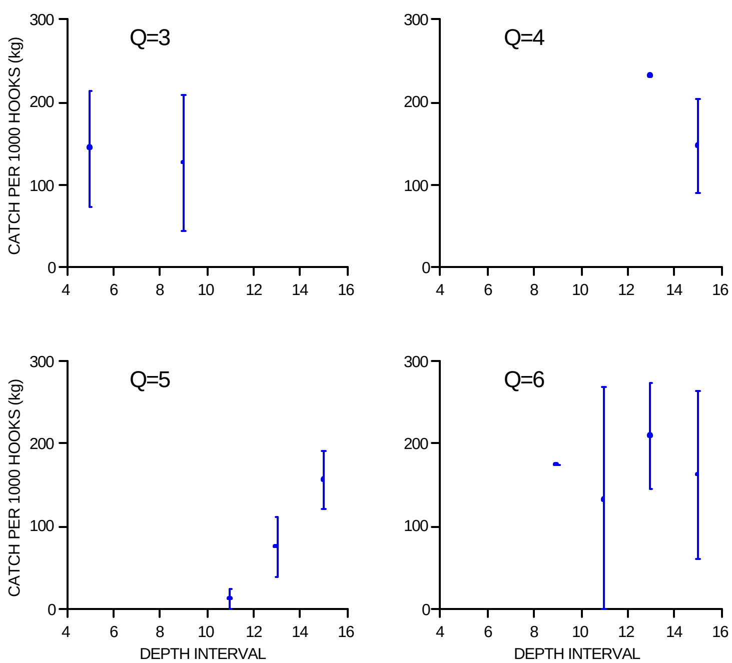

Fig. 3. Catch rates (kg 1 000 hook^{-1}) of roughhead grenadier in long line surveys by depth stratum and area (± 1 SD). All data pooled.

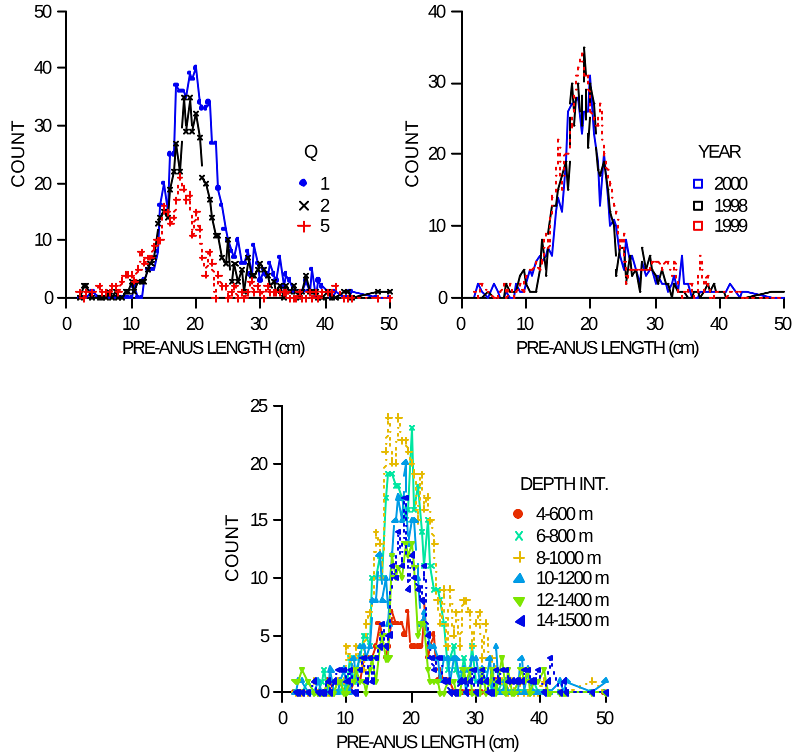

Fig. 4. Pre anal length distribution of roughhead grenadier, from scientific trawl surveys combined. Left: Length distribution from three areas. Right: Length distribution from three years. Under: Length distribution within different depth strata.

