White anglerfish (*Lophius piscatorius*): weight-length relationships, weight conversion factors and somatic indices from two stocks in north-eastern Atlantic waters (ICES Div. VIIIc-IXa2 and Div. VIIb,c,h,j,k)

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Abstract

Weight-length relationships, weight conversion factors and somatic indices are presented from a decade (2006 to 2015) for two stocks of *Lophius piscatorius* in northern Iberian Atlantic waters (ICES Div. VIIIc-IXa2) and in Celtic Sea, south-western Ireland and Porcupine Bank (Div. VIIb,c,h,j,k). A total of 7219 specimens (3596 and 3623 respectively in each stock) were sampled from commercial landings and research surveys. Total length (Lt), total weight (Wt), “commercial” weight (Wgl) and “scientific” weight (Wg) were obtained. The parameters (a, b) in the power relationships weight-length for combined sexes were:

$Lt = 0.025\ Wt^{2.853}$; $Lt = 0.020\ Wgl^{2.868}$; $Lt = 0.024\ Wg^{2.861}$ in Div. VIIIc-IXa2;
$Lt = 0.027\ Wt^{2.826}$; $Lt = 0.023\ Wgl^{2.825}$; $Lt = 0.023\ Wg^{2.816}$ in Div. VIIb,c,h,j,k.

Significant differences between stocks were found. The conversion factors between total and gutted weight were: Wt = 1.181 Wgl; Wt = 1.241 Wg in Div. VIIIc-IXa2;
Wt = 1.210 Wgl; Wt = 1.262 Wg in Div. VIIb,c,h,j,k.

The parameters can be used in the process of annual assessment of the state of each stock. Gonadosomatic index (GSI), hepatosomatic index (HSI) and Le Cren’s condition factor, indicators of reproductive and nutritional status, were seasonally analyzed and compared between sexes and stocks. Significant better condition and higher GSI and HSI were found in mature females. Specimens in Div. VIIb,c,h,j,k showed better condition and higher GSI. The parameters obtained were compared with those from previous studies, showing similarities.

Keywords: weight-length relationships; gonadosomatic index; hepatosomatic index; condition factor; *Lophius piscatorius*.

1. Introduction

The white anglerfish (*Lophius piscatorius*) is an important commercial species in the European fisheries, with catches of ~38000 t in Atlantic waters in 2014 (ICES, 2015; ICES, 2016). It is a bottom-living species mainly found from 50 m to 1000 m depth and distributed from the Barents Sea to the Strait of Gibraltar, being also found in the Mediterranean Sea (Whitehead et al., 1986; Quero and Vayne, 1997).

The annual assessment of the state of the stock in ICES Div. VIIb-k and VIIIa,b,d, and the stock in Div. VIIIc and IXa is performed in the ICES Working Group for the Bay of Biscay and the Iberian waters Ecoregion (WGBIE) (ICES, 2015).

Weight-length relationships allow us to calculate the different weights of individuals which length is known. They are important biological parameters, having a wide application in fish biology and fisheries management, such as for predicting weight from length data, or for the calculation of production and biomass of a fish stock. The conversion factor, total weight - gutted weight, is also useful in fisheries management due to the commercial landings of this species are available in gutted weight. Variations of the somatic indices, such as the gonadosomatic and hepatosomatic indices and the condition factor over the year can indicate seasonality of the reproductive and nutritional status, and may be useful to corroborate biological processes such as the spawning season.

The only known estimates of weight-length relationships and weight conversion factor from the stock Div. VIIb-k and VIIIa,b,d, were performed in Div. VIIIa,b,d (Guillou, 1978; Pereda et al., 1998; Quincoces, 2002). For the stock Div. VIIIc and IXa, Olaso and Pereda (1983) estimated the parameters in Div. VIIIc and Pereda et al. (1998) in Div. VIIIc-IXa. The last work was carried out many years ago and those parameters are used for the annual stock assessment process. However updated, and as accurate as possible, parameters are required in order to have the most reliable input data for the stock assessment.

The aim of the study is to improve the knowledge of the biological parameters of white anglerfish from two areas of the main Atlantic stocks of these species: Celtic Sea, south-western Ireland and Porcupine Bank (Div. VIIb,c,h,j,k) and northern Iberian Atlantic waters (Div. VIIIc-IXa2), presenting updated information on weight-length relationships and weight conversion factors. These values are relevant because they can be already used in the process of the assessment of the state of both stocks in ICES, replacing those previous estimated. The physiological state throughout the year is also analyzed by means of the condition factor, gonadosomatic and hepatosomatic indices, and is compared between sexes and areas.

