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Flemish Cap cod biological parameters

by

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Abstract

This document presents the estimated parameters values of the Von Bertalanffy growth model VBGM, the *a* and *b* parameters from the length weight relationship, and the L_{50} and a_{50} of the cod Div. 3M stock using recent individual length-at-age data of the 2015-2022 period collected by the Spanish Scientific Observers and the Flemish Cap survey.
The VBGM parameters estimated with the data collected in the Flemish Cap survey are higher than those estimated with the data collected by Spanish Scientific Observers in the commercial fleet. With the data from the Flemish Cap survey, a L_{inf} of 179 cm and 136 cm and a t_{max} of 44 and 32 years for females and males, respectively, are estimated.

The estimated value of the parameters of the lenght-weight relationship is quite similar in the case of the values estimated with the survey data and the total data and differences by sex are minimal. The estimated value of the parameters of the lenght-weight relationship using the observers and survey data together are a=0.0071 and b=3.055.
The estimated L_{50} using the female maturity data obtained in the Flemish Cap survey is 54.2 cm and the estimated a_{50} with these data is 4.9 years.

Introduction

Length, weight and age are very useful biological data in fish stock assessment and environmental monitoring programs. Stock assessments are usually developed considering individual growth, obtained from length-at-age data, and this is often the basis for fishery management decisions. Growth parameters are also central to estimate fish mortality by indirect methods when the use of "empirical" estimates is not possible and often form the basis for yield-per-recruit models used to predict effects of catch limits and size limits and to develop other regulations. In addition, they are used to compare morphology between different fish species in the same taxonomic group, or between fish populations from different regions or periods, to study the ontogenetic allometric changes.

Flemish Cap is a deep-water mountain located in the NAFO Division 3M. Two features provide high degree of isolation to the Flemish Cap ecosystem. First, the Cap is separated from the Newfoundland shelf by the Flemish Pass, a channel characterized by depths beyond 1 100 m and 30 miles wide in the narrowest point at 400 m

depth. This feature hinders the migration to and from surrounding areas for juvenile and adult stages of shallow demersal species, such as Atlantic cod (*Gadus morhua)* and American plaice (*Hippoglossoides platessoides)*. Second, a quasi-permanent anti-cyclonic gyre dominates the oceanography over the Cap, producing a retention effect on eggs and larvae, that would eventually stay over the Flemish Cap and recruit to the population. This isolation provides to the Flemish Cap a high degree of independence in the dynamic of its populations in relation to the Grand Banks.

The cod fishery on Flemish Cap has traditionally been a directed fishery by Portuguese trawlers and gillnetters, Spanish pair trawlers and Faroese longliners in the second half of the twentieth century. Since 1974, when a TAC was established for the first time, estimated catches ranged from 48 000 tons in 1989 to a minimum value of 5 tons in 2004. The fishery was closed in 1999 and this stock had been on fishing moratorium since 1999 to 2009 following its collapse, which has been attributed to three simultaneous circumstances: a stock decline due to overfishing, an increase in catchability at low abundance levels and a series of very poor recruitments starting in 1993. The good shape of the stock led to a reopening of the fishery with 5 500 tons of catch in 2010. The current fishery is composed mainly by trawlers from Portugal, Spain, Russia and Estonia and long-liners from Faroe Islands (Denmark) and Norway.

The Flemish Cap NAFO Division 3M cod stock is evaluated by the NAFO Scientific Council and managed by the NAFO Commission. In addition to the minimum landing size of 41 cm for cod and the minimum mesh size of 130 mm adopted for all groundfish, in 2020 the Commission adopted technical measures to try to protect the productivity of Division 3M cod stock. These measures included the closure of the directed fisheries of the 3M cod during the first quarter of the year, as well as the mandatory use of sorting grids in the cod directed trawl fishery (NAFO, 2024).

This document presents the estimated parameters values of the Von Bertalanffy growth model, the *a* and *b* parameters from the length weight relationship, and the L_{50} and a_{50} of the cod Div. 3M stock using recent individual length-at-age data. Information on natural mortality (M) of this stock estimated in the last assessment approved by the NAFO Scientific Council is also included.

Material and Methods

A total of 14 881 specimens of cod were examined to investigate their age-length relationship as an indicator of growth and their length-weight relationship as an indicator of body allometry. 3 500 of them were collected in Flemish Cap by Spanish Scientific Observers on board the commercial fleet in the period 2015-2022. The rest, 11 381, were collected in the Flemish Cap EU survey in the same period.