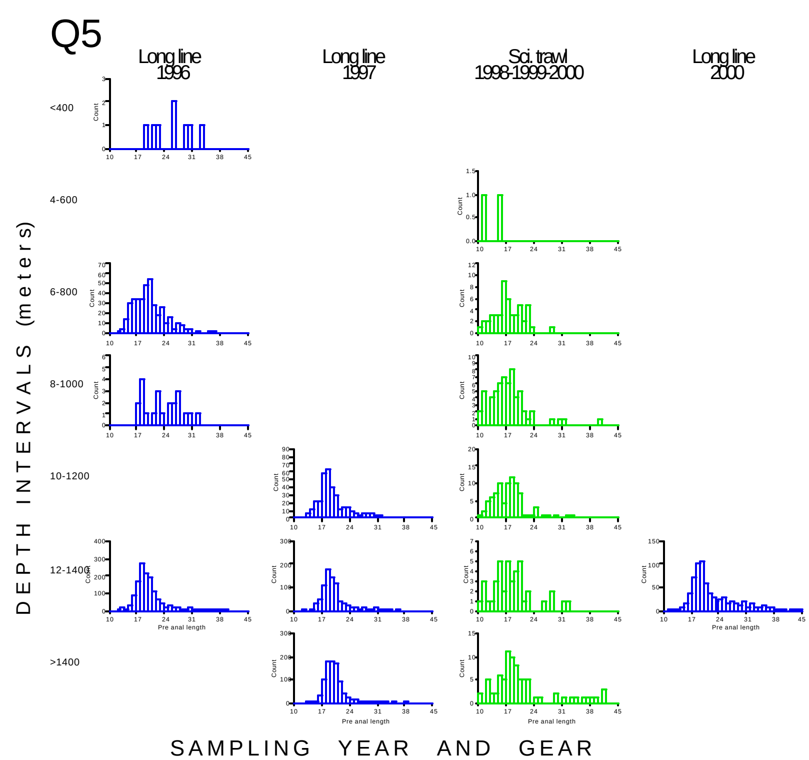

Fig. 5. Length distribution of roughhead grenadier. Above) Example from area Q2 – data from scientific (green) and commercial (red) trawl catches. Below) Area Q5 – data from scientific trawl (green) and long line surveys (blue).

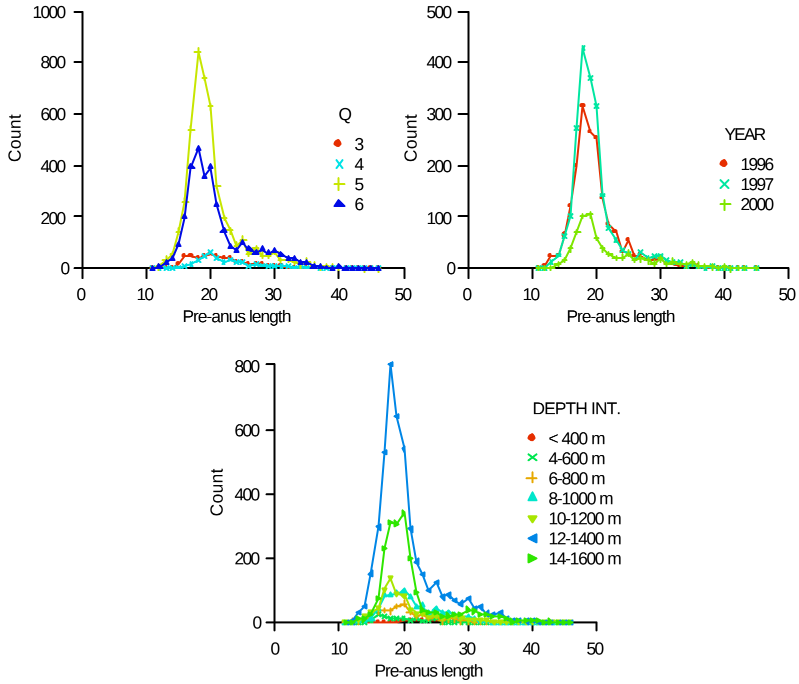

Fig. 6. Length distribution of roughhead grenadier from the pooled long line surveys. Left: Different areas (Q). Right: Data from area Q5 by years. Below: Length distribution by depth strata.