2. Materials and methods

2.1. Sampling

The area sampled by Instituto Español de Oceanografía (IEO) covered the main areas where the Spanish commercial fleet capture anglerfish: Celtic Sea, south-western Ireland and Porcupine Bank (ICES Div. VIIb,c,j,h,k) (northern stock of the southern shelf) and northern Iberian Atlantic waters (ICES Div. VIIIc-IXa2) (southern stock of the southern shelf) (Fig. 1). Individuals came from the landings of that fleet and from two research fishing surveys carried out by IEO during the same period and zone. The surveys “Demersales” (in Div. VIIIc-IXa2) and “Porcupine” (in Div. VIIb,c,k) took place in September-October each year of the studied time-series.

The sampling period was a decade, from January 2006 to December 2015. The sampling unit was the quarter, and the most of the whole length range of each species was intended to be represented.

The following collected data from each specimen were analyzed:

- Total length: Lt (cm), length class of 1 cm;
- Total weight: Wt (g);
- Gutted weight (without liver): Wg (g), also named “scientific” weight;
- Gutted weight with liver: Wgl (g), also named “commercial” weight;

The complete data collection for each individual depended on the sampling source, because there were different ways to land and commercialize anglerfish in the fish markets. A great effort was performed to obtain ungutted individuals from the commercial fleet to obtain total weight, because the specimens landed by the Spanish fleet are already gutted, and the presence or absence of liver depends on the fish market where they are landed. As a result of that, the type of commercial weights is quite alike. Therefore, the available range of fish lengths for estimating the weight-length relationship varied according to the type of weight estimated. Thus, total weight was available for a total of 7219 white anglerfish, the gutted weight for 6401 specimens, and the gutted weight with liver for 6113 specimens. The numbers of specimens studied by stock are shown in detail in Table 1.

2.2. Data analysis

Weight-length relationships for combined sexes were calculated for the total weight, gutted weight and gutted weight with liver. Several regression functions were tested and the power function showed the best coefficient of determination (r^2) for the three weight-length relationships studied (Wt-Lt; Wg-Lt; Wgl-Lt): $Wt = a(Lt)^b$; $Wg = a(Lt)^b$; $Wgl = a(Lt)^b$

where: W= total weight [Wt (g)], gutted weight [Wg (g)], or gutted weight with liver [Wgl (g)]; Lt = total length (cm); a, b = parameters of the regression.

The different relationships considered for calculation the weight conversion factors for combined sexes were: total weight (Wt) - gutted weight (Wg) and total weight (Wt) - gutted weight with liver (Wgl). The function used to relate the weights was a linear function with values "0" to intercept with the x-axis: $Wt = aWg$; $Wt = aWgl$

where: Wt = total weight (g); W = gutted weight [Wg (g)] or gutted weight with liver [Wgl (g)]; a = parameter of the regression.

The following weight indices were quarterly estimated by sex because no enough monthly data were available for estimating representative values for both males and females in both species.

- Gonadosomatic index (GSI): $GSI = (Wgo / Wg) \times 100$

where: Wgo = gonadal weight (g); Wg = gutted weight (g).

- Hepatosomatic index (HSI): $HSI = (Wl / Wg) \times 100$

where: Wl = liver weight (g); Wg = gutted weight (g).

- Le Cren's (1951) relative condition factor (K): $K = Wg / a\, Lt^b$

where: K = Le Cren's condition factor; Wg = gutted weight (g); Lt = total length (cm); a, b = parameters of the regression.

Average values of these indices were estimated over one-year period, pooling the ten sampled years. In order to analyze possible differences in the indices between mature and immature individuals, two length ranges were distinguished according to the L_{50} value for each sex estimated by Quincoces (2002) (55 cm in males and 80 cm in females).

Possible differences between both studied stocks in the weight-length relationships and in the weight conversion factors were analyzed by ANCOVA. The comparisons of the GSI, HSI and K between stocks, sexes and immature and mature specimens were carried out using a Mann-Whitney test, and the comparisons among quarters were also performed using a Kruskal-Wallis test. SPSS Statistics 17.0 was used in the analyses.