Table 1 shows the number of specimens by year and source used in this study. The period 2015-2022 was selected due to the low variability of certain biological parameters such as average weights, maturity at age and the age at first maturity estimated in the last approved assessment of cod Div. 3M (Garrido *et al.*, 2023)

The collected fish were weighed in grams and the total length was measured to the nearest lower centimeter. Estimation of age from otolith reading was performed for all individuals. The ages have been determined by the Spanish Oceanographic Institute (IEO-CSIC) fisheries team for the fish collected by the Spanish Scientific Observers and by the team of the Marine Research Institute (IIM-CSIC) for the fish collected in the Flemish Cap survey. Sex was determined by macroscopic examination of the gonads.

To assess growth, the von Bertalanffy growth model (VBGF) was used. There are many versions or parameterizations of the VBGF. The most common version, used in this analysis, is due to Beverton (1954) and Beverton and Holt (1957), who modified the original version introduced by von Bertalanffy (Cailliet *et al.*, 2006). This version of VBGF is represented by:

$$E[L|t] = L_{inf} * \left(1 - e^{-K(t-t_0)}\right)$$

where

$E[L|t]$ is the expected or average length at time (or age) t,
L_{inf} is the asymptotic average length,
K is the so-called Brody growth rate coefficient (units are yr^{-1}), and
t_0 is a modeling artifact that is said to represent the time or age when the average length was zero.

The potential longevity (t_{max}) was estimated using Pauly & Munro's (1984) formula: $t_{max} = \frac{3}{K} + t_0$.

In respect of allometry, the relation of total length (L) to total weight (W) was examined applying the exponential regression function (Le Cren, 1951): $W = a\,L^b$, where a is the intercept parameter or shape coefficient and b is the slope or allometric parameter. The linearized equation was derived with ordinary least squares regression after log-transformation: $ln(W) = ln(a) + bln(L)$. The length-weight relations were estimated both by sex and by combined sexes.

To estimate the length and age at first maturity (L_{50} and a_{50}), length, age and maturity information from 2 448 female cod collected in the Flemish Cap survey in the 2015-2022 period was used. The maturity was estimated by the IIM using the microscopic (histological based) maturity data from ovaries. Table 2 presents the number of female individuals available by year to estimate the L_{50} and a_{50}. Generalized Linear Models (GLMs) with a binomial error distribution and a logit link were fitted to the proportion of fish mature by length and age class. L_{50} and a_{50} estimated in this analysis were derived from the model parameters and the confidence intervals (CIs) were estimated using bootstrap (500 iterations).

Statistical analyses were performed in the computing environment R version 4.3.2 (R Core Team, 2023). There are a number of different tools that can be used to estimate these biological parameters in R, in this case ggFishPlots package (Vihtakari, 2023) was used to carry out the analysis. The ggFishPlots package allows quickly plotting and calculating life history parameters required by stock assessment models.

Results

Table 3 shows the Von Bertalanffy growth parameters values and bootstrap-estimated 95% confidence intervals split by sex and for both sexes together with the Spanish Scientific Observers data (2015-2022). The values obtained are different by sex, a different growth is observed between females and males, with females reaching a higher L_{inf} (133.9 cm) and t_{max} (31 years) than males, with a L_{inf} = 108.7 cm and t_{max} = 23 years. The 95% confidence intervals for the parameter L_{inf} for males is 102-118 cm, and 123-150 cm for females; while the intervals for t_{max} are 20-28 years and 26-38 years, respectively.

Figure 1 shows the cod Div. 3M Von Bertalanffy growth model split by sex (Red line = Females and Blue line = Males) fitted with the commercial data collected by the Spanish Scientific Observers (box plots) in the 2015-2022 period. It can be seen that the growth of males and females is quite similar until age 6. From that age onwards, females grow more than males and reach a higher L_{inf}.

Table 4 shows the Von Bertalanffy growth parameters values and bootstrap-estimated 95% confidence intervals split by sex and for both sexes together estimated with the Flemish Cap survey data (2015-2022). With the data from the Flemish Cap survey, a L_{inf} of 179 cm and 136 cm and a t_{max} of 44 and 32 years for females and males, respectively, are estimated. In this case, the estimated confidence intervals are narrower than those estimated with the observers' data. The interval for L_{inf} for males is 131-141 cm and 172-189 cm for females, while the intervals for t_{max} are 30-33 years and 41-48 years respectively.

