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Biology of the sand smelt, *Atherina presbyter* (Teleostei: Atherinidae), off the Canary Islands (central-east Atlantic)

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Synopsis

Atherina presbyter is a common fish off the Canary Islands. Age, growth, reproduction, and mortality of the species are studied based on sampling carried out from July 1995 to June 1996. The parameters of the total length–total weight relationship are: $a = 0.004521$, and $b = 3.0771$. Otoliths age readings indicate that the sampled population consists of four age groups (0–III years). The von Bertalanffy growth parameters for all individuals are: $L_\infty = 122$ mm total length, $k = 0.79$ year^{-1}, and $t_0 = -0.21$ years. Individuals grow quickly in their immature first year, attaining approximately 60% of their maximum length. After the first year, the annual growth rate drops rapidly, because the energy is probably diverted to reproduction. It is a gonochoristic species with no evidence of sexual dimorphism.The gonad is present as a single diffuse testis in males and as a single discrete ovary in females. The overall ratio of males to females is not significantly different from 1 : 1. The reproductive period of the species is protacted (February to June). The peak of the reproductive effort occurs in April–May. The size at first maturity is 68 mm. The population is being heavily exploited.

Introduction

The family Atherinidae is represented by a single genus *Atherina* in the eastern Atlantic (Quignard & Pras 1986, Creech 1992a). Members of this genus are commonly referred to as sand smelt. Historically, there has been considerable confusion as to the number and delineation of species in the genus (Creech 1992b). Kiener & Spillman (1969) and Maugé (1990) defined four species: *A. hepsetus* Linnaeus, 1758, *A. boyeri* Risso, 1810, *A. lopeziana* Rossignol & Blache, 1961, and *A. presbyter* Cuvier, 1829. Bamber & Henderson (1985) proposed the synonymy of *A. presbyter* with *A. boyeri*. However, recent studies have demonstrated that differences are present between populations of *A. presbyter* and *A. boyeri*, consistent with the existence of two species (Creech 1990, 1991, 1992b).

The population biology of *A. boyeri* has been extensively investigated at a large number of locations in the eastern Atlantic and in the Mediterranean (Kiener & Spillman 1969, Boscolo 1970, Kohler 1976, Gon & Ben-Tuvia 1983, Palmer & Cully 1983, Bamber & Henderson 1985, Fernández-Delgado et al. 1988, Henderson & Bamber 1987, Henderson et al. 1988, Creech 1990, 1991, 1992a, Fouda 1995, Tomasini et al. 1996). In contrast, published information on *A. presbyter* is very scarce. It only consists in feeding aspects (Anadon 1963, Kislalioglu & Gibson 1977, Turnpenny et al. 1981, Lens 1986, Moreno & Castro 1995), morphometry, genetic and systematic aspects (Schultz 1948, Bamber & Henderson 1985, Quignard & Pras 1986, Creech 1991, 1992b, Vasil'eva 1996), and geographical distribution (Quignard & Pras 1986, Maugé 1990).

The present paper contains the results of an investigation of *A. presbyter* in the Canary Islands (central-east Atlantic). Age, growth, spawning cycle, maturity and mortality are examined in order to understand the life of the species and to contribute to the management of the fishery exploiting the stock. The importance of this work is enhanced by the fact that catches of *A. presbyter* have been declining and the fishing effort on it has been increasing in the area.

A. presbyter is a small pelagic fish species inhabiting inshore waters. This species occurs along the east Atlantic ocean coasts, from Kattegat and Scotland to Mauritania and penetrates into Mediterranean near the Strait of Gibraltar (Quignard & Pras 1986, Maugé 1990). In the central-east Atlantic, it is apparently confined to Canaries, Mauritania and Cape Verde islands (Maugé 1990).

In the Canary Islands, *A. presbyter* is of a great interest both as commercial target and as bait in the seasonal live-bait tuna fishery. This species is captured near surface in the littoral zone, mainly with beach seines and liftnets. It is caught consistently year-round without significant seasonal differences in landings.

Materials and methods

A. presbyter samples were collected at fortnightly intervals from commercial catches taken between July 1995 and June 1996 off Gran Canaria (Canary Islands). A total of 3101 individuals was obtained by random sampling. A subsample of 1028 specimens was taken by a random length stratified method for biological analysis.

