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A Review on Roughhead Grenadier (*Macrourus berglax*) Biology and Population Structure on Flemish Cap
(NAFO Division 3M) 1991-2004 Based Upon EU Flemish Cap Bottom Survey Data

by

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ABSTRACT

The European Union has conducted since 1988 an annual bottom trawl survey in Flemish Cap (NAFO Division 3M) in the 200-720 m depth range. The information on roughhead grenadier population structure recorded during the last 14 EU surveys (1991-2004) in Flemish Cap is presented. Depth distribution of captures, length/age distribution of captures, growth rates, sex-ratios, catch curves, and total biomass estimated by the swept area method are presented.

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 and multiaged population structure with differences in growth and mortality between males and females.

INTRODUCTION

The roughhead grenadier (*Macrourus berglax* Lacépède, 1802) is an abundant and widespread fish species in the north Atlantic and is usually found both on the shelf and on the continental slope (Scott and Scott, 1988; Savvatimsky, 1994). It is predominant in depths ranging from 400 to 1200 m, although they may inhabit depths between 200-2 000 m (Snelgrove and Haedrich, 1985; de Cardenas *et al.*, 1996). It has, however, been found in depths up to 2 700 m (Wheeler, 1969).

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 tons) to 1990 (3 244 tons), since then total catches has been about 4 000 t and increased 7 200 t in 1998 remaining at this level in 1999. The catches decreased to about 4 000 tons in 2003 (NAFO, 2004).

Since 1988 EU has conducted an annual random-stratified bottom trawl survey in Flemish Cap (NAFO Div. 3M) in the 200-720 m depth range. In 2003 and 2004 the survey was extended to depths down to 1 400 m. The objective of this scientific survey is to obtain abundance indices and to study the population structure and biological parameters of the main species in the area. From 2003 onward, the survey was carried out with a new R/V *Vizconde de Heza*, which replaced the former C/V *Cornide de Saavedra*.

Limited information on age structure and growth rate of *M. berglax* is available in scientific literature. Savvatimsky (1971, 1984, 1989, 1994) and Jorgensen (1996) have carried out studies on this species in the NW

Atlantic (NAFO Div. 0, 2GHJ, 3K and 1ABCD, respectively), basing findings on age readings from scales. The age structure and growth parameters of roughhead grenadier have been estimated by Murua (2003) from otolith readings of specimens captured in NAFO Div. 3LMN. Validation of age estimates derived from otolith reading has been presented by Rodríguez-Marín *et al.* (2002). Eliassen (1983) also performed age estimation by otolith reading from roughhead caught in the continental slope of Norway.

This paper presents some biological data and population structure of roughhead grenadier in Flemish Cap during the period 1991-2003. The results are presented taking into account that the survey only covers the shallowest distribution area of roughhead grenadier.

MATERIAL AND METHODS

Data on roughhead grenadier for the 1991-2004 period were collected on the annual random-stratified bottom trawl surveys carried out by the European Union on the area (Casas, 2005). In order to maintain the data series, comparative fishing trials were carried out to develop conversion factors for the species sampled in 2003 and 2004. In total, 130 paired hauls with *Cornide de Saavedra* and *Vizconde de Heza* were done (in which 23 roughhead grenadier appeared) and the conversion factor to transform the Cornide values to Vizconde de Heza equivalents were estimated (Gónzalez-Troncoso, 2005). As the depth coverage was increased in 2003 and 2004, the data presented here refers to survey results of depth <720 meters, i.e. the common depth coverage in all the time series. Data on length distribution by sex is only available from 1993 onwards and age structure data is only available for the 1994-2003 period. Otolith sampling began in 1994, and since then a total of 5 303 otoliths have been read. Annual length-age keys have been applied for each year.

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 9 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 has been done and 80% of agreement has been reached. Differences were ±1 year in otoliths between 2-10 years and 1, 2 years in older than 10 years (Rodríguez-Marín *et al.*, 2002).

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 pre-anal-fin length (AFL) and data are given in 1 cm intervals. Total weight was recorded accurate to the nearest 10 g.

RESULTS AND DISCUSSION

Total biomass of roughhead grenadier estimated by the swept area method by strata is presented in Table 1 and for the whole bank in Fig. 1. Biomass increased from 1989 to 1993, since then the biomass has decreased steadily, with the exception of 1998 year, up to 2000, and in 2001 total biomass increased again. Biomass decreased in 2002 to the level of 1 211 tons and then increased reaching the highest level (3 597 tons) of the time series in 2003. Mean catch per trawl by strata and whole bank data are presented in Table 2. The results indicate that roughhead grenadier occupies the deepest part of the area studied and the abundance and biomass increase with depth, as is evidenced by other authors (de Cardenas *et al.*, 1996; Murua and de Cárdenas, in press).

Table 3 shows length distributions of roughhead grenadier for the 1991-2004 period. Captures are dominated by the 14-20 cm length classes, 50% of the total catch. The average AFL for both sexes is 14.92 cm. This value is smaller than the values found by Savvatimsky (1994) and de Cardenas *et al.* (1996). The former gives an average AFL of 19.8 cm (51.25 cm total length) for Div. 3K, and the latter gives a mean AFL of 21.12 cm (54.39 cm TL) for specimens caught in a long-line survey in Div. 3LMN. These differences are related to the fishing gear employed and depth where fish were caught, because length has a tendency to increase with depth, from the shallowest stratum to the deepest (Cárdenas *et al.*, 1996). It should be noted that the proportion of 2-8 length range has increased considerably to around 39 and 32% during 2003 and 2004 survey respectively; which in turn may be interpreted as a sign of a good 2001 year class recruiting to the population. Moreover, due to this increase the proportion of the 14-20 length range decreased to around 35% in 2003 and 2004 (Table 3).

Annual length frequencies by sex are presented in Fig. 2. 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 26 cm while females are larger reaching 36 cm long. Average AFL for females is also greater than for males. Female's mean AFL for the 1993-2004 period in Flemish Cap was 15.5 cm, while mean AFL for males was 14.6 cm. This sexual difference is consistent with data found in the literature. Savvatimsky (1989) gives an average AFL of 18 cm (47 cm total length) and 21.2 cm (54.6 cm total length) for males and females respectively in 3LKN. Those differences have also been seen in the commercial fleet in 3LN, where females are larger than males (Junquera *et al.*, 2001).