3. Results

3.1. Weight-length relationships

The parameters resulting from the fitting of the value pairs, total length and weights, of both sexes combined to the power model were obtained. The results of the total weight (Wt) - total length (Lt), gutted weight with liver (Wgl) - total length (Lt) and gutted weight (Wg) - total length (Lt) relationships, their coefficients of determination, sample size and length and weight ranges for each studied area are shown in Table 1, and plotted in Fig. 2.

The regression lines indicated a close relationship and similar parameters in both stocks (eg. just differences between slopes of 1-1.5%). Nevertheless, the comparisons showed significant differences (ANCOVA, $p<0.001$) in the slopes between both stocks in the three weight-length regressions analyzed.

3.2. Weight conversion factors

The conversion factors, sample sizes and length and weight ranges for total weight (Wt) - gutted weight with liver (Wgl) and for total weight (Wt) - gutted weight (Wg) linear relationships in each studied area are shown in Table 2.

Similar Wt-Wgl conversion factors were obtained in both analyzed areas (1.18-1.21). The Wt-Wg conversion factor was also similar in both studied areas (1.24-1.26) (Table 2). Although only small differences were observed in the value of the conversion factors obtained between stocks (just differences of 1.5-2.5%), significant differences (ANCOVA, $p<0.001$) were found between the factors in the two weight-weight regressions (Wt-Wgl and Wt-Wg) analyzed.

3.3. Somatic indices

Significant differences ($p<0.05$) between both areas were found, showing higher K in Div. VIIb,c,h,j,k (values ~0.95-1.05) than in Div. VIIIc-IXa2 (~0.80-0.85) in both sexes (Fig. 3). Although similar GSI are observed in both areas (Fig. 3), higher GSI in Div. VIIb,c,h,j,k ($p<0.05$) also was found in both sexes. Significant differences ($p<0.05$) in HSI between both areas were only found in females (Fig. 3).

In the comparison between sexes, significant differences ($p<0.05$) in K were found, with better condition in females (~5%) in both areas studied (Fig. 3). Higher GSI and HSI in females in both areas were also found in mature specimens ($p<0.05$) (Fig. 3). In immature specimens, no significant differences in GSI between sexes were obtained ($p>0.05$), and higher HSI in immature females were found, except in Div. VIIIc-IXa2.

When mature and immature specimens were compared, significant differences ($p<0.05$) were found for males, with higher GSI and HSI in mature in both sexes (Fig. 3). No significant differences ($p>0.05$) in K were obtained between mature and immature females (Fig. 3). Higher K in immature males was found.

The results of the seasonal comparison are presented separately for mature and immature given the differences found between them. In mature specimens, GSI and HSI showed significant variations ($p<0.05$) among quarters in almost all comparisons in both sexes and stocks (Table 3). K values showed no major seasonal differences in most comparisons performed. Analyzing in detail which quarters showed the differences found, the mature males from both stocks showed higher GSI in the third and mainly fourth quarter (values ~1.5) ($p<0.05$) than in the other quarters (~1) (Fig. 3). Females showed fairly constant throughout the year because few pre-spawning and spawning females were captured. Higher HSI ($p<0.05$) were found in the second, third and fourth quarters (Fig. 3). K values were similar throughout the year in both stocks and sexes in mature (Fig. 3). In summary, in mature white anglerfish, high values of HSI generally begin to be observed one quarter before than the high values of GSI do. In immature specimens, no as clear seasonal trends as those found in mature were obtained neither in GSI, with values lower than 1, nor in HSI, with values close to 3-4 (Fig. 3).

4. Discussion

The parameters estimated here are available to be used in the assessment process of the two studied stocks in Div. VIIb-k and VIIIa,b,d, and in Div. VIIIc and IXa. Regarding the stock Div. VIIb-k and VIIIa,b,d, that of highest landings of both studied, previous published parameters are not known in Div. VIIb-k, one of the main fishing areas of this species, so these here presented are relevant.

The presentation of the results from a broad sampling period, pooling the information of a time series (a decade), was considered the most appropriate, as the data of one or a few years did not provide adequate representation of the range of lengths landed of this species.

The collection of samples to estimate the total weight of the specimens is difficult since individuals are landed gutted by the commercial fleet. Collecting the large specimens also is difficult, given their scarcity in the commercial catches.