Each fish was measured to the nearest mm for total length (TL), and weighed to the nearest 0.001 g for total body weight (TW). The weight of the gonads (GW) was measured to the nearest 0.001 g, and the sex and the stage of maturation were ascertained macroscopically. Stages of maturation were classified as follows (Holden & Raitt 1975): I = immature, II = resting, III = ripe, IV = ripe and running, V = spent. Sagittal otoliths of the fish were removed, cleaned, and stored dry.

The total length–total weight relationship was calculated over the whole period, both for males and females separately and for the population as a whole, applying a linear regression (Ricker 1973). The age was determined by interpreting growth rings on the otoliths. Counts for each specimen were performed twice, on two separate occasions, and only coincident readings were accepted. An index of average percent error (APE) developed by Beamish & Fournier (1981) was used to compare the precision of age determinations. The evolution of the mean monthlymarginal increments was analysed to validate the ageing method. The distance between the outer edge of the outermost translucent zone and the periphery of each otolith was measured in mm. Measurements were always made along the longest axis of the otolith. The 1st April 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 relationship by mean of the Marquardt's algorithm for non-linear least squares parameter estimation (Saila et al. 1988).

The sex-ratio (males : females) for the whole sample and different size classes was calculated. The reproductive season was determined according to Anderson & Gutreuter (1983) based on the monthly development of the gonadosomatic index (GSI). The length-at-sexual maturity (length at which fifty percent of the specimens had become mature) was estimated by means of a logistic function which was fitted to the proportion of mature individuals (stages III, IV, and V) by size class using a non-linear regression (Saila et al. 1988).

Length-frequency data of the catches were converted to age-frequency using the von Bertalanffy growth parameters (Pauly 1983). The total mortality rate (Z) was calculated from the length-converted catch curve using the program ELEFAN (Gayanilo et al.[1]). The rate of natural mortality (M) was determined using the method of Tanaka (1960). Following the estimation of Z and M, the fishing mortality rate (F) was estimated by subtraction. The exploitation ratio (E) was estimated dividing F by Z (Gulland 1971). The length-at-first capture (LC_{50}) was determined from the selection ogive generated from the length-converted catch curve (Pauly 1983).

Results

Males ranged in size between 52 and 113 mm total length and females between 49 and 115 mm. The range of immature individuals was 14 to 73 mm. The parameters of the total length–total weight relationship for males and females separately and for the population as a whole are given in Table 1. No significant difference in the allometric coefficient of the regression was found between males and females (t-test, $t = 0.27 < t_{0.05,550} = 1.65$). Isometric growth was observed in both sexes and for the whole sample.

[1] Gayanilo, F.C., Jr., M. Soriano & D. Pauly. 1988. A draft guide to the compleat ELEFAN. ICLARM Software 2, Contribution No. 435: 1–65.

Table 1. Parameters of the total length–total weight relationship for males, females and all fish of *A. presbyter* collected off the Canary Islands, and the possibility of isometry tested by Student t-test. *($t < t_{0.05, n>250} = 1.65$).

	a	b	se (b)	r^2	n	t-test
Males	0.006536	3.04102	0.06137	0.959	269	0.66*
Females	0.006542	3.04922	0.05920	0.962	283	0.83*
All fish	0.006118	3.07712	0.05638	0.982	1028	1.36*

Of the total otoliths examined, 912 (88.7%) were readable and used for the study of age and growth. APE value was only 2.4%. The mean monthly marginal increments in the whole otoliths with one translucent zone ranged from 0.25 to 0.36 mm between May and August. They subsequently declined to 0.05 mm in December, before gradually increasing to 0.15 by April. The marginal increments in otoliths with two and three translucent zones also declined markedly between November and March and followed a similar trend. Thus, irrespective of the number of translucent zones in the otoliths, the marginal increments declined markedly and then rose progressively only once during 12 months period, demonstrating that the translucent zones are formed annually.

Sampled population consisted predominantly of two age groups (I and II), except during the late spawning and post-spawning period when the presence of the age group 0 was recorded. Recruitment took place in May and June. Over 60% of the growth was achieved by the end of the first year (Table 2). By the end of the second year, fish had attained a mean length of 95 mm. After they had spawned, few individuals of the age group III were encountered. No evidence was found to indicate that fish of the age group III survived to spawn for a fourth season.

