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Distribution, population structure and dynamics of the black anglerfish (*Lophius budegassa*) (Spinola, 1987) in the Eastern Mediterranean Sea

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ABSTRACT

This study provides a contribution to the knowledge on distribution, population structure and dynamics of *Lophius budegassa* in the North-western Ionian Sea (Eastern Mediterranean Sea) as well as an estimation of its exploitation condition. Data were collected during 23 trawl surveys carried out in spring-summer and autumn from June 1995 to November–December 2006. Specimens were collected between 13 and 745 m. No significant trends were shown in the fluctuation of the abundance indices throughout the study period, indicating a stable condition in the stock distributed from the shelf to the upper slope. A decreasing trend with depth was only shown in the density index values. The greatest biomass values were recorded in autumn and the highest incidence of juveniles (TL < 14 cm) was observed mainly during the spring. The sizes of the specimens in the catch were between 3.5 and 114 cm TL. However, the sampled population was mostly made up of specimens smaller than 24 cm TL. The females measured between 8 and 114 cm TL and the males between 10 and 93 cm TL. The sex ratio fluctuated greatly during the investigated period and according to depth. The smallest mature female and male measured 30.5 and 17 cm TL, respectively. Mature individuals were collected both in spring and autumn. Their contribution to the sampled population was generally rather negligible, mostly in females. The estimated growth parameters were quite different between sexes with females ($L_\infty = 68.45$ cm; $k = 0.112\ y^{-1}$; $t_0 = -1.18$ y; $\Phi' = 2.72$) achieving older size-age than males ($L_\infty = 60.30$ cm; $k = 0.109\ y^{-1}$; $t_0 = -1.56$ y; $\Phi' = 2.60$). The age and growth performance examined in this study was confirmed by means of back calculation and, for the first years, by length–frequency analysis.

The mortality rate (Z) calculated using the growth parameters derived from the direct age estimation varied between the annual value of 0.54 in 2001 and that of 0.87 in 2000 and 2003. The natural mortality rate (M) was computed using different approaches. In females it was between 0.24 and 0.23 while in males was between 0.25 and 0.24.

Adopting two sets of growth parameters for sex combined and the M value of 0.22 and the value of 0.39, two scenarios for fishing mortality rates and exploitation ratios were obtained. Although, the total and fishing mortality rates and exploitation ratios fluctuated throughout the sampling period no significant trends were detected. The E values changed between 0.59 and 0.77 and no significant differences were observed with the two scenarios.

A growth overfishing condition was detected for the stock in the North-western Ionian Sea. The exploited stock of *L. budegassa* in the Ionian Sea mainly consists of juveniles younger than 3–4 years old. Although, spawners are extremely scarce, most probably as a consequence of fishing pressure, the continuity of recruitment seems to be guaranteed by adults distributed in "refuge areas" where trawl fishing does not occur.

1. Introduction

The black anglerfish (*Lophius budegassa*) (Spinola, 1987) is a demersal fish with a wide depth distribution, from coastal waters to around 800 m. It is distributed in the north-eastern Atlantic, from the British Isles to Senegal and throughout the Mediterranean Sea (Fisher et al., 1987; Relini et al., 1999). Studies on age and growth have been conducted in the Atlantic (Dupouy et al., 1986; Peronnet et al., 1992; Duarte et al., 1997; Quincoces et al., 1998; Landa et al., 2001) as well as annual evaluations of fishing mortality and the exploitation status of the stocks (ICES, 2007a). In the Mediterranean studies dealing with age and growth (Tsimenidis and Ondrias, 1980; Tsimenidis, 1984; Garcia-Rodriguez et al., 2005) were provided together with an insight on distribution, abundance and size

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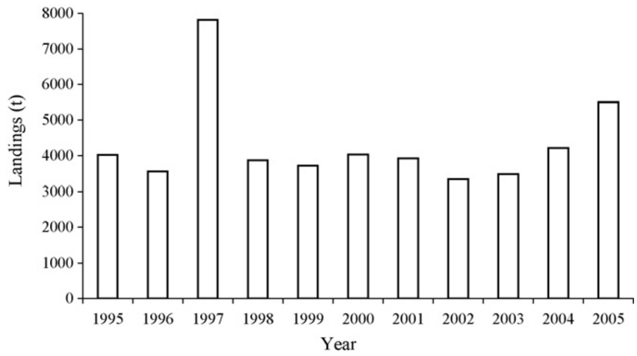

Fig. 1. *Lophius* landings recorded from 1995 to 2005 in the Mediterranean Sea (FAO data).

composition (Ungaro et al., 2002; Maravelias and Papaconstantinou, 2003). In the Mediterranean both *Lophius* species (*L. budegassa* and *L. piscatorius*) represent important fractions in the catches from bottom trawling although depth and geographic factors can affect distribution and abundance (Relini et al., 1999; Ungaro et al., 2002, Maravelias and Papaconstantinou, 2003). FAO Fishery Statistics (2006) report fluctuating catches of both *Lophius* species of around 4000 tons per year in the period 1995–2005 with a landing peak of about 8000 tons during 1997 (Fig. 1). Even though official statistics do not distinguish between the two species due to their similar external characteristics, since the main distinguishing feature is the colour of the peritoneum (dark in *L. budegassa* and pale in *L. piscatorius*), there are Mediterranean areas, such as the Ionian Sea (Eastern Mediterranean Sea), where *L. budegassa* is by far more abundant than *L. piscatorius* (Relini et al., 1999). Although *L. budegassa* is a species appreciated in the Ionian fisheries, as in many Mediterranean basins, and it is a target species of the Mediterranean programme on demersal resources (Bertrand et al., 2000), there are no comprehensive studies on the population dynamics of this fish.

The aim of this paper is to contribute to the knowledge on the distribution, population structure, recruitment, age and growth, maturity and mortality of *L. budegassa* in the North-western Ionian Sea (Eastern Mediterranean Sea) as well as evaluating the exploitation condition in the context of a study period of 11 years between 1995 and 2006.

2. Materials and methods

2.1. Data collection

Data were collected during 23 experimental trawl surveys carried out in the framework of national (GRU.N.D.) (Relini, 1998, 2000) and international (MEDITS) (Bertrand et al., 2000, 2002) projects on the assessments of the demersal resources in the Mediterranean Sea. These surveys were carried out, in autumn and spring, respectively, in the period 1995–2006. The investigated area is the North-western Ionian Sea, from Cape Otranto to Cape Passero (Eastern Mediterranean Sea) (Fig. 2). The examined depth is between 10 and 800 m. During each survey a random stratified sampling design was adopted and 74 daylight hauls were allocated proportionally to the following depth strata: 10–50 m, 51–100 m, 101–200 m, 201–500 m, 501–800 m. Only during October–November 1995 the same experimental design was adopted, carrying out 36 hauls. Commercial (GRU.N.D.) and experimental (MEDITS) trawl nets were used with a stretched mesh size of 40 and 20 mm in the cod-end, respectively. The Scanmar Sonar System was applied on the trawl net in order to estimate the horizontal net opening during each experimental haul (Fiorentini et al., 1994).

2.2. Methods

Catch data were standardized for each haul in terms of density (N/km^2) and biomass (kg/km^2) index (Cochran, 1977; Pauly, 1983). The changes with time and depth of both the abundance indexes were evaluated using the non-parametric Spearman correlation (Conover, 1980). Differences between the abundance indices of the two seasons were detected by means of the non-parametric Kruskall–Wallis test (Conover, 1980).

The total length TL (cm) and weight (g) were measured. The length–frequency distributions were computed for each survey and the difference between the size structure in the females and males was analysed by means of the non-parametric Kolmogorov–Smirnov test (Conover, 1980). In addition, the mean sizes calculated in each survey for females and males were compared by means of the parametric Student's *t*-test.

The median length was also calculated for the whole sampled population during each survey in order to evaluate eventual changes by time and depth. The changes with time and depth in the median length were analysed by means of the non-parametric Spearman correlation and the differences between spring and autumn surveys were verified using the non-parametric Kruskall–Wallis test. The median length was adopted in order to minimize the effect due to the differences between sexes, extreme values and asymmetric distributions.

