Abstract—The roudi escolar *Promethichthys prometheus* is common in deep hook-and-line and longline catches of a small-scale fishery along the slope off the Canary Islands. Population structure, reproduction, growth, and mortality of the species were studied from sampling undertaken from August 1992 to July 1995. Range of length of fish in the catches was between 36 and 80 cm TL, with a main distribution between 56 and 66 cm. The overall ratio of males to females was 1:1.74. Females predominated in all sizes. The sex ratio varied throughout the period of study; the lowest discrepancy between males and females, however, was during the reproductive period. A vertical space partitioning among sexes was observed, with males predominating from 600 to 800 m depth, females from 300 to 500 m. The reproductive period of the species was from April to September, with a peak in spawning in June–July. The size at first maturity was 47.41 cm. The parameters of the length-weight relationship for all fish were a=0.004521 and b=2.98932. Age readings of otoliths indicated that the exploited population consisted of nine age groups (III–XI years). The von Bertalanffy growth parameters for all individuals were L_∞=93.61 cm, k=0.18/years, and t_0 =−1.54 years. The rates of mortality for all fish were Z=0.49/years, M=0.35/years, and F=0.14/years. The length at first capture for the whole population was 51.57 cm.

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Biology of a deep benthopelagic fish, roudi escolar *Promethichthys prometheus* (Gempylidae), off the Canary Islands

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The family Gempylidae consists of 16 genera and 23 species. Only seven species are found off the Canary Islands, one of which is the roudi escolar *Promethichthys prometheus* (Cuvier, 1832), the only species recognized to date in the genus *Promethichthys* (Nakamura and Parin, 1993).

The roudi escolar is a benthopelagic marine fish that has a worldwide distribution in tropical and warm temperate waters. This species generally inhabits waters between 100 and 800 m in depth over seamounts and continental and insular slopes. It migrates upward at night, probably forming schools (Nakamura, 1981; Parin, 1986; Nakamura and Parin, 1993).

Published information on *P. prometheus* is very scarce. The majority of studies describe its morphological characteristics, geographical and depth distribution, and ecology (Nakamura, 1981; Parin, 1986; Nishikawa, 1987; Nakamura and Parin, 1993). Only Lorenzo and Pajuelo (1995) have studied some biological aspects of the species. These authors carried out a preliminary study on the sex ratio, reproduction, and age and growth of roudi escolar off the Canary Islands (central-east Atlantic) on the basis of a small number of specimens during one life cycle. This paper is an extension of their work, analyzing, in addition to all those aspects, population structure and mortality.

The roudi escolar is common in the catches of the deep hook-and-line and longline small-scale fishery over the slope off the Canary Islands. In this area, this species is captured year round without significant seasonal differences in landings.

Materials and methods

Between August 1992 and July 1995, the TL (cm) of 1879 specimens of roudi escolar was measured monthly from commercial catches of the small-scale fleet. Fish were caught with baited hook-and-lines and longlines at depths of 285–870 m around the islands of the Canary archipelago (Fig. 1).

A subsample was taken by a random stratified method from each sample for biological examination. In total, 776 individuals were analyzed. For each fish, the TW (0.1 g) and the weight of the gonads (0.01 g) were measured, and sex and stage of maturation were ascertained macroscopically. The latter was classified as follows: I = immature; II = resting; III = ripe; IV = ripe and running; V = spent. Sagittal otoliths of the fish were extracted, cleaned, and stored dry. The length-frequency distribution of individuals in catches was calculated. Data were pooled for 1992–95.

