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Roughhead Grenadier (*Macrourus berglax*) Biology and Population Structure in NAFO Divisions 3LMN

by

Hilario Murua
Fish, Resour. – AZTI Foundation, Herrera Kaia, Portualde z/g, 20110 Pasaia, Basque Country, Spain

Abstract

Roughhead grenadier, *Macrourus berglax*, is becoming an important commercial fish in NAFO Regulatory Area and reliable information is needed for its assessment. The fishery for roughhead grenadier is unregulated as it has been mainly taken as by-catch in the Greenland halibut fishery.

Several aspects of the biology and population structure of the roughhead grenadier are studied based upon samples collected on the Flemish Cap survey (1991-2000, NAFO Div. 3M) and on commercial vessels (1997-2000, NAFO Div. 3LMN).

The European Union has conducted since 1988 an annual bottom trawl survey in Flemish Cap (NAFO Div. 3M) in the 200-720 m depth range. The information on roughhead grenadier population structure recorded during the last 10 years (1991-2000) in Flemish Cap is presented. In addition, samples taken on board of Spanish commercial vessels (800-1700 m depth) was analysed to complete the coverage of the sampling due to the small proportion of the roughhead grenadier distribution area covered by the EU survey.

Length and age composition of catches, age-length keys, growth parameters, length/weight relationship, sex-ratios and reproductive biology data are presented in this paper.

Age and length composition of the catches showed clear differences between the two sexes. The importance of males in the capture declines in larger fish, disappearing from the capture in largest length classes. Results show that roughhead grenadier has a prolonged life cycle, slow growth, low fecundity and multiaged population structure with differences in growth and mortality between males and females.

Introduction

The roughhead grenadier, *Macrourus berglax* Lacepède, is an abundant and widespread fish species in both sides of the north Atlantic. In the Northwest Atlantic, this species is found commonly on the continental slope, at depths between 400 and 2000 (Parson 1975; de Cárdenas et al. 1996) and in temperatures ranging from about –0.5 to 5.4 ºC (Atkinson and Power 1987).

Roughhead grenadier is becoming an important commercial fish in NAFO Regulatory Area and reliable information is needed for its assessment. The fishery for roughhead grenadier is unregulated as it has been mainly taken as by-catch in Greenland halibut fishery. Catches of roughhead grenadier increased sharply from 1989 (333 tones) to 1990 (3 268 tones), since then total catches has been about 4 000 tones taken primarily by Portugal and Spain as by-catch in the fishery directed to Greenland halibut. Catches increased to 7 139 tones in 1998 remaining at this level in 1999, and decreased to 4 767 tones in 2000. The largest proportion of these catches are taken in Div. 3LMN and no catches are recorded in SA 2 (Junquera et al., 2001)

Limited information on age structure, growth rate and reproductive biology is available in scientific literature. Savvatimsky (1971, 1984, 1989, 1994) and Jorgensen (1996) carried out studies on this species in the NW Atlantic, basing findings on age readings from scales. The age structure and growth parameters of roughhead grenadier have been estimated by Casas (1994), Sainza (1996), Alpoim (1997), Sarasua *et al*., (1998), Rodríguez-Marín *et al*., (1998), Sarasua *et al*., (1999), Murua *et al*., (1999) and Murua (2000 and 2001) from otolith readings of specimens captured in NAFO Divisions 3LM. Eliassen (1983) also performed age estimation by otolith reading from roughhead caught in the continental slope of Norway. Information about the reproductive biology of this species has been presented by different authors. Eliassen and Falk-Petersen (1985), Savvatimsky (1984, 1989) and Murua et al. (2000) carried out studies about the timing of spawning, egg diameter, egg and ovary development and fecundity of roughhead grenadier.

The aim of this paper is to present the information on roughhead grenadier in NAFO Area 3LMN on length and age composition of catches, age-length keys, growth parameters, length/weight relationship, sex-ratios and reproductive biology data based upon data collected during the EU-Flemish Cap survey (1991-2000) and in the Spanish commercial fishery (1998-2000). The samples taken on board of commercial vessels (800-1700 m depth) were used to complete the coverage of the sampling due to the small proportion of the roughhead grenadier distribution area covered by the EU survey (200-720 meters).

Materials and Methods

Data on roughhead grenadier for the 1991-2000 period were collected on the annual random-stratified bottom trawl surveys carried out by the European Union on the area (methodology is described by Saborido and Vázquez, 2001). Data on age structure and sex-ratio in the survey are only available for the 1994-2000 period, because otolith sampling began in 1994. Annual length-age keys have been applied for each year. For years when otoliths were not sampled the mean 96-97 age-length key (the most consistent readings) were applied. Additionally, biological sampling of the commercial fleet was obtained in NAFO Divisions 3LMN during the period 1998-2000. Taking into account both samplings, a total of 6085 otoliths were sampled between a length range of 3-48.5 cm and 5150 of them have been read (Table 1).

Otoliths were broken through the nucleus and read by transmitted light (Casas, 1994). Many difficulties in reading Macrouridae age from otoliths and scales have been reported previously (Savvatimsky, 1984). Age reading in larger fish (more than 10 years old) is even more complicated, because many rings are present and they lie close to each other. Nevertheless, intercalibration of readings between three readers was done and 80% of agreement has been reached. Differences were $\pm$ 1 year in otoliths between 2-10 years and 1, 2 years in older than 10 years (Rodríguez-Marín *et al*., 1998).

Individuals were measured from tip of snout to base of first anal-fin ray, in 0.5 cm intervals, as adopted by NAFO in June 1980 (Atkinson, 1991) as a standard measurement for roundnose and roughhead grenadiers. Length is presented as anal-fin length (AFL) and data are given in 1 cm intervals. Total weight was recorded accurate to the nearest 10 g.

On the other hand, a total of 702 roughhead grenadier ovaries were sampled during different cruises carried out in the NAFO Regulatory Area Divisions 3LMN during 1998, 1999 and 2000 (Table 2). 475 ovaries were collected by observers aboard of Spanish commercial trawler vessels during the period 1998 and 2000 and 165 ovaries were collected during the Flemish Cap bottom trawl surveys carried out in July 1998-2000, respectively. In addition, 62 ovaries were sampled during a Selectivity survey carried out in NAFO Divisions 3LMN during April 1999.

Gonads were extracted and preserved in a standard solution of 4 % buffered formaldehyde (Hunter 1985). All gonads were weighed to the nearest gram in the laboratory. The preserved ovaries provided material for histological descriptions, oocyte size-frequency distribution and estimates of fecundity.

Each ovary was classified histologically according to the most advanced oocyte stage present in the ovary. We followed Murua and Motos's (2000) criteria for description of oocyte staging in roughhead grenadier ovaries. The presence/absence of oocyte and postovulatory follicle stages was recorded. Immature females were classified as having all the oocytes in the ovary in the primary growth stage. On the other hand, the presence of at least one of the following oocyte development categories in the ovary served to classify a female as mature: cortical alveoli (CA), vitellogenesis, maturation, postovulatory follicles (POF) or atretic oocytes.

The proportion of histological mature females by length and age was fitted to a logistic equation as described by Ashton (1972):

$$\overline{P} = \frac{e^{a+bAFL}}{1+e^{a+bAFL}} \qquad \text{Eq. 1}$$

and the logit transformation:

$$\ln \frac{\overline{P}}{1-\overline{P}} = a + bAFL \qquad \text{eq. 2}$$

where $\overline{P}$ is the predicted mature proportion
α and β are the coefficients of the logistic equation
AFL is the anal-fin length in cm.

A standard statistical package was used to fit the relationship to the data, to estimate the coefficients and to calculate the predicted values. Length at first maturity (AFL_{50} = anal-fin length of 50 % mature) was obtained as the ratio of the coefficients ($-\alpha/\beta$), by substituting $\overline{P}$ by 0.5 in equation (2).

The Gonadosomatic Index was calculated as GSI = gonad weight x 100 / total fish weight. For fish that has only registered the gonad weight and the total anal-fin length, the different coefficients of the total anal fin length / total weight relationship was applied.

Estimates of total fecundity, i.e. total number of advanced yolked oocytes present in the ovary that will (potentially) be spawned throughout the forthcoming reproductive season, were derived using the gravimetric method (Hunter et al. 1989). After detailed examination, the size of 1.1 mm was assumed to be the size threshold where the hiatus is developed, i.e. the advanced yolked oocytes are separated from early vitellogenic oocytes. This diameter may be the threshold size at which recruitment of vitellogenic oocytes to the advanced mode does not occur any more in the current season (Murua and Motos, 2000). Consequently all the oocytes bigger than 1.1 mm were measured under the stereomicroscope.