In each survey, the recruitment index (RI) was calculated as the percentage of juveniles on the whole sampled population. In particular, the individuals with size less than 14 cm TL were considered juveniles for spring (Ungaro et al., 2002), while according to growth process, those with size less than 20 cm TL were considered juveniles for autumn. The changes with time and depth in the RI were analysed by means of the non-parametric Spearman correlation and the differences between spring and autumn surveys were verified using the non-parametric Kruskall–Wallis test.

Statistical differences between the number of females and males by survey and depth strata were determined using the *G*-test (Sokal and Rohlf, 1969).

Maturity for females and males was observed in specimens larger than 10 cm TL applying the Nikolsky (1963) scale. In particular, the species was considered a determinate spawner (Alfonso-Diaz and Hislop, 1996) and the following maturity stages were recorded: (I) virgin; (II) immature (developing and resting); (III) maturing; (IV) mature; (V) running ripe; (VI) spent. The adopted scale distinguishes the virgin (I) and immature (II) stages, which are both considered as immature stage in the scale proposed for the maturity of anglerfish by the ICES (2007b) working group. The percentage of mature specimens (mature and running ripe) was calculated in each survey for females and males separately.

With the aim of studying the age and growth of *L. budegassa*, a collection of 931 specimens sampled during the trawl surveys carried out from 2002 to 2006, was used. Age estimation was carried out according to the methodology proposed during "Age workshops on European anglerfish in Atlantic waters" (Dupouy, 1997; Anon, 2000; Dupouy et al., 2002; Duarte et al., 2005) and applied in some specific studies on the growth of *L. budegassa* (Dupouy et al., 1986; Peronnet et al., 1992; Duarte et al., 1997, Landa et al., 2001). In particular, the first dorsal fin ray (*illicium*) was cleaned of organic residuals using a 40% NaOH solution and kept frozen. The *illicia* were mounted in epoxy resin and cut using a low speed diamond wheel saw with micrometric knob. According to Duarte et al. (1997), 500 μm thick sections were taken from 5 mm above the peduncle up to the middle of the *illicium*. The sections were glued

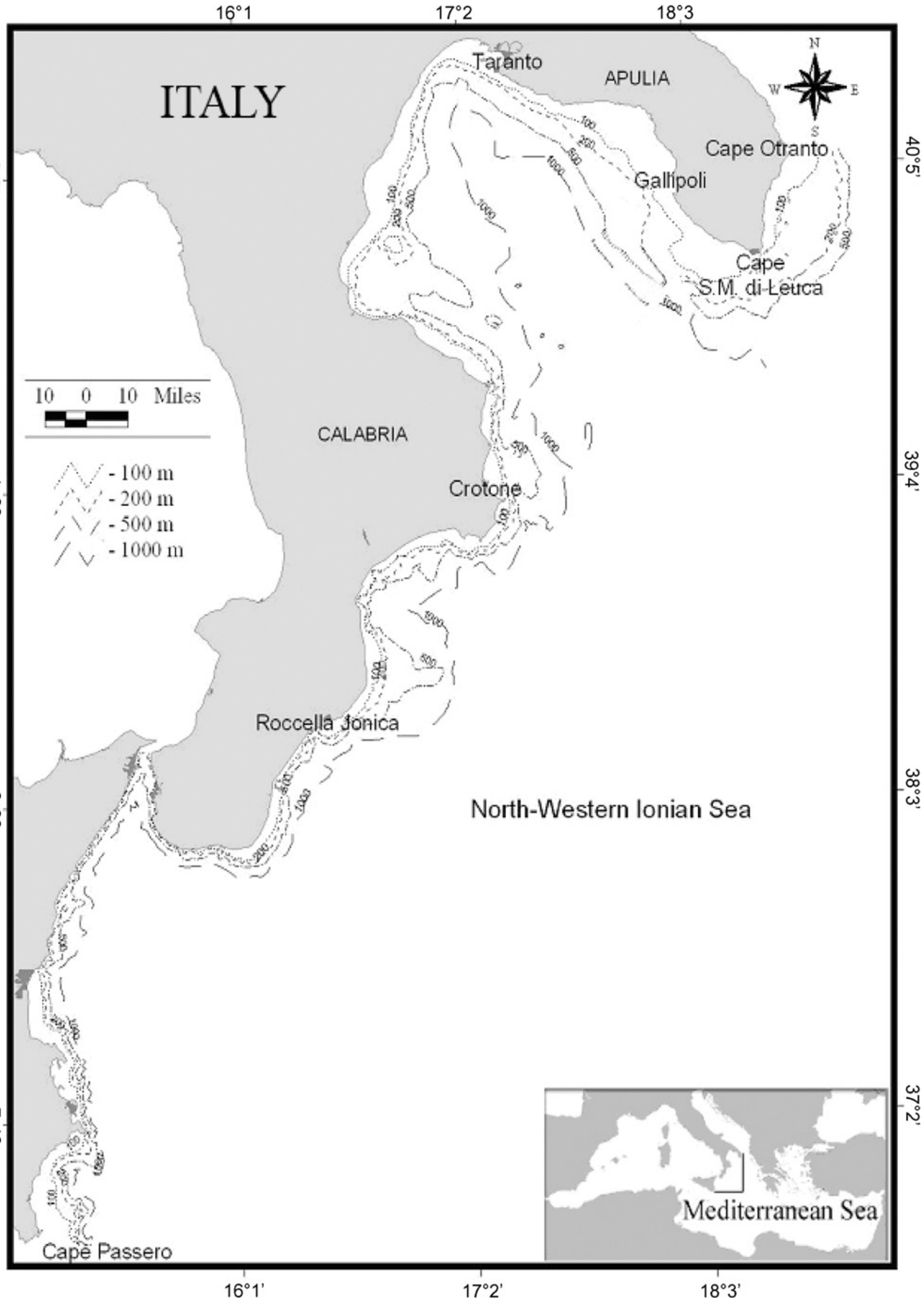

Fig. 2. Map of the study area.

onto the slide with Entellan adhesive. Observations were carried out under a Leica optical stereomicroscope using a 10× ocular and a 10× objective. Sometimes the cross-sections were scarcely visible because of a "scratch effect" due to the diamond wheel saw. In these cases, the sections were buffed on a felt rotating plate and the rings were enhanced with alumina paste. A digital video system linked to the stereomicroscope was used to acquire images of the alternating growth zones. Wide opaque and narrow translucent zones were observed in the sections, marking the faster and the slower growth zones, respectively (Dupouy, 1997). The alternation of these two zones is assumed to correspond to 1 year.

According to Lo Bianco (in Costa, 1999), the shifting from the pelagic larval to the benthic phase occurs at a size of 3.5–6.0 cm TL. In fact, the young-of-the-year were observed at these sizes showing a clear demersal ring. Considering that the reproduction of *L. budegassa* occurs during the early winter season (Bigelow and Schroeder, 1953; Maravelias and Papaconstantinou, 2003; Carbonara et al., 2005), the birth date was conventionally defined as the 1st of January (Duarte et al., 1997). The age-length keys (ALKs) were elaborated for females and males separately and for both sexes combined. The Von Bertalanffy Growth Function (VBGF) was adopted using the "Length at Age" routine in FiSAT II (Gayanilo et al., 2006). The differences in the lengths at age by sex were compared by means the ANCOVA test in the SYSTAT 12.0 programme. The growth performance (ϕ') was calculated according to Munro and Pauly (1983) in the form of $\phi' = \log_{10}(k) + 2\log_{10}(L_\infty)$, in order to compare the present estimates with others carried out using different methodologies or referred to other study areas.

