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Atlantic cod predation on redfish in Flemish Cap

by

González Iglesias, C.[1], González–Costas, F and González–Troncoso, D.

Instituto Español de Oceanografía
P. O. Box 1552. Vigo, Spain
[1]conchi.gonzalez@vi.ieo.es

Abstract

The aim of this study is to estimate the predation on redfish by Atlantic cod in Flemish Cap in the period 2000-2010 and the impact of the cod stock recovery in recent years on the prey stock. Atlantic cod samples of stomach contents were taken in the Flemish Cap survey (NAFO Div. 3M). The analysis was done jointly from all individuals, undifferentiated sexes. They were established four size groups of Atlantic cod with a different predation rate on redfish: less than 30 cm, 30-59 cm, 60-79 cm and ≥80 cm. Results show a clear increasing trend in the daily consumption of redfish by cod since 2005. Cod less than 30 cm (one year old) does not consume redfish. Cod with lengths more than 30 cm presents an increasing trend in the quantity of the redfish preyed in the analyzed period. This trend is more evident in the cod more than 60 cm, ages older than 5 years old. Redfish more than 27 cm (older than 8 years old) does not appear in the cod diet. Redfish estimated biomass consumed by total cod biomass is higher than redfish biomass estimated in the last approved assessment disappeared by natural mortality in the period 2000-2005.

Introduction

In the predation estimation the feeding behavior of the predator should be taken into account. Atlantic cod (*Gadus morhua*) shows a significant feeding intensity variation along the 24 hours with slight geographical variations in the behavior depending on the dominant prey. Despite this, cod would have two peaks of maximum consumption, during the morning and evening; these peaks were clearer when the main component of the diet showed different behavior over 24 hours, as in the case of sand eel (*Ammodytes dubius*) (Adlerstein and Welleman, 2000).

It has also been indicated the impact of abundance changes of the main prey in the cod diet (the drop in the abundance of capelin, *Mallotus villosus*, and the consequent change to other prey; the predominance sand eel or capelin, etc.). These aspects cause changes in feeding intensity and therefore in the daily ration (Orlova and Chumakov, 1993). These authors estimated a daily ration of Newfoundland cod of 1-2% at the beginning of 60´s, mainly eating sand eel, and 2.8-3.1% when years later (mid 60´s) the capelin predominated in the diet; the daily ration in the Barents Sea cod was 2-3% during the same periods and feeding mostly capelin.

Other estimates of the daily ration that could be closer to the Flemish Cap cod are in the compilation made by Livingston and Goiney (1984): 1.3-3.1% in Norwegian sea cod from 23 to 40 cm at 4-5ºC and mainly feeding fish; 1.1-2.8% individuals of 18-94 cm at 6-12ºC in the North Sea and Faroes; and 1.0-2.5% in the Georges Bank cod feeding of fish and crustaceans.

It is known that different methods of estimating the feeding rate (based on the rate of gastric evacuation or bioenergetic models) give different results, in which besides the model, both the predator age/length and temperature are affecting (consumption increased as well as both increased). In the cod case, differences among the models tend to decrease as increasing the size/age of the predator (Hansson *et al*., 1996).

Consumption estimation by predation is an important factor in stock under fishery when it has an important trophic role for other species. This happens with redfish (Sebastes) distributed in Flemish Cap, which is an important component of food for cod; further given the high feeding intensity of this predator. Characteristics of food composition and biomass at age of predator should be considered.

The aim of this study is to estimate the predation by Atlantic cod on redfish in Flemish Cap in the period 2000-2010 and the impact of the cod stock recovery in recent years on the prey stock.

Materials and Methods

Atlantic cod (*Gadus morhua*) samples of stomach contents were taken in the Flemish Cap survey (NAFO Div. 3M) throughout the period 2000-2010. This survey has been carried out in summer since 1988 (Casas and González-Troncoso, 2011). Table 1 shows the sampled individuals (3898 individuals), indicating the length range (total length to the nearest lower cm) and the sampled depth range. This table also shows the number of Atlantic cod individuals with stomach content (3675 individuals) and the number of cod individuals with redfish (*Sebastes sp*) presence in stomach content (450 individuals).

Samples were gathered through a stratified by sex and predator length random sampling. Cod individuals were grouped by size ranges of 10 cm (0-9, 10-19, 20-29, 30-39 cm, etc), sampling 50 females and 50 males by length range and year. The volume of the stomach content was measure using a trophometer (Olaso, 1990), and the percentage of each prey in the total volume were collected. Prey length was also measured when digestion stage permitted it.