The relationship between age and length, derived from the assumed annual periodicity of the otoliths growth rings, is described by the growth parameters: $L_\infty = 122$ mm total length, $k = 0.79$ year^{-1}, and $t_0 = -0.21$ years (Table 3). No significant differences in growth parameters were found between sexes (Hotelling s T^2-test, $T^2 = 5.29 < {T_0}^2_{0.05,3,456} = 7.89$).

The gonad was present as a single diffuse testis in the male and as a single discrete ovary in the female. Of the 1028 fish examined, 269 (26.2%) were males and 283 (27.5%) females. The sex of the remaining 476 (46.3%) individuals could not be identified macroscopically and were immature as they had very thin and traslucent gonads. The overall ratio of males to females was 1 : 1.05 and χ^2 analysis revealed this not to be significantly different from a 1 : 1 ratio (Table 4). Sex-ratios for males and females grouped into 5-mm length classes had not significant departures from the 1 : 1 ratio.

When all the males and females were considered, irrespective of their maturity stage, the monthly mean values of GSI increased rapidly from February to April before decreasing until June (Figure 1). From July to January the values were low. The same temporal variation pattern was recorded for both sexes. The monthly mean GSI, calculated only for males

Table 2. Age–length distribution for all fish of *A. presbyter* collected off the Canary Islands.

Size (mm)	Age group (years)			
	0	I	II	III
15	11			
20	28			
25	36			
30	40			
35	56			
40	70			
45	77			
50	65			
55	47	2		
60	15	11		
65	3	28		
70		47		
75		65	4	
80		41	13	
85		33	36	
90		10	59	
95		6	45	
100		2	25	4
105			8	11
110			2	9
115			1	2
n	448	245	193	26
x	42.5	74.2	94.9	109.1
SD	6.3	5.1	4.6	2.5

Table 3. Parameters of the von Bertalanffy growth curve for males, females and all fish of *A. presbyter* collected off the Canary Islands.

	L_∞ (mm)	k (year^{-1})	t_0 (years)	r^2
Males	121.3	0.72	0.39	0.979
Females	121.5	0.69	0.47	0.981
All fish	121.8	0.79	0.21	0.989

Table 4. Number of males, females and juveniles of *A. presbyter* collected off the Canary Islands by 5-mm size class and sex-ratio tested by chi-square analysis. *($\chi^2 < \chi_t{}^2{}_{1,0.05} = 3.84$).

Size (mm)	Males	Females	Juveniles	Sex-ratio	χ^2
15			12		
20			28		
25			36		
30			41		
35			58		
40			72		
45			79		
50	1	1	66	1 : 1.00	
55	1	2	49	1 : 2.00	0.33*
60	6	8	15	1 : 1.33	0.28*
65	23	20	12	1 : 0.86	0.21*
70	20	25	7	1 : 1.25	0.55*
75	37	41	1	1 : 1.10	0.21*
80	39	43		1 : 1.08	0.19*
85	41	35		1 : 0.85	0.47*
90	38	42		1 : 1.10	0.20*
95	25	28		1 : 1.12	0.17*
100	17	18		1 : 1.05	0.03*
105	14	9		1 : 0.64	1.08*
110	5	8		1 : 1.60	0.69*
115	2	3		1 : 1.50	0.20*
Total	269	283	476	1 : 1.05	0.36*

and females with ripe and running gonads, produced a similar variation pattern with higher values. GSI indicated that spawning takes place over a period of approximately 5 months. Fish of the age groups 0 and I showed lower values of GSI than those of the II and III.

No significant difference in length-at-sexual maturity was found between males and females (t-test, $t = 0.43 < t_{0.05,550} = 1.65$). The length at which fifty percent of fish had become mature was 68 mm total length (Figure 2). All males and females were mature by the end of their second year at a mean length of 93 mm.

The length-converted catch curve is shown in Figure 3. The rates of total mortality (Z), natural mortality (M) and fishing mortality (F), and the exploitation ratio (E) were calculated separately for the age groups 0 and I–III. The values for the age group 0 were: Z = 4.66 year^{-1}, M = 1.01 year^{-1}, F = 3.65 year^{-1} and E = 0.78, and for the age groups I–III were: Z = 2.54 year^{-1}, M = 1.01 year^{-1}, F = 1.53 year^{-1} and E = 0.61. The length-at-first capture was: $LC_{50} =$ 36 mm.