Back calculation is a common technique used to obtain estimates of the fish sizes corresponding to its earlier ages, which are often biased or defective in direct readings (Francis, 1990; Panfili et al., 2002). Considering the relationship between *radius* in *illicium* and the size (TL) in the specimen, it was assumed that the width of each growth zone is proportional to the somatic growth. Thus, the measurement of *radius* of each growth zone was taken using the digital video system. The distance between the centre of *illicium* and the external edge of each observed growth zone was measured in the section in μm (R_i). In particular, the demersal ring (R_0) and the external edge of *illicium* (R_T) were recorded, for each observed specimen, using the digital system coupled to the stereomicroscope. In both sexes, the TL and R_T pair values were analysed by means of linear regression analysis. The values of the intercept in the linear regressions represents an estimation of the size at birth (TL_{birth}), which takes into account the allometric relationship between TL and R_T, and reduces the eventual errors in the back-calculated size of younger fish (Lee's phenomenon) (Landa and Pineiro, 2000). Using the "size at birth-modified" model proposed by Fraser–Lee (in Campana, 1990), the TL_i corresponding to each year of life (i) were back-calculated for females, males and both sexes combined, taking into account the relevant values of TL_{birth}:

$$TL_i = TL_{birth} + (TL - TL_{birth})\left(\frac{R_i}{R_T}\right)$$

The differences between sexes in the back-calculated mean lengths at age were verified using the non-parametric Kruskall–Wallis test.

The mean TL calculated for each age class using the readings of *illicium* (direct method) and the corresponding back-calculated mean TL were compared by means of the non-parametric Mann–Whitney *U*-test (Conover, 1980).

A length–frequency analysis was carried out looking for alternative growth estimates comparable with those from the direct readings of *illicium*. Two cumulated length distributions (LFDs) were calculated for sexes combined, pooling all the spring and autumn surveys, respectively. The main modal components in the LFDs were separated by means of the Bhattacharya's method and the growth parameters were estimated applying the "Length at Age" routine in FiSAT II (Gayanilo et al., 2006). The differences between the selected modal components and the estimated mean lengths at age derived from direct readings were verified by means of the non-parametric Mann–Whitney *U*-test.

The total mortality rate (Z) was computed for the whole sampled population each year using pooled data from the spring and autumn surveys. The "length-converted catch curve" method was applied as reported in FiSAT II (Gayanilo et al., 2006). The value of growth parameters estimated for both sexes combined was adopted in order to calculate Z values. In particular, the growth parameters derived from both direct readings of *illicium* and length–frequency analysis were adopted to estimate the Z values. The changes during the study period were evaluated by means of the non-parametric Spearman correlation. In addition, the differences between the Z values from the two growth parameter sets were evaluated by means the non-parametric Mann–Whitney *U*-test.

The natural mortality rate (M) was computed using the methods proposed by Pauly (1980) and Djabali et al. (1993), allowing an estimation of the fishing mortality rate for the whole population ($F = Z - M$). The exploitation ratio ($E = F/Z$) was computed for each year and the changes during the study period were evaluated by means of the non-parametric Spearman correlation. The comparison between the estimates of F and E values, calculated using the growth parameters derived from the direct readings of *illicium* and those from the length–frequency analysis was verified by means the non-parametric Mann–Whitney *U*-test.

3. Results

3.1. Distribution, abundance and sizes

Specimens of *Lophius budegassa* were collected between 13 and 745 m of depth (Table 1). The finding percentage, calculated as positive hauls over the total, fluctuated between 28 and 61% and the number of specimens collected between 53 and 760. The highest density value of 1574.60 N/km^2 was estimated at a depth of 150 m while the lowest 8.72 N/km^2 was observed at a depth of 563 m, indicating a significant decreasing trend with depth ($r_s = 0.81$; $p < 0.05$) (Fig. 3). The biomass index values fluctuated between 0.01 kg/km^2 (528 m) and 266.51 kg/km^2 (145 m) not indicating any depth tendency. Considering the whole depth range (10–800 m), the highest mean density index (218 ± 311 N/km^2) was recorded in September–October 2002 and the lowest (34 ± 33 N/km^2) in June 1997 (Fig. 4). The highest (24.29 ± 42.83 kg/km^2) and the lowest mean biomass index values (3.96 ± 5.08 kg/km^2) were recorded in October–November 1995 and June 1997, respectively. Both the abundance indices greatly fluctuated during the study period without any significant trends. However, the mean biomass index values were significantly higher in autumn than in spring ($p < 0.05$).

The sizes in the sampled population were between 3.5 and 114 cm TL. The females and males measured between 8 and 114 cm TL and between 10 and 93 cm TL, respectively. Both in females and males the maximum sizes were recorded in single individuals. The most abundant modal lengths were at 10–12 cm TL in

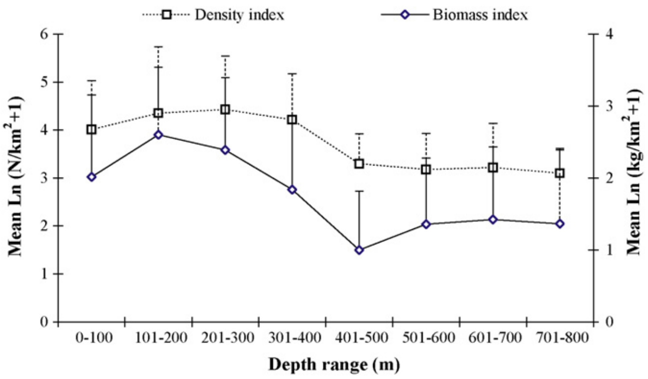

Fig. 3. Relationship between the mean ln-transformed abundance indexes (with standard deviation) and depth for *L. budegassa* sampled in the North-western Ionian Sea during 1995–2006.

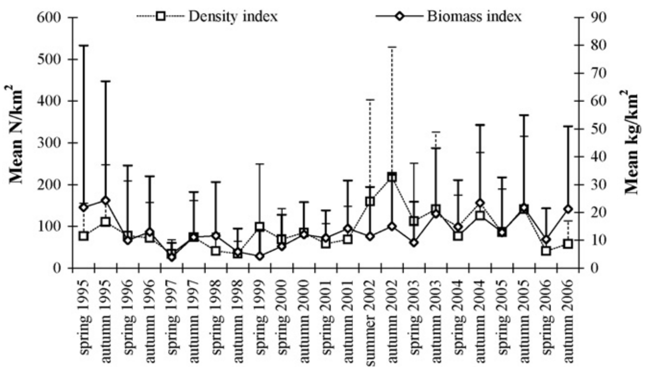

Fig. 4. Distribution of the mean density index values (N/km^2) and mean biomass index values (kg/km^2) (with standard deviation) calculated in depth range 10–800 m for the population of *L. budegassa* sampled in the North-western Ionian Sea during 1995–2006.

Table 1
Survey date, number of hauls, percentage of positive hauls, depth range of finding, number of specimens and average number of specimens by haul of *L. budegassa* collected during the trawl surveys carried out during 1995–2006 in the North-western Ionian Sea

Year	Month	No. of hauls	Positive hauls (%)	Depth range of finding (m)	No. of specimens	Average number of specimens by haul
1995	June	74	28	53–657	117	2
1995	October–November	36	47	60–595	140	4
1996	June	74	36	33–553	128	2
1996	November–December	74	49	35–576	209	3
1997	June	74	34	30–535	58	1
1997	September–October	74	39	50–543	172	2
1998	May	74	31	55–573	53	1
1998	September	74	30	48–563	58	1
1999	May	74	46	32–543	192	3
2000	May	74	57	36–610	179	2
2000	September–October	74	54	48–675	275	4
2001	May	74	51	29–583	132	2
2001	September–October	74	50	53–533	206	3
2002	July	70	57	58–725	434	6
2002	September–October	74	59	57–621	760	10
2003	June	70	61	39–688	299	4
2003	October–November	70	59	35–745	484	7
2004	June	70	53	13–661	165	2
2004	October	70	56	23–714	365	5
2005	June	70	51	32–719	222	3
2005	November–December	70	59	47–687	320	5
2006	June	70	53	50–674	111	2
2006	November–December	70	37	111–695	91	1

spring and 16–18 cm TL in autumn (Fig. 5). The size structures of females were significantly different from males ($D = 0.064$; $p < 0.01$) and the mean sizes of females were significantly greater than males ($t = 2.648$; $p < 0.05$). The sex ratio greatly fluctuated during the investigated period ($G = 109.146$; $p < 0.001$) and with depth ($G = 59.671$; $p < 0.001$) (Figs. 6 and 7), indicating a slight dominance of males in the area.