The mean AFL-age key for 1994-2004 are given by sex in Table 4. Table 5 shows age composition by sexes for roughhead grenadier in Flemish Cap in 1993-2004. The oldest male found in the period studied was 19 years old and the oldest female 20 years old. Mean age for females in Flemish Cap in the 1993-2004 period was 7.0 years, while mean age for males was 6.8 years. Savvatimsky (1994) for Div. 0B, 2GH and 3K found similar differences.

Interannual differences in length and age are shown in Fig. 2 and 3. The 1990-1991 cohorts dominated the catches during the 1995-1999. The importance of these annual classes has declined sharply during last years. In 2003 and 2004, more than 20 and 25% of the individuals in 2003 and 2004, respectively, were composed by individuals of 2001 year-class; this 2001 year-class is by far the most abundant year-class either at age 2 or age 3 in the time series.

Female-ratio in the whole study period is 50%. This value 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 explained due to the different area covered by both surveys. As length increases in relation to depth in many species, the 'bigger deeper' distribution (Merrett *et al.*, 1991; Gordon and Bergstad, 1992), the female ratio might increase also in the deeper water areas.

Figures 4 and 5 present sex-ratio by age and by length respectively, for the whole study period. In the sex-ratio, female proportion fluctuated around 40%-50% up to 20 cm in length (the first 10-12 years) and increased to 75% at 22 cm (13 years) and 80% at 24 cm (14 years). Following this length, females made up 100% of the catch. Similar sex-ratio, with males being more abundant in the central part of the population, is described by Savvatimsky (1994) for north-western Atlantic.

The increment in the female-ratio can be due to 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.

Logarithmic regression lines (Fig. 6), fitted to mean length at age by sex, show that males growth rate declines when reaching 9 years old, around 18 cm long, while females do not decline growing until reaching 20 years old, around 34-35 cm. This result was also observed by Savvatimsky (1994), Jorgensen (1996) and Rodríguez-Marín *et al* (2002). Moreover, mean length at age for all year studied is similar for males and females for ages under 9 years, but males grow slower from this length onwards. Mean lengths at age are higher than those obtained by Savvatimsky (1994) for NAFO Div. 0B, 2GH and 3K. Savvatimsky (1994) and Jorgensen (1996) described similar growing pattern using scales for ageing 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 ageing method used 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.*, 2002). Table 6 shows the estimated parameters of the Von Bertalanffy equations (fitting individual length at age by non-linear regression (Marquardt, 1963)) and the equations for logarithmic growth regression curves for all the period studied.

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. Total mortality by sex was calculated from catch curves, fitting regression lines by sex to ages fully recruited to the fishery, using data of eleven years (1994-2004). Both sexes are fully recruited at age 8 and the mortality obtained is different for both sexes: 0.47 for females and 0.60 for males (Fig. 7). These values are different compared to last year figures (0.25 for females and 0.48 for males), however, this could be because last year a plus group of 18+ and 16+ were used for females and males, respectively, in the

estimation which in turn made the decline in larger fish less remarkable. In any case, the different values indicate that there exist differences in mortality between sexes.

Length-weight relationships by sex are shown in Table 7 for all the years studied. The relationship between fish length (AFL) and fish weight was assumed to be adequately expresses by the exponential function. Figure 8 shows the length-weight relationship by sexes in 2004 survey.

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. The complex multy-mode length structure and a slow growth are characteristic of deepwater fishes, including grenadiers (Hureau *et al*., 1979; Casas, 1994; Savvatimsky, 1994). All this results must be taken with care due to the small proportion of the roughhead grenadier distribution area covered by the survey.

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Table 1.- Total biomass of roughhead grenadier estimated by the swept area method by strata during the EU bottom survey (1991-2004); biomass series transformed to Vizconde de Heza equivalents.

Strata	Depth (m)	Biomass estimated by the swept area meted (tons)													
		1991	1992	1993	1994	1995	1996	1997	1998	1999	2000	2001	2002	2003	2004
1 – 6	125-252					8	22							9	10
7	253-360										3				10
8	253-360	1					11	3		7		16	2	13	28
9	253-360	5	28	21	3	21	153	18	40	45	29	29		30	282
10	253-360						6	1		18	68	18			48
11	253-360									3	8	6			3
12	261-540	108	100	413	55	126	46	137	55	191	81	236	154	165	292
13	261-540	18	60	18	32	75	5	18	78	92	50	116	121	123	299
14	261-540	85	139		73	67	270	77	194	135	103	292	124	346	877
15	261-540	64	52	321	82	180	84	69	101	72	103	60	16	87	259
16	541-720	229	432	1333	523	256	397	211	405	150	225	338	272	352	594
17	541-720	180	123		98	129	27	116	204	96	67	370	380	101	244
18	541-720	356	215		756	414	154	224	189	313	219	383	27	877	423
19	541-720	289	429	915	352	282	187	322	424	129	92	216	116	245	228
TOTAL		**1335**	**1577**	**3021**	**1975**	**1558**	**1362**	**1197**	**1691**	**1250**	**1047**	**2079**	**1211**	**2348**	**3597**
Error biomass		264	142	149	250	270	487	169	223	277	169	243	338	196	284
Mean AFL (cm)		16.35	15.82	15.84	16.62	15.25	15.76	16.01	15.61	16.34	16.48	16.55	16.10	12.00	13.32

Table 2.- Mean catch per trawl by strata and whole bank (1991-2004); series transformed to Vizconde de Heza equivalents.