Two indices were used to analyse the feeding activity:

- Feeding Intensity Index (FI): percentage of individuals with stomach content.

$$FI = \frac{n}{N} 100$$

where n is the number of individuals with stomach content and N is the total number of individuals sampled.

- Mean Weight Fullness Index (MWFI): percentage of stomach content weight in terms of the predator weight.

$$MWFI = \frac{\sum \frac{W_{sc}}{W_p} 100}{n}$$

where W_{sc} is the stomach content wet weight of the prey p, and W_p is the wet weight of predator p.

Redfish consumption was measured also with both indices: $FI_{redfish}$ and $MWFI_{redfish}$. The first indicates the percentage of individuals of Atlantic cod that eat redfish and the second index quantifies the mean amount (g) of redfish consumed per 100 g of wet weight of predator.

The approach to estimate the predation on the redfish by the Atlantic cod was:

1) Calculate the percentage of this prey ($MWFI_{redfish}$) regarding the total consumption (MWFI).
2) We have not own cod daily ration information, so we use the value indicated in the review of Livingston and Goiney (1984) obtained by Braaten and Gokstad (1980) with a mean value of 1.9. The mean value is more suitable to the following considerations:
   - Cod eats redfish throughout the year but diminishes the feeding intensity in winter (Albikovskaya and Gerasimova, 1993); however we assume a constant redfish mortality rate by predation throughout the year.
   - Daily ration varies with size; nevertheless we apply the same daily ration to all individuals.

3) Knowing that the daily ration is the daily food amount (g) that an individual needs for every 100 g of body weight, we assume that the percentage of $MWFI_{redfish}$ regarding the MWFI at the sampling time is the same as the predator eats of redfish in the daily ration. It was assumed that this survey ratio, obtained in summer, is constant through the year.

Results

Feeding Intensity of Atlantic cod and percentage of feeding on redfish ($FI_{redfish}$). Figure 1 shows the cod feeding intensity (FI) and the redfish feeding intensity ($FI_{redfish}$). Atlantic cod is a species with high feeding intensity, similar in both sexes, 94.5% y 94.1% in males and females respectively in the analysed period. From individuals with food, 9.3% of males and 13.5% of females ate redfish. The number of Atlantic cod feeding on redfish increased along the period 2000-2010 with a maximum in 2006 ($FI_{redfish}$ = 15.6%).

Predator and prey length relationship. The cases observed in which the size of redfish was measured (only 68 measurements) are not representative of predation on this prey, but it can be concluded that sizes with more measurements would be most abundant in the cod diet. Figure 2 presents the measured redfish in relation with the predator size. All redfish measured have less than 27 cm which would correspond with individuals less than 9 years old (Ávila de Melo *et al*., 2011). There is a slight trend of increasing prey size as Atlantic cod grows ($R^2 = 0.21$; d.f. = 66; $p<0.05$), and largest redfish (≥ 24.4 cm and >6 years) was eaten by large Atlantic cod (>80 cm approximately).

Consumption of redfish ($MWFI_{redfish}$). The mean redfish consumption in Atlantic cod females was 0.25 g per 100 g of predator and 0.18 g in males (Table 2). However, when comparing the same length range of males and females no significant differences in redfish consumption between both were found. Therefore, the analysis was done jointly from all individuals, undifferentiated sexes.

The amount of food eaten by Atlantic cod shows fluctuations with a decreasing trend in the last years. However, the opposite occurs with the redfish consumed, being low and quite stable in 2000-2005 and increased notably from 2006 (Figure 3).

Atlantic cod <30 cm does not eat redfish. Most predation is carried out by cod individuals from 60 to 100 cm and reaches a maximum in those around 80 cm (Table 2 and Figure 4). The amount of this prey consumed by individuals of 30-39 cm and 40-49 cm did not show significant differences, as well as among those size groups > 80 cm. Based on these results and on the observed amount of redfish preyed by the different size fractions (of 10 cm) of Atlantic cod, we establish the following size groups of Atlantic cod with a different predation rate on redfish: 30-59 cm, 60-79 cm and ≥80 cm (Figures 4 and 5). These groups correspond to the following Atlantic cod age classes: ages 2-4, ages 5-6 and ages 7+, whereas Atlantic cod <30 cm would have 1 year (González-Troncoso and Vázquez, 2011).