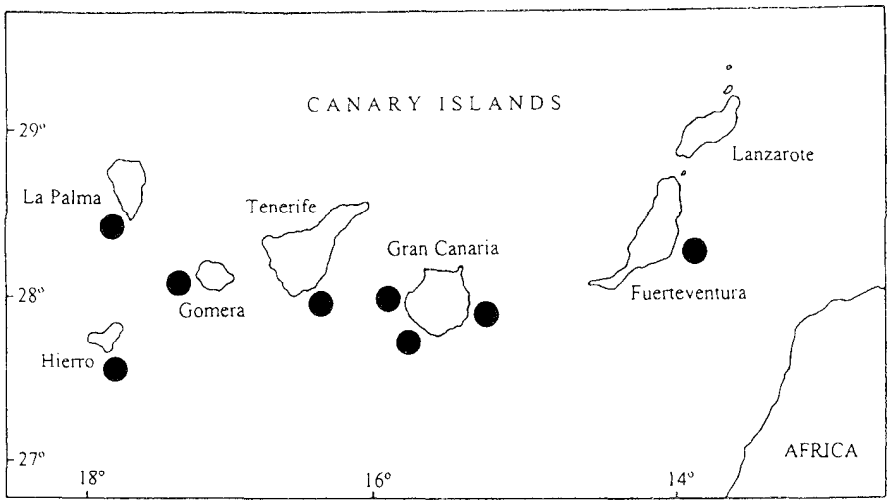

Figure 1
Location of sampling areas (●) in the Canary Islands.

The sex ratios (males:females) for the whole sample, for different size classes, for quarters of a year, and for depth strata were calculated. The reproductive season was determined on the basis of monthly variations of the gonadosomatic index (GSI) according to Anderson and Gutreuter (1983). The length at sexual maturity (length at which fifty percent of the specimens became mature) was estimated by means of a logistic function that was fitted to the proportion of the mature individuals (stages III, IV, and V) by using a nonlinear regression (Saila et al., 1988).

The ratio of total length to total weight was calculated over the whole period for males and females separately, as well as for the population as a whole, by applying a linear regression (Ricker, 1973). Age was determined by interpreting growth rings on the otoliths; whole otoliths were placed in a watch glass with a blackened bottom and containing glycerin and examined under a compound microscope with reflected light. Counts for each specimen were performed at least twice and only coincident readings were accepted. An index of average percent error (APE) developed by Beamish and Fournier (1981) was used to compare the precision of age determinations. Ageing was validated indirectly by examination of monthly changes in appearance of the margins of the otoliths (Morales-Nin, 1987). The date 1 July was considered as birthdate to assign the individual ages to age groups. The von Bertalanffy growth curve was fitted to data of the resulting age-length key by means of the Marquardt's algorithm for nonlinear least squares parameter estimation (Saila et al., 1988).

Length-frequency data were converted to age frequencies by using the estimated von Bertalanffy growth parameters (Pauly, 1983, 1984). The rate of total mortality (Z) was calculated from the length converted catch curve by using ELEFAN program (Gayanilo et al., 1988). The rate of natural mortality (M) was determined from the equation of Pauly (1980). Following estimation of Z and M, the rate of fishing mortality (F) was calculated by substraction. The length at first capture was estimated from the selection ogive generated from the length converted catch curve (Pauly, 1984).

Results

The size-frequency distribution showed a length range of 36 to 80 cm TL in the catches, with a main distribution between 56 and 66 cm (Fig. 2).

Of the 776 fish examined, 282 (36.3%) were male, 491 (63.3%) female. The sex of the remaining 3 (0.4%) individuals could not be identified macroscopically because they were immature and had very thin, translucent gonads. The overall ratio of males to females was 1:1.74 and χ^2 analysis revealed this to be significantly different from a 1:1 ratio (Table 1). Females predominated in all size intervals. Sex ratios for males and females grouped into 5-cm length classes had significant departures from the 1:1 ratio for all size intervals (Table 1). The ratio of males to females varied throughout the period of study, but there were no significant differences from the 1:1 ratio during the spring and summer months (Table 2). There was a relationship between the sex of roudi escolar and depth; males predominated at 600 to 800 m depths, females at 300 to 500 m (Table 3).