Strata	Area	Depth (m)	Average weight per trawl (Kg.)													
			1991	1992	1993	1994	1995	1996	1997	1998	1999	2000	2001	2002	2003	2004
1 – 6	467	125-252	0.00	0.00	0.00	0.00	0.13	0.58	0.00	0.00	0.00	0.00	0.00	0.00	0.34	0.19
7	108	253-360										0.04				0.16
8	82	253-360	0.02					0.22	0.05		0.14		0.32	0.03	0.26	0.54
9	34	253-360	0.21	1.16	0.88	0.14	0.88	6.39	0.77	1.69	1.90	1.23	1.23		1.25	10.78
10	128	253-360						0.08	0.01		0.24	0.94	0.24			0.56
11	107	253-360									0.04	0.12	0.10			0.04
12	90	261-540	2.12	1.96	8.08	1.07	2.47	0.91	2.68	1.09	3.74	1.58	4.63	3.01	3.23	4.05
13	31	261-540	0.93	3.15	0.97	1.68	3.94	0.27	0.97	4.12	4.83	2.66	6.11	6.38	6.48	11.41
14	72	261-540	1.85	3.02		1.59	1.47	5.88	1.69	4.23	2.95	2.25	6.36	2.69	7.54	16.15
15	85	261-540	1.26	1.03	6.33	1.62	3.54	1.66	1.36	1.99	1.42	2.02	1.18	0.31	1.71	5.03
16	82	541-720	4.75	8.94	27.60	10.82	5.31	8.21	4.37	8.39	3.11	4.66	6.99	5.64	7.29	9.25
17	23	541-720	10.93	7.46		5.98	7.81	1.63	7.05	12.41	5.82	4.09	22.47	23.08	6.14	8.53
18	22	541-720	22.22	13.45		47.28	25.84	9.61	14.03	11.82	19.54	13.66	23.95	1.68	54.81	25.65
19	54	541-720	9.17	13.59	29.02	11.16	8.95	5.94	10.21	13.43	4.08	2.90	6.85	3.68	7.77	5.93
Weighted averaged per trawl (Kg)			**1.66**	**1.96**	**3.76**	**2.46**	**1.94**	**1.69**	**1.49**	**2.10**	**1.56**	**1.31**	**2.58**	**1.50**	**2.92**	**4.47**
S. D.			0.31	0.34	0.61	0.21	0.28	0.34	0.21	0.30	0.42	0.24	0.35	0.22	0.76	0.45
Nº of valid tows			117	117	101	116	121	117	117	119	117	120	120	120	114	124

Table 3.- Roughhead grenadier length distribution and mean AFL (,000) for each year of the 1991-2004 period (transformed series to Vizconde de Heza equivalents).

AFL (cm)/Year	91	92	93	94	95	96	97	98	99	00	01	02	03	04
1		7	3											
2		13											99	21
3	4	16				3	3	48	9	3	65	40	369	294
4	6	57	42		16	26	15	14	8	15	12	16	119	59
5	16	232	200	28	24	127	9	53	15	42	133	118	1220	566
6	26	73	77	22	31	45	36	44	16	35	56	59	881	481
7	69	121	380	53	46	25	87	45	14	31	65	90	437	705
8	25	64	184	154	61	51	86	57	20	34	133	99	506	1576
9	43	45	98	96	126	45	71	194	33	63	71	60	319	495
10	45	46	167	237	325	116	92	173	92	28	57	23	520	493
11	111	63	146	207	289	123	32	121	209	89	98	48	321	420
12	248	69	190	125	521	171	176	157	105	110	139	54	337	631
13	291	128	168	107	267	271	198	220	144	152	168	87	332	584
14	312	334	288	269	128	323	396	495	193	177	399	177	393	635
15	231	374	513	243	176	217	310	563	321	129	404	199	611	592
16	238	312	790	212	253	306	197	462	428	290	430	283	666	697
17	280	219	610	408	294	233	82	314	363	279	367	235	511	746
18	311	221	499	429	348	222	111	171	290	196	468	194	583	696
19	223	147	349	341	310	238	120	158	150	171	336	206	359	519
20	190	199	251	192	201	209	109	117	106	111	269	156	225	376
21	72	106	195	129	108	88	79	106	95	79	158	136	180	266
22	68	77	133	78	53	78	83	115	35	67	70	77	111	202
23	38	71	168	55	12	24	61	37	41	28	60	54	121	143
24	26	33	66	57	19	36	61	64	24	30	65	23	20	115
25		33	35	56	19	16	33	50	29	28	79	27	10	85
26	18	59	54	33	13	23	39	28	0	28	35	18	8	72
27	14	28	21	19	20	16	39	17	7	6	37	28	14	31
28	21	28	40	6	9	6	16	5	11	10	48	6		28
29	14	20	40	36	0	0	11	17	6	5	12	23		10
30	14	41	12	14	6	6	0	13	19	5	34	6		19
31		9		24	4	5	5			5	12			19
32		13		8	5	11	6				6			
33	6												5	9
34	7							5		6		6	8	
35										5				
36		6		8										
Total	**2966**	**3265**	**5718**	**3647**	**3684**	**3060**	**2565**	**3862**	**2784**	**2259**	**4288**	**2550**	**9277**	**11585**
Mean AFL (cm)	**16.35**	**15.82**	**15.84**	**16.62**	**15.25**	**15.76**	**16.01**	**15.61**	**16.34**	**16.48**	**16.55**	**16.10**	**12.00**	**13.32**

Table 4.- Mean Age-Length key (1994-2004).

Males																					
Length / Age	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20	Total
2	1																				1
3	18	3																			21
4	2	14																			16
5		24	5																		29
6		20	14																		34
7		1	26																		27
8		3	28	10																	41
9		1	29	29	3																62
10			8	38	15																61
11			2	27	38	7															74
12			1	6	41	28	8	1													85
13				2	21	46	22														91
14					16	46	33	12	1												108
15					2	29	39	29	6												105
16					3	17	44	41	29	7	1										142
17						9	25	35	33	28	4										134
18						1	10	31	37	34	21	4	3		1						142
19							6	14	29	35	27	17	5	2	1		1				137
20								3	18	25	22	27	11	3							109
21								1	9	7	16	24	8	3	1	4	1				74
22										2	7	6	4	3					1	1	24
23												1	1	3			1				6
24														1						1	2
25																					
26											2										2
Total	21	66	113	112	139	183	187	167	162	138	100	79	32	15	3	4	2	1	1	2	1527

Table 4.- (continued)

Females	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20	21	Total
2																						
3	12	4																				16
4	1	15																				16
5		34	6																			40
6		22	16																			38
7	1	11	40	1																		53
8		2	41	9																		52
9			27	30	4																	61
10			11	45	16	1																73
11			1	33	36	4																74
12				13	37	28	1	1														80
13				2	40	42	9	1	1													95
14					18	44	28	9														99
15					5	34	37	25	4	1												106
16					2	16	40	35	12	3												108
17						8	35	37	23	4												107
18							14	29	34	22	1											100
19							3	23	46	29	11	3										115
20								9	34	36	22	7	1									109
21								4	12	36	23	7	5	1								88
22									4	21	37	21	12	3								98
23									2	4	24	19	12	3	4							68
24									1	6	11	22	20	7	2							69
25										1	7	14	16	15	4	1						58
26										1	2	15	12	5	7	3	1					46
27										1	1	3	10	10	10	1	2		1		1	40
28													5	14	6	5	1					31
29												2	2	4	4	8	1	2				23
30											1		2	5	9	2	5					24
31														1	2	3	4	4	1	1		16
32												1		1	2	4	4	2	1			15
33															1	1	5	2	1			10
34																1	2	2	3	1	1	10
35																1	1	1	5			8
Total	**14**	**88**	**142**	**133**	**158**	**177**	**167**	**173**	**173**	**165**	**140**	**114**	**97**	**69**	**51**	**30**	**26**	**13**	**12**	**2**	**2**	**1946**

