

Age and growth of *Crystallogobius linearis* (von Dübén, 1845) (Teleostei: Gobiidae) from the Adriatic Sea*

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SUMMARY: Age and growth of the crystal goby *Crystallogobius linearis* (von Dübén, 1845) were investigated by means of daily growth increment counts on the sagittal otoliths. Samples of *C. linearis*, obtained as by-catch of the *Aphia minuta* fishery, were collected in a coastal area of the central Adriatic Sea between March and September 1996. Otolith age-readings were carried out on 167 specimens, ranged from 14 to 41 mm of total length, and indicated that the population was composed of individuals from two to seven months old. Growth of both males and females appeared practically linear over the whole size range studied, although in females a slight decrease in growth rate of older specimens was observed. Furthermore, the hatch date distribution of *C. linearis*, obtained by the backcalculation of the ageing data, indicated a long breeding season of at least eight months. The results of this study indicated that, as reported from literature for most nektonic gobies, the crystal goby is also characterised by a short life span, during which a high reproductive effort is displayed throughout a long breeding season.

Key words: *Crystallogobius linearis*, ageing, Adriatic Sea.

INTRODUCTION

The Gobiidae is a very large family of perciform teleosts, accounting for about 1800 inshore marine, estuarine and freshwater species that inhabit tropical and warm temperate areas. In the Mediterranean Sea, 24 genera and 62 gobiid species have been recorded to date (Quignard and Tomasini, 2000).

Among the diverse modes of life of gobiids, some neritic species have been of special zoological interest because of the persistence of post-larval features of habit and anatomy into their adulthood (Miller,

1973). In European seas, such progenetic features occur in three monotypic genera: *Aphia*, *Crystallogobius* and *Pseudaphia*. All these species show body transparency and scarcity of melanophores, persistence of the swimbladder and a short and virtually straight alimentary canal. There is also a common evolutionary trend towards a reduction of the first dorsal fin, a change from ctenoid to cycloid scales and a more or less pronounced sexual dimorphism in dentition (Miller, 1973). The genus *Crystallogobius* appears to be the most specialised of this group. A reduction of the first dorsal fin to II rays in males and its complete loss in females, the total absence of scales and very enlarged caniniform teeth in the jaws of adult males are observed.

*Received September 12, 2000. Accepted May 28, 2001.

The crystal goby *Crystallogobius linearis*, described for the first time by Düben (1845) and commonly synonymised as *Crystallogobius nilssoni* (Düben and Koren, 1846), is widely distributed in both the northeastern Atlantic boreal and in Mediterranean regions. *C. linearis* is a nektonic species, living from coastal to offshore waters up to 400 m depth on sand-mud bottoms (Miller, 1986). It was described as an “annual” species, whose adults die after their first breeding season at the age of about one year (Collett, 1878). All the following studies on *C. linearis* were carried out in the first two decades of this century and reported, almost exclusively, data on reproduction and morphology of early life stages. The eggs of the crystal goby are demersal, having been recorded in empty tubes of sedentary polychaetes such as *Chaetopterus* and *Protula*, respectively in north Atlantic (Appellöf, 1892; Grieg, 1899; Clark, 1914) and Mediterranean waters (Raffaele, 1895; Lo Bianco, 1909). As in many other gobiids, males of *C. linearis* guard the eggs in the serpulid tubes (Raffaele, 1895). In the north Atlantic, larval development of the crystal goby has been described from 4 mm of total length onwards (Petersen, 1919).

Spawning probably occurs in the summer season, from May to August in the north Atlantic (Oslofjord) and from July to September in the Mediterranean (Gulf of Naples) (Padoa, 1953; Miller, 1986). Postlarvae of *C. linearis* were recorded from May to October off Plymouth (Allen, 1917; Clark, 1920) and from June to September on the west coast of Ireland (Fives, 1970).

In the Mediterranean *C. linearis* is the target species of small scale fisheries both in north-east Spain (off Catalonia) and in the Ligurian Sea (Camogli) (Relini Orsi and Fanciulli, 1977; Camiñas and Martorell, 1991), whereas it represents a by-catch species in the *Aphia minuta* fishery carried out in south-east Spain, off the Balearic Islands and in the central Adriatic Sea (Iglesias and Martorell, 1992; Martínez-Baño *et al.*, 1993; Frogli *et al.*, 1998).