Results

Annual length frequencies by sex for Flemish Cap survey are presented in Figure 1. This figure shows that captures are dominated by the 14-20 cm length classes, 55 % of the total catch. The importance of males in the capture declines in larger fish and they disappear from the capture in largest length classes. Largest male found in the scientific surveys was 24 cm while females are larger reaching 35 cm long. Average AFL for females is also greater than for males. Female's mean AFL for the 1993-2000 period in Flemish Cap was 16.76 cm, while mean AFL for males was 15.44 cm and both sexes combined 15.56 cm. In the commercial catches of the Spanish fleet the pattern seen is the same, the importance of males declines and disappear in largest length classes of captures. In this case, the mean length for the Spanish catches in 1997 was around 19 cm and since then has been around 16 cm.

The mean AFL-age key for 1994-2000 Flemish Cap survey, as well as mean length at age and standard deviation are given by sex in Table 3. The AFL-age key based on upon otoliths sampled on board of commercial vessels (1999-2000) gives an mean length at age similar to those obtained in the Flemish Cap survey (table 4), although in the last case more age group are present. There are some differences in the mean AFL for age 2 and 3 but this fact is due to the length range is composed by smaller lengths in the survey than in the commercial data (3 cm length-group onwards are present in the survey, while the 9 length class is the first one in the commercial data). In both cases, mean length at age is similar for males and females for ages under 9 years, but males grow slower from this length onwards.

Interannual differences in length and age are shown in Figure 1 and 2 for the Flemish Cap survey data. The 1984-1986 cohorts dominated the catches during the first years. The importance of these annual classes has declined sharply during last 4 years and the 1990-91 cohorts (fish of 9-10 years) now dominate captures. On the other hand, Total catches of the Spanish fishery is composed mainly by ages between 6 and 9 with a peak in age 6 in 2000. The oldest age group found in the scientific survey was 16 years for males and 18 for females in comparison with the 16 years and 28 years.

Female-ratio in the Flemish Cap survey whole study period is 51%. Figures 3 and 4 present sex-ratio by age and by length respectively, for the whole study period. In the sex-ratio, female proportion fluctuates around 40 %-50 % the first 10-12 years (up to 20 cm in length). It increases from age 13 (length 20 cm) upwards. Female-proportion reaches 73 % in year-group 13 (20 cm) and 80 % in year-group 14 (24 cm). Females are 100 % of the captures after that. Similar sex-ratio pattern is found on the commercial length and age distribution of captures. The female proportion fluctuates around 40-50 % up to 18 cm, then increases from 18 cm upwards and reaches 70-80 % at 20 cm. After that length females are 100 % of the commercial catches.

The increment in the female-ratio can be due to two different reasons: sexual differences in growth rate, in mortality or a combination of both. In this case, there are certainly sexual differences in growth, which are reflected in the mean length at age and in the different growth curves presented in this study.

The von Bertalanffy growth equation parameters for the survey were estimated applying the mean length values at age estimated from the annual ALK (Table 5). Von Bertalanffy growth curves and logarithmic regression lines based on survey and commercial data (Figure 5), fitted to mean length at age by sex, show that males growth rate declines when reaching 18 cm long, around 9 years old, while females do not decline growing until reaching 34-35 cm, around 20 years old.

On the other hand, it seems that there are some differences in mortality between both sexes, since males disappear from the capture in larger length-classes; this phenomenon has been also observed for other species, i.e. Greenland halibut (De Cárdenas, 1996). Total mortality by sex was calculated from catch curves, fitting regression lines by sex to ages fully recruited to the fishery. The catch curves (Figure 6) was elaborated from data for six years (1994-1999) for the Flemish Cap survey and for the commercial data (1999-2000). Both sexes are fully recruited at age 8, and in fact a different mortality is obtained: 0.29 for females and 0.59 for males for Flemish Cap survey and 0.47 for females and 0.69 for males for commercial data.

Length-weight relationships by sex are shown in Table 6 for all the years studied in the Flemish Cap survey and for commercial data (1999-2000). The relationship between fish length (AFL) and fish weight was assumed to be adequately expresses by the exponential function. Figure 7 shows the length-weight relationship for both sexes for the data gathered by the Flemish Cap survey and commercial vessels in 2000.

Table 7 shows the number of immature and mature females at different stages of development, in terms of length and age categories. 480 females, out of the 702 females sampled by length, were immature (67 %) and 222 were mature (33 %). In the samples described within the present investigation, representing fish in the length range 12-44 cm, 37 % of the adult females showed cortical alveoli stage as the most advanced stage of oocyte development; this indicates either the onset of oocyte development, towards maturation or a post-spawning condition where the more advanced stages are in atresia. The mode of the advanced oocyte clutch appears in the early vitellogenesis stages in around 55 % of the ovaries; likewise, in late vitellogenesis and migration in about 8 % of the ovaries.

On the other hand, 76 % of females out of 507 females sampled by age were immature and 24 % were mature. Within the mature females samples, representing fish in the age range 11-26, 45 % of the adult females showed cortical alveoli stages as the most advanced stage of oocyte development, 44 % showed early vitellogenesis and the remaining 11 % late vitellogenesis and migration.

Fig 8 shows the maturity curves related to length and age obtained, using the parameters (table 8) obtained from the fitted logit model. The proportions of mature female, by length and age, provide a good fit to the logistic model (R^2=

93 % and R^2= 95 %, respectively). The length at first maturity, expressed as anal-fin length (AFL_{50}), for roughhead grenadier females was 28.2 cm and the age at first maturity (A_{50}) for roughhead grenadier females was 15.6 years.

Only 17 ovaries, out of 702 ovaries, were sampled with advanced matured oocytes (VIT 3 and oil globule formation); all of these had the hiatus fully developed and, consequently, oocytes larger than 1.1 mm would be spawned a few months later (Murua and Motos, 2000). None of the females used for estimating fecundity showed postovulatory follicle.

The derived estimates of the total standing stock of advanced yolked oocytes varied from 4.8 to 15.7 per gram of gutted mature female. In this way, depending upon female length and weight, the total standing stock of advanced yolked oocytes per individual ranged from 8522 eggs to 61 844 eggs. The relationship between total fecundity and fish length, age and weight was analysed and the best fit to the data was obtained using an exponential regression model. Figure 9 shows that total fecundity increased significantly with female anal-fin length (F=11, p=0.0047), age (F=17.68, p=0.0018), and total weight (F=12.44, p=0.0031). The relationship between total fecundity and age gives the best fit to the data, which explains with explain 63.89 % of the variability in total fecundity.

An ANOVA on total fecundity using months as a main factor din not show any difference between months (p-value = 0.262). Length was used as a covariate in this analysis to allow for the increasing relationship between total fecundity and length.

The GSI monthly evolution and the for mature females (>28 cm) and the percentage of maturity stages by month (>28 cm) (Figure 10) pooled for all year do not show any clear pattern from which could be inferred an observable spawning period.

Discussion

The length composition of trawl catches differed between Flemish Cap survey and the commercial catches but this probably related directly to trawling depth, although the mean length for both sexes did not differ significantly between the survey and commercial catch from 1997 onwards. On the other hand, the difference in the mean length by sex of the catches of the survey is consistent with data found in the literature. Savvatimsky (1989) gives an average AFL of 18,9 cm (50.8 cm total length) and 22,5 cm (58.6 cm total length) for males and females respectively in 3KLN, although in this case the values are higher than the present study. However, this difference could be easily explained due to the different area covered by both surveys.

The mean length at age obtained in this study are higher than those achieved by Savvatimsky (1994) for NAFO Divs. 0B, 2GH and 3K. Savvatimsky (1994) and Jorgensen (1996) described similar growing pattern using scales for aging fish, they found that the differences between sexes in size at age come about from 10 years onwards. This fact could be explained due to the different aging method used in their studies and in ours, or due to different latitude of the sampling areas where specimens were obtained, because temperature differences would cause slower growth, and a delay in reaching sexual maturity (Rodríguez-Marín *et al*., 1998).