The recruitment index values fluctuated between 12 and 91% without any significant temporal trend. No significant differences were recorded in the RI values between the spring and autumn surveys throughout the study period (Fig. 8). The changes of the RI values with depth were no significant in both seasons and no significant differences were observed between the spring and autumn surveys (Fig. 9).

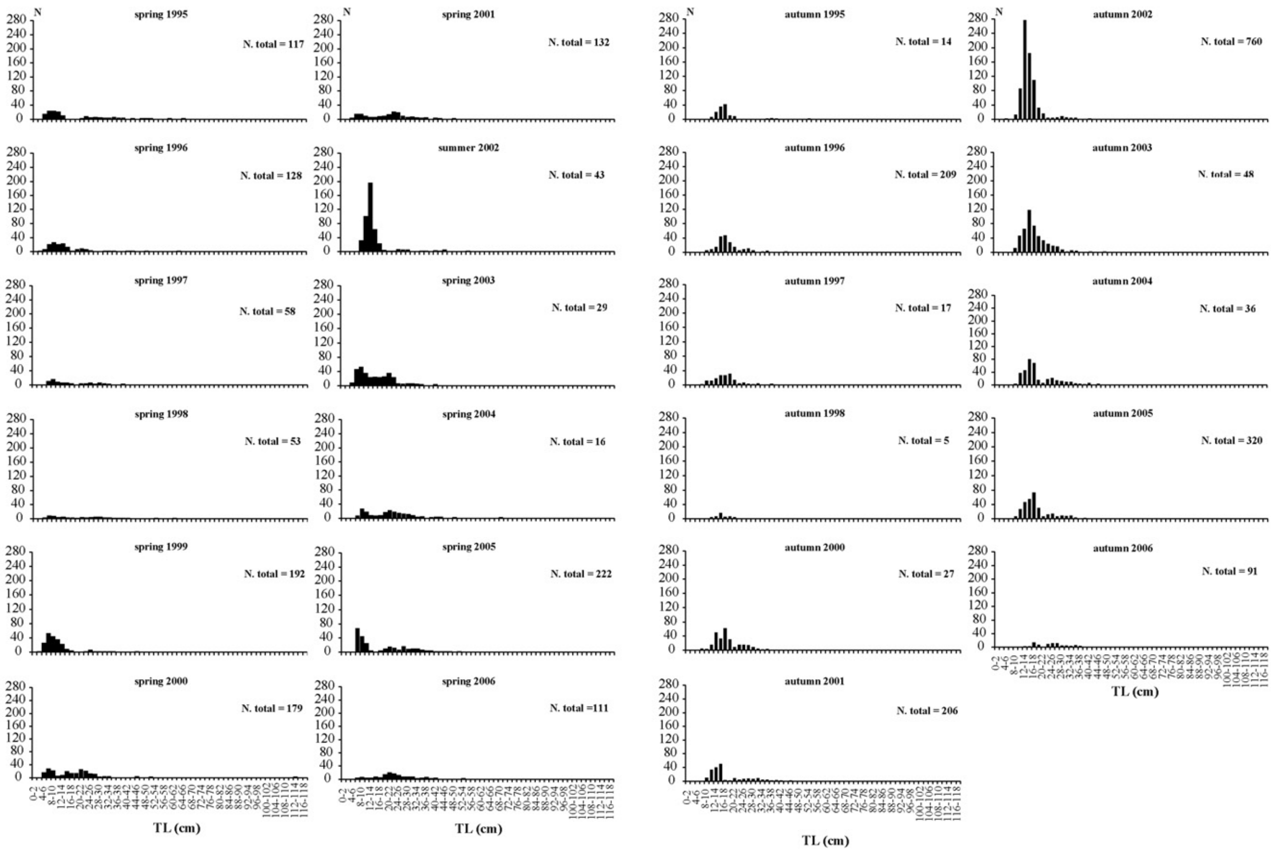

Fig. 5. Length–frequency distribution calculated for the specimens of *L. budegassa* collected during the spring and autumn surveys in the North-western Ionian Sea.

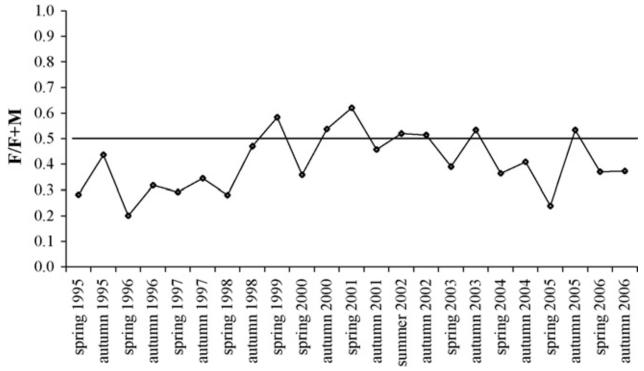

Fig. 6. Sex ratio by survey calculated for *L. budegassa* collected in the North-western Ionian Sea from June 1995 to November–December 2006.

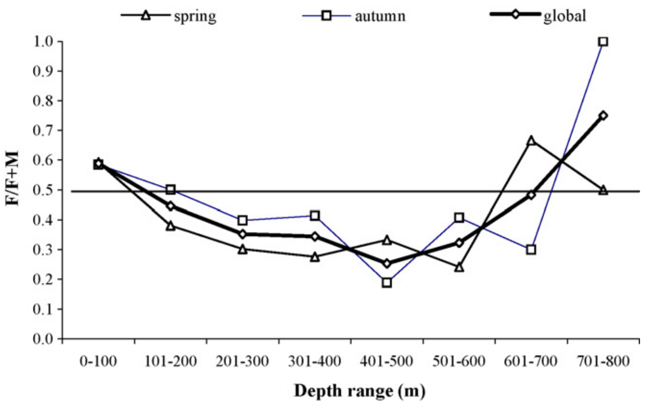

Fig. 7. Sex ratio by depth range calculated for *L. budegassa* collected in the North-western Ionian Sea from June 1995 to November–December 2006.

The median sizes of the sampled population fluctuated between 8.8 and 25 cm TL throughout the study period without any significant trend (Fig. 10). However, the median lengths in autumn were significantly greater than in spring ($p < 0.05$). The changes of the median sizes by depth were no significant (Fig. 11).

3.2. Maturity

Mature individuals (IV + V) were collected both in spring and autumn (Table 2). However, their percentages in the sampled population were generally rather negligible mostly in females. The

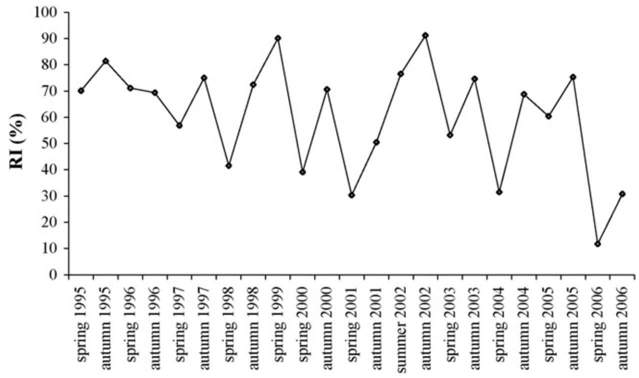

Fig. 8. Changes by time in the recruitment index (RI) calculated for *L. budegassa* collected in the North-western Ionian Sea from June 1995 to November–December 2006.

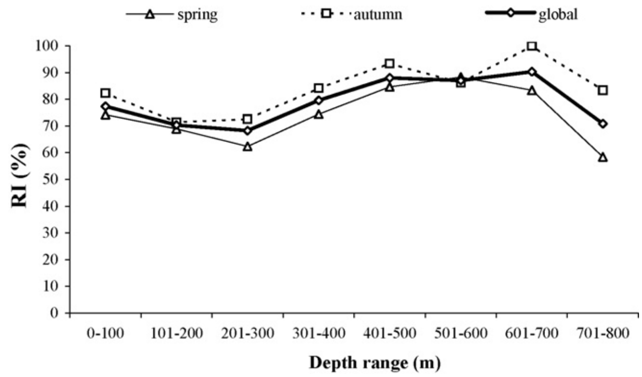

Fig. 9. Changes by depth in the recruitment index (RI) calculated for *L. budegassa* collected in the North-western Ionian Sea from June 1995 to November–December 2006.