Daily redfish consumption regarding the total feed. The percentage of redfish consumption increased since 2006 in the three size/age groups of Atlantic cod noted above (Table 3). Based on mean daily ration of 1.9 (g of food per 100 g of predator per day), the same ratio indicated above (Table 3) corresponds to redfish in relation to the daily ration (Figure 6), and it would be the daily consumption of this prey (Table 4). There is a clear increase in the daily consumption of redfish by cod from 2005. This change occurs clearer in the cod sizes more than 60 cm (Table 4).

Estimation of daily and annual redfish consumption by Atltantic cod population. Table 5 shows the estimated biomass of Atlantic cod at different ages based on the 2011 assessment results (González-Troncoso and Vázquez, 2011). These results are at the begining of the year and were transformed at middle of the year. The mean year biomass at age was calculate as the addition of the initial and final year biomass divided by two. To estimate the daily redfish consumption by cod (Table 5) the mean year biomass at age was applied to $MWFI_{redfish}$ (g of redfish per 100 g of cod per day) and after the daily consumption of redfish raised to the annual assuming constant rate.

In the period 2000-2010 the highest consumption of redfish throughout the period was carried out by Atlantic cod of age 8+, as more than 57% of the predated redfish biomass were predate by the 8+ group. To point it out that this group is estimated with more uncertanty in the assessment. Figure 7 presents year redfish consmption by cod till age 7 and by total biomass (1-8+). It can be appreciated that in the 1-8+ there is an increasing trend with three different levels: 2000-2001 with around 1 000 tons/year, 2002-2004 with 5 000 tons/year and 2005-2008 with 10 000 tons/year. In 2010 a huge increase occurs reaching an estimated value of 32 530 tons derived mainly from the increase of 8+ Atlantic cod biomass. For the 1-7 biomass there are only two different levels: 2000-2005 around 1,000 tons/year and 2006-2010 around 10,000 tons/year.

Based on last approved assessment results for redfish Div. 3M (*Avila de Melo et al, 2011*) the redfish biomass ages 4 till 8 that disappeared by natural mortality was calculated. Figure 8 shows the biomass consumed by cod ages 1-7 and 1-8+ estimated by $MWFI_{redfish}$ and the redfish biomass ages 4 till 8 disappeared by natural mortality (M) estimated based on the assessment results. The values of the biomass consumed by cod till 8+ seems to by higher than the values expected by the natural mortality in the 2000-2005 period and in 2010. The biomass consumed by cod between ages 1-7 are less than the natural mortality level in the hole period except for the year 2000. The ratio of redfish preyed by cod 1-7 and the redfish biomass disappeared by the effect of M ranges between 28% and 68%.

Discussion

In Flemish Cap during summer cod less than 30 cm (age 1) does not eat redfish. Cod begins to prey redfish in age 2 and remarkably increases its consumption from age 5-6, which reflects a change in their feeding habits, feature unchanged from the pattern shown decades ago (Paz *et al*., 1989; Paz *et al*., 1993). Lilly (1985) observed that cod less than 27 cm scarcely ate this prey during the winter and that the main eater fraction was individuals from 27 to 100 cm, with a maximum in those from 54 to 80 cm. Albikovskaya and Gerasimova (1993) indicated similar results. Paz *et al*. (1993) identified three trophic phases corresponding to ages <3, 3-5 and 6-10, which would involve a different diet and therefore they would have different rate of predation on redfish. In the present study four phases were defined: age 1 (<30 cm), ages 2-4 (30-59 cm), ages 5-6 (60-79 cm) and ages 8+ (≥80cm).

Results indicate a positive trend between the predator size and the preyed redfish size, although cod tends to prey mostly on juvenile classes. Both aspects would be consistent with previous studies on Flemish Cap, in which the cod preyed juvenile redfish from 1 to 3 year old and only larger specimens of cod preyed large redfish, although they eat this prey in less frequency of occurrence and percentage regarding to number of redfish foods, but they eat them in greater proportion in relation to prey weight (Lilly, 1985, Paz *et al*. 1989).