Figure 2 shows the cod Div. 3M Von Bertalanffy growth model split by sex (Red line = Females and Blue line = Males) fit with the data collected in the Flemish Cap survey (box plots) in the 2015-2022 period. In this case it can also be observed that the cod specimens grow in a similar way until age 5/6 and from that age the growth of the males and females is different, with the growth of the females being greater.

Tables 3 and 4 show the values of the parameters estimated with the joint data of the two sexes for the information collected by the Scientific Observers and the Flemish Cap survey respectively. Figure 3 shows the cod Div. 3M Von Bertalanffy growth model split by type of data source and combining data from both sexes collected in the 2015-2022 period (Red line = Observers data and Blue line = survey data). It can be seen that the VBGM fitted with the data collected in the survey presents a greater growth than that fitted with the data collected by the observers. L_{inf} estimated with data from the survey is 169 cm while the estimate with data from observers is 125 cm, and the t_{max} obtained is 42 years and 28 years, respectively. The greatest differences in the growth model fitted with the different data start to be appreciable at age 6. The age range with information coming from the Spanish Scientific Observers (2-15) is smaller than in the data collected in the survey (1-19).

Table 5 shows the length-weight model parameters and their 95% confidence intervals by sex and both sexes, estimated with ggFishPlots R function using the Spanish Scientific Observers data for cod Div. 3M. Table 6 presents those parameters estimated with the Flemish Cap survey data and Table 7 with all the data (Spanish Scientific Observers and Flemish Cap survey data together). The estimated value of the parameters of the lenght-weight relationship is quite similar using the survey data and the total data (Observers plus survey), but some differences are observed in the case of estimates with only Spanish Scientific Observers data. Differences by sex are minimal, and they are negligible when using the Spanish Scientific Observers data. The values obtained using all the data together are: a=0.007 and b=3.064 for the females, a=0.0075 and b=3.042 for males, and a=0.0071 and b=3.055 for both sexes together.

As the differences observed in the estimated values by source of data or sex are minimal, figure 4 shows the fit of the length-weight relationship with all the data without distinguishing between sexes .

Table 8 shows the estimated length at first maturity (length at which 50% of fish are mature, L_{50}), its confidence intervals using 500 bootstrap replicates and the logit regression parameters calculated with the ggFishPlots package using the microscopic maturity data obtained in the Flemish Cap survey from 2015 to 2022. The estimated L_{50} with these data is 54.2 cm. Figure 5 shows the maturity-at-length curve and the L_{50} with the 95% confidence intervals estimated as well as the size distribution of the immature and mature individuals analyzed.

Table 9 presents the estimated age at first maturity (age at which 50% of fish are mature, a_{50}), its confidence intervals using 500 bootstrap replicates and the logit regression parameters calculated with the ggFishPlots package using the microscopic maturity data obtained in the Flemish Cap survey from 2015 to 2022. The estimated a_{50} with these female data is 4.9 years for the 2015-2022 period. Figure 6 shows the maturity-at-age curve and the a_{50} with the 95% confidence intervals estimated as well as the age distribution of the immature and mature female individuals analyzed.

The natural mortality at age (M) was estimated in the last approved cod Div. 3M assessment (Garrido *et al.*, 2023). Table 10 presents the prior and posterior medians for the natural mortality at age, with an average for ages 3-5 of 0.28.

Table 11 presents a summary of the values of the different biological parameters obtained with the data from the Flemish Cap survey for both sexes combined. The values of the parameters estimated with the survey data have been chosen for two main reasons. The first one is that the survey data contains information from many more individuals and the coverage of the sampling in sizes and number of specimens per year is much more balanced than that of the sampling carried out by Spanish Scientific Observers. The second reason is that the age length key approved by the SC is the one obtained by the IIM from the survey data.

Discussion

Data collected in the Flemish Cap survey have a greater number of observations and a wider range of sizes/ages than those collected by the Spanish Scientific Observers.

The VBGM parameters estimated with the data collected in the Flemish Cap survey are higher than those estimated with the data collected by Spanish Scientific Observers in the commercial fleet. These differences may be due to the fact that the survey data has a wider range of sizes/ages information or to differences in the age readings made by the IEO (Observer data) and IIM (survey data) teams or combined effect of both circumstances. The longevity of cod estimated with the survey data sex combined (2015-2022) is around 40 years, being 28 years with the observers data, and the L_{inf} estimated was 169 cm with the survey data and 125 cm with the observers data. The maximum age read in the specimens captured in the Flemish Cap survey since 1988 has been 19 years and the maximum size observed was 142 cm. In the specimens collected by the Spanish Scientific Observers since 2006, the maximum size was 139 cm and the maximum age was 17 years.