The female-ratio in the Flemish Cap survey whole study period (51 %) is lower that the one found by De Cardenas *et al*. (1996) in 3LMN, where females made up 71,4% of the catch. However, this difference could be easily explained due to the different area covered by both surveys. As length increases with depth in many species (De Cárdenas *et al*., 1996; Junquera *et al*., 1992), female ratio might also increase in deeper areas, and this is in agreement with the results presented by Savvatimsky and Gorchinsky (2001) for roughhead grenadier based on the Russian fishery. On the other hand, similar sex-ratio pattern, with males being more abundant in the central part of the population, is described also by Savvatimsky (1994) for Northwestern Atlantic.

The differences found in total mortality estimated by the catch curve between the survey and the commercial could be easily explained due to the different trawling depth, and consequently the different age classes covered by both sampling. In this case, the oldest age group found in the scientific survey was 16 years for males and 18 for females in comparison with the 16 years and 28 years.

The anal-fin length – weight relationship for both sexes gathered by the Flemish Cap survey and commercials sampling in 2000 are very similar, in this way a fish of 20 cm would weight 652 g (Flemish Cap) and 641 g (Commercial sampling) gives a similar weight. Savvatimsky (1989) presented a total length weight relationship that differs from the relationship found in the present study, taking into account his study a fish of same length would weight 787 grams.

The anal-fin length and age at first maturity (AFL_{50} and A_{50}) found for roughhead grenadier females, in this study, was 28.2 cm and 15.6 age. In order to allow for comparison with data found in the literature, we converted the estimates of total length at first maturity found in the literature to anal-fin length at first maturity using the total length anal-fin length relationship presented by de Cárdenas *et al.* (1996). The anal-fin length and age values at maturity estimate from this particular collection are slightly higher than those determined by Eliassen & Falk-Petersen (1985) for roughhead grenadier from the NE Atlantic waters (L_{50}= 25.4 cm and A_{50} = 15 years) and by Murua and Motos (2000) from the NW Atlantic waters (L_{50} = 26.2 cm and A_{50} = 13-14 years). Whereas the differences in L_{50} and A_{50} are relatively small and can lie within the variability range.

Estimates of total fecundity of roughhead grenadier are available in the literature (table 9). Eliassen and Falk-Petersen (1985) has indicated that total fecundity varies from 2 000 to 71 000 eggs per female, when measuring a range of oocytes between of 1.35 to 3.05 mm. Savvatimsky (1989) found a total fecundity that varies between 23 100 and 54 100 eggs per female, taking into account into account a range of oocyte diameters from 2.0 to 2.7 mm. On the other hand, Murua and Motos (2000) gave a value of total fecundity ranging between 14 400 and 79 220, when measuring oocytes bigger than 1.1 mm. These results are within the same range as the results of the present study (table 9), but, unfortunately, the sample size used here was unsatisfactory to estimate total fecundity with any confidence.

In despite of the insufficient information to study the entire annual cycle of gonad development, some authors detailed a spawning season for the roughhead grenadier in the NW Atlantic. Geistdoerfer (1979) reported a well-defined spawning season, which lasted from the end of spring to the beginning of the summer in the Labrador Sea. Savvatimsky (1984) has stated that this species spawn during winter and early spring in the Grand Bank. On the other hand, Murua and Motos (2000) has inferred that the spawning period starts around February and end around July in NAFO Divisions 3LMN. The GSI pattern for mature females and the proportion of maturity stages by month for mature females described in this study do not show any clear pattern. This result seems to be in discordance with the data presented by the other authors, although the conclusion of those authors is based on a partial coverage of the entire annual cycle. In contrast, the present study, when pooled the data of the three years studied, covers the entire annual cycle of gonadal development (except January), even though in some months the number of samples was small. Taking into account that still there is insufficient evidence to support a well-defined spawning period, we can conclude that it seems that this species has not a well-defined spawning period in the Northwest Atlantic.

Data available show that roughhead grenadier has a prolonged life cycle and multiaged population structure with differences in growth and mortality between males and females and. The complex multy-mode length structure, slow growth and a low fecundity are characteristic of deepwater fishes, including grenadiers (Hureau *et al*., 1979; Casas, 1994; Savvatimsky, 1994).

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Table 1.- Number of otoliths collected and the length range sampled during the period of study in different NAFO Divisions. In brackets the number of otoliths read for age determination.

Year	Month	Survey	Number of otoliths by area (NAFO Div.)			Total length range (cm)
			3L	3M	3N	
1994	July	Flemish Cap		239		6.5-32
1995	July	Flemish Cap		488		4-32
1996	July	Flemish Cap		390		3-32
1997	July	Flemish Cap		397		3.5-31.5
1998	July	Flemish Cap		610		3-34
1999	July	Flemish Cap		563		3-30.5
2000	July	Flemish Cap		617		3-35
1999	April	Commercial	158 (149)	82 (77)	78 (71)	9.5-34
	May	Commercial	26	16 (14)		19.5-35
	June	Commercial	5	30 (23)		22.5-34.5
	September	Commercial	203 (197)			9.5-41
	October	Commercial	136 (132)	21 (17)		11.5-39.5
	November	Commercial	90 (84)	90 (82)		10-41
	December	Commercial		13		17-36
2000	February	Commercial	112 (91)	34 (13)	53 (41)	9-40
	March	Commercial	44 (29)	288 (179)	41 (39)	7-40
	April	Commercial		198 (103)		9-47
	May	Commercial		188 (92)		7-37
	October	Commercial	118 (55)	30 (30)		7-37
	November	Commercial	299 (112)	35 (29)	99 (70)	8.5-48.5
	December	Commercial	211 (63)	37 (32)	49 (38)	7.5-39
Total			1402	4363	320	
Total				6085		3-48.5

Table 2.- Number of gonads collected and analysed during the period of study in NAFO Divisions 3LMN.

Year	Month	Survey	Number of gonads by area				Total length range (cm)
			3L	3M	3N	3LMN	
1998	July	Flemish Cap		84			19,5-34
		Commercial				89	12-37
1999	April	Selectivity	53	8	1		17-34
	May	Commercial	26	10			20,5-35
	June	Commercial	5	18			22,5-34,5
	September	Commercial	15				12,5-30
	October	Commercial	22				22-36,5
	November	Commercial	22	48			14-41
	December	Commercial		13			17-36
2000	February	Commercial	63	13			14,5-33,5
	March	Commercial	20	30			15,5-31,5
	May	Commercial			16		22-36
	July	Flemish Cap		78			20-38,5
	July	Commercial		10			28-35
	August	Commercial	7	4			30-39
	September	Commercial		3	13		31-36
	October	Commercial	4		5		32-44
	November	Commercial	8	2	3		26,5-43,5
	December	Commercial	6	3			31,5-41
Total			251	314	48	89	
Total				702			12-44

Table 3.- (continued)

emales	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	Total
3	3																			3
4		6																		6
5		19																		19
6		13	10																	23
7		10	25																	35
8		2	26	7																35
9			15	20	3															38
10			8	31	11															50
11			1	20	25	3														49
12				10	23	21	1	1												56
13				1	27	30	8	1	1											68
14					14	29	17	7												67
15					4	27	23	18	4	1										77
16					2	11	27	20	8	2										70
17						7	28	24	14	1										74
18							13	22	20	9										64
19							3	19	31	18	5	2								78
20								8	25	25	12	5								75
21								4	12	22	11	6	3							58
22									4	15	23	16	8	3						69
23									2	2	10	10	9	2	2					37
24									1	5	7	11	14	6	2					46
25										1	6	5	12	9	4					37
26										1	1	12	6	2	6	2				30
27										1	1	1	7	7	5		1			23
28													3	6	3	1				13
29												1	1	1	4	4				11
30											1		1	2	5		1			10
31															1	1		2		4
32												1		1	1	1				4
34																1		1		2
35																			1	1
Total	**3**	**50**	**85**	**89**	**109**	**128**	**120**	**124**	**122**	**103**	**77**	**70**	**64**	**39**	**33**	**10**	**2**	**3**	**1**	**1232**
%	**0,22**	**3,6**	**6,13**	**6,42**	**7,86**	**9,23**	**8,65**	**8,94**	**8,8**	**7,43**	**5,55**	**5,05**	**4,61**	**2,81**	**2,38**	**0,72**	**0,14**	**0,22**	**0,07**	**88,8**
an Length	**3,0**	**5,7**	**7,9**	**10,1**	**12,2**	**13,9**	**15,8**	**17,1**	**18,8**	**20,4**	**22,1**	**23,4**	**24,5**	**25,9**	**27,2**	**29,3**	**28,5**	**32,0**	**35,0**	**16,8**
St. Dv.		**1,06**	**1,19**	**1,15**	**1,50**	**1,47**	**1,54**	**1,87**	**1,84**	**1,96**	**1,99**	**2,35**	**2,02**	**2,33**	**2,34**	**2,50**	**2,12**	**1,73**		

Table 3.- Mean Age-Length key (1994-2000).