The redfish is a main prey for cod throughout the year in Flemish Cap (Albikovskaya and Gerasimova, 1993). The prey consumption observed in summer was 0.22 (MWFI) versus the value of 0.27 to 0.71 in winter (measured with the TFI index, which is the ratio of prey weight in regards to predator size) indicated by Lilly (1985). Due to the high intensity and the food quantity consumed, a considerable redfish predation was caused. Therefore, redfish preyed is dependent of the different age class abundance of the predator. An increased redfish predation estimated in Flemish Cap following the remarkable cod stock recovery is reflected, even more for older individuals (González-Troncoso and Vázquez, 2011).

The different methods for estimating consumption present great differences in order to compare them, as reflected the study of Hansson *et al*. (1996) with North Sea cod. Regarding the redfish mortality caused by the cod predation in Flemish Cap, Albikovskaya and Gerasimova (1993) estimated the daily consumption in the period 1981 to 1984 as 121, 26, 104 and 65 tons in each year, corresponding to an annual consumption from 33 050 tons in 1981 to 17 723 tons in 1984 which represents 92% and 107% of cod stock biomass respectively. The estimated daily intake in our study ranged from 7 to 3 tons in 2000 and 2001 respectively to 89 tons in the year 2010. These values would cause an annual consumption of 1 088 tons in 2001 and 1 051 tons in 2008 (94% and 45% of cod stock biomass at the beginning of the year) reaching 32 530 tons in 2010 (68% of cod stock biomass). In the latter year consumption would be close to the estimated for 1981 by Albikovskaya and Gerasimova.

It must be taken into account that this percentage is higher when the age group with greatest consumption (usually age 8+) represents a high proportion of the total biomass, and the percentage regarding cod stock biomass decreases when there are abundant age classes eating less redfish. In fact, the amount of food redfish would be 187% regarding to cod biomass in 2005 and 68% in 2010 (Table 5).

It was assumed a daily ration of 1.9 despite of it geographic, seasonal and size changes and annual consumption must be analyzed together with the population abundance of the different age fractions.

Conclusions

Cod less than 30 cm (one year old) does not consume redfish. Cod with lengths more than 30 cm presents an increasing trend in the quantity of the redfish prey in the analyzed period. This trend is more evident in the cod greater than 60 cm, ages older than 5 years old.

The redfish quantity consumed by cod in the analyzed period presents a clear increase since 2005 due to the rise of the redfish consumed by each cod and to the increase of the cod biomass.

Redfish more than 27 cm (older than 8 years old) does not appear in the cod diet.

Redfish estimated biomass consumed by total cod biomass is higher than redfish biomass estimated in the last approved assessment disappeared by the natural mortality in the period 2000-2005. This could be because of the big effect of the cod plus group in the estimations.

Redfish estimated biomass consumed by cod biomass (ages 1-7) is less than the redfish biomass disappeared by the natural mortality estimated in the last approved assessment for the whole period except 2000.

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Table 1. Characteristics of Atlantic cod sampled in the bottom trawl survey on Flemish Cap (NAFO Div. 3M), 2000-2010.

Year	Month	Indivs. sampled			Length range (cm)				Depth (m)		Indivs. with stomach content			Indivs. with *Sebastes* in the stomach content		
					Males		Females									
		Males	Fem.	Total	Min.	Max.	Min.	Max.	Min.	Max.	Males	Fem.	Total	Males	Females	Total
2000	July	107	127	234	15	111	18	113	135	330	107	127	234	5	14	19
2001	July	161	207	368	17	80	16	106	132	343	155	205	360	9	12	21
2002	July	110	133	243	32	102	30	92	130	332	109	133	242	7	19	26
2003	June	66	91	157	15	94	17	92	130	449	58	79	137	3	11	14
2004	Jun/Au.	183	233	416	32	97	27	99	136	306	183	230	413	10	28	38
2005	Jul/Au.	167	216	383	15	106	15	91	132	256	154	203	357	7	26	33
2006	July	345	341	686	15	98	15	116	134	439	311	315	626	41	66	107
2008	Jun/Jul	397	434	831	14	106	13	108	131	431	387	400	787	53	52	105
2010	Jun/Jul	261	319	580	15	110	15	117	132	484	233	286	519	32	55	87
Total		1797	2101	3898	14	111	13	117	126	484	1697	1978	3675	167	283	450

Table 2. Mean $MWFI_{redfish}$ preyed by Atlantic cod in Flemish Cap (NAFO Div. 3M, 2000-2010).