Table 5.- Roughhead grenadier age composition (,000) in Flemish Cap 1994-2004.

| | 1994 | | | 1995 | | | 1996 | | | 1997 | | | 1998 | | | 1999 | | |
Age	M	F	Tot	M	F	Tot	M	F	Tot	M	F	Tot	M	F	Tot	M	F	Tot
1	0	0	0	0	0	0	0	0	129	0	0	0	14	6	51	5	0	15
2	0	12	46	16	26	107	25	14	56	11	13	46	36	82	128	0	25	36
3	14	32	136	85	93	209	29	66	110	56	121	186	108	118	227	18	29	49
4	145	122	488	181	235	467	117	86	225	51	102	153	121	116	237	128	82	215
5	114	147	506	353	433	861	158	183	352	74	80	157	90	49	139	111	86	198
6	189	103	570	306	245	592	381	202	586	241	204	451	142	202	346	97	150	247
7	213	96	566	332	156	516	192	155	350	252	355	613	406	314	725	303	142	445
8	148	111	493	267	177	458	219	116	338	63	98	163	523	383	907	358	258	616
9	98	124	379	117	139	263	144	69	216	73	85	158	115	135	250	248	174	422
10	32	103	181	29	80	113	163	99	264	56	42	98	131	95	226	110	87	197
11	0	88	109	6	28	35	179	75	254	56	95	151	81	54	135	69	41	109
12	32	39	82	0	23	23	53	40	93	72	93	164	73	109	182	36	44	79
13	0	36	40	0	20	20	12	26	37	39	85	124	44	108	152	19	36	56
14	0	15	15	0	5	5	0	33	33	5	37	42	25	51	76	26	35	61
15	8	17	27	0	15	15	0	4	4	0	42	42	0	48	48	4	29	33
16	0	8	8	0	0	0	0	11	11	0	8	8	0	22	22	0	3	3
17	0	0	0	0	0	0	0	0	0	0	6	6	0	12	12	0	0	0
18	0	0	0	0	0	0	0	0	0	0	5	5	0	0	0	0	0	0
19	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
20	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Total	993	1054	3647	1693	1674	3684	1672	1179	3060	1051	1469	2565	1908	1903	3862	1531	1221	2784
Mean Age	6.8	7.8	6.9	6.2	6.3	6.1	7.4	7.3	7.1	7.4	7.9	7.6	7.5	8.0	7.6	7.8	8.0	7.8

| | 2000 | | | 2001 | | | 2002 | | | 2003 | | | 2004 | | | All | | |
Age	M	F	Tot	M	F	Tot	M	F	Tot	M	F	Tot	M	F	Tot	M	F	Tot
1	0	0	3	29	6	63	17	3	39	86	31	467	69	26	215	219	71	983
2	18	30	77	99	90	208	84	71	189	953	1038	2140	181	205	465	1423	1606	3498
3	59	49	108	94	172	271	96	124	220	482	576	1077	1322	1798	3119	2362	3176	5713
4	36	14	50	42	77	120	14	43	57	305	367	672	406	604	1009	1546	1847	3693
5	151	132	283	124	159	283	62	46	108	281	336	617	379	498	877	1898	2150	4381
6	135	142	277	225	218	445	75	114	189	380	254	635	670	432	1105	2842	2267	5442
7	97	121	218	261	273	540	142	148	290	483	359	843	495	308	810	3175	2428	5915
8	108	123	231	280	217	505	165	119	283	620	281	901	606	346	956	3356	2228	5850
9	226	114	339	285	220	509	131	110	241	309	226	535	498	461	962	2244	1857	4275
10	183	155	338	294	369	666	118	148	266	255	220	475	519	374	896	1890	1771	3719
11	18	55	72	63	167	231	120	84	204	227	245	472	258	206	465	1079	1136	2238
12	33	62	95	54	77	131	99	145	243	115	120	236	200	190	391	766	943	1721
13	17	40	57	7	74	81	30	45	75	52	36	88	22	125	147	242	631	877
14	22	33	55	6	98	104	10	53	63	18	12	30	23	66	90	137	439	575
15	6	16	22	7	48	55	8	12	19	0	17	17	0	18	18	33	266	301
16	12	5	17	0	30	30	20	18	39	17	0	17	0	21	21	50	126	175
17	0	0	0	0	29	29	0	9	9	25	14	39	0	23	23	25	92	117
18	0	11	11	6	6	12	0	10	10	0	0	0	0	6	6	6	39	45
19	0	5	5	0	0	0	0	0	0	10	0	10	0	6	6	10	11	20
20	0	0	0	0	6	6	0	5	5	0	8	8	0	3	3	0	21	21
Total	1120	1107	2259	1876	2335	4288	1191	1306	2550	4617	4141	9277	5648	5715	11585	23300	23105	49561
Mean Age	7.8	8.2	7.9	7.4	8.3	7.8	7.9	8.4	8.0	6.0	5.5	5.5	6.3	6.0	6.1	6.8	7.0	6.7

Table 6a.- Logarithmic growth regression curves, fitted to mean length at age data, for male and female roughhead grenadier from EU Survey (1993-2004). * Data from 1993-2002: original Cornide de Saavedra data without transformation. 2003-2004 original Vizconde de Heza data.