There is a clear difference in the VBGM parameters values estimated for males and females regardless the source of data, being L_{inf} and t_{max} higher for females than for males.

For an ideal fish, which maintains in perfect equality the dimensions of its body in length and weight, the growth pattern follows the cube law (Le Cren, 1951). In such cases, fish grow isometrically and the *b* value (regression coefficient) of the relationship between length and weight is equal to 3. Under natural conditions, most fish do not follow the cube law, and *b* value could be significantly greater or lower than the ideal value, indicating that the growth pattern is allometric. In the case of the cod Div. 3M, in this study the value of this parameter estimated for males and females with the different data are quite similar and close to 3 indicating quite isometric growth in all cases.

The L_{50} estimated with the data collected in the Flemish Cap survey from the period 2015-2022 (54.2 cm) is quite similar to that estimated by year by Garrido *et al.* (2020) with data from the period 2010-2018, 53 cm. The a_{50} estimated with the data collected in the Flemish Cap survey from the period 2015-2022 (4.9 years) is very similar to that estimated annually by Garrido *et al.* (2023), where the average for the period 2015-2022 is 4.6. These results show certain stability of the estimated values of these parameters in the period analyzed (2015-2022).

The authors choose the values of the parameters estimated with the survey data as the best available for two main reasons. The first one is that the survey data contains information from many more individuals and the coverage of the sampling in sizes and number of specimens per year is much more balanced than that of the sampling carried out by Spanish Scientific Observers. The second reason is that the age length key approved by the SC is the one obtained by the IIM from the survey data.

Acknowledges

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Table 1. Number of cod Div. 3M specimens collected by the Spanish Scientific Observers (Observers) and in the Flemish Cap survey (Survey) per year in the period 2015-2022 used in this analysis.

Data	Year	Females	Males	Total
Observers	2015	514	470	984
	2016	268	200	468
	2017	85	60	145
	2018	104	58	162
	2019	589	561	1 150
	2020	0	0	0
	2021	70	55	125
	2022	253	213	466
	Total	1 883	1 617	3 500
Survey	2015	878	697	1 575
	2016	794	617	1 411
	2017	763	631	1 394
	2018	649	552	1 201
	2019	665	578	1 243
	2020	638	631	1 269
	2021	873	833	1 706
	2022	819	763	1 582
	Total	6 079	5 302	11 381

Table 2. Number of females cod Div. 3M specimens collected in the Flemish Cap survey per year in the period 2015-2022 used to estimate L_{50} and a_{50}.

Year	Females Ind.
2015	393
2016	347
2017	331
2018	221
2019	279
2020	289
2021	272
2022	316
Total	2 448

Table 3. Cod Div. 3M von Bertalanffy growth function coefficients and bootstrap-estimated 95% confidence intervals by sex and for both sexes together obtained with the ggFishPlots R function using the Spanish Scientific Observers data (2015-2022). L_{inf} (asymptotic average length), K (growth rate coefficient), t_0 (age at length 0) and t_{max} (life span; $t_0 + 3/K$).

	Females		
	Estimated	95% CIs low	95% CIs high
L_{inf}	133.9	123.1	149.7
K	0.0949	0.0772	0.1129
t_0	-0.5571	-0.9605	-0.2086
t_{max}	31	26	38

	Males		
	Estimated	95% CIs low	95% CIs high
L_{inf}	108.7	102.2	118.2
K	0.1291	0.1058	0.1506
t_0	-0.3624	-0.7778	-0.0274
t_{max}	23	20	28

	Females+Males		
	Estimated	95% CIs low	95% CIs high
L_{inf}	124.9	118.3	134.1
K	0.1036	0.0892	0.1168
t_0	-0.5456	-0.843	-0.2856
t_{max}	28	25	33

Table 4. Cod Div. 3M von Bertalanffy growth function coefficients and bootstrap-estimated 95% confidence intervals by sex and for both sexes together obtained with the ggFishPlots R function using the Flemish Cap survey data (2015-2022). L_{inf} (asymptotic average length), K (growth rate coefficient), t_0 (age at length 0) and t_{max} (life span; $t_0 + 3/K$).