The GSI showed higher values for females than for males (Fig. 3). The same temporal variation pat-

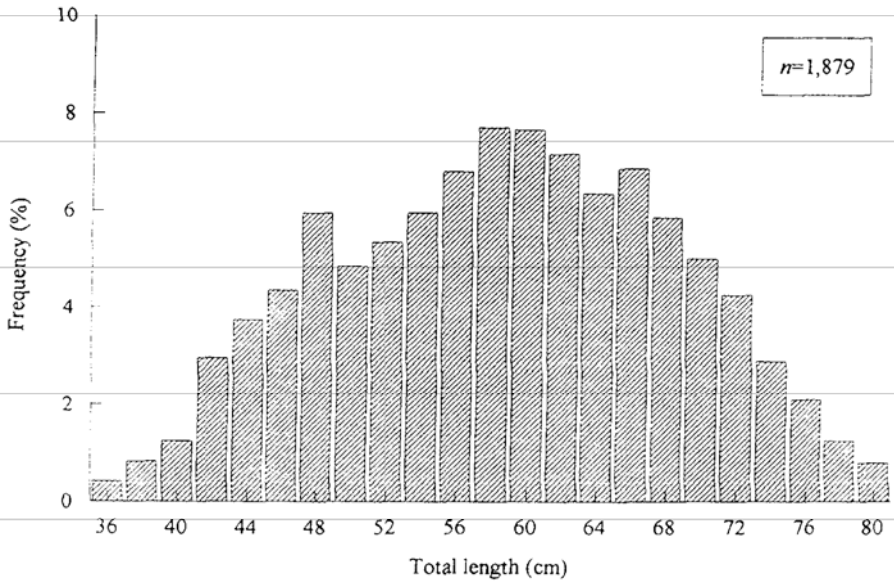

Figure 2

Length-frequency distribution for *P. prometheus* caught off the Canary Islands (August 1992–July 1995).

Table 1

Number of males and females of *P. prometheus* caught off the Canary Islands by 5-cm size class and sex ratio tested by chi-square analysis. *=$\chi^2 > \chi_t^2{}_{1,0.05}=3.84$.

Length (cm)	Males	Females	Sex ratio	χ^2
35.1–40.0	5	14	1:2.80	4.26*
40.1–45.0	21	40	1:1.90	5.91*
45.1–50.0	29	52	1:1.79	6.53*
50.1–55.0	45	71	1:1.57	5.82*
55.1–60.0	60	94	1.1.56	7.50*
60.1–65.0	48	84	1:1.75	9.80*
65.1–70.0	36	62	1:1.72	6.89*
70.1–75.0	26	48	1:1.76	6.54*
75.1–80.0	12	26	1:2.16	5.15*
Total	282	491	1:1.74	56.50*

Table 2

Number of males and females of *P. prometheus* caught off the Canary Islands by quarter and sex ratio tested by chi-square analysis. *= $\chi^2 > \chi_t^2{}_{1,0.05}=3.84$.

Quarter	Males	Females	Sex ratio	χ^2
3/92	16	23	1:1.44	1.25
4/92	13	35	1:2.69	10.08*
1/93	13	37	1:2.85	11.52*
2/93	24	37	1:1.54	2.77
3/93	24	34	1:1.42	1.72
4/93	14	38	1:2.71	11.07*
1/94	29	51	1:1.75	6.05*
2/94	36	49	1:1.36	1.98
3/94	39	50	1:1.28	1.35
4/94	24	44	1:1.83	5.88*
1/95	31	59	1:1.90	8.71*
2/95	19	34	1:1.79	4.24*

tern was recorded for both sexes. Highest values occurred between April and September, peaking during June–July. From October to March the values were low.

No significant difference in length at sexual maturity was found between males and females (t-test, $t=1.31<t_{0.05,385}=1.65$). The length at which fifty percent of the fish became mature was 47.41 cm TL (Fig. 4).

Males were found to be between 38 and 80 cm TL, females between 36 and 80 cm. The length range of immature individuals was from 36 to 38 cm. The parameters of the total length to total weight relationship for males and females separately, and for the population as a whole, are given in Table 4. No significant difference in the allometric coefficient was found between males and females (t-test, $t=1.53<t_{0.05,771}=1.65$). Isometric growth was observed in both sexes and for the whole population (Table 4).