4.1. Weight-length relationships and weight conversion factor

The parameters estimated for each stock should only be used in the assessment process of that specific stock, as significant differences have been found between both stocks in almost all the relationships analyzed. However it should be taken into account that when large sample sizes are compared, such as in this study, the statistical tests have so much power that even minimum differences are flagged as statistically significant.

The variability of values among studies (Guillou, 1978; Olaso and Pereda, 1983; Pereda and Villamor, 1991; Pereda et al., 1998; Quincoces, 2002; present study) may be influenced by the difference in the time period studied, but these differences seem to be more related to the different range of values analyzed in each study. The parameters here obtained are similar to those previously obtained of both anglerfish whose values are used in the stock assessment process (Pereda et al., 1998). However, the number of specimens here collected is higher, in addition to representing a broader range of lengths. These improvements in sampling contribute to obtaining more representative and robust parameters. Poor biological information is consistently problematic for all assessment methods. The quality and quantity of data affect the reliability of all stock assessments (Arnold and Heppell, 2015). With more accurate knowledge of state of the stocks, a more efficient management can be performed.

Taking into account the biological significance of the slopes of the weight-length relationships obtained, both species showed $b<3$, meaning the large specimens have changed their body shape to become more elongated (Froese, 2006).

The dispersion of values in the weight-length relationships is greater when using the total weight than using gutted weight (Fig. 2), mainly due both to the influence of the stomach contents and to the gonad weight in the total weight.

The weight conversion factors here estimated are also very useful for a better estimation of the total annual landing because they are landed gutted (without liver) in some Spanish fish markets and gutted (with liver) in other ones.

4.2. Somatic indices

This is the first evidence of comparison of somatic indices between both stocks. The better condition in Div. VIIb,c,h,j,k could be related probably with more favorable feeding and environmental conditions compared to those in Div VIIIc-IXa2.

The better condition found in females when sexes were compared could be related to their high needs in reproduction process. The ripe ovary of *Lophius* can be very large (> 10 m long) with up to 1, 1.5 and 2.4 million eggs in *L. piscatorius, L. litulon* and *L. americanus* respectively (Fulton, 1891; Armstrong, et al., 1992; Afonso-Dias and Hislop, 1996; Yoneda et al., 2001). Quincoces (2002) also found an overall better condition in females in northern Bay of Biscay.

In the comparison between mature and immature specimens, the higher GSI found in mature specimens is directly due to the reproduction process. The higher HSI is also related to it, since the liver is the organ where the vitellogenin (precursor protein of yolk) is synthesized, that is taken by developing oocytes (Wallace and Selman, 1981; Nagahama, 1987). An overall slightly better condition in immature specimens was also found in northern Bay of Biscay (Quincoces, 2002).

In the seasonal analyses throughout the year, higher GSI in mature males were obtained in third and fourth quarters in both studied areas. Spawning males throughout the year were found by Landa et al. (2012) in these same areas, with also a slightly higher proportion in the second, third and fourth quarters. Similar GSI values throughout the year were obtained for mature females, due to the scarce pre-spawning, spawning and post-spawning females caught in the studied areas. Quincoces (2002) found significant higher GSI values in females in northern Bay of Biscay just in November December and May-June, Coinciding with the beginning and end of the overall spawning period in those Atlantic waters, but spawning females are not caught in the intermediate months. Due to this scarcity of spawning females caught it is difficult to clearly delineate the spawning period in white anglerfish in these areas (basically from November-December to June-July) (Duarte et al. 2001; Landa et al., 2012).

Although no seasonal differences in HSI were found in Div VIIb,c,h,j,k, an increase from the first to the third quarter was observed in both sexes in Div.VIIIc-IXa2. It seems consistent finding higher HSI just in the quarter when they were not spawning.

The similarity in the condition (K) for mature individuals throughout the year in most comparisons performed may be related to their extended spawning period, especially noteworthy in males, with ripe individuals for almost all year (Duarte *et al*., 2001; Quincoces, 2002). This lack of seasonality in the condition may be reflecting physiological conditions that would allow a constant supply of energy for the extensive spawning period in this species.