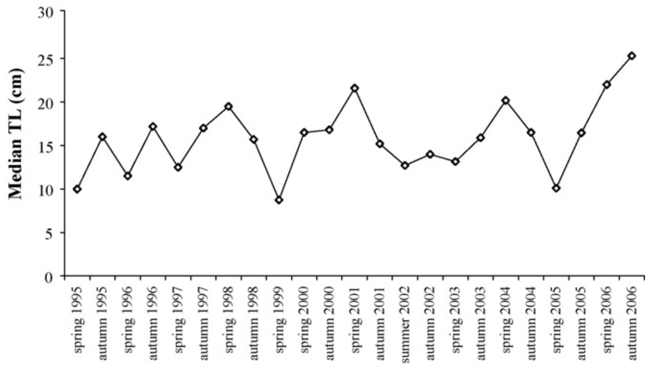

Fig. 10. Trend of the median length calculated in the depth range 10–800 m for *L. budegassa* sampled in the North-western Ionian Sea during 1995–2006.

smallest mature female and male measured 30.5 and 17 cm TL, respectively.

3.3. Age and growth

3.3.1. Direct readings

A total of 931 *illicia* were collected from 326 females (sizes between 10 and 71 cm TL), 305 males (sizes between 11.5 and 42 cm TL), and 300 juveniles (sizes between 4 and 11.5 cm TL). About 9% of *illicia* were excluded in both sexes because they were unreadable.

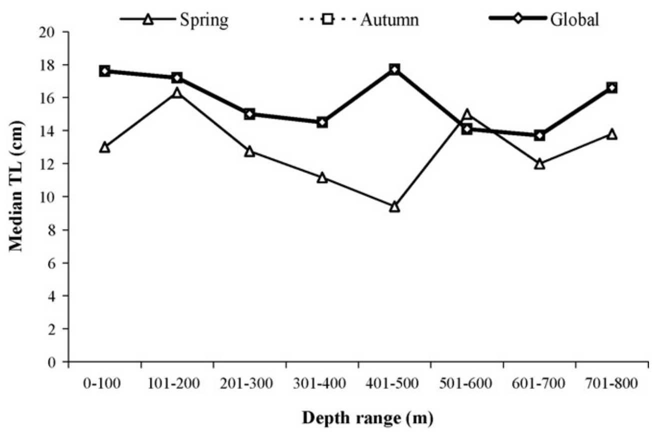

Fig. 11. Median length by depth for the population of *L. budegassa* sampled in the North-western Ionian Sea from June 1995 to November–December 2006.

Table 2
Total number of females and males of *L. budegassa* collected in the North-western Ionian Sea from 1995 to 2006 with indication of percentage of mature specimens and relative size range

	Females				Males			
	Total		Mature		Total		Mature	
	N	TL range (cm)	%	TL range (cm)	*N*	TL range (cm)	%	TL range (cm)
June 1995	11	21.5–64.5	9.09	64.5	28	10–46	42.86	22–43.5
October–November 1995	58	10–63	3.45	53–63	75	10–42.5	4.00	32.5–42.5
June 1996	7	15–24	0.00	–	28	11.5–62	7.14	35–41
November–December 1996	57	11–71	3.51	60–71	122	10–43	4.10	24–40.5
June 1997	7	14–38	0.00	–	17	13–31.5	0.00	–
September–October 1997	39	14.5–54.5	0.00	–	74	12.5–43	5.41	24–43
May 1998	7	22.5–52.5	0.00	–	18	16–40.5	11.11	30.5–38
September 1998	8	17–55	0.00	–	9	14–40	33.33	27–40
May 1999	7	11–45	0.00	–	5	26–35	40.00	31.5–35
May 2000	86	18–114	3.45	30.5	52	15–51	1.92	24.5
September–October 2000	29	14–66.5	1.16	47	74	15–37.5	13.51	24–37.5
May 2001	49	11–48	0.00	–	30	16–42	6.67	27–33
September–October 2001	32	18–55.5	0.00	–	38	16–45	21.05	30–45
July 2002	13	24–54	0.00	–	12	21–45	16.67	29–34
September–October 2002	167	12–58	0.00	–	158	12–93	2.53	32.5–39
June 2003	43	14–41.5	0.00	–	67	12–34	2.99	33–34
October –November 2003	213	11–69	0.47	41	186	12–51	1.61	30–39
June 2004	40	13–68	0.00	–	70	16–42	17.14	26–42
October 2004	132	8–60	0.76	45.5	191	11–41	11.52	17–41
June 2005	21	17–51	4.76	51	67	17.5–43	16.42	26–40
November–December 2005	152	12–71	1.97	39–71	133	11–42	21.05	22–42
June 2006	37	12.5–52	2.70	41	63	14–40	17.46	25–40
November–December 2006	34	13–58	5.88	54–58	57	13.5–40	28.07	26.5–40

The observed *illicia* had the specific circular shape showing an opaque nucleus in the middle. The thickness of the growth rings remained quite constant with increasing age. The first wide opaque zone corresponded to the demersal ring (Fig. 12). According to Lo Bianco (in Costa, 1999), the shifting from the pelagic larval to the benthic phase occurs at a size of 3.5–6.0 cm TL. In fact, the young-of-the-year were observed at these sizes showing a clear demersal ring. Starting from the demersal ring, the course of the narrow translucent and opaque zone conventionally corresponded to one year. The minimum (1) and maximum (17) ages were observed in a specimen of 10 cm TL and in two females with sizes of 71 cm TL, respectively. The minimum (1) and maximum (10) ages in males corresponded to specimens of 11.5 cm TL and 42 cm TL, respectively. In the juveniles with sizes less than 5.5 cm TL, the observed sections showed only the demersal ring. In particular, the minimum age (0) was assigned in 2 specimens with 4.3 cm TL.

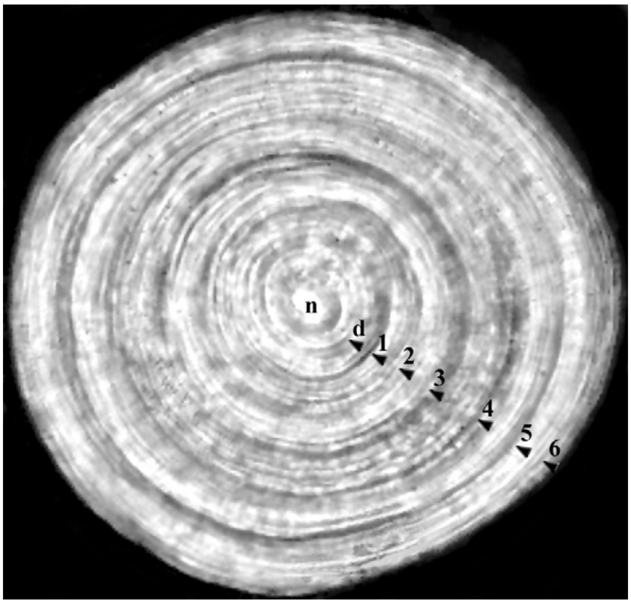

Fig. 12. Section of *illicium* with indication of the nucleus (n), the demersal (d) and annual rings observed in a female of *L. budegassa* (36.5 cm TL and estimated age of 6+ years) collected in the North-western Ionian Sea.

The growth parameters were estimated for females and males separately and for both sex combined using the corresponding age-length keys. The mean lengths at age estimated from a reduced number of specimens were not included in the growth estimations. Thus, the maximum ages in the adopted ALKs were 8 for both females and males. The growth was high significantly different between the two sexes with females obtaining lengths at age greater than males ($F = 81.41$; $p < 0.001$).The estimated growth parameters and the growth performance values were reported in Table 3.