Of the otoliths examined, 670 (86.4%) were readable and used for the study of age and growth. The

APE value was only 3.4%. A false hyaline ring interrupting the normal growth pattern of the otolith was identified within the fourth annual opaque zone and in all subsequent opaque zones. Marginal zone analysis showed that one annulus was formed per year (Fig. 5). The percentage of otoliths with opaque edge was high in the months from April to September, and between June and August in particular.

Fish aged 3 to 11 years were present in the samples (Table 5). Growth parameters determined for males, females, and the entire population are shown in Table 6. No significant differences in the growth parameters were found between sexes (Hotelling's T^2-test, $T^2=5.29<T_{0\ 0.05,3,666}^{2}=7.88$).

The length converted catch curve is shown in Figure 6. The rates of total mortality, natural mortality, and fishing mortality were $Z=0.49$/year, $M=0.35$/year, and $F=0.14$/ year, respectively. The size at first capture was 51.57 cm TL.

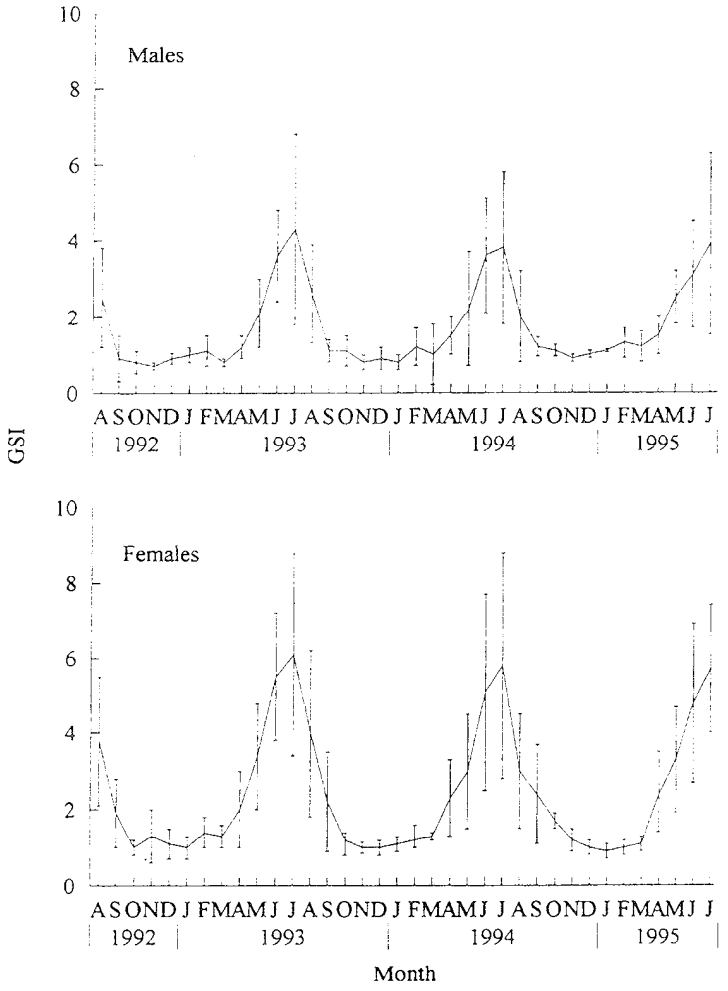

Figure 3

Monthly evolution of the gonadosomatic index (GSI) for males and females of *P. prometheus* caught off the Canary Islands (August 1992–July 1995).

Discussion

Promethichthys prometheus is distributed along the slope to a depth of 800 m (Nakamura and Parin, 1993). In waters off the Canary Islands, greatest concentrations of this species are found between 400 and 700 m depth. Below this depth, the species is replaced by other trichiuroid fish present in the area, e.g. the black scabbardfish, *Aphanopus carbo* Lowe, 1839 (Uiblein et al., 1996).