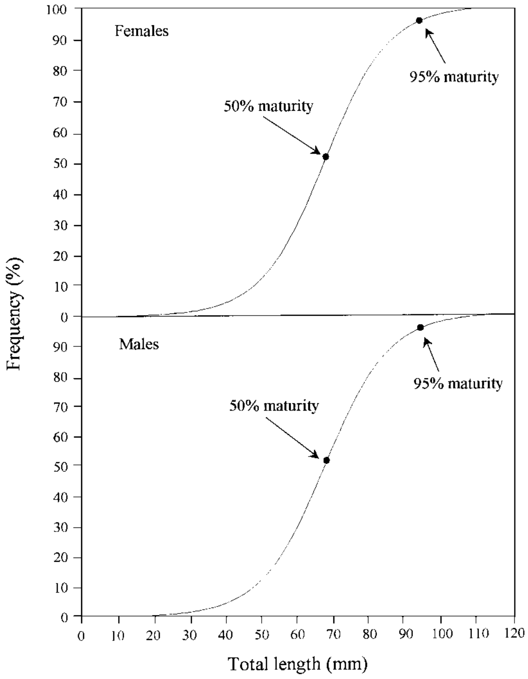

Figure 1. Sexual maturity ogive for females and males of *A. presbyter* collected off the Canary Islands.

Discussion

Otoliths of *A. presbyter* off the Canarian archipelago show the ring pattern common to teleost fishes. One opaque and one translucent ring are laid down each year on the otoliths, allowing age determination with relative ease. These rings are generally believed to be deposited during periods of fast and slow growth, respectively (Williams & Bedford 1974). Seasonal growth cycles might be related to physiological changes produced by the influence of temperature, feeding regime and reproductive cycle (Morales-Nin & Ralston 1990). The opaque rings are formed during spring-summer months, when the sea surface temperature reaches the highest values (24°C), and the hyaline rings during winter months, when the temperature reaches the lowest values (17°C) and the breeding occurs in the species. Fernández-Delgado et al. (1988) also found that annuli formation in otoliths of *A. boyeri* from the estuary of the Guadalquivir River takes place during spring and summer (April to July). The evidence presently available suggests that a seasonal temperature difference of 2–3°C might be sufficient to cause ring formation (Morales-Nin & Ralston 1990). During

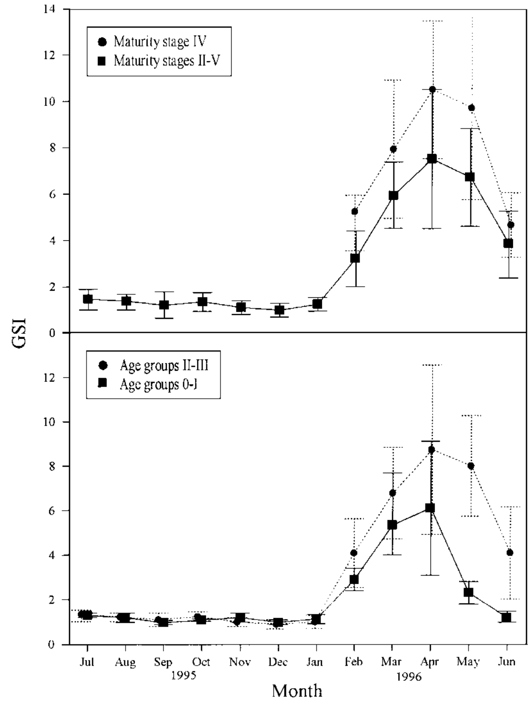

Figure 2. Mean monthly development of the gonadosomatic index (GSI) for *A. presbyter* collected off the Canary Islands at maturity stages (IV and II–V) and at age groups (0–I and II–III).