A sub-sample of 70 sections of *illicium* was extracted according a *sex ratio* of 1:1. The size range was between 12.5 and 60 cm TL in females and between 12.5 and 35 cm TL in males. Moreover, 8 sections of the *illicium* collected from juveniles with sizes from 6.8 to 9.7 cm TL were added to the sample.

In the sections, the distance between the centre of the *illicium* and the external edge of each observed growth zone was measured. Regression analysis showed a highly significant linear correlation between TL and the external edge of *illicium* (R_T) in both sexes ($p < 0.001$) (Fig. 13). The intercept was 8.7 cm and 6.9 TL in females and males, respectively. Therefore, the application of the "size at

Table 3
Growth parameters with standard error (S.E.) and growth performance (Φ') estimated for the females (F), males (M) and sex combined (F + M) by direct readings of *illicia* collected from *L. budegassa* specimens sampled in the North-western Ionian Sea from 2002 to 2006

Growth parameters	F	M	F + M
No. of specimens	292	273	565
L_∞ (cm) ± S.E.	68.450 ± 15.479	60.300 ± 7.670	68.390 ± 25.730
k (year^{-1}) ± S.E.	0.112 ± 0.044	0.109 ± 0.003	0.100 ± 0.065
t_0 (year) ± S.E.	−1.176 ± 0.390	−1.562 ± 0.270	−1.430 ± 0.670
Φ'	2.721 ± 0.320	2.600 ± 0.449	2.670 ± 0.565

Table 4
Mean TL_i by age class, calculated for females, males and sex combined in *L. budegassa* by means of back calculation method

	Age (year)									
	0	1	2	3	4	5	6	7	8	9
Females										
Mean TL_i (mm)	115.08	143.44	171.46	200.36	226.91	256.40	286.29	315.54	347.04	383.15
S.D.	13.84	13.92	15.91	18.88	25.60	21.84	25.58	27.29	31.67	38.64
Males										
Mean TL_i (mm)	99.64	128.91	158.77	189.19	218.79	256.24	274.02	305.35	344.65	386.87
S.D.	13.07	15.07	17.59	18.03	18.28	37.54	19.30	21.45	6.40	13.70
Sex combined										
Mean TL_i (mm)	107.36	136.22	165.20	194.99	223.24	256.33	280.96	311.92	346.69	383.84
S.D.	15.50	16.19	17.87	19.24	22.86	29.91	23.74	25.67	29.34	35.17

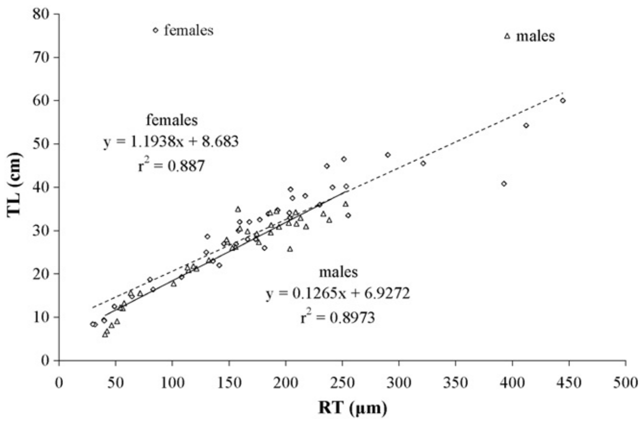

Fig. 13. Linear regression between TL and the external edge of *illicium* (R_T) from females and males of *L. budegassa* collected in the North-western Ionian Sea.

birth-modified" model gave estimates of TL_i corresponding to each age (i). The back-calculated sizes corresponding to ages older than 9 years were excluded because derived from an insufficient number of specimens. The mean TL_i calculated for each age component in females, males and both sexes combined are reported in Table 4. No statistical differences were observed in the back-calculated mean lengths at age between females and males throughout the reported age interval. In addition, the differences between the mean lengths at age estimated by the direct method and the corresponding back-calculated were not significant in both sexes ($p > 0.05$).

3.3.2. Length–frequency analysis

The main modal components observed in the cumulated length–frequency distributions are reported in Table 5. In particular, the first modal components were about 9 and 22 cm TL in spring and 15 and 25 cm TL in autumn, respectively. The growth parameters and the growth performance value estimated for both sexes combined by means the modal progression analysis ($L_\infty = 68.53 \pm 7.08$ cm TL; $k = 0.29 \pm 0.07\,y^{-1}$; $t_0 = -0.10 \pm 0.16$ y; $\Phi' = 3.13 \pm 0.52$) indicated a faster growth rate in respect to that obtained from the direct readings of *illicium* ($p < 0.05$).

Table 5
Identification of the modal components (TL in cm) with indication of standard deviation (S.D.) and separation index (S.I.) in the cumulated length–frequency distributions (sex combined) calculated for the specimens of *L. budegassa* sampled in the spring and autumn surveys in the North-western Ionian Sea

Modal class	Spring			Autumn		
	TL (cm)	S.D.	S.I.	TL (cm)	S.D.	S.I.
1	9.26	2.34	–	14.95	2.72	–
2	21.88	3.13	4.61	25.24	3.18	3.49
3	29.84	3.65	2.35	33.43	2.69	2.79
4	41.07	1.66	4.23	44.67	3.11	3.88
5	49.43	2.00	4.57	54.54	1.35	4.43
6	52.00	4.55	2.78	–	–	–

3.4. Mortality and exploitation ratio

The mortality rate (Z) calculated using the growth parameters derived from the direct age estimation varied between the annual value of 0.54 in 2001 and that of 0.87 in 2000 and 2003. The Z values derived from the length–frequency analysis ranged between 0.97 (1995) and 1.66 (2003) (Fig. 14). Both the Z estimates highly fluctuated throughout the sampling period without any particular trend. However, the mortality rate values estimated using the growth parameters derived from length–frequency analysis were significantly greater than those derived from direct age estimation ($p < 0.001$).

The natural mortality rate computed using the growth parameters calculated in females and males from the direct age estimation (DAE) and the methods proposed by Pauly (1980) were 0.24 and 0.25, respectively. A slight difference was observed in the M values for females (0.23) and males (0.24) estimated with Djabali et al. (1993). However, the same M value of 0.22 was estimated with both the methods for sex combined. Adopting this latter value, the fishing mortality rate and the relevant exploitation ratio were computed for sexes combined throughout the study period. The M value of 0.39 estimated with Djabali et al. (1993) and derived from length–frequency analysis (LFA), was also adopted producing an alternative set of F and E estimates (Table 6). The fishing mortality rates and exploitation ratios derived from DAE and LFA fluctuated throughout the sampling period without any particular trend. Although, both Z and F values obtained with the two sets of growth parameters differed significantly ($p < 0.001$), the

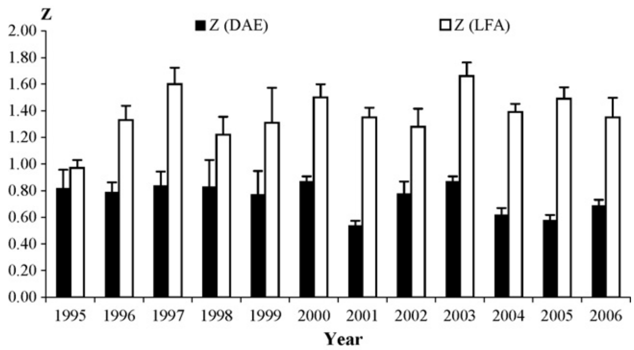

Fig. 14. Total mortality rate Z estimated using the growth parameters derived from direct age estimation (DAE) and from length–frequency analysis (LFA) for *L. budegassa* in the North-western Ionian Sea during 1995–2006.