| Year	MALES Regression	r^2	FEMALES Regression	r^2
1993*	AFL (cm) = 8.8156 Ln (A) - 1.8999	0.986	AFL (cm) = 12.999 * Ln (A) - 8.6786	0.979
1994*	AFL (cm) = 13.034 Ln (A) - 8.1095	0.924	AFL (cm) = 12.394 * Ln (A) - 5.4082	0.941
1995*	AFL (cm) = 8.8152 Ln (A) - 0.2014	0.951	AFL (cm) = 12.268 * Ln (A) - 5.1506	0.950
1996*	AFL (cm) = 8.9440 Ln (A) - 1.6428	0.991	AFL (cm) = 12.241 * Ln (A) - 6.1702	0.955
1997*	AFL (cm) = 8.7078 Ln (A) - 1.6519	0.992	AFL (cm) = 12.118 * Ln (A) - 6.4209	0.955
1998*	AFL (cm) = 7.1799 Ln (A) + 1.3319	0.968	AFL (cm) = 9.5935 * Ln (A) - 1.4863	0.918
1999*	AFL (cm) = 7.4754 Ln (A) + 1.1001	0.962	AFL (cm) = 9.6124 * Ln (A) - 1.1061	0.924
2000*	AFL (cm) = 7.835 * Ln (A) – 0.0057	0.990	AFL (cm) = 12.923 * Ln (A) – 7.6958	0.933
2001*	AFL (cm) = 7.266*Ln (A) + 1.4463	0.975	AFL (cm) = 10.291 * Ln (A) – 1.9577	0.942
2002*	AFL (cm) = 7.079 *Ln (A) + 1.2645	0.973	AFL (cm) = 10.551 * Ln (A) – 2.5121	0.913
2003	AFL (cm) = 7.208 *Ln (A) + 1.3007	0.971	AFL (cm) = 9.443 * Ln (A) – 1.1958	0.904
2004	AFL (cm) = 7.677 *Ln (A) + 0.7459	0.964	AFL (cm) = 10.707 * Ln (A) – 2.3919	0.923

Table 6b.- Parameters of the Von Bertalanffy growth curves, fitted to individual length at age using non-linear regression, by sex for the EU Survey 1993-2004 (Data from Flemish Cap survey < 720).

Year	MALES t_o	L_∞	K	FEMALES t_o	L_∞	K
1993	1.074	21.9	0.197	0.634	46.4	0.060
1994	1.768	22.8	0.254	-0.054	57.6	0.048
1995	-1.576	37.1	0.073	-0.681	51.9	0.053
1996	0.490	23.5	0.172	0.346	77.0	0.032
1997	1.425	22.9	0.176	0.533	51.2	0.050
1998	0.270	27.5	0.109	0.460	46.3	0.056
1999	-0.132	27.9	0.104	0.405	57.8	0.044
2000	0.199	25.8	0.128	-0.079	68.7	0.034
2001	0.950	23.9	0.159	0.350	52.3	0.051
2002	0.072	25.0	0.128	-0.089	63.8	0.054
2003	0.050	26.0	0.120	-0.357	42.4	0.061
2004	0.186	30.0	0.103	-0.054	58.3	0.045

Table 7.- Length weight relationship for roughhead grenadier males and females from EU Survey (1993-2004).

	MALES			FEMALES	
Year	Regression	r^2		Regression	r^2
1993	W (g) = 0.0793 * AFL (cm)$^{3.0883}$	0.9734		W (g) = 0.1016 * AFL (cm)$^{2.9934}$	0.9895
1994	W (g) = 0.1489 * AFL (cm)$^{2.8437}$	0.9694		W (g) = 0.1015 * AFL (cm)$^{2.9935}$	0.9895
1995	W (g) = 0.1131 * AFL (cm)$^{2.9409}$	0.9818		W (g) = 0.1139 * AFL (cm)$^{2.9344}$	0.9859
1996	W (g) = 0.1244 * AFL (cm)$^{2.8889}$	0.9802		W (g) = 0.1367 * AFL (cm)$^{2.8536}$	0.9851
1997	W (g) = 0.1209 * AFL (cm)$^{2.8840}$	0.9812		W (g) = 0.1202 * AFL (cm)$^{2.8898}$	0.9923
1998	W (g) = 0.1338 * AFL (cm)$^{2.8621}$	0.9669		W (g) = 0.1199 * AFL (cm)$^{2.9015}$	0.9866
1999	W (g) = 0.1290 * AFL (cm)$^{2.8670}$	0.9718		W (g) = 0.1174 * AFL (cm)$^{2.8950}$	0.9866
2000	W (g) = 0.1423 * AFL (cm)$^{2.8148}$	0.9776		W (g) = 0.1708 * AFL (cm)$^{2.7537}$	0.9744
2001	W (g) = 0.2747 * AFL (cm)$^{2.5821}$	0.9637		W (g) = 0.1922 * AFL (cm)$^{2.716}$	0.9859
2002	W (g) = 0,143 * AFL (cm)$^{2.8218}$	0.9878		W (g) = 0,119 * AFL (cm)$^{2.884}$	0.9921
2003	W (g) = 0,103 * AFL (cm)$^{2.9376}$	0.9797		W (g) = 0,101 * AFL (cm)$^{2.9391}$	0.9911
2004	W (g) = 0,109 * AFL (cm)$^{2.9125}$	0.9879		W (g) = 0,0096 * AFL (cm)$^{2.9512}$	0.9924