Males

Length / Age	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	20	Total
3	3	1																4
4	2	5																7
5		9																9
6		10	8															18
7		1	14															15
8		2	13	5														20
9		1	15	19	1													36
10			6	27	9													42
11			2	20	24	2												48
12			1	4	29	20	7											61
13				2	18	31	15											66
14					13	32	18	9	1									73
15					2	20	25	15	6									68
16					3	17	34	26	19	6	1							106
17						9	22	23	20	19	2							95
18						1	10	23	24	22	14	2	3					99
19							6	13	22	24	18	10	3	2	1			99
20								3	12	18	10	21	7	2				73
21								1	9	6	11	14	7	3	1	2		54
22										2	2	4	2	1			1	12
23													1	2				3
24														1			1	2
Total	**5**	**29**	**59**	**77**	**99**	**132**	**137**	**113**	**113**	**97**	**58**	**51**	**23**	**11**	**2**	**2**	**2**	**1010**
%	**0,5**	**2,9**	**5,8**	**7,6**	**9,8**	**13,1**	**13,6**	**11,2**	**11,2**	**9,6**	**5,7**	**5,0**	**2,3**	**1,1**	**0,2**	**0,2**	**0,2**	**99**
Mean Length	**3,4**	**5,5**	**8,1**	**10,1**	**12,2**	**14,1**	**15,5**	**16,8**	**17,9**	**18,6**	**19,3**	**20,2**	**20,2**	**21,2**	**20,0**	**21,0**	**23,0**	**15,1**
St. Dv.	**0,55**	**1,33**	**1,43**	**1,10**	**1,44**	**1,55**	**1,76**	**1,58**	**1,68**	**1,42**	**1,31**	**0,97**	**1,31**	**1,66**	**1,41**		**1,41**	

Table 4.- Mean Anal-Fin Length for roughhead grenadier in NAFO Div. 3LMN during the study period, Flemish Cap survey (1994-2000) and commercial data (1999 and 2000).

MALES

	Flemish Cap 94-00			Flota 99			Flota 00		
	AFLength range 3-24 cm			AFLength range 9,5-24,5 cm			AFLength range 7-23,5 cm		
Age	n	Mean AFL	St. Dev	n	Mean AFL	St. Dev	n	Mean AFL	St. Dev
1	5	3,40	0,55						
2	29	5,52	1,33	1	9,50		10	8,25	0,95
3	59	8,12	1,43	1	10,50		18	9,17	0,71
4	77	10,06	1,10	6	11,17	0,68	21	10,64	0,73
5	99	12,17	1,44	14	12,14	0,66	24	12,00	0,66
6	132	14,06	1,55	20	13,48	0,83	44	13,24	1,06
7	137	15,46	1,76	24	14,98	0,71	30	14,52	1,08
8	113	16,81	1,58	31	16,32	1,17	42	15,73	1,12
9	113	17,94	1,68	22	17,20	0,96	44	17,13	1,17
10	97	18,57	1,42	20	19,05	1,26	39	18,19	1,06
11	58	19,29	1,31	24	19,67	1,09	20	19,58	1,13
12	51	20,16	0,97	14	20,89	0,79	16	19,94	1,17
13	23	20,22	1,31	10	22,25	0,75	7	21,00	1,00
14	11	21,18	1,66	14	22,96	1,23	6	22,25	0,94
15	2	20,00	1,41	2	23,25	1,06	4	22,88	0,75
16	2	21,00	0,00				1	20,50	
17									
18									
19									
20	2	23,00	1,41						

FEMALES

	Flemish Cap 94-00			Flota 99			Flota 00		
	AFLength range 3-35 cm			AFLength range 10,5-41 cm			AFLength range 7-48,5 cm		
Age	n	Mean AFL	St. Dev	n	Mean AFL	St. Dev	n	Mean AFL	St. Dev
1	3	3,00	0,00						
2	50	5,66	1,06				7	7,50	0,71
3	85	7,87	1,19	5	10,80	0,27	19	9,63	0,62
4	89	10,10	1,15	5	11,40	0,55	21	10,67	0,62
5	109	12,17	1,50	9	12,89	0,55	35	12,19	0,91
6	128	13,91	1,47	11	13,86	0,98	49	13,28	0,90
7	120	15,82	1,54	13	15,35	1,05	36	14,99	0,81
8	124	17,11	1,87	22	16,48	1,05	37	16,26	1,03
9	122	18,84	1,84	15	18,50	0,91	60	18,33	1,43
10	103	20,43	1,96	10	19,90	1,43	40	19,88	1,53
11	77	22,12	1,99	14	21,57	1,11	37	21,39	1,44
12	70	23,36	2,35	16	22,25	1,37	50	22,54	1,54
13	64	24,53	2,02	23	23,78	1,41	49	23,88	1,70
14	39	25,92	2,33	32	25,69	1,26	58	25,76	2,04
15	33	27,21	2,34	31	26,90	1,28	48	26,98	1,67
16	10	29,30	2,50	16	27,88	1,24	31	28,84	1,90
17	2	28,50	2,12	11	28,50	1,10	17	29,12	1,88
18	3	32,00	1,73	18	30,33	1,19	19	30,63	1,54
19	1	35,00	0,00	15	31,17	1,28	26	31,96	2,25
20				22	33,16	1,48	16	33,66	1,78
21				14	33,75	1,20	15	35,93	2,61
22				9	36,28	1,97	10	37,05	4,54
23				9	35,78	1,03	7	38,79	2,74
24				2	38,50	0,71	5	39,60	2,72
25				5	39,10	1,24			
26				1	41,00				
27									
28							1	47,00	

Table 5.- Parameters of the Von Bertalanffy growth curves by sex for the EU Survey 1993-2000.

	MALES			FEMALES		
Year	$\mathbf{t_o}$	$\mathbf{L_?}$	**K**	$\mathbf{t_o}$	$\mathbf{L_?}$	**K**
2000	-0,177	22,9	0,128	0,581	73,8	0,034
1999	-0,132	27,9	0,104	0,405	57,8	0,044
1998	0,270	27,5	0,109	0,460	46,3	0,056
1997	1,425	22,9	0,176	0,533	51,2	0,050
1996	0,490	23,5	0,172	0,346	77,0	0,032
1995	-1,576	37,1	0,073	-0,681	51,9	0,053
1994	1,768	22,8	0,254	-0,054	57,6	0,048
1993	1,074	21,9	0,197	0,634	46,4	0,060

Table 6.- Length weight relationship for roughhead grenadier males and females from EU Flemish Cap (FC) Survey (1993-2000) and from commercial (COM) vessels data in 1999 and 2000.

		MALES		FEMALES	
Year	**Data**	Regression	r^2	Regression	r^2
1993	FC	W (g) = 0.0793 * AFL (cm)$^{3.0883}$	0.9734	W (g) = 0.1016 * AFL (cm)$^{2.9934}$	0.9895
1994	FC	W (g) = 0.1489 * AFL (cm)$^{2.8437}$	0.9694	W (g) = 0.1015 * AFL (cm)$^{2.9935}$	0.9895
1995	FC	W (g) = 0.1131 * AFL (cm)$^{2.9409}$	0.9818	W (g) = 0.1139 * AFL (cm)$^{2.9344}$	0.9859
1996	FC	W (g) = 0.1244 * AFL (cm)$^{2.8889}$	0.9802	W (g) = 0.1367 * AFL (cm)$^{2.8536}$	0.9851
1997	FC	W (g) = 0.1209 * AFL (cm)$^{2.8840}$	0.9812	W (g) = 0.1202 * AFL (cm)$^{2.8898}$	0.9923
1998	FC	W (g) = 0.1338 * AFL (cm)$^{2.8621}$	0.9669	W (g) = 0.1199 * AFL (cm)$^{2.9015}$	0.9866
1999	FC	W (g) = 0.1290 * AFL (cm)$^{2.8670}$	0.9718	W (g) = 0.1174 * AFL (cm)$^{2.8950}$	0.9866
2000	FC	W (g) = 0.1423 * AFL (cm)$^{2.8148}$	0.9776	W (g) = 0.1708 * AFL (cm)$^{2.7537}$	0.9744
		BOTH SEXES			
1999	COM	W (g) = 0.0946 * AFL (cm)$^{2.9507}$			0.9677
2000	COM	W (g) = 0.0903 * AFL (cm)$^{2.9601}$			0.9795

Table 7.- Numbers of immature, mature (cortical alveoli (C.A.), vitellogenesis (VIT), oil globule formation and migration (O.G. + M) and total females of roughhead grenadier sampled by length and age intervals.