Regarding the immature individuals in the stock VIIb-k and VIIIa,b,d, Quincoces (2002) also found a seasonality of the condition throughout the year in northern Bay of Biscay similar to that here shown in Div VIIb,c,h,j,k, with also higher values in the third quarter. Taking into account the present results and those of Quincoces (2002), and considering both stocks as a whole, the immature individuals of both sexes seem show an overall better condition mainly in summer and, not so remarkable, in autumn. Immature specimens do not transfer energy to gonad development and that energy would be reflected in a better condition. The good condition in summer may be related to the best environmental conditions and food intake that may favor a more active metabolism.

To conclude, this study provides new knowledge on biological parameters of white anglerfish but still more information of spawning females is needed to solve aspects related to their reproduction in these areas.

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Table 1. Parameters of the three weight-length relationships for white anglerfish estimated in the present study and previous studies: total weight (Wt) - total length (Lt); gutted weight with liver (Wgl) - total length (Lt); gutted weight (Wg) - total length (Lt).

	Stock	**VIIIc-IXa**			-	**VII-VIIIa,b,d**			
	ICES Div.	**VIIIc-IXa**	VIIIc-IXa	VIIIc	VIII	**VIIb,c,h,j,k**	VIIIa,b,d	VIIIa,b,d	VIIIa,b,d
	Area	**Southern Bay of Biscay & Galician waters**	Southern Bay of Biscay, Galician & Portuguese waters	Southern Bay of Biscay	Bay of Biscay	**Celtic Sea, Southwestern Ireland & Porcupine**	Northern Bay of Biscay	Northern Bay of Biscay	Northern Bay of Biscay
	Author	**Present study**	Pereda et al. (1998)	Olaso & Pereda (1983)	Pereda & Villamor (1991)	**Present study**	Quincoces (2002)	Pereda et al. (1998)	Guillou (1978)
Wt-Lt	a	**0.025**	0.027	0.021	0.024	**0.027**	0.019	0.026	-
	b	**2.853**	2.839	2.885	2.850	**2.826**	2.915	2.841	-
	n	**3596**	1011	235	239	**3623**	565	563	-
	r^2	**0.992**	0.988	0.989	0.985	**0.989**	0.960	0.988	-
	Length range (cm)	**11-165**	14-121	-	-	**5-135**	12-111	12-111	-
	Weight range (g)	**16-58000**	40-24500	-	-	**2-49000**	6-20789	33-20789	-
Wgl-Lt	a	**0.020**	0.018	-	-	**0.023**	0.018	0.019	-
	b	**2.868**	2.914	-	-	**2.825**	2.885	2.885	-
	n	**3040**	451	-	-	**3073**	1140	1129	-
	r^2	**0.996**	0.987	-	-	**0.987**	0.977	0.993	-
	Length range (cm)	**11-158**	14-163	-	-	**7-135**	12-136	12-111	-
	Weight range (g)	**17-44536**	30-73700	-	-	**4-34183**	27-26000	27-26000	-
Wg-Lt	a	**0.024**	0.021	0.016	0.022	**0.023**	0.015	0.017	0.022
	b	**2.861**	2.851	2.917	2.822	**2.816**	2.922	2.903	2.831
	n	**3047**	803	271	239	**3354**	159	157	-
	r^2	**0.991**	0.993	0.993	0.991	**0.991**	0.989	0.993	-
	Length range (cm)	**11-162**	14-135	-	-	**7-135**	12-111	12-111	-
	Weight range (g)	**16-51400**	36-23000	-	-	**4-33000**	27-14659	27-15985	-

Table 2. Parameters of the two weight-weight relationships for white anglerfish estimated in the present study and previous studies: total weight (Wt) - gutted weight with liver (Wgl); total weight (Wt) - gutted weight (Wg).