Size range	Males			Females		
(cm)	$MWFI_{redfish}$	sd	No.	$MWFI_{redfish}$	sd	No.
10-19	0.000	0.00	192	0.000	0.00	173
20-29	0.000	0.00	251	0.000	0.00	259
30-39	0.007	0.12	306	0.004	0.07	330
40-49	0.026	0.29	318	0.007	0.07	291
50-59	0.032	0.25	232	0.068	0.46	286
60-69	0.216	0.70	244	0.259	0.85	270
70-79	0.692	1.63	132	0.432	1.27	231
80-89	1.295	2.35	82	1.251	2.00	156
90-99	1.370	1.36	32	1.298	1.71	69
100-109	1.265	1.10	6	0.766	1.03	26
≥110	0.015	0.02	2	2.281	3.33	10
Total	0.178	0.83	1797	0.247	0.96	2101

Table 3. Redfish consumption ($MWFI_{redfish}$) observed in the sampling (summer, Div. 3M) and their percentage regarding the total food.

Size range of Atlantic cod		2000	2001	2002	2003	2004	2005	2006	2008	2010
30-59 cm	Mean $MWFI_{redfish}$	0.01	0.01	0.01	0.06	0.03	0.01	0.05	0.02	0.03
	% $MWFI_{redfish}$ eaten relative to $MWFI_{Total}$	0.4%	0.7%	0.3%	5.4	1.3%	0.4%	4.2%	1.0%	1.4%
60-79 cm	Mean $MWFI_{redfish}$	0.10	0.37	0.50	0.11	0.17	0.36	0.73	0.39	0.13
	% $MWFI_{redfish}$ eaten relative to $MWFI_{Total}$	4.7%	19.5%	22.7%	14.8%	7.2%	17.0%	38.5%	35.1%	6.1%
≥80 cm	Mean $MWFI_{redfish}$	0.67	0.09	1.15	0.51	0.84	1.38	2.07	1.70	0.84
	% $MWFI_{redfish}$ eaten relative to $MWFI_{Total}$	19.2%	6.8%	36.8%	39.5%	29.1%	61.9%	71.4%	69.0%	73.4%

Table 4. Daily ration of Atlantic cod based in redfish (g of food per 100 g of predator per day).

Size range of Atlantic cod	2000	2001	2002	2003	2004	2005	2006	2008	2010
30-59 cm	0.01	0.01	0.01	0.10	0.02	0.01	0.08	0.02	0.03
60-79 cm	0.09	0.37	0.43	0.28	0.14	0.32	0.73	0.67	0.12
≥80 cm	0.37	0.13	0.70	0.75	0.55	1.18	1.36	1.31	1.39

Table 5. Atlantic cod biomass (tons) at age and daily consumption (tons) of redfish.

Atlantic cod mean year biomass at age									
Year	**1**	**2**	**3**	**4**	**5**	**6**	**7**	**8+**	**Total**
2000	31	12	106	102	94	502	1645	5	2497
2001	44	125	18	116	136	144	633	846	2060
2002	0	197	245	17	138	160	190	1460	2406
2003	58	18	360	278	29	167	226	1549	2685
2004	5	601	67	708	509	45	259	2078	4271
2005	74	40	1177	98	917	615	0	1658	4579
2006	738	2210	48	1737	120	1151	720	220	6943
2008	491	2783	8055	5993	75	2211	152	524	20284
2010	1476	3850	5058	7805	11331	7094	137	4323	41074
Redfish daily estimated consumption (tons) by Atlantic cod at age.									
2000	0.0	0.0	0.0	0.0	0.1	0.5	6.1	0.0	6.7
2001	0.0	0.0	0.0	0.0	0.5	0.5	0.8	1.1	3.0
2002	0.0	0.0	0.0	0.0	0.6	0.7	1.3	10.2	12.9
2003	0.0	0.0	0.0	0.0	0.1	0.5	1.7	11.6	13.9
2004	0.0	0.1	0.0	0.1	0.7	0.1	1.4	11.4	13.9
2005	0.0	0.0	0.1	0.0	2.9	2.0	0.0	19.6	24.6
2006	0.0	1.8	0.0	1.4	0.9	8.4	9.8	3.0	25.3
2008	0.0	0.6	1.6	1.2	0.5	14.8	2.0	6.9	27.5
2010	0.0	1.2	1.5	2.3	13.6	8.5	1.9	60.1	89.1
Redfish annual estimated consumption (tons) by Atlantic cod at age									
2000	0	0	4	4	31	165	2221	7	2432
2001	0	5	1	4	183	194	301	401	1088
2002	0	7	9	1	217	251	484	3731	4700
2003	0	1	13	10	29	171	620	4239	5083
2004	0	44	5	52	260	23	519	4171	5074
2005	0	1	43	4	1071	719	0	7141	8979
2006	0	645	14	507	319	3068	3574	1090	9217
2008	0	203	588	438	183	5408	725	2506	10051
2010	0	422	554	855	4963	3107	696	21934	32530