Roughhead grenadier biomass (tons) during 1988-2004
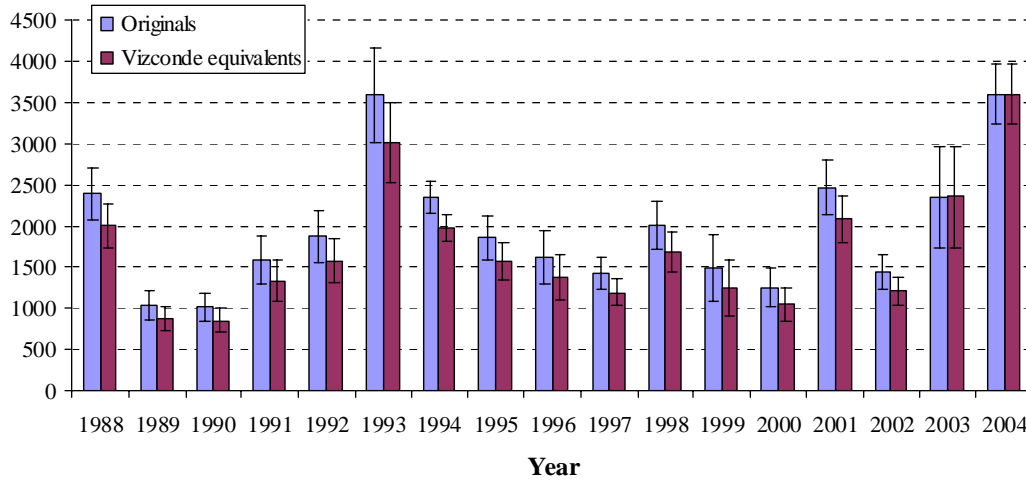
Fig. 1.- Total biomass estimated by the swept area method during the EU Flemish Cap bottom trawl survey (1988-2004).
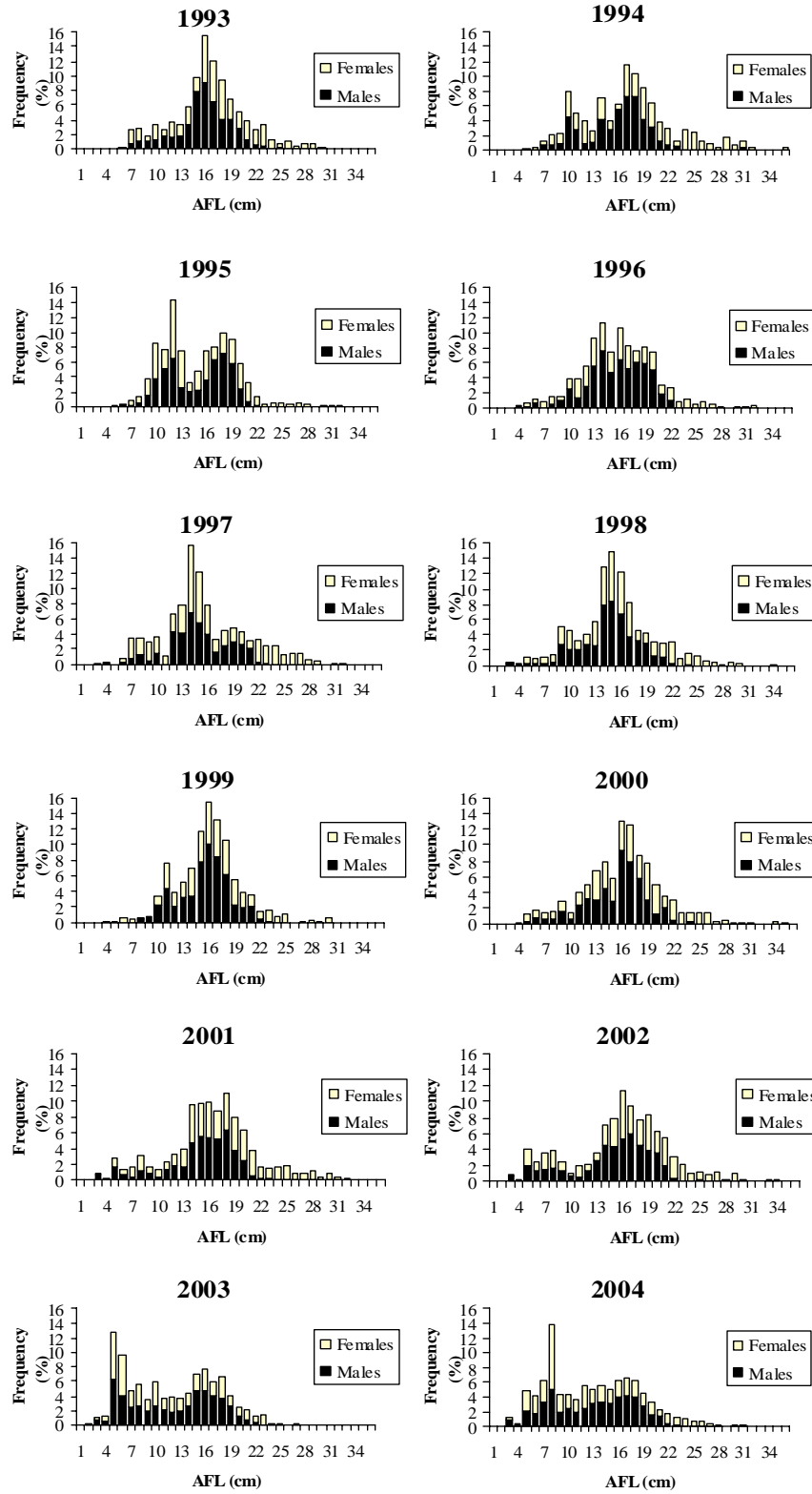
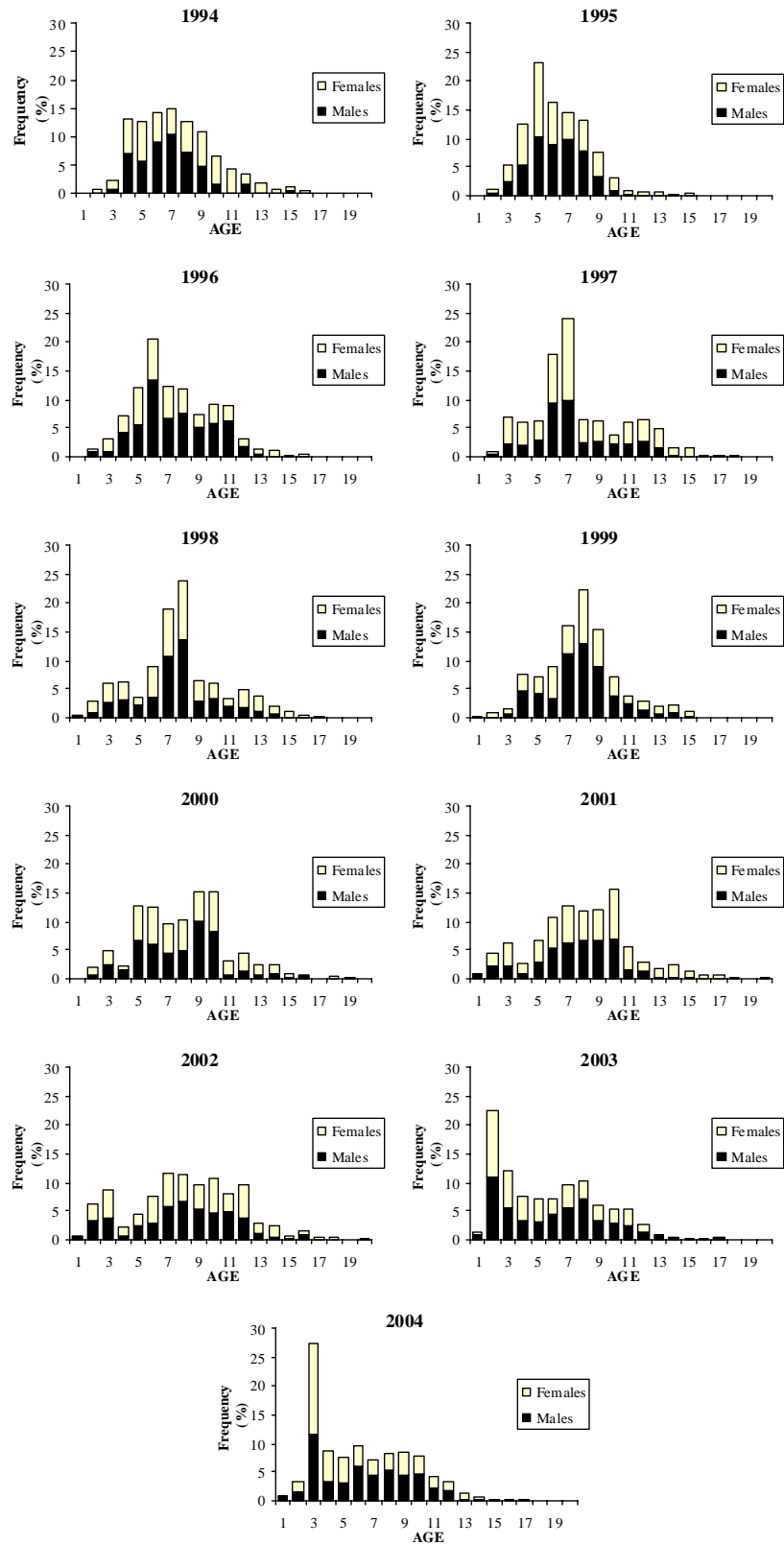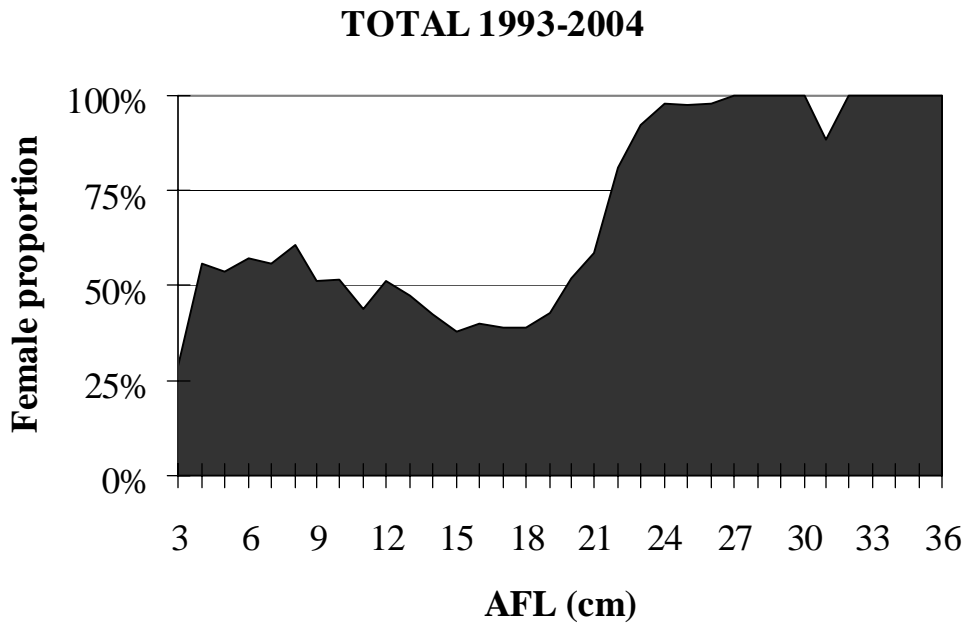**Fig. 2.-** Annual length distribution by sex in Flemish Cap 1993-2004.