In the Adriatic Sea, *C. linearis* was first recorded in Dalmatian waters (Kolombatovic, 1900: in Soljan, 1963). However, no data on this species have been reported to date from this area, probably because it is rarely caught due to its small size (up to 40 mm) and sparse distribution.

In 1996 an ichthyological survey was carried out all year round in a coastal area of the central Adriatic to provide data on the local small-scale fishery of the transparent goby *A. minuta*. Among the by-catch

species, many individuals of *C. linearis* were sampled mainly in offshore waters throughout spring and summer. All the specimens of crystal goby were then separated and analysed, with the aim of improving the current knowledge concerning some aspects of their life history.

In particular, this paper deals with the study of age and growth by counting the daily growth increments in otoliths.

MATERIALS AND METHODS

Samples of *C. linearis* were collected as by-catch in the coastal area off the harbour of Ortona (central Adriatic Sea) from March to September 1996 (no data in August). For each further analysis, the specimens of all months of catch were pooled together (see Table 1). Sampling was carried out from 10 to 40 m depth on the sea bed by a local fishing vessel equipped with a small-meshed semipelagic trawl with three concentric bags with a codend from 16 to 5 mm mesh size (stretched).

Each sample was sorted in the laboratory and the specimens of *C. linearis* were separated from the other species and stored in 80% alcohol solution. Wet weight (mg) and total length (TL), measured to the lowest mm below, were recorded for each specimen, and the sex was determined under a dissecting microscope. In order to study age and growth, five fresh specimens per 1 mm size interval were selected for each sex when possible. Sagittal otoliths were extracted and dried for several days in vials. Left otoliths were mounted on microscope slides with an epoxy resin (Petropoxy) and kept on a stove for polymerisation. Each otolith was polished by hand on a wet polishing cloth using 0.05 μm alumina powder, in order to maximize the readable area of the otolith surface. Care was taken to locate the position of the nucleus, as well as the outermost increments. From these preparations two counts were made from the primordium to the margin and vice-versa, and the

TABLE 1. – Samples of *C. linearis* selected for each study (specimens for month of catch)

	Month of catch					
	March	April	May	June	July	September
Total catches	4	7	48	248	31	13
Ageing data	4	6	32	81	12	13
L/W relationship	4	7	48	111	31	13
Age at maturity			21	38	7	5

mean value was considered. When the counts differed by more than ten increments they were discarded. Increment counts were performed using a light microscope at magnification 630x with immersion oil. The microscope was equipped with a television camera connected to a video-analysis image program (OPTIMAS 6.5). The software was also used to measure the maximum diameter of each otolith specimen to an accuracy of 0.01 mm.

The Von Bertalanffy growth function was preliminarily fitted to our age-length data, but the data did not meet the criterion of convergence required by the VONBER program of the statistical package LFSA (Sparre, 1987). So, by means of the REGRES program, which performs an ordinary least squares linear regression analysis, a straight line was fitted to the age-length data pairs obtained by the increment counts of otoliths. The linear regression parameters were calculated for each sex and for the whole population. The slopes (growth rate) of the straight lines, obtained for males and females, were compared by means of an F-test for the difference between two regression coefficients (Sokal and Rohlf, 1969). Furthermore, from the ageing data and the date of capture, the monthly distribution of birth-dates of our specimens was backcalculated.

In order to estimate age at maturity, all aged females were pooled in one month age classes. Age versus proportion of mature females was then plotted and fitted to the following logistic equation:

$$P = \frac{1}{1 + e^{-(\alpha + \beta A)}}$$

where P is the estimate proportion of mature fish, A is the age in months and α and β are coefficients. The values of the coefficients are obtained by the linearisation of the above equation as follows:

$$\ln \frac{P}{1 - P} = \alpha + \beta A$$

where α is the intercept and β the slope. The age at maturity (A50), defined as the age at which 50 % of the fish are at the mature stage, is then estimated as the negative ratio of coefficients, $-\alpha/\beta$, by substituting $P = 0.5$ in the linear equation.