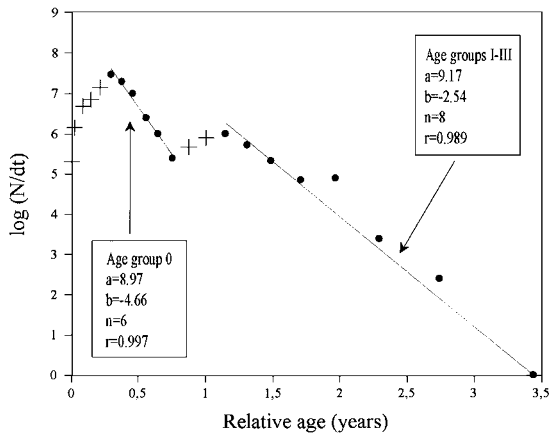

Figure 3. Length-converted catch curve for all fish of *A. presbyter* collected off the Canary Islands at age groups (0 and I–III). The initial data point (+) were not used in the regressions.

the maturity period, the metabolic energy seems to be diverted from growth, causing the formation of thin increments which are in turn reflected in hyaline seasonal growth rings.

The highest age class observed is III years. The short life cycle exhibited by *A. presbyter* concurs with the expectations of Kiener & Spillman (1969), Fernández-Delgado et al. (1988), Maugé (1990), Creech (1992a) and Rosecchi & Crivelli (1992), which proposed a 3–4 years age structure as typifying populations of Atherinidae species. As a whole, growth of *A. presbyter* is rapid, with males and females growing equally fast. The growth parameters obtained are reasonable because the theoretical maximal length value is higher than the size of the largest fish sampled and the growth coefficient value indicates rapid attainment of maximal size, characteristic of the short life species. *A. presbyter* grows quickly in its immature first year, attaining approximately 60% of the maximum length. After the first year, the annual growth rate drops rapidly. It can be related to sexual maturity, because in the studied area all individuals are mature by the second year of life. Hence, energy is probably diverted to reproduction, resulting in less energy available for somatic growth.

A. presbyter from the Canary Islands is a gonochoristic species with no evidence of sexual dimorphism. The near equal ratio of males to females is similar to ratios quoted by Boscolo (1970), Kohler (1976) and Creech (1992a) for other Atherinidae.

The spawning of *A. presbyter* occurs during five months. A prolonged breeding season is generally characteristic of repeat spawners (Nikolskii 1963) and fish living in variable and unstable and/or highly productive environments (Tomasini et al. 1996). In this area, the spawning period of several fish species is protracted (Lorenzo & Pajuelo 1996, Pajuelo & Lorenzo 1995, 1996, 1998). Tomasini et al. (1996) observed that the spawning period of *A. boyeri* in brackish lagoons of southern France spreads over 8 months (February–September). Protracted spawning appears to be a feature of the biology of Atherinidae (Boscolo 1970, Castel et al. 1977, Palmer & Cully 1983, Gon & Ben-Tuvia 1983, Henderson et al. 1988, Creech 1992a, Rosecchi & Crivelli 1992, Tomasini et al. 1996). Depending on environmental conditions and energy accumulation available, reproductive effort in atherinid species is more or less important during the spawning season (Tomasini et al. 1996).

Length-at-sexual maturity does not differ between males and females, corresponding to 67 mm total length. In the age–length relationship, this size corresponds to 0 and 1 year old specimens. In the Suez Canal, Fouda (1995) also found that males and females of *A. boyeri* attain sexual maturity when age is approximately 1 year.

The length-converted catch curve shows a typical form of two modes and justify the estimation of two values of Z (Pauly 1983). In both cases, the exploitation ratio is higher than 0.50. Gulland (1971) suggested that, as a rule of thumb, a fish stock is optimally exploited at a level of fishing mortality which generates $E = 0.50$, where $F_{opt} = M$, but in the present study $F > F_{opt} = M$. More recently, Pauly (1987) proposed a lower optimum fishing mortality, $F_{opt} = 0.4\,M$ ($F > F_{opt}$). Therefore, *A. presbyter* off the Canary Islands is being heavily exploited.

In the Canarian Archipelago, where a conservation legislation on fisheries exists, a limit of catch has been implemented for *A. presbyter*. In this case, the regulation is of limited benefit. Measures such as closed seasons, closed areas or changes in fishing pattern would be desirable to safeguard the spawning stock and the recruits. If the stock decline continues, a further possible option, decommercialization, would certainly be beneficial to the stock, but the social and political arguments surrounding such a decision are beyond the scope of this paper.

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