Fig. 3.- Annual age composition by sex in Flemish Cap 1994-2004.

TOTAL 1994-2004

Fig. 4.- Female ratio by age in Flemish Cap 1994-2004.

TOTAL 1993-2004

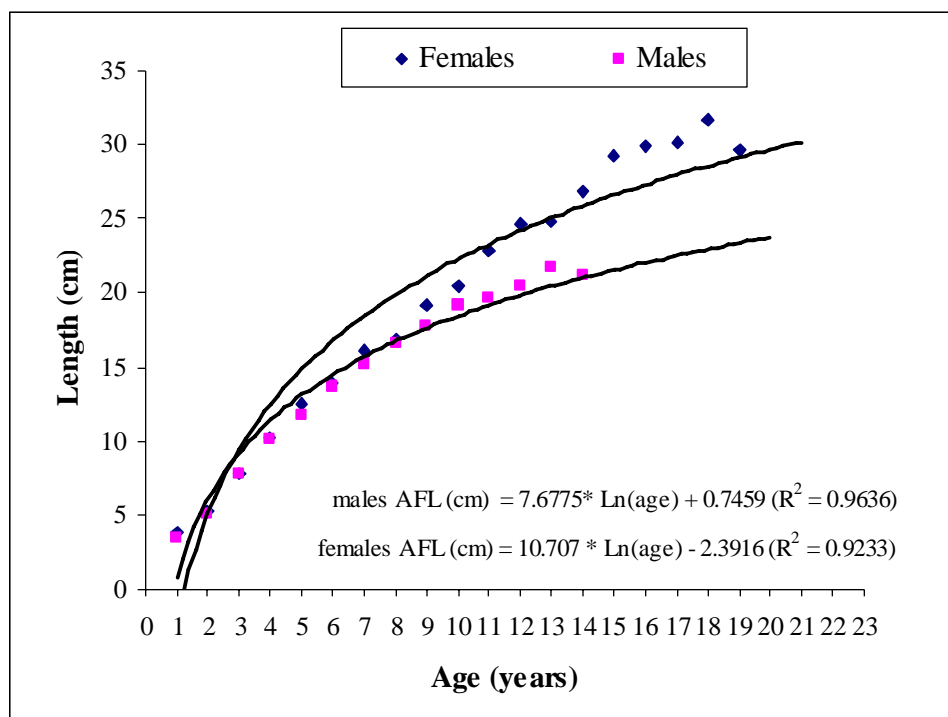**Fig. 5.-** Female ratio by length in Flemish Cap 1993-2004.