Length (cm)	Immature	Mature				Total
		C.A.	VIT 1	VIT 2	O.G + M	
11-13	10					10
13-15	7					7
15-17	24					24
17-19	36	1				37
19-21	88	1				89
21-23	101	1				102
23-25	97	3	3			103
25-27	72	13	3			88
27-29	34	10	7	1		52
29-31	8	18	14	2		42
31-33	3	16	26	7	1	53
33-35		10	28	2	1	41
35-37		5	20		1	26
37-39		3	11		1	15
39-41		2	6		1	9
41-43			2			2
43-45			1		1	2
Total		83	121	12	6	
Total	480	222				702

Age	Immature	Mature				Total
		C.A.	VIT 1	VIT 2	O.G + M	
5	1					1
6	1					1
7	12					12
8	15					15
9	43					43
10	53					53
11	41	2				43
12	65	2				67
13	68	5				73
14	46	5	2			53
15	29	10	1			40
16	7	6	7	1		21
17	1	2	5	2		10
18	4	6	8	2		20
19		9	6	1		16
20		2	10	1	1	14
21		3	6		1	10
22		1	3	1		5
23		2	3		1	6
24					1	1
25			1		1	2
26			1			1
Total		55	53	8	5	
Total	386	121				507

Table 8.- Logit parameters of the roughhead grenadier female maturity curve for length and for age (AFL_{50} = anal-fin length at first maturity and A_{50} = age at first maturity).

	Length		Age	
Parameters	α	β	α	β
Estimate	-14.705	0.521	-13.054	0.834
Standard error	2.068	0.081	1.644	0.1120
T	-7.11	6.40	-7.93	7.44
P level	0.0004	0.0007	0.0002	0.0003
Number of females	702		507	
AFL_{50} / A_{50} ($-\alpha/\beta$)	28.2 cm		15.6 years	
R squared	93 %		95 %	

Table 9.- Total fecundity values found in the literature.

Source	Year	Total Fecundity (nº of matured eggs)	Size range of eggs (mm)	Number of individuals
Yanulov	1962	25 000	-	-
Savvatimsky	1989	23 100-54 400	2.0 - 2.7	4
Eliassen and Petersen	1985	2 000-71 000	1.35 - 3.05	24
Murua and Motos	1996	14 400 - 79 220	> 1.1	16
The present study	1998-00	8522 – 61844	> 1.1	17

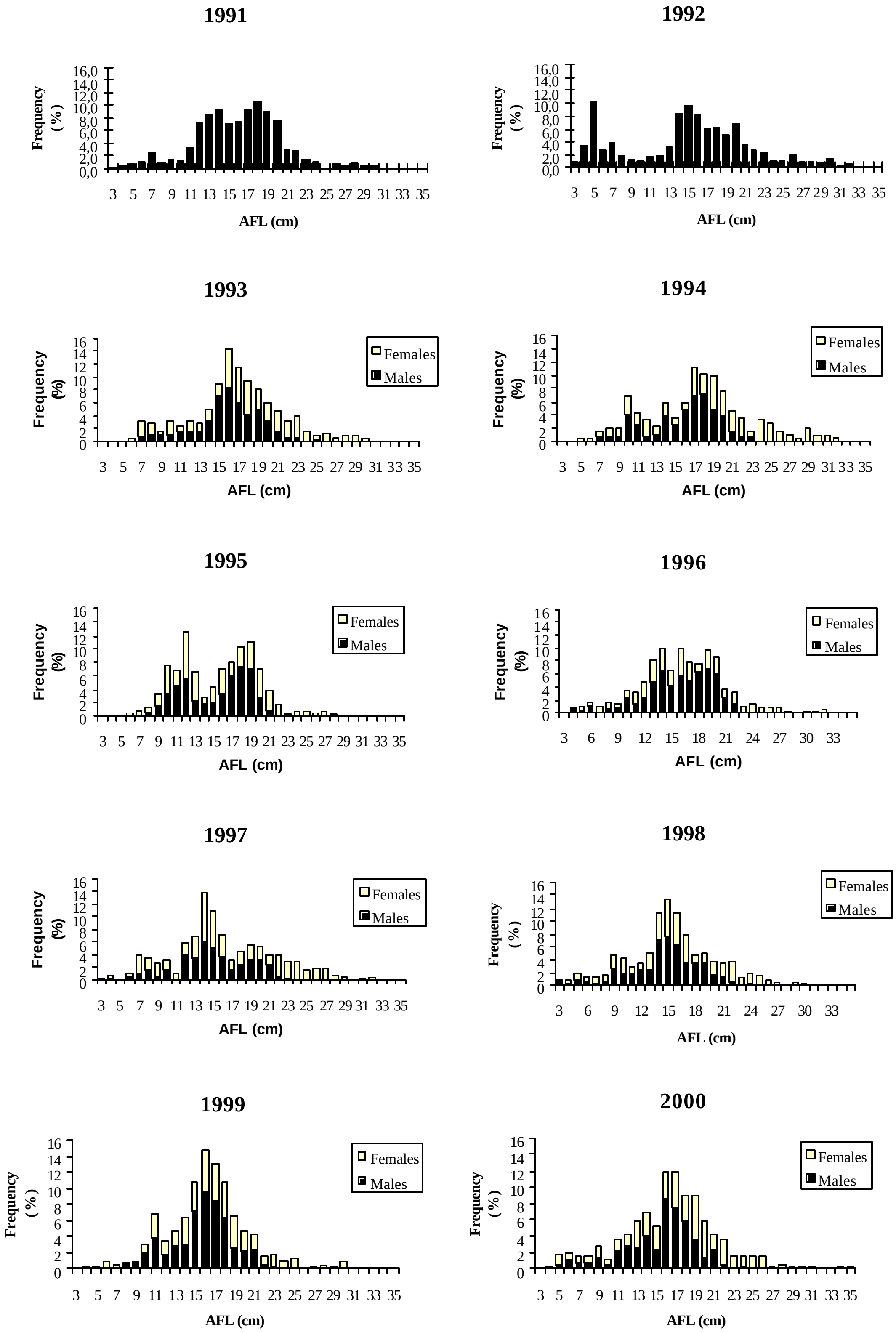


Figure 1.- Annual length distribution by sex (except 1991-1992) in Flemish Cap 1991-2000.