The roudi escolar off the Canary archipelago is a gonochoristic species with no evidence of sexual dimorphism. The sex ratio is clearly unbalanced in favor of females. This fact could be explained by the differences between sexes in the spatial distribution. The lowest discrepancy between sexes observed during the reproductive season seems to confirm this conclusion. Because of the space partitioning between sexes and because females are fished more than males, this species could be classed as vulnerable to unrestrained fishing. Therefore, fishing for roudi escolar is an activity that has the potential to threaten its target population compared with fishing for more reliable and robust stocks (Csirke, 1988). This fishery will require a prudent exploitation strategy to reduce the potential risk of a collapse.

The roudi escolar has a definite reproductive period (extending from April to September, with a peak in spawning activity in June–July) which agrees with information reported by Parin (1986) and Nakamura and Parin (1993). These authors pointed out that the

Table 3

Number of males and females of *P. prometheus* caught off the Canary Islands by depth stratum and sex ratio tested by chi-square analysis. $*=\chi^2>\chi_{t\ 1,0.05}^{2}=3.84$.

Depth (m)	Males	Females	Sex ratio	χ^2
201–300	4	26	1:6.50	16.13*
301–400	21	136	1:6.47	84.23*
401–500	35	187	1:5.34	104.07*
501–600	28	39	1:1.39	1.81
601–700	76	48	1.0.63	6.32*
701–800	85	41	1:0.48	17.12*
801–900	32	12	1.0.37	9.09*

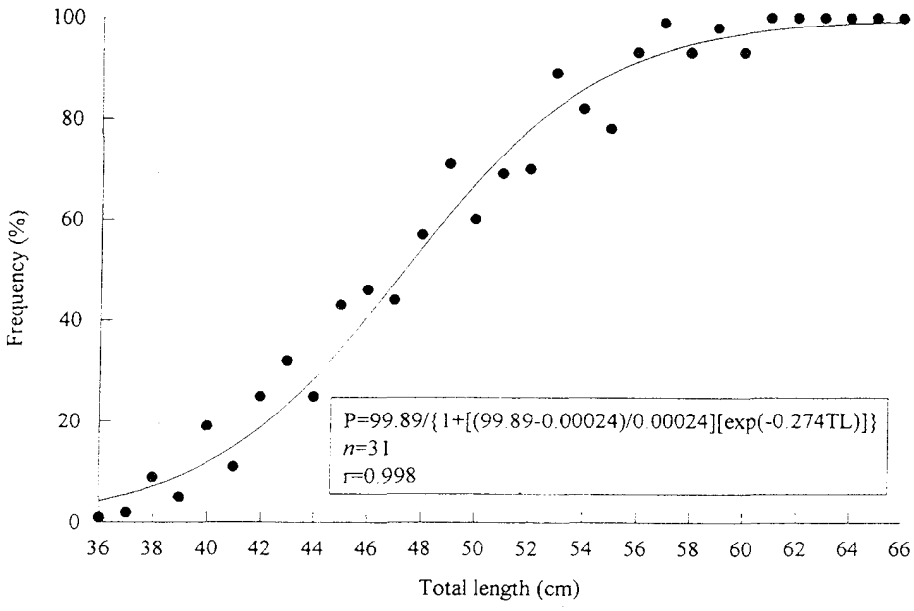

Figure 4

Sexual maturity ogive for *P. prometheus* caught off the Canary Islands (August 1992–July 1995).

spawning of this species occurs from August to September in the Atlantic off Madeira. Nishikawa (1987) found the highest concentration of gempylid larvae at the end of the summer months in the Pacific waters of Japan. In the Canary archipelago, the spawning of roudi escolar seems to be related to water temperatures, occurring when these reach greatest values. Possible significance of seasonal temperature variation to maturation and spawning in other bony fish species off the Canary Islands has been discussed by Lorenzo and Pajuelo (1996) and Pajuelo and Lorenzo (1995, 1996). Reproduction in roudi escolar does not involve horizontal migrations because during the spawning season the specimens are observed in the same areas where they are fished all year round. The lowest discrepancy in the number of males and females observed during the spawning period suggests an aggregation for breeding. Males and females were found aggregated mainly at depths of 450–650 m during this period.