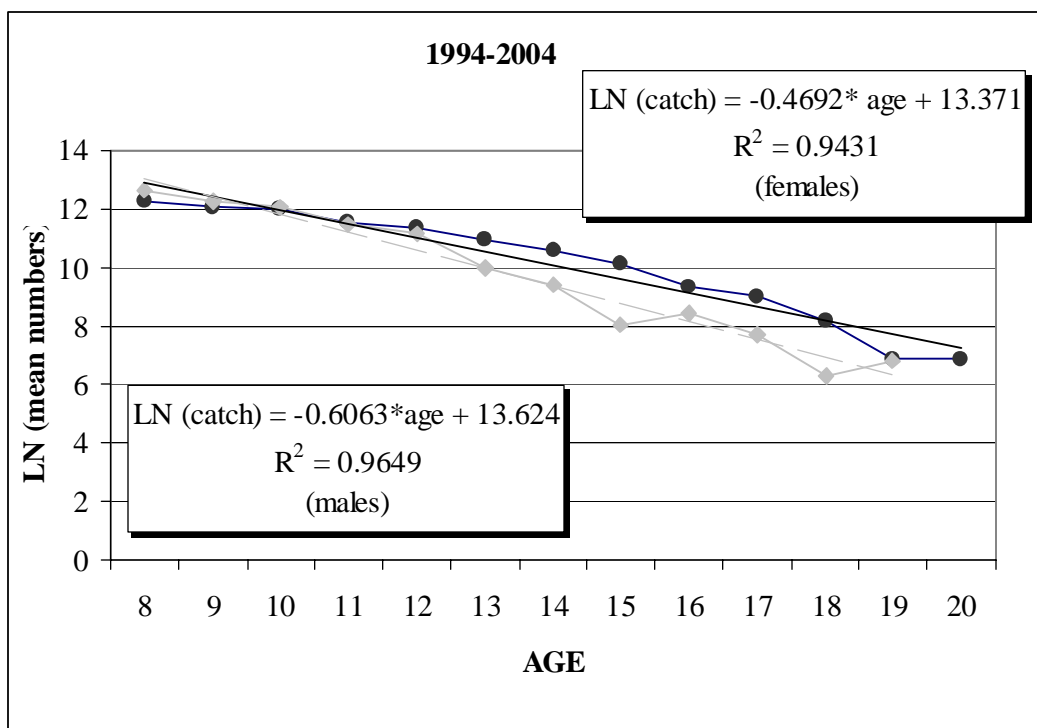**Fig. 6.-** Logarithmic growth curve by sexes in Flemish Cap 2004.

The figure shows length (cm) versus age (years) for Females and Males with equations:

$$\text{males AFL (cm)} = 7.6775 * \text{Ln(age)} + 0.7459 \quad (R^2 = 0.9636)$$

$$\text{females AFL (cm)} = 10.707 * \text{Ln(age)} - 2.3916 \quad (R^2 = 0.9233)$$

1994-2004

$$\text{LN (catch)} = -0.4692 * \text{age} + 13.371$$
$$R^2 = 0.9431$$
(females)

$$\text{LN (catch)} = -0.6063 * \text{age} + 13.624$$
$$R^2 = 0.9649$$
(males)

Fig. 7.- Catch curves by sex for roughhead grenadier in Flemish Cap 1994-2004.

a

W (g) = 0,1093 * AFL (cm) 2,9125
R2 = 0,9879
Males

b

W (g) = 0,0096 * AFL (cm) 2,9512
R2 = 0,9924
Females
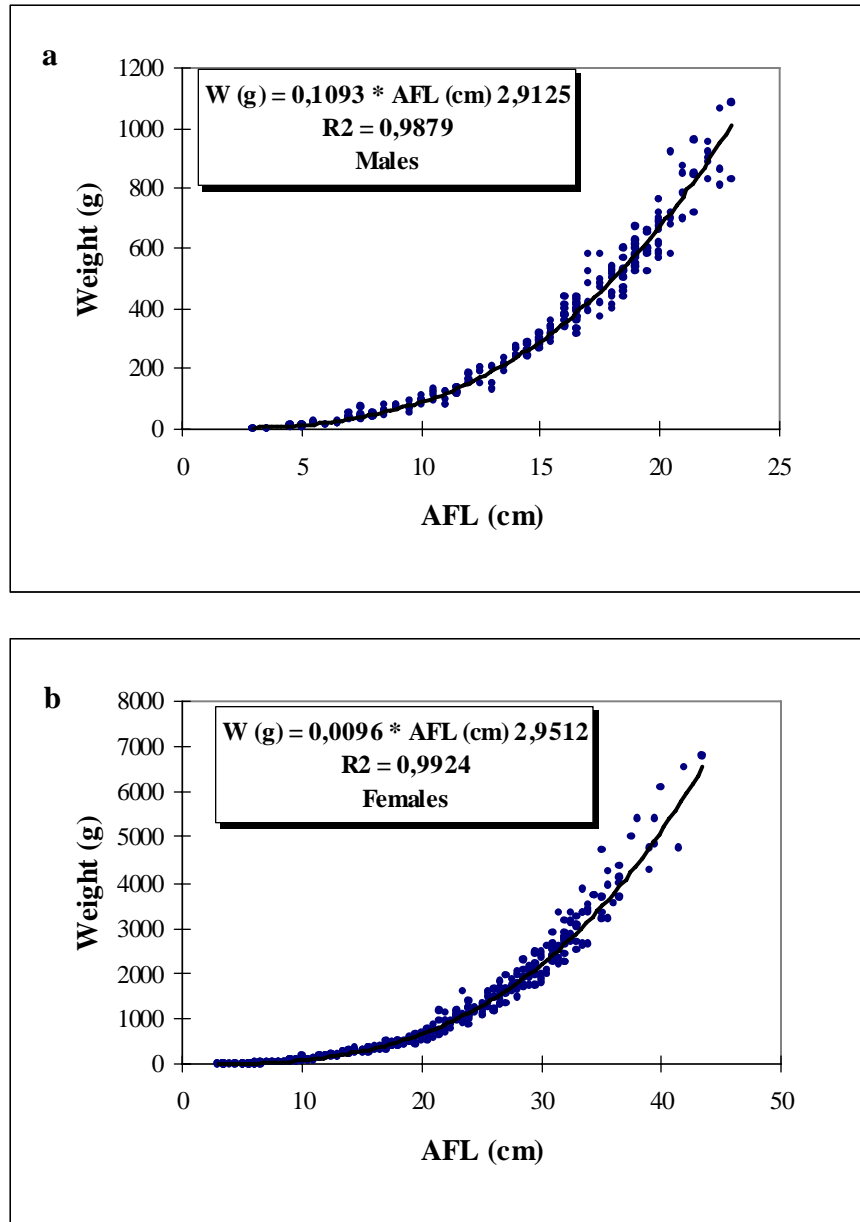
Fig. 8.- Length weight relationship for (a) males and (b) females of roughhead grenadier in 2004.