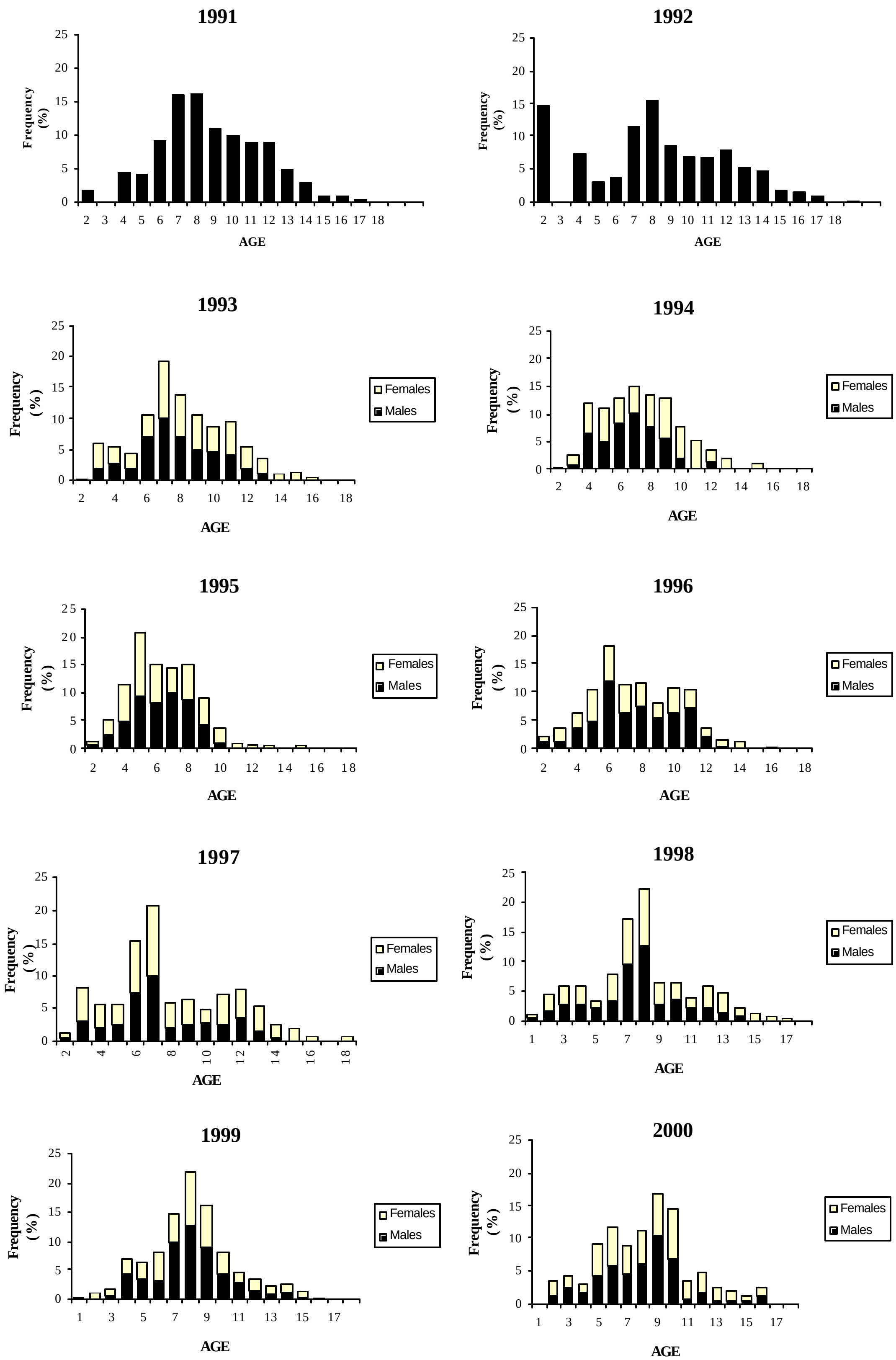


Figure 2.- Annual age composition by sex (except 1991-1992), in Flemish Cap 1991-2000.

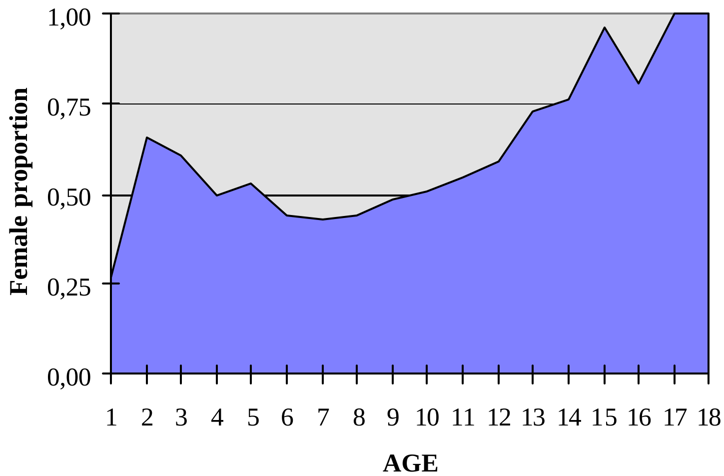


Figure 3.- Female ratio by age in Flemish Cap 1993-2000.

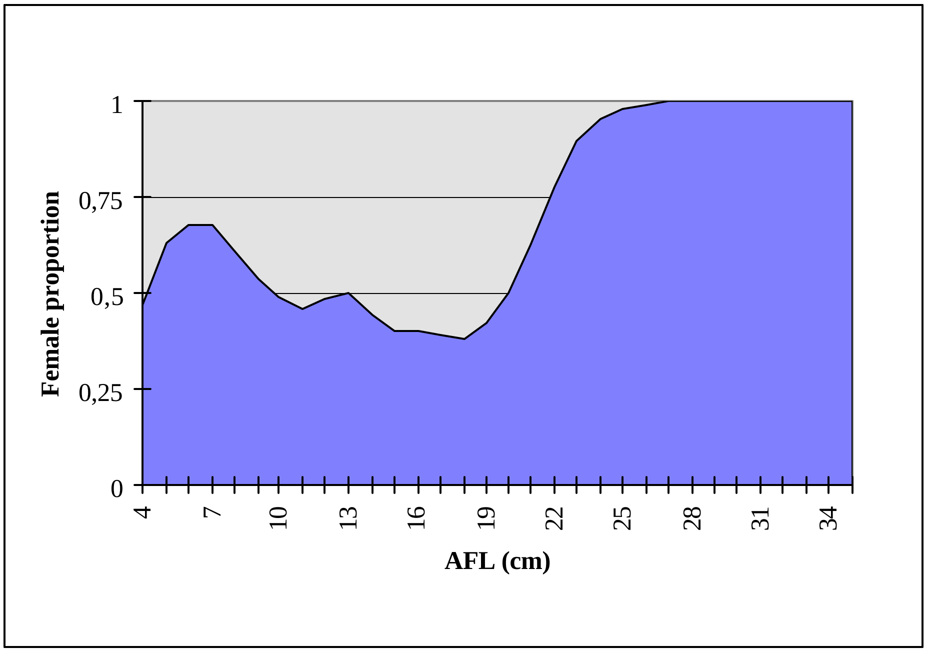


Figure 4.- Female ratio by length in Flemish Cap 1993-2000.

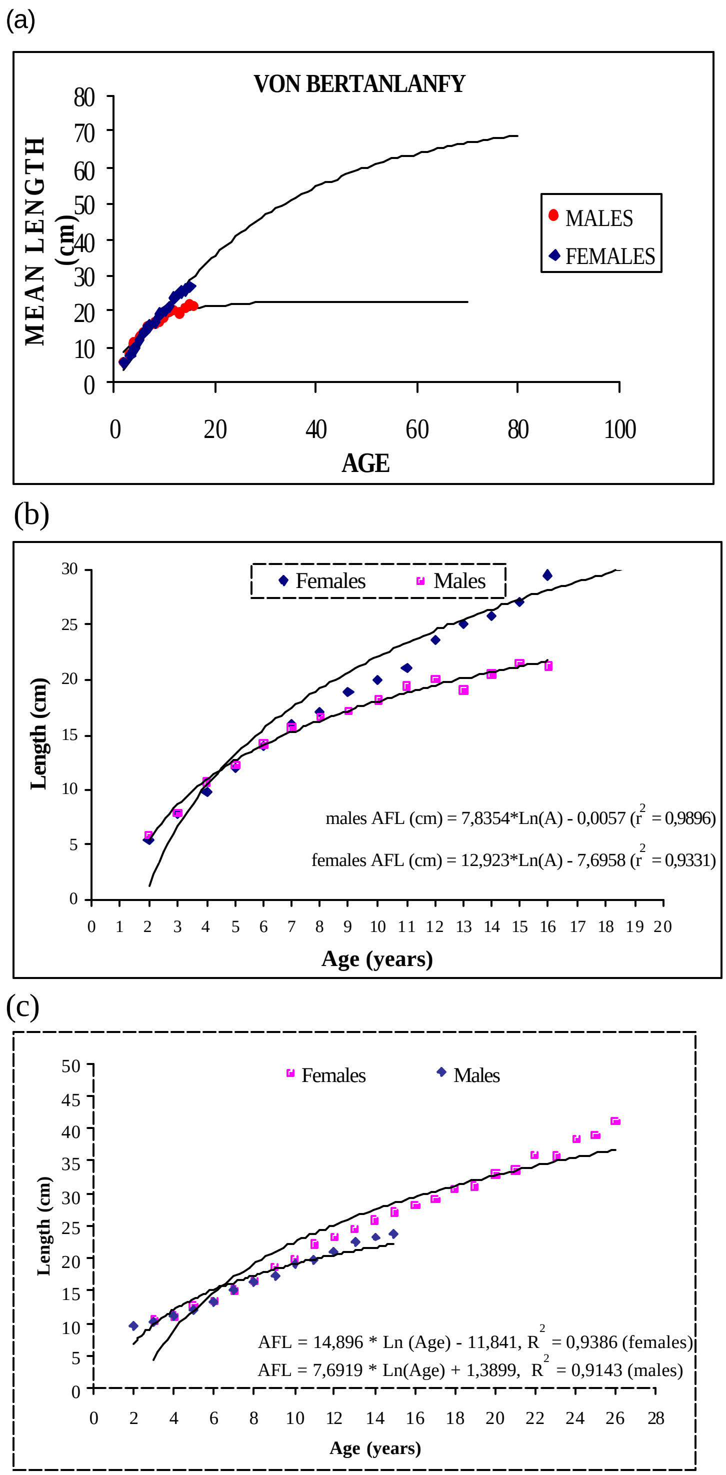
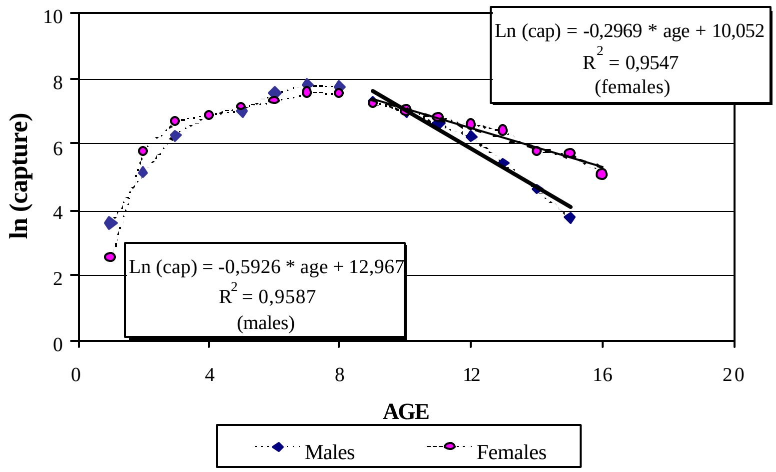