Length at sexual maturity does not differ between males and females, corresponds approximately to 48 cm TL. In the age-length relationship, this size corresponds to 4-year-old specimens. The size at which fifty percent of the fish become mature is less than the length at first capture and the majority of the total catch is longer than this length, indicating a good exploitation pattern from the biological point of view. Furthermore, a low value of fishing mortality rate was obtained.

Table 4

Parameters of the length-weight relationship for males, females and all fish of *P. prometheus* caught off the Canary Islands and the possibility of isometry tested by Student's *t*-test. *= $t > t_{0.05,n>250} = 1.65$.

	a	*b*	SE(b)	r^2	*n*	*t*-test
Males	0.004128	2.95321	0.03721	0.959	282	1.25
Females	0.004987	2.96214	0.03140	0.981	491	1.20
All fish	0.004521	2.98932	0.02341	0.992	776	0.45

The alternate pattern of opaque with translucent zones was easily distinguishable on the otoliths of the roudi escolar. These zones are deposited owing to alternating periods of rapid and slow growth (Williams and Bedford, 1974). The opaque zone is formed when the water temperature is higher, and food is abundant, and the translucent is formed when temperature is lower and the species spawns. This finding demonstrated the validity of using otoliths for estimating the age and growth of roudi escolar. The false hyaline zones observed within the fourth opaque ring and in subsequent opaque rings are probably spawning bands, because this species spawns in the summer months, when the opaque zone is formed in the otoliths. Morales-Nin (1987) pointed out that when the spawning does not take place during the period of hyaline zone formation, a false ring, known

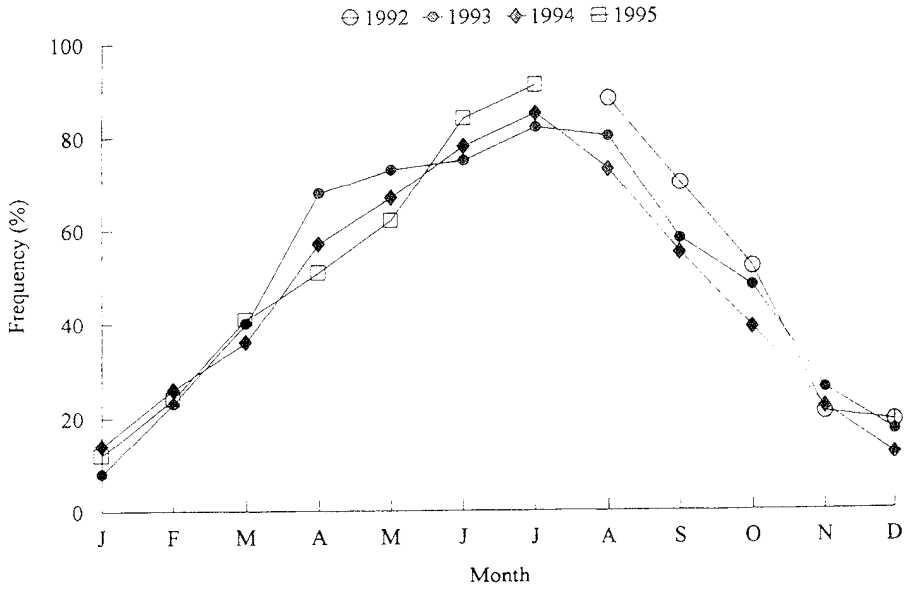

Figure 5

Monthly percentage of otoliths with opaque edge for *P. prometheus* caught off the Canary Islands (August 1992–July 1995).