Stock		**VIIIc-IXa**		**VII-VIIIa,b,d**		
ICES Div.		**VIIIc-IXa**	VIIIc-IXa	**VIIb,c,h,j,k**	VIIIa,b,d	VIIIa,b,d
Area		**Southern Bay of Biscay & Galician waters**	Southern Bay of Biscay, Galician & Portuguese waters	**Celtic Sea, Southwestern Ireland & Porcupine**	Northern Bay of Biscay	Northern Bay of Biscay
Author		**Present study**	Pereda et al. (1998)	**Present study**	Quincoces (2002)	Pereda et al. (1998)
Wt-Wgl	a	**1.181**	1.129	**1.210**	1.156	1.145
	n	**3031**	354	**3061**	562	559
	r^2	**0.996**	0.997	**0.992**	0.993	0.998
	Wt range (g)	**16-58000**	40-19460	**2-49000**	33-20789	33-20789
	Wgl range (g)	**17-44536**	30-17050	**4-34183**	27-15985	27-17311
Wt-Wg	a	**1.241**	1.176	**1.262**	1.324	1.248
	n	**3037**	722	**3341**	157	157
	r^2	**0.996**	0.998	**0.992**	0.991	0.997
	Wt range (g)	**16-58000**	46-19814	**2-49000**	33-20789	33-20789
	Wg range (g)	**16-51400**	36-17133	**4-33000**	27-14659	26-15985

Table 3. Results of the Kruskal–Wallis tests comparing among quarters three indices: gonadosomatic index (GSI), hepatosomatic index (HSI) and Le Cren's condition factor (K) in both sexes of white anglerfish from both studied areas. (p<0.05: *; p<0.01: **; p<0.001: ***).

mature		Div VIIb,c,h,j,k	Div.VIIIc-IXa
males	GSI	***	***
	HSI	n.s.	**
	K	n.s.	n.s.
females	GSI	***	*
	HSI	n.s.	***
	K	n.s.	***
immature			
males	GSI	**	**
	HSI	*	**
	K	***	**
females	GSI	n.s.	***
	HSI	n.s.	***
	K	n.s.	*

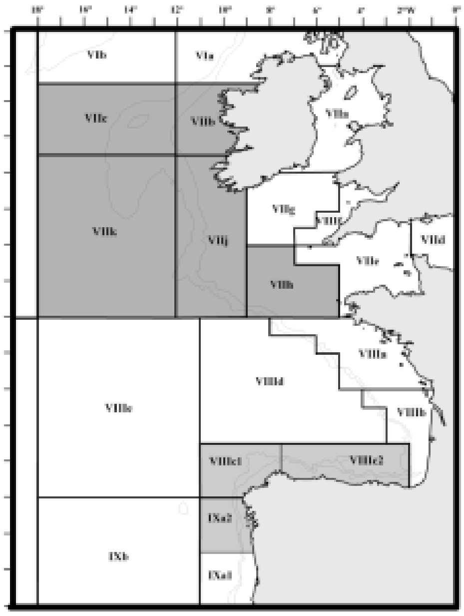
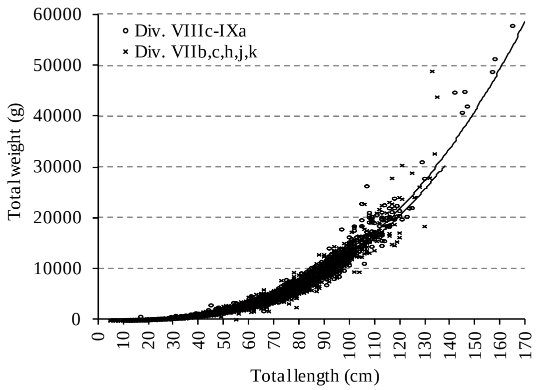
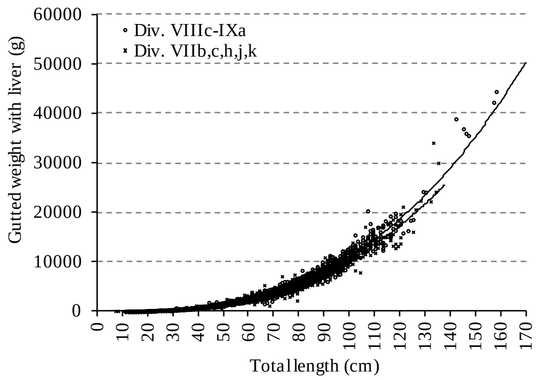


Fig. 1. Sampling ICES Divisions of North-east Atlantic: Celtic Sea, south-western Ireland and Porcupine Bank (Div. VIIb,c,j,h,k) (dark grey); and northern Iberian Atlantic waters (Div. VIIIc-IXa2) (southern stock of the southern shelf) (light grey).