	Females		
	Estimated	95% CIs low	95% CIs high
L_{inf}	179.4	172.2	189.0
K	0.0669	0.062	0.0717
t_0	-0.4935	-0.569	-0.4252
t_{max}	44	41	48

	Males		
	Estimated	95% CIs low	95% CIs high
L_{inf}	135.7	131.0	140.6
K	0.0938	0.0884	0.0995
t_0	-0.443	-0.509	-0.38
t_{max}	32	30	33

	Females+Males		
	Estimated	95% CIs low	95% CIs high
L_{inf}	168.6	163.2	174.3
K	0.0711	0.0675	0.0747
t_0	-0.526	-0.577	-0.477
t_{max}	42	40	44

Table 5. Length-weight model parameters estimated and their 95% confidence intervals with ggFishPlots R function using Spanish Scientific Observers data for cod Div. 3M females, males and both sexes together.

	Females		
	Estimated	95% CIs low	95% CIs high
a	0.006	0.005	0.007
b	3.098	3.07	3.12

Males		
Estimated	95% CIs low	95% CIs high
0.006	0.005	0.007
3.094	3.07	3.12

	Females+Males		
	Estimated	95% CIs low	95% CIs high
a	0.006	0.006	0.006
b	3.098	3.08	3.12

Table 6. Length-weight model parameters estimated and their 95% confidence intervals with ggFishPlots R function using Flemish Cap survey data for cod Div. 3M females, males and both sexes together.

	Females		
	Estimated	95% CIs low	95% CIs high
a	0.007	0.007	0.007
b	3.062	3.06	3.07

Males		
Estimated	95% CIs low	95% CIs high
0.0076	0.007	0.008
3.039	3.03	3.05

	Females+Males		
	Estimated	95% CIs low	95% CIs high
a	0.0072	0.007	0.007
b	3.052	3.05	3.06

Table 7. Length-weight model parameters estimated and their 95% confidence intervals with ggFishPlots R function using all the data (Flemish Cap survey and Spanish Scientific Observers data together) for cod Div. 3M females, males and both sexes together.

	Females		
	Estimated	95% CIs low	95% CIs high
a	0.007	0.007	0.007
b	3.064	3.06	3.07

Males		
Estimated	95% CIs low	95% CIs high
0.0075	0.007	0.008
3.042	3.04	3.05

	Females+Males		
	Estimated	95% CIs low	95% CIs high
a	0.0071	0.007	0.007
b	3.055	3.05	3.06

Table 8. Cod Div. 3M female length at first maturity (L_{50}) in cm, and their confidence intervals using 500 bootstrap replicates, estimated with microscopic maturity data obtained in the Flemish Cap survey from 2015 to 2022. Also, the logit regression parameters. Individuals colum shows the number of females with information used in the analysis.

L_{50}	95% CI low	95% CI high	intercept	slope	individuals
54.2	53.6	54.9	-15.40085	0.284	2 448

Table 9. Cod Div. 3M female age at first maturity (a_{50}) in cm, and their confidence intervals using 500 bootstrap replicates, estimated with microscopic maturity data obtained in the Flemish Cap survey from 2015 to 2022. Also, the logit regressions parameters. . Individuals colum shows the number of females with information used in the analysis.

a_{50}	95% CI low	95% CI high	intercept	slope	individuals
4.9	4.9	5.0	-12.56059	2.543	2 448

Table 10. Prior and posterior medians for the natural mortality by age estimated in the last cod Div. 3M assessment approved by SC.

Age	1	2	3	4	5	6	7	8+
Prior	1.26	0.65	0.44	0.35	0.3	0.27	0.24	0.24
Posterior	1.31	0.6	0.34	0.24	0.25	0.37	0.33	0.42

Table 11. Summary of the cod Div. 3M biological parameters estimated with the Flemish Cap survey data (2015-2022) for both sex combined. L_{50} and a_{50} were calculated only for females.

Stock Cod Div. 3M Biological Parameters		
K [year^{-1}]	0.0806	ggFishPlots
L_{inf} [cm]	134.8	ggFishPlots
t_0 [years]	-1.57	ggFishPlots
M	0.28	scr23-009.pdf
a	0.0076	ggFishPlots
b	3.044	ggFishPlots
L_{50} [cm]	54.2	ggFishPlots
a_{50} [years]	4.9	ggFishPlots