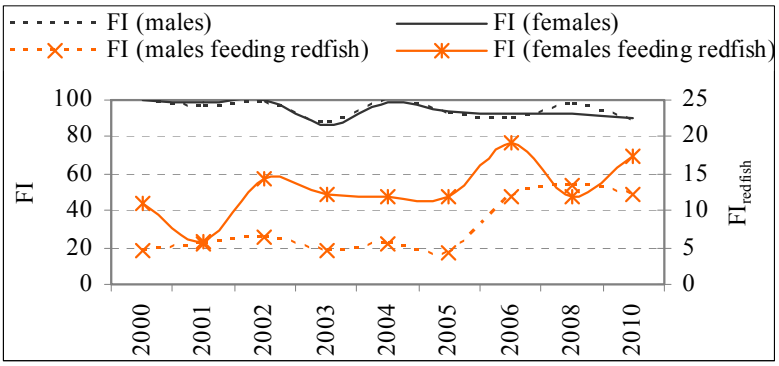

Figure 1. FI and $FI_{redfish}$ of Atlantic cod by year in Flemish Cap (NAFO Div. 3M).

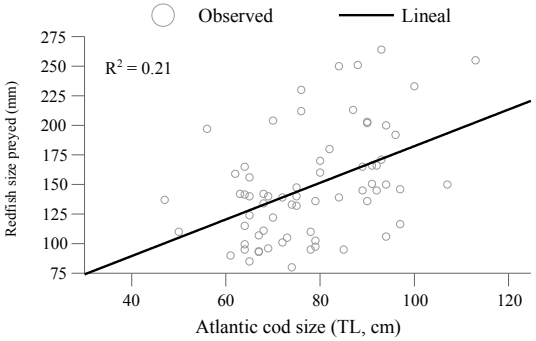

Figure 2. Prey and predator length relationship.

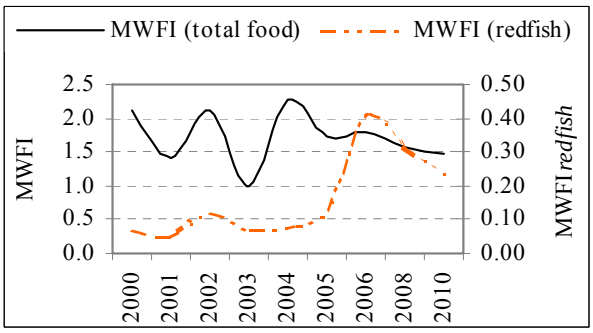

Figure 3. Total food and redfish consumption by Atlantic cod per year in NAFO Div. 3M.

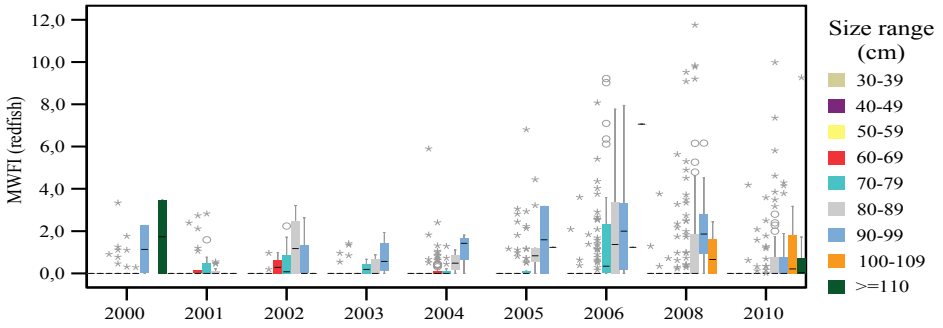

Figure 4. MWFI$_{redfish}$ of Atlantic cod by year and size range (TL) in NAFO Div. 3M.