Table 6
Total mortality rate (Z), fishing mortality rate (F) and exploitation ratio (E) calculated using the growth parameters derived from direct age estimation (DAE) and length–frequency analysis (LFA) for *L. budegassa* in the North-western Ionian Sea during 1995–2006

Year	DAE			LFA		
	Z	*F*	*E*	*Z*	*F*	*E*
1995	0.82	0.60	0.73	0.97	0.58	0.60
1996	0.79	0.57	0.72	1.33	0.94	0.71
1997	0.84	0.62	0.74	1.60	1.21	0.76
1998	0.83	0.61	0.73	1.22	0.83	0.68
1999	0.77	0.55	0.71	1.31	0.92	0.70
2000	0.87	0.65	0.75	1.50	1.11	0.74
2001	0.54	0.32	0.59	1.35	0.96	0.71
2002	0.78	0.56	0.72	1.28	0.89	0.70
2003	0.87	0.65	0.75	1.66	1.27	0.77
2004	0.62	0.40	0.65	1.39	1.00	0.72
2005	0.58	0.36	0.62	1.49	1.10	0.74
2006	0.69	0.47	0.68	1.35	0.96	0.71

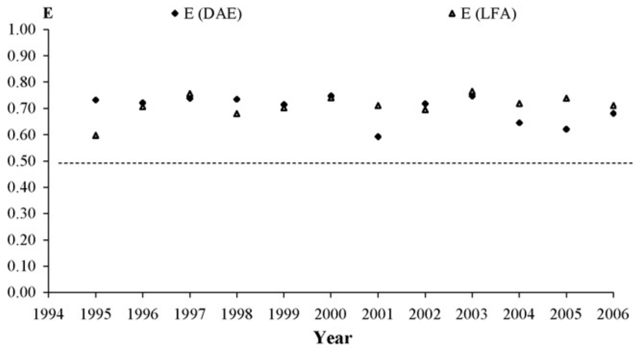

Fig. 15. Trend of the exploitation ratio (E) calculated using the growth parameters derived from direct age estimation (DAE) and length–frequency analysis (LFA) for *L. budegassa* in the North-western Ionian Sea during 1995–2006 (optimal exploitation ratio is indicated with dotted line as a reference point).

differences in the exploitation ratio values were not significant ($p > 0.05$) (Fig. 15).

4. Discussion

The black anglerfish *L. budegassa* was found to be distributed down to 745 m in the North-western Ionian Sea, confirming the wide depth distribution of the species also in the Eastern Mediterranean. The maximum lengths measured in both females (114 cm TL) and males (93 cm TL) represent the largest sizes observed in specimens sampled during trawl surveys in the Mediterranean Sea (Ungaro et al., 2002; Garcia-Rodriguez et al., 2005). A decreasing trend with depth was shown only in the density indices values. The greater biomass values recorded during autumn seem to be due to a greater fraction of larger specimens caught in this season. The lack of correlation between size and depth suggests a sedentary life for this fish, with the juveniles belonging to the new generations living in the same areas in which the recruitment of the species occurs. No significant trends were shown in the fluctuation of the abundance indices throughout the study period, indicating a stable condition in the stock distributed from the shelf to the upper slope.

According to the observations on the reproductive period of this fish, from November to May (Duarte et al., 2001; Maravelias and Papaconstantinou, 2003; Carbonara et al., 2005), mature females and males were collected in both spring and autumn. However, the availability of these specimens, mostly in females, was found to be rather scarce on the fishing bottoms of the Ionian Sea, as it was also reported for the Aegean waters (Maravelias and Papaconstantinou, 2003). In addition, adult individuals of *Lophius* species can also be distributed deeper than the investigated bathymetric range (10–800 m) or between rocky bottoms and within coral habitats (Olu, 2004), where trawling generally does not occur.

Recruitment of the species occurs during spring and the presence of juveniles in autumn is due to the growth occurring in the younger specimens. In fact, the two main modal components showed at 10–12 cm and 22–24 cm TL in spring, similar to those observed in other Mediterranean areas (Ungaro et al., 2002; Garcia-Rodriguez et al., 2005), correspond to the 16–18 cm and 24–26 cm TL modal lengths showed during the autumn surveys. This progression in the modal lengths might be explained with the growth rate between the investigated seasons, which is in agreement with that reported in Garcia-Rodriguez et al. (2005).

The population structure of *L. budegassa* mostly consisted of specimens with a size less than 24 cm TL, both in spring and autumn. Therefore, considering the estimates of mortality and exploitation ratio, a growth overfishing condition could be indicated for the stock, because the catches mainly consisted of juveniles. However, the continuity in the recruitment seems to be guaranteed by spawners avoiding the catch because they are distributed in “refuge areas” (deeper areas, rocky bottoms, coral habitats) where trawl fishing does not occur. On the contrary, the fluctuation observed in the recruitment and consequently in the distribution of the abundance could be due to stochastic environmental phenomena which might drastically influence the success in the early life stages (eggs-larvae) as reported for *L. piscatorius* (Hislop et al., 2000, 2001). In addition, Maravelias and Papaconstantinou (2003) also indicated a post-larval shifting as a potential responsible of the aggregated distribution of juveniles in the Aegean Sea.

The estimated mean lengths at age and the growth parameters were quite different between the two sexes with females achieving an older size-age than males, confirming previous studies (Table 7). This different growth pattern should be considered mainly in the case of an increasing exploitation of the species in the North-western Ionian Sea and in other Mediterranean areas (Maravelias and Papaconstantinou, 2003), where *L. budegassa* represents an important marketable fraction of the catch.

Some differences observed between different studies on age and growth are mostly due to the different size range of specimens examined. In addition, local environmental conditions might play a role influencing the variability in the growth of this species in different areas. However, the age and growth performance examined in this study result quite similar to those reported in previous studies both in the Mediterranean and the Atlantic. In fact, excluding the age-length keys estimated for females and males in the Aegean Sea (Tsimenidis and Ondrias, 1980), the growth parameters and the growth performance values estimated in the present study are comparable to those obtained for the stock distributed along the Mediterranean Spanish coasts (Garcia-Rodriguez et al., 2005). The International Council for the Exploration of the Sea (ICES) characterized two *L. budegassa* stocks exploited by trawling, one distributed along the Irish, English and French coasts, the other settled along southern Spanish and Portuguese coasts. The growth parameters are available for both these Atlantic stocks (Dupouy et al., 1986; Duarte et al., 1997; Landa et al., 2001) with the L_∞ values estimated for the females and males in the Atlantic areas greater than those calculated in the Northern Ionian Sea (present study). However, the Atlantic growth rates (k) are similar to those estimated in the present study, for both females and males.

Apart from the results on growth parameters, the greater size-age generally recorded in the Atlantic than in the Mediterranean could be also related to differences in productivity and

Table 7
Growth parameters of *L. budegassa* estimated in different areas of the Atlantic and Mediterranean Sea

	MEDITERRANEAN									ATLANTIC								
	North-western Ionian Sea (present study)					Iberian Sea (Garcia-Rodriguez et al., 2005)		Aegean Sea (Tsimenidis and Ondrias, 1980)		Southern (Landa et al., 2001)			Southern (Duarte et al., 1997)			North-eastern (Dupouy et al., 1986)		
	Illicium			Modal length	Back calculation	*Illicium*	Modal length	Otolith		*Illicium*			*Illicium*			*Illicium*		
	Females	Males	Combined	Combined	Combined	Combined	Combined	Females	Males	Females	Males	Combined	Females	Males	Combined	Females	Males	Combined
Maximum age	8	8	8	5	9	9	5	8	6			10						
L_∞ (cm)	68.45	60.30	68.39	68.53	57.6	90.00	102.00			93.5	71.5	93.50	105.9	81.7	101.7	105.00	76.00	94.00
k (y^{-1})	0.112	0.109	0.100	0.29	0.09	0.08	0.15			0.10	0.13	0.10	0.08	0.11	0.08	0.07	0.10	0.09
t_0 (y)	−1.18	−1.56	−1.43	−0.10	−1.64	−0.10	−0.05			0.50	0.05	0.38	−0.20	−0.10	−0.20	0.50	0.56	0.66
Φ'	2.72	2.60	2.67	3.13	2.49	2.81	3.20			2.94	2.82	2.94	2.95	2.86	2.91	2.89	2.76	2.90
n	292	273	565			170		228	217			1038			391			