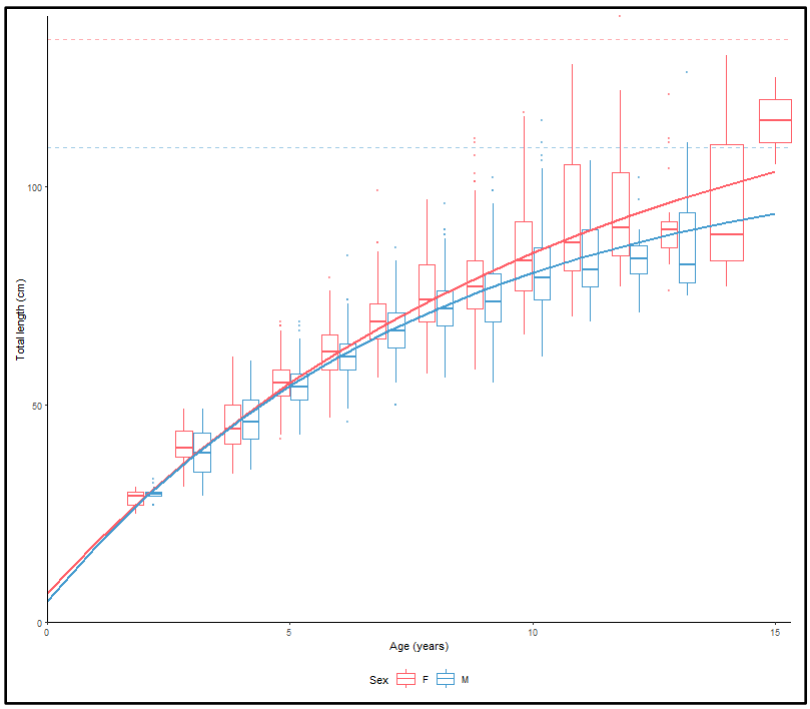

Figure 1. Cod Div. 3M Von Bertalanffy growth model by sex (Red line = Females and Blue line = Males) fitted with the commercial data collected by the Spanish Scientific Observers (box plots) in the 2015-2022 period. Horizontal dotted lines are the estimated L_{inf} (asymptotic average length).

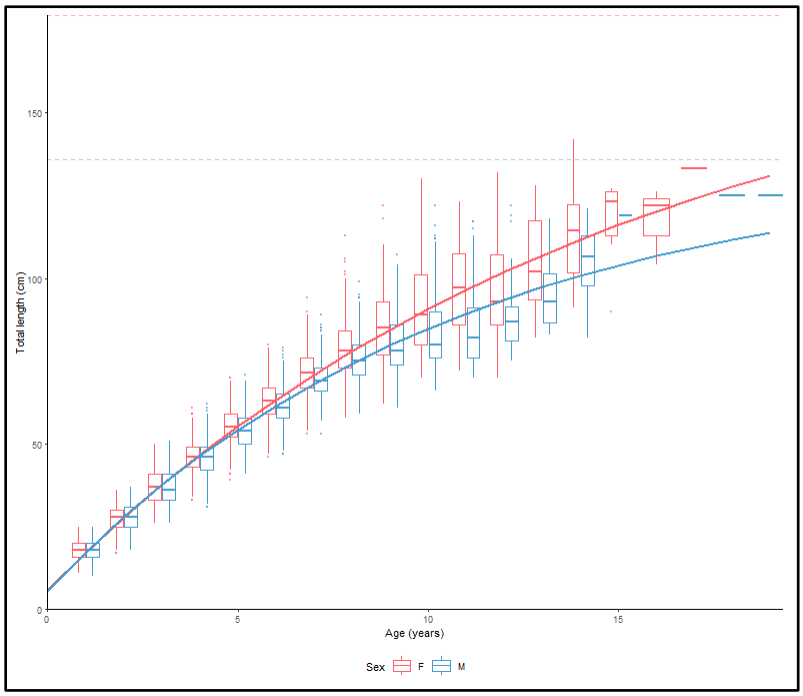

Figure 2. Cod Div. 3M Von Bertalanffy growth model by sex (Red line = Females and Blue line = Males) fitted with the Flemish Cap survey data (box plots). Horizontal dotted lines are the estimated L_{inf} (asymptotic average length).