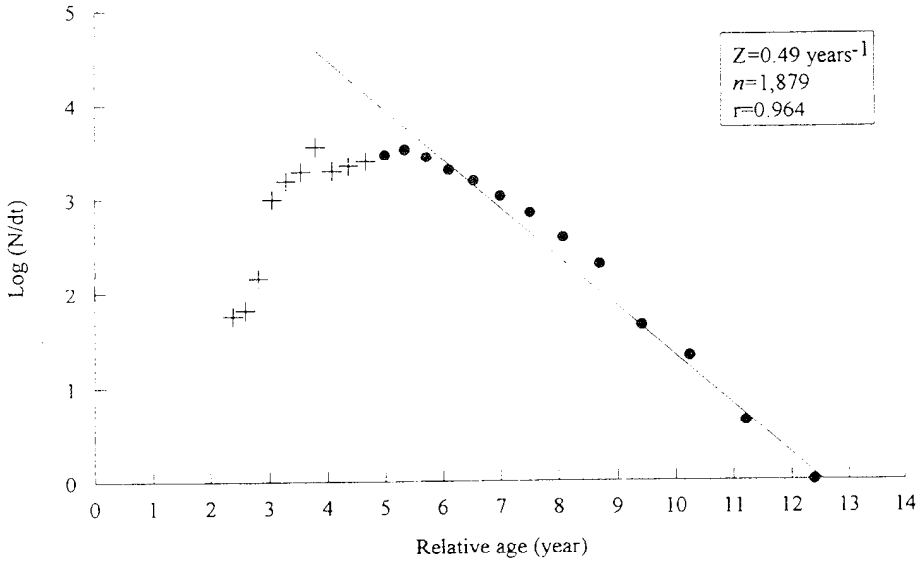

Figure 6

Length converted catch curve for *P. prometheus* caught off the Canary Islands (August 1992–July 1995). The initial data points (+) were not used in the regression.

as a spawning ring, may form within an opaque zone, dividing it into two.

The oldest age class observed was XI years, although this class, as well as age classes IX and X, were poorly represented in the landings. As a whole, growth of the roudi escolar is relatively fast and males and females grow at equal rates. The growth parameters obtained are reasonable because the theoretical maximal length value is greater than the size of the largest fish sampled and because the growth coefficient value indicates relatively rapid attainment of maximal size.

Table 5

Age-length key for all fish of *P. prometheus* caught off the Canary Islands.

Size (cm)	Age group (years)								
	III	IV	V	VI	VII	VIII	IX	X	XI
36	2								
37	1								
38	2								
39	4								
40	6								
41	9								
42	9	1							
43	7	3							
44	4	4							
45	3	8							
46	3	7							
47		9							
48	2	13	1						
49		17	2						
50		14							
51		7	4						
52		5	6						
53		4	8						
54		3	10	1					
55			16	3					
56		2	22	3					
57		1	19	6					
58			12	7					
59			8	11	2				
60			4	17	2				
61			2	28	3				
62			3	21	6				
63			1	11	8				
64				8	14	2			
65				7	20	1			
66				3	23	4			
67				1	16	7			
68				2	10	10	1		
69					6	12	4		
70					3	17	4		
71					2	11	7	1	
72					1	6	9	2	
73						5	9	2	
74						1	7	3	1
75						2	5	6	1
76							2	4	2
77							1	3	2
78									1
79								1	
80									1
n	52	98	118	129	116	78	49	22	8
$\bar{x}$	41.6	48.9	55.7	61.1	65.5	69.4	72.4	74.9	76.7
SD	2.4	2.8	2.6	2.6	2.4	2.2	2.0	1.8	1.7

Table 6

Parameters of the von Bertalanffy growth curve for males, females, and all fish of *P. prometheus* caught off the Canary Islands.

	L_∞ (cm)	k (per year)	t_0 (years)	r^2
Males	91.93	0.18	−1.66	0.964
Females	94.03	0.17	−1.58	0.978
All fish	93.61	0.18	−1.54	0.988

Acknowledgments

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