Age	North-western Ionian Sea (present study)					Iberian Sea (Garcia-Rodriguez et al., 2005)		Aegean Sea (Tsimenidis and Ondrias, 1980)		Southern (Landa et al., 2001)			Southern (Duarte et al., 1997)			North-eastern (Dupouy et al., 1986)		
	Illicium			Modal length	Back calculation	*Illicium*	Modal length	Otolith		*Illicium*			*Illicium*			*Illicium*		
	Females Mean length (cm) estimated by VBGF	Males	Combined	Combined	Combined	Combined Mean length (cm)	Combined Mean length (cm) estimated by VBGF	Females Mean length (cm)	Males	Females Mean length (cm) estimated by VBGF	Males	Combined	Females Mean length (cm) estimated by VBGF	Males	Combined	Females Mean length (cm) estimated by VBGF	Males	Combined
0.5	11.55	12.14	12.00	10.94	10.09		8.03											
1.5	17.48	17.11	17.37	25.44	14.18		21.12	15.74	15.71	8.90	12.28	11.09	13.47	13.18	9.30	7.10	6.82	6.84
2.5	22.79	21.57	22.22	36.29	17.92	15.71	32.38	21.34	20.50	16.95	19.50	16.63	20.57	20.32	16.40	13.72	13.40	14.35
3.5	27.54	25.57	26.62	44.40	21.33	22.38	42.08	26.16	24.65	24.23	25.84	22.19	27.13	26.72	23.00	19.89	19.36	21.20
4.5	31.80	29.16	30.59	50.48	24.45	26.67	50.43	31.16	29.67	30.83	31.41	27.86	33.19	32.44	29.00	25.64	24.75	27.47
5.5	35.62	32.37	34.19	55.02	27.31	28.52	57.61	36.37	33.95	36.79	36.29	33.32	38.78	37.57	34.60	31.01	29.63	33.19
6.5	39.04	35.26	37.44	58.42	29.91	33.86	63.79	41.20	39.90	42.19	40.59	38.83	43.94	42.17	39.80	36.01	34.04	38.43
7.5	42.10	37.84	40.39	60.97	32.30	39.45	69.12	44.82		47.07	44.35	42.14	48.70	46.29	44.50	40.67	38.03	43.21
8.5	44.85	40.16	43.05	62.87	34.47	40.25	73.7	49.14		51.49	47.66	48.42	53.10	49.98	48.90	45.02	41.65	47.58
9.5	47.31	42.24	45.47	64.30	36.47	48.42	77.64			55.49	50.57	54.39	57.16	53.28	53.00	49.08	44.91	51.58
10.5	49.51	44.11	47.65	65.36	38.28		81.03			59.10	53.12	58.98	60.91	56.24	56.70	52.86	47.87	55.23
11.5	51.48	45.78	49.62	66.16	39.95		83.95			62.38	55.36	61.98	64.37	58.89	60.20	56.38	50.55	58.57
12.5	53.25	47.28	51.41	66.76	41.47		86.47			65.34	57.33	63.64	67.56	61.27	63.40	59.67	52.97	61.62
13.5	54.83	48.62	53.02	67.20	42.85		88.63			68.02	59.06	72.04	70.51	63.40	66.30	62.73	55.16	64.40
14.5	56.25	49.83	54.49	67.54	44.12		90.49			70.44	60.57	74.33	73.23	65.30	69.00	65.59	57.15	66.95
15.5	57.52	50.91	55.81	67.79	45.28		92.1			72.64	61.91	75.95	75.74	67.01	71.60	68.26	58.94	69.28
16.5	58.66	51.88	57.01	67.97	46.34		93.48			74.62	63.08	79.47	78.06	68.54	73.90	70.74	60.56	71.41
17.5	59.68	52.75	58.09	68.11	47.31		94.66			76.42	64.10	79.71	80.20	69.91		73.06	62.03	73.35
18.5	60.59	53.53	59.07	68.22	48.20		95.68			78.04	65.00	82.00	82.18	71.14		75.22	63.36	75.13
19.5	61.41	54.23	59.96	68.30	49.01		96.56			79.52	65.80	83.60	84.00	72.24		77.23	64.56	76.75
20.5	62.15	54.86	60.76	68.36	49.75		97.32			80.85	66.49	87.00	85.68	73.23		79.11	65.65	78.24
21.5	62.80	55.42	61.49	68.40	50.42		97.97			82.05	67.10	93.00	87.24	74.11		80.86	66.64	79.59

The reference, the investigated area, the method, the growth performance (Φ') and the mean lengths at age were indicated.

temperature between the two geographic regions (Beverton and Holt, 1959; Garcia-Rodriguez et al., 2005).

Considering the maximum sizes recorded in this study, the longevity of this fish can be much older than 17 years in females and 10 years in males. In addition, since the age and growth estimates are fundamental for the stock assessment in the age structured models, it could be interesting to expand the covered size range for the age and growth estimation, including big specimens from commercial landings. In addition, in order to avoid the underestimation of growth, it seems useful to improve and validate the estimates using alternative methods to interpret age in skeleton parts (de Pontual et al., 2006; Landa et al., 2008). Indeed, the significant differences in the growth revealed by direct readings between the two sexes were not confirmed by back-calculation.

The analysis of the demographic structure and the estimated growth parameters suggest as the exploited stock of *L. budegassa* in the North-western Ionian Sea is characterized by a slight dominance of males and it mainly consists of juveniles younger than 3–4 years old. In addition, taking into account the size at first maturity (50%), estimated in females around 66 cm TL in the Mediterranean Sea (Ungaro et al., 2002) and 54 cm TL in Spanish waters in the Atlantic (Duarte et al., 2001), spawners seem to be extremely scarce in the harvested population, most probably as a consequence of the fishing pressure carried out in the North-western Ionian Sea. Indeed, the present results reveal that on average 70% of the total mortality of *L. budegassa* in the North-western Ionian Sea is due to fishing mortality and that the exploitation ratio is by far over an optimal exploitation.

At present, the management measures adopted for demersal resources in the EU Mediterranean are addressed to the reduction of fishing effort by means of limitation of licences, the adoption of a minimum landing sizes for the main commercial species and a minimum mesh size in the trawl cod-ends (40 mm squared). In addition, closed seasons and no take-zones are established in order to reduce the fishing mortality, mainly in juveniles. However, in the Ionian Sea no such take-zones have not been adopted as yet.

Although a small reduction in fishing effort has occurred in the last 10 years in the Ionian Sea, no changes in the mortality rates or exploitation ratio were shown within the study period. Reduction in fishing effort could probably be offset by the increasing fishing efficiency. Unfortunately, there is no previous information on the fishing mortality and exploitation ratios of this fish in the Mediterranean and the only existing data regard exclusively the Atlantic (ICES, 2007a), where the exploitation status of the stocks is annually investigated. In this latter basin, both *Lophius* species (*L. budegassa* and *L. piscatorius*) are subject to a common TAC and trends in biomass estimates have shown a relative decline. Therefore, both species are considered to be at a low level, at present.

In the North-western Ionian Sea, black anglerfish specimens are mainly caught when they weigh 100–200 g even if older individuals could potentially reach sizes of up to 110 cm TL and weights of 10–14 kg. Therefore, delaying the catch of juveniles might prevent the actual growth overfishing condition in the exploited stock. In addition, this management option might produce a remarkable increase in the biomass allowing a consequently higher economic yield. Nevertheless, the overfishing condition in *L. budegassa* remains quite difficult to remedy because even though an increase in the mesh size of the trawl cod-end is possible, the specimens belonging to the first year classes would still be caught due to the wide form of their mouth and head. In addition, the adoption of this technical measure should take into account that those specimens must be rapidly thrown back into the sea while still alive and not badly damaged. The survival of caught specimens is aided by a thick layer of protective mucus increasing resistance after the catch with age. Another measure to reduce fishing mortality on juveniles could be the institution of no-take zones where the high concentration of these individuals occurs (nursery areas). However, the sparse distribution of this fish on muddy bottoms irrespective of depth would seem to represent a hindrance to the identification of nursery areas.

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