The relationship between total fish length and maximum otolith diameter was investigated by means of linear regression analysis.

Finally, the length-weight relationship was calculated both for the whole population and for each sex independently. The exponential equation in the commonly used form was fitted to the data:

$$W = a TL^b$$

where W is the total wet weight (mg), TL the total length of fish (mm) and a and b are regression parameters. By linearisation of the above equation, the log-transformed length-weight data were computed to determine the regression parameters. The allometric indexes (b) obtained for males and females were then compared using an F-test (Sokal and Rohlf, 1969).

RESULTS

Otolith morphology

The sagittae of *C. linearis* were disc-shaped in small specimens and slightly oval in large specimens because of an increase in the relative size of the rostrum. The inner side of the otolith was concave and the outer convex.

The maximum otolith diameter, recorded in fishes from 14 to 41 mm TL, ranged from 0.28 to 0.71 mm. The relationship between maximum otolith diameter (OD) and total fish length (TL) was linear and is summarised in the following equation:

$$OD = 0.123 + 0.0145 TL; n = 213 \quad r^2 = 0.86$$

In agreement with the characteristic otolith microstructure of gobids described by Brothers (1984), the sagittae of *C. linearis* showed an elongated primordium with a slight central constriction surrounded by a series of increments composed of

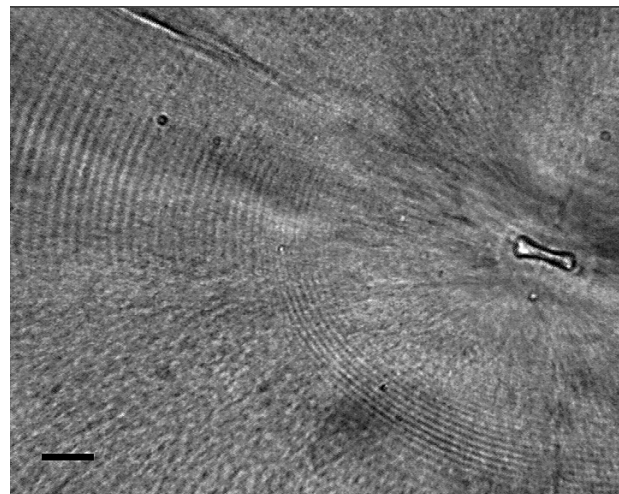


FIG. 1. – Core region of the sagittal otolith of *C. linearis*, showing the elongated primordium (on the right side). Scale bar = 10 μ m.

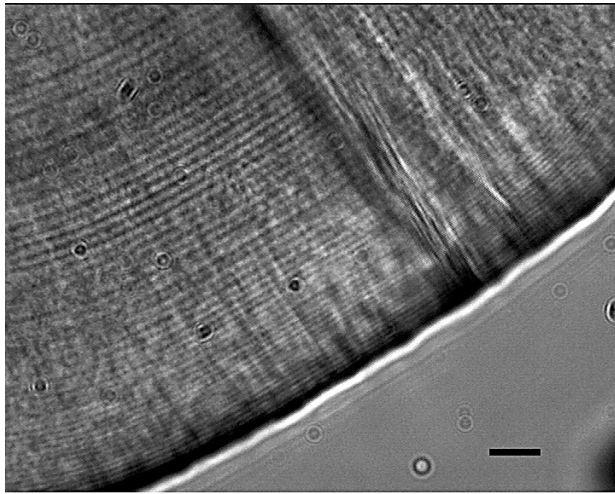


FIG. 2. – Edge of the sagittal otolith of *C. linearis*, showing the narrower outermost increments. Scale bar = 10 μ m.

alternate dark and light zones (Fig. 1). No accessory primordia or transition zones were observed in any of the specimens. Close to the primordium, the microincrements were very fine and narrow and sometimes difficult to count. The thickness of the microincrements, ranging from about 1 to 3 μ m, increased progressively towards the otolith margin. In larger specimens, the thickness of the microincrements decreased again close to the otolith margin (Fig. 2).

Age and growth

Among the Aphyine gobies, the daily increment deposition was validated