Fig. 5 a, b and c.- Von Bertanlanffy (a) and logarithmic (b) growth curve by sexes in Flemish Cap 2000 and logarithmic (c) growth curve by sexes in NAFO 3LMN based on commercial sampling in 2000.

(a)



(b)

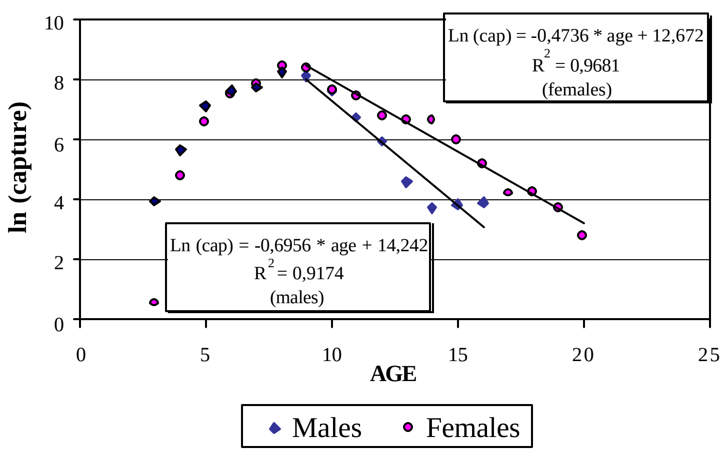
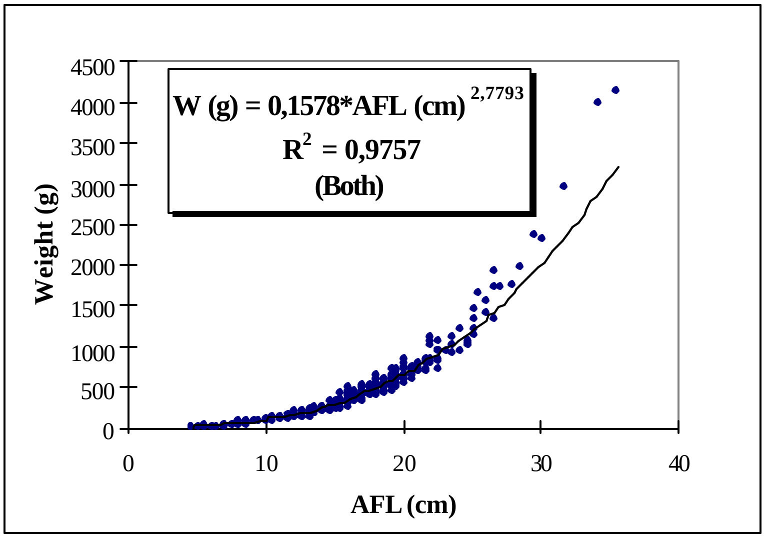


Figure 6.- Catch curves by sex for roughhead grenadier: (a) in Flemish Cap 1994-2000 and (b) Commercial data (1999-2000).

(a)



(b)

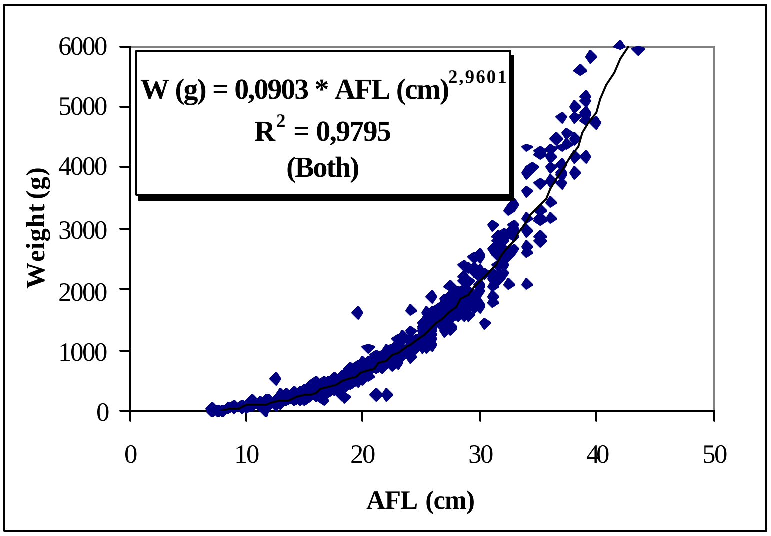
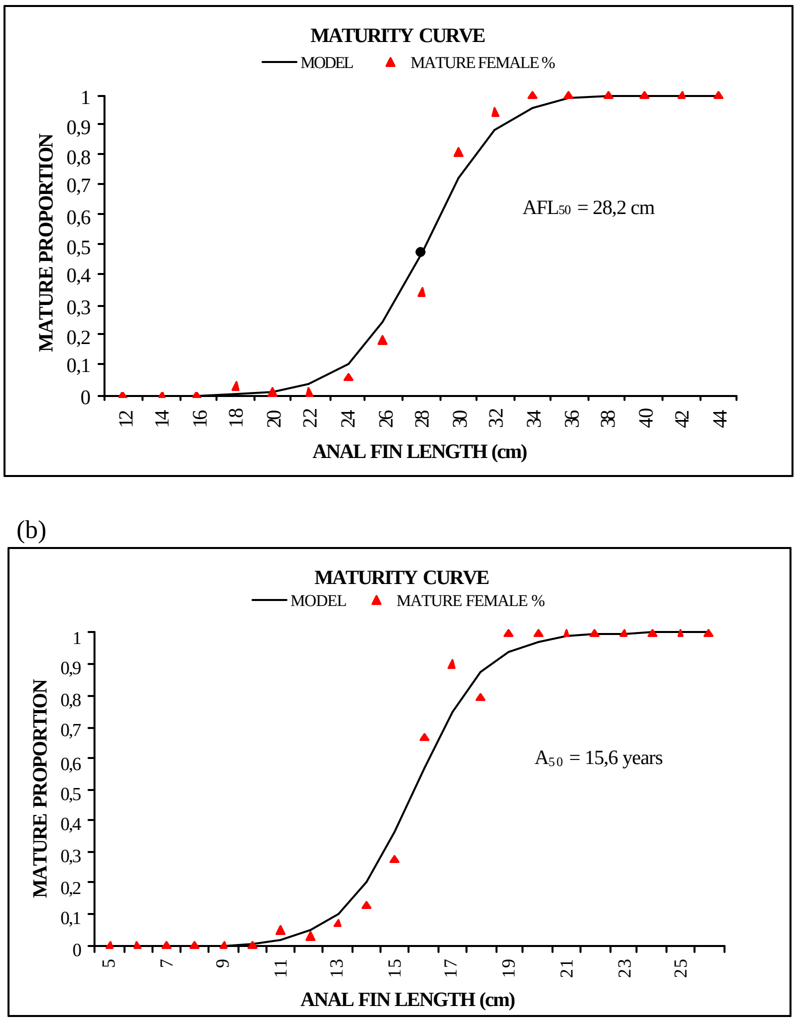


Figure 7.- Annual Anal-fin Length-Total Weight relationship for sexes combined for roughhead grenadier in NAFO Divisions 3LMN based on data on Flemish Cap survey (a) and commercial fishery (b) in 2000.