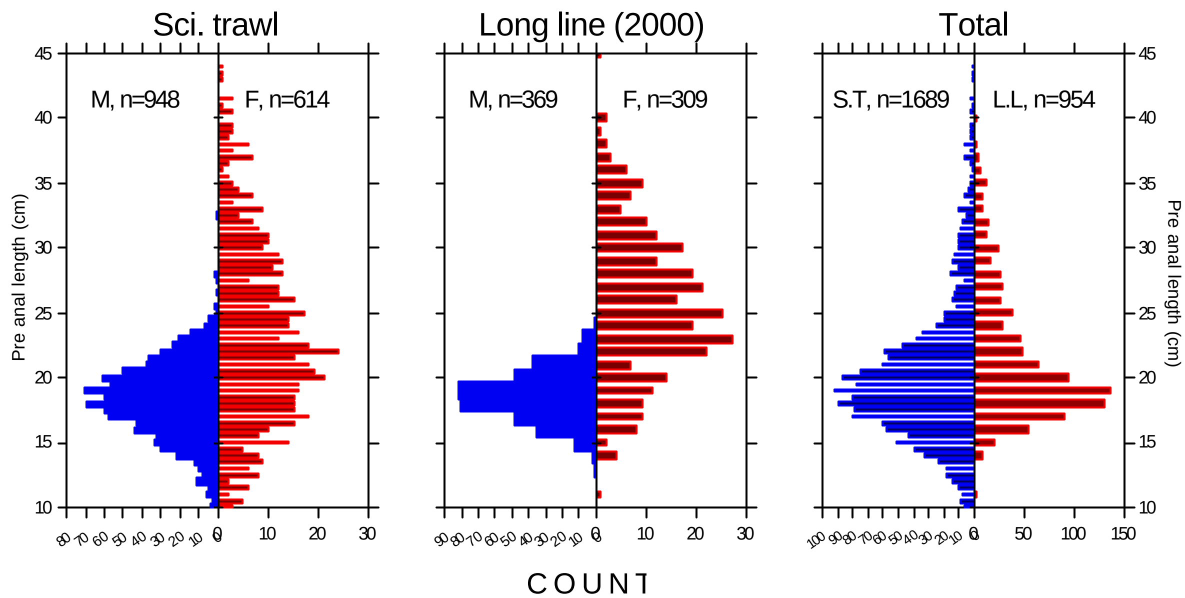

Fig. 7. Pre-anal length distribution of roughhead grenadier, divided by sex and gear. Left: Data from scientific trawl surveys combined. Midle: data from long line survey during 2000. Right: Total length distribution from the two gears.

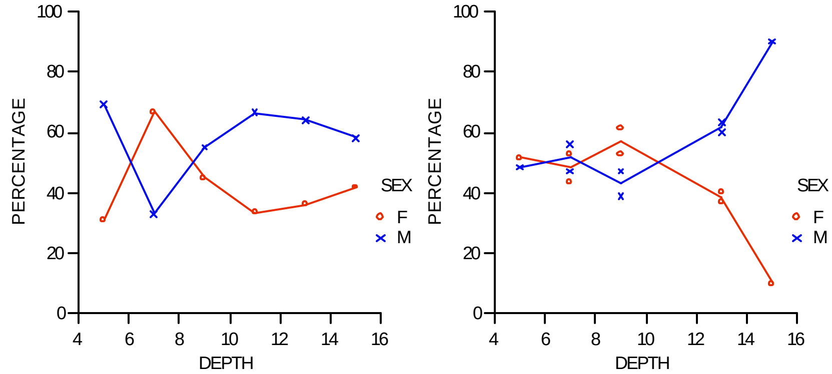

Fig. 8. Occurrence of males and females in catches by depth strata. Left: Pooled data from scientific trawl surveys (N=1462). Right: data from long line surveys in 1994, 1996, 1997 and 2000) (N= 3374).

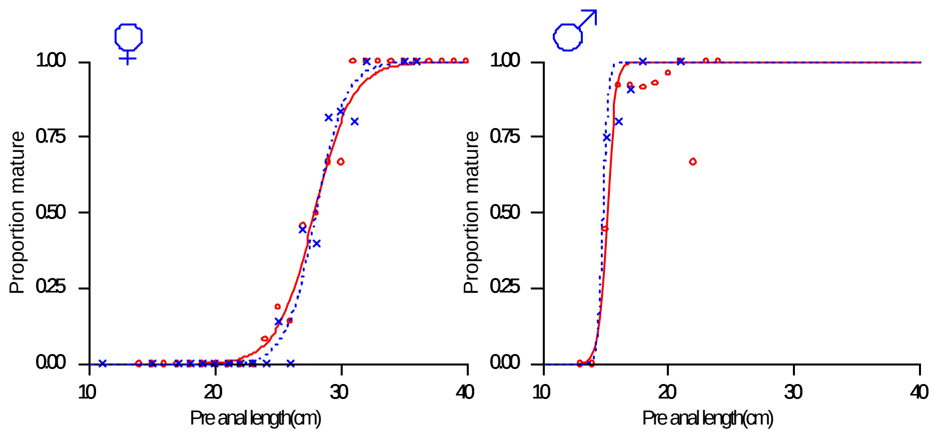

Fig. 9. Portion mature/maturing roughhead grenadier and fitted logistic growth curves. Left: females Q5 (Kap Bille Bank) and Q3 (Heimland ridge), circles/solid line and crosses/dotted line respectively. Right: similar plot for males.

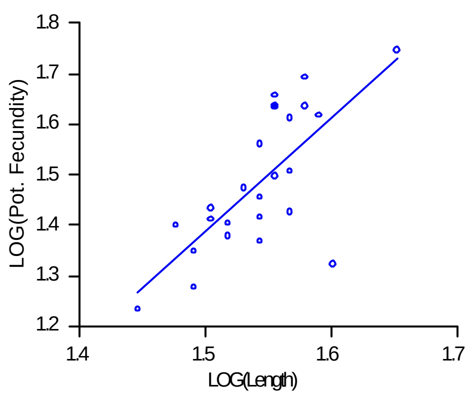

Fig. 10. Logarithmic relationship between potential fecundity and pre anal length of roughhead grenadier. Log (Pot. fecundity) = -1.9994 + 2.2573*Log (Length), n = 25.