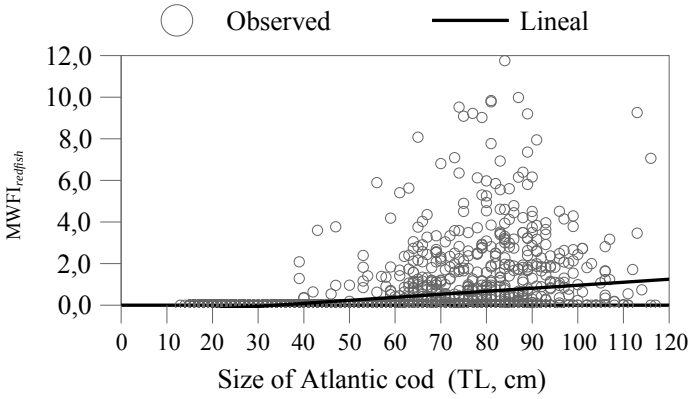

Figure 5. MWFI$_{redfish}$ of Atlantic cod by size.

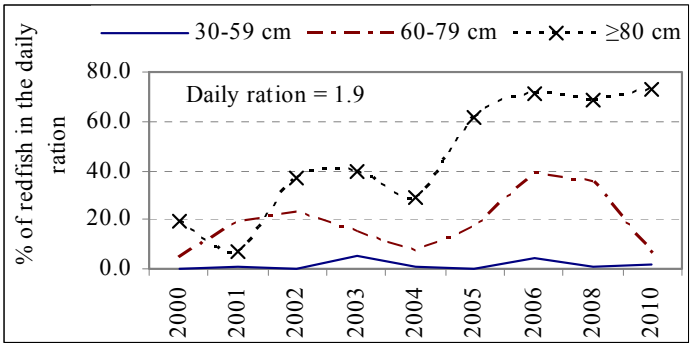

Figure 6. Redfish percentage in the daily ration of Atlantic cod.

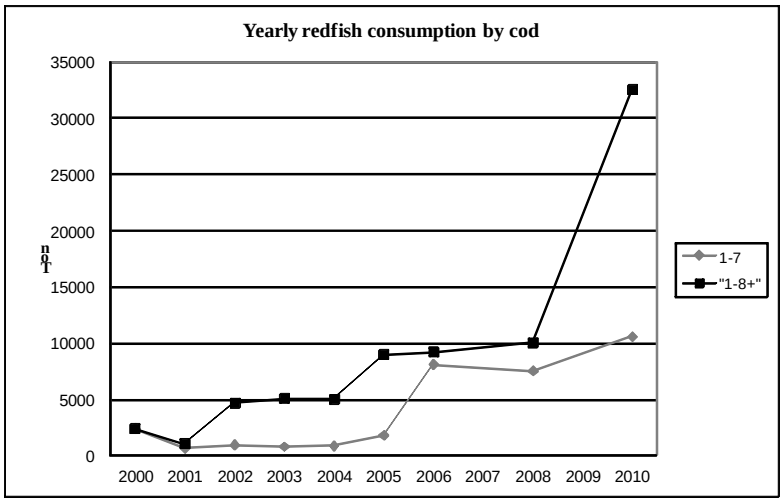

Figure 7. Yearly redfish consumption estimated by cod.

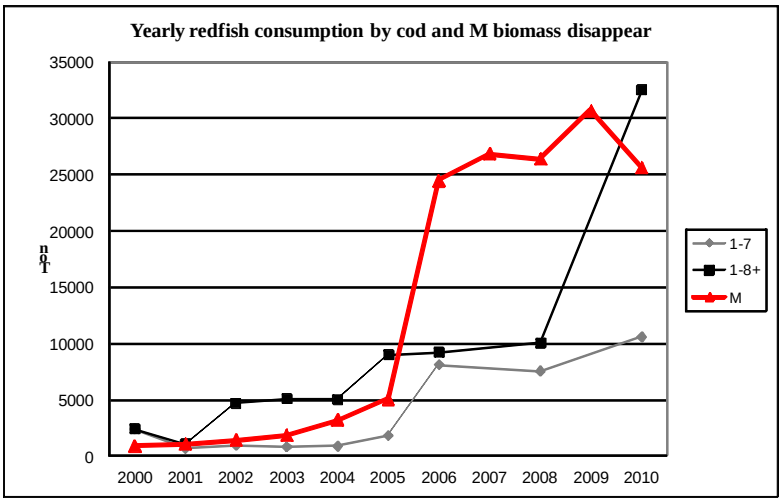

Figure 8. Yearly redfish consumption estimated by cod and mortality