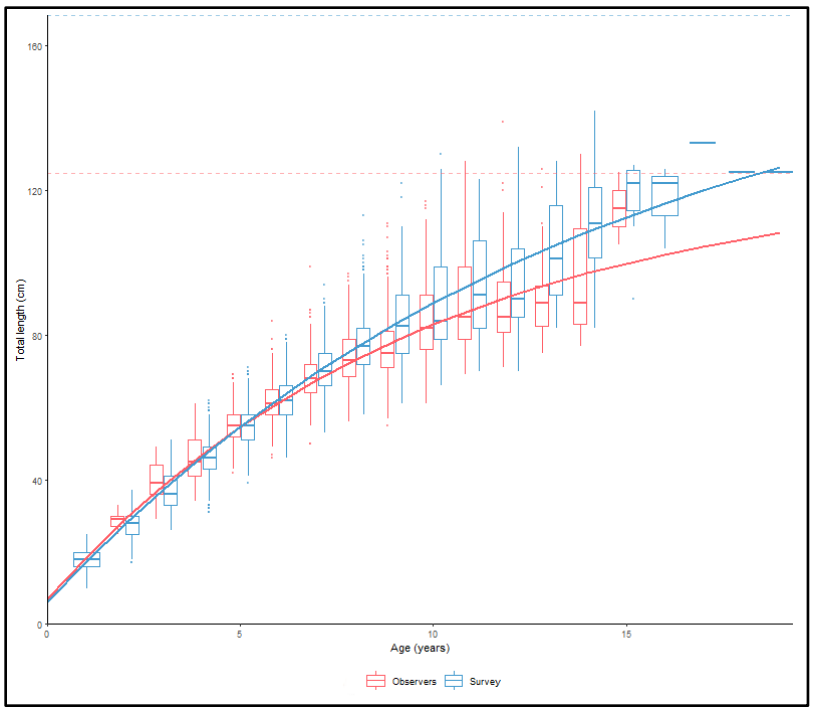

Figure 3. Cod Div. 3M Von Bertalanffy growth model by data source (Red = Observers, Blue = Survey) combining data from both sexes. Horizontal dotted lines are the estimated L_{inf} (asymptotic average length).

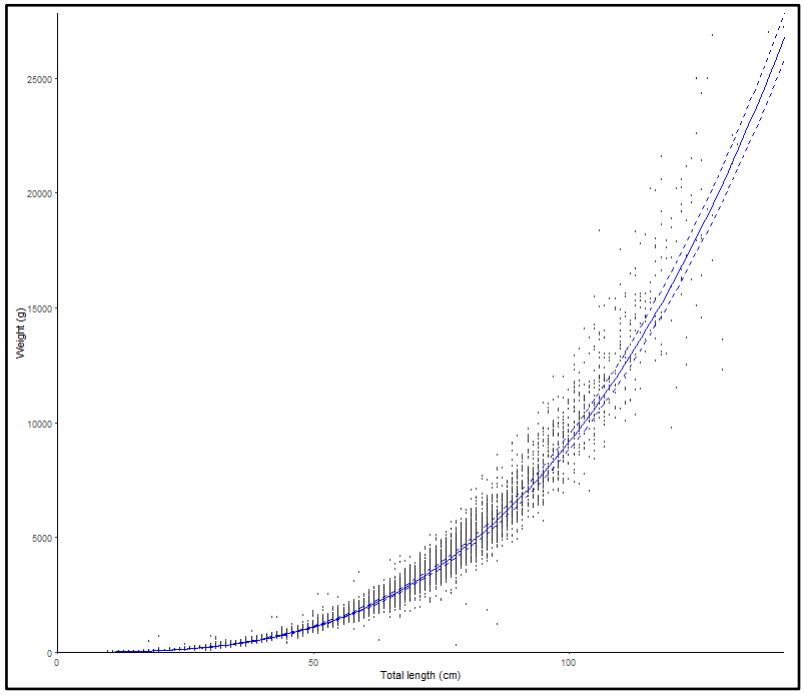

Figure 4. Length-weight model for both sexes together fitted with the Spanish Scientific Observers and Flemish Cap survey data together (dots).