A)



B)



C)

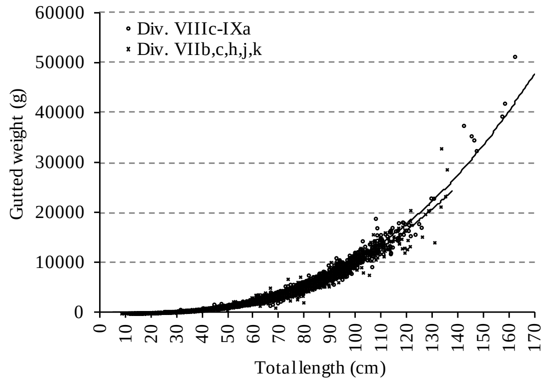
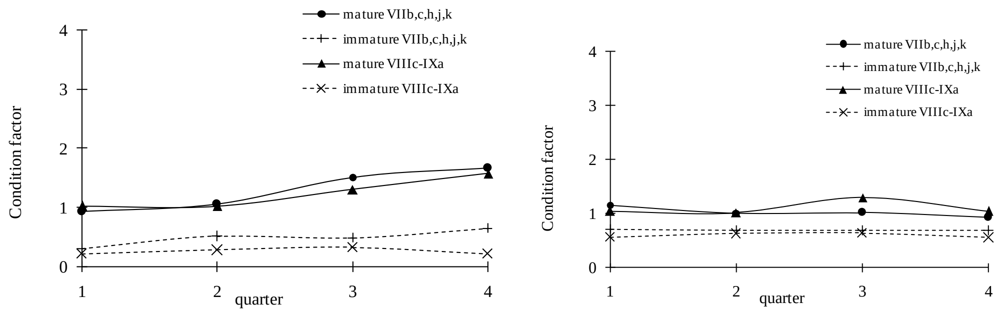
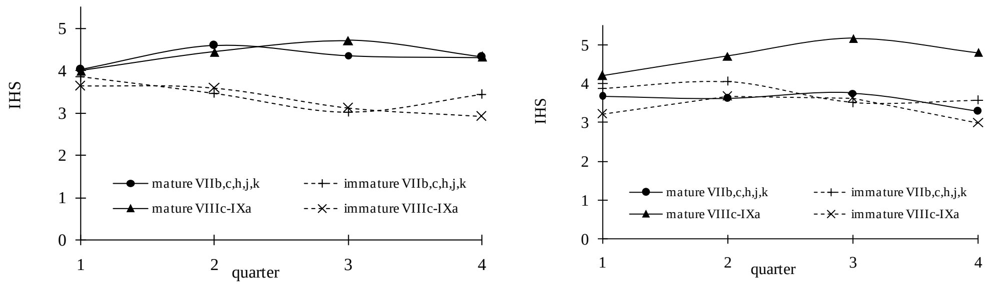


Fig. 2. Weight - length relationships estimated for white anglerfish in ICES Div. VIIIc-IXa2 and Div. VIIb,c,h,j,k: A) total weight (Wt) - total length (Lt), B) gutted weight with liver (Wgl) - total length (Lt), C) gutted weight (Wg) - total length (Lt).

A)



B)



C)

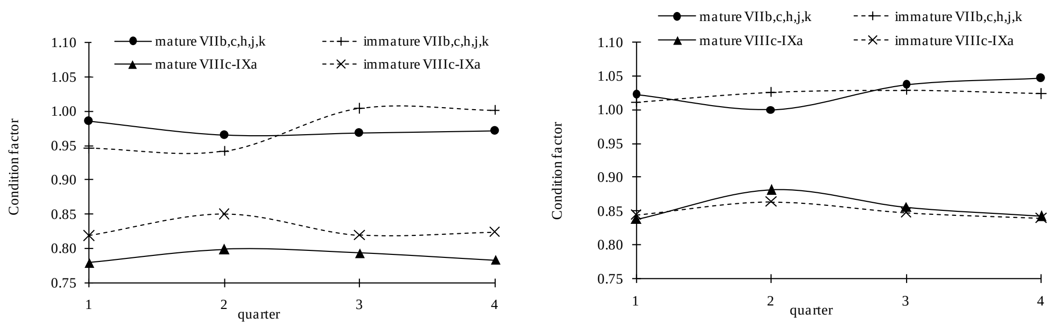


Fig. 3. Seasonal variations of the median values of: A) gonadosomatic index (GSI), B) hepatosomatic index (HSI) and C) Le Cren's condition factor (K); in males (left) and females (right) white anglerfish.