(a)



(b)

Figure 8.- Proportion of mature females, in relation to length (a) and to age (b), together with the logit regression fitting curve.

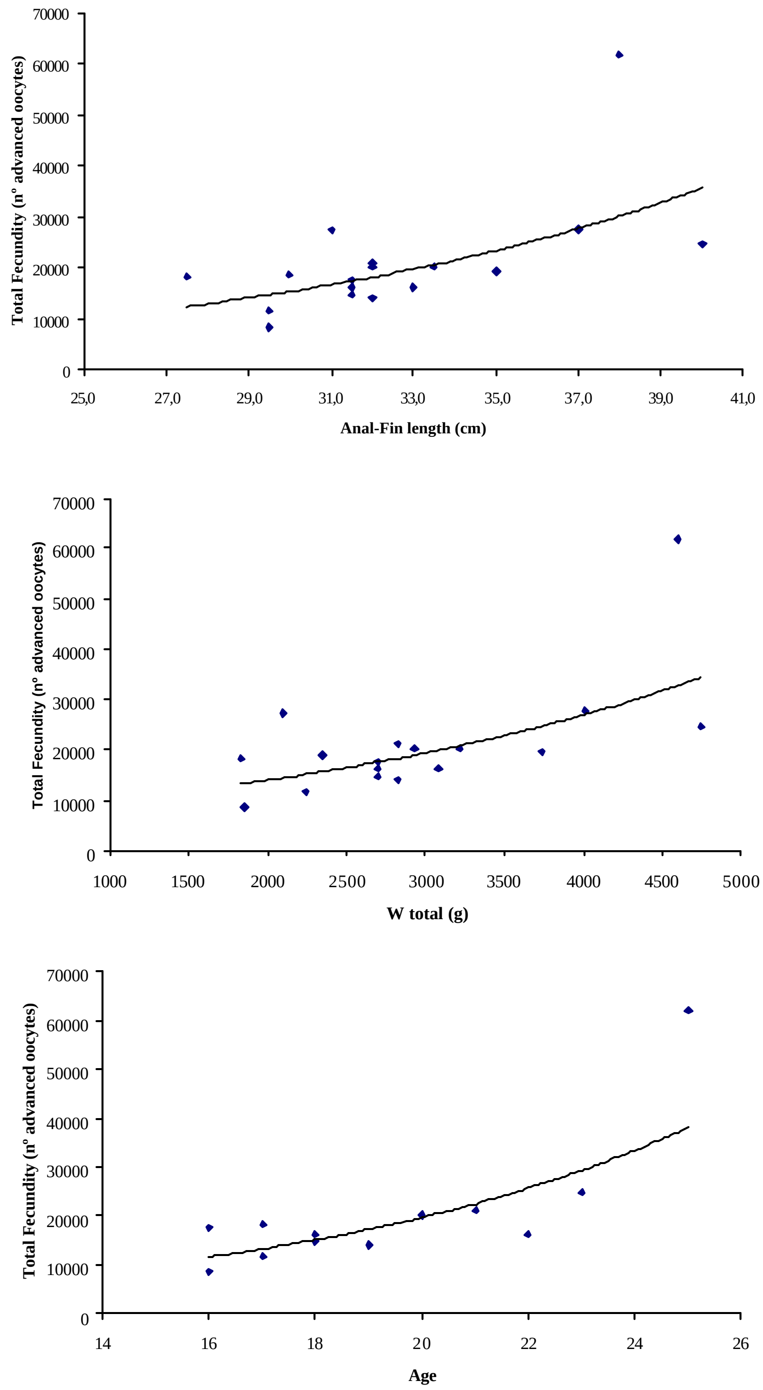
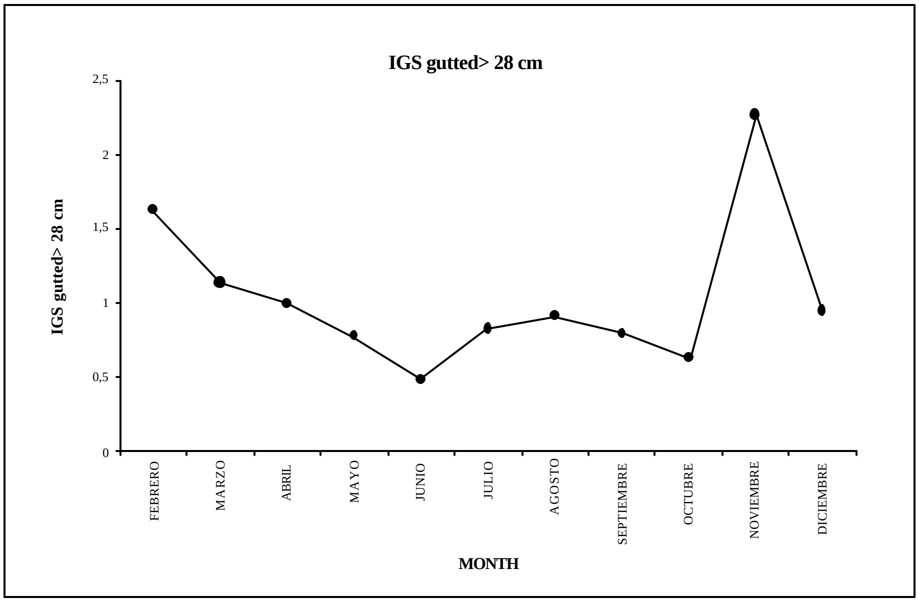


Figure 9.- Total fecundity and female anal-fin length, total weight and age relationships for roughhead grenadier females sampled in 1998, 1999 and 2000. Exponential regressions fits for anal-fin length, total weight and age are shown, respectively: Ft = 1229.3 * Exp $^{(0.0842 * AFL)}$, R^2 = 42.23 %, N = 17; Ft = 7269.2 * Exp $^{(0.003 * Wt)}$, R^2 = 45.34 %, N = 17; Ft = 1401.5 * Exp $^{(0.132 * Age)}$, R^2 = 63.89 %, N = 12.

(a)



(b)

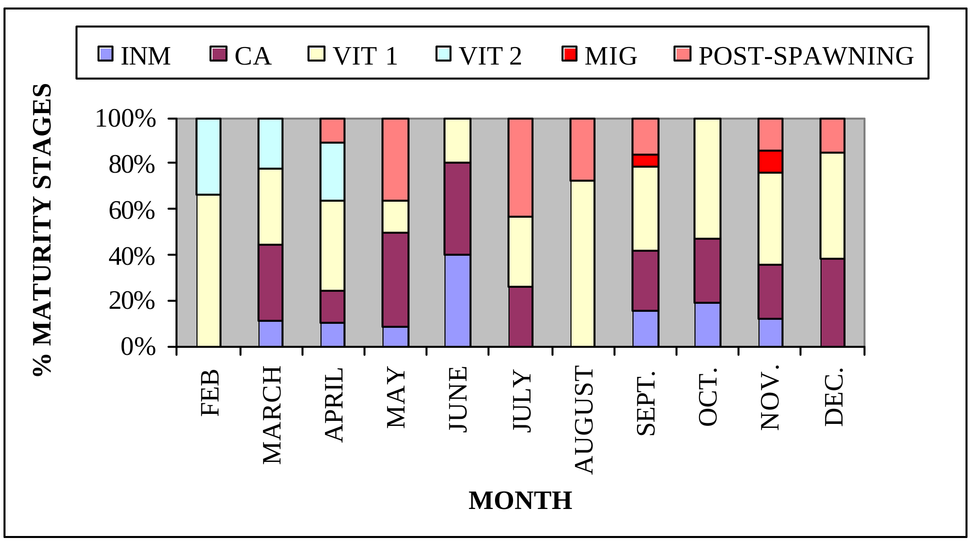


Figure 10.- Gonadosomatic Index for females greater than the anal fin length at maturity monthly evolution (a) and the evolution of the proportion of maturity stages by month (b) calculated using pooled material from the period studied (1998-2000) in the NAFO Divisions 3LMN. Totals sample size was 220 fish (6 in February, 9 in march, 30 in April, 22 in may, 8 in June, 28 in July, 11 in August, 20 in September, 21 in October, 52 in November and 13 in December).