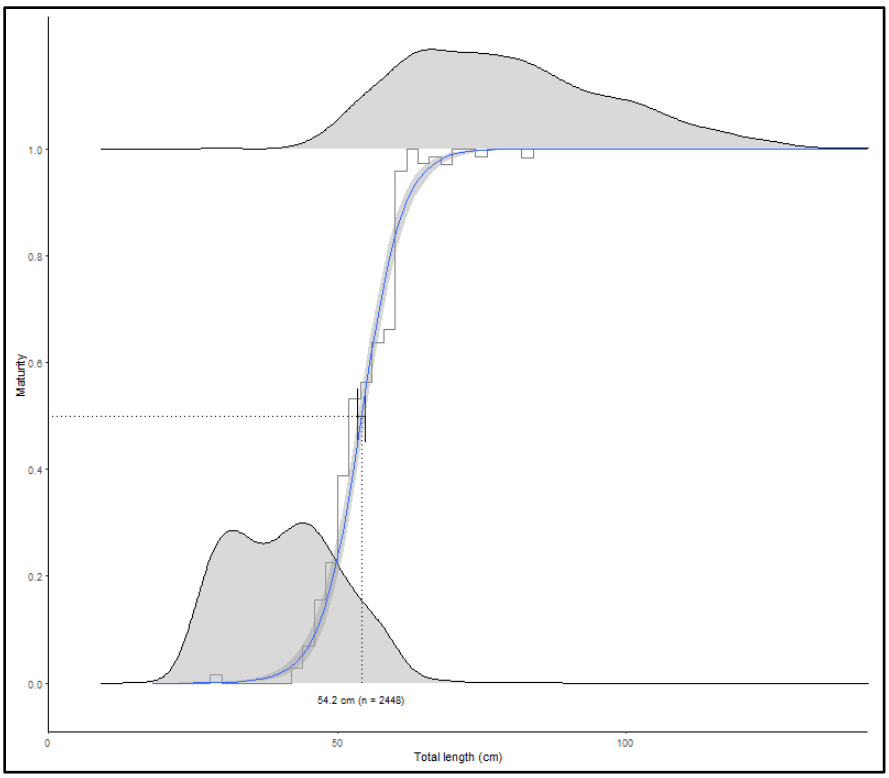

Figure 5. Maturity/length curve and the L_{50} with the 95% confidence intervals using 500 bootstrap replicates as well as the size distribution of the immature and mature individuals analyzed collected in the Flemish Cap survey in the 2015-2022 period.

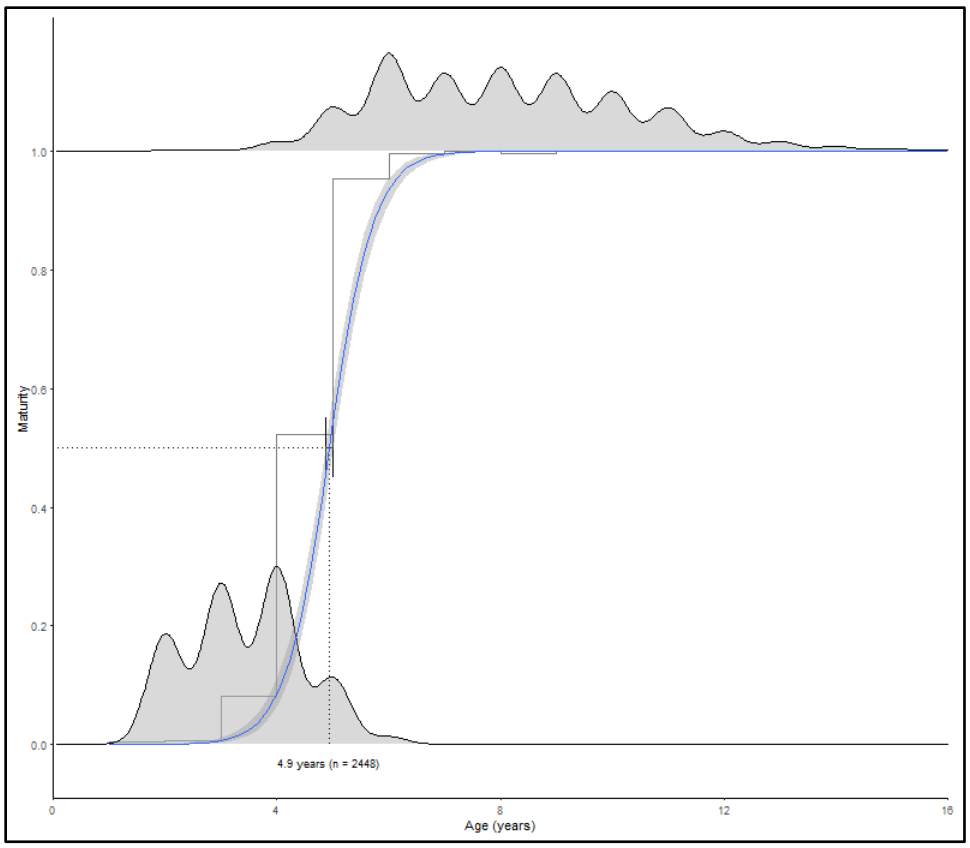

Figure 6. Maturity/age curve and the a_{50} with the 95% confidence intervals using 500 bootstrap replicates as well as the age distribution of the immature and mature individuals analyzed collected in the Flemish Cap survey in the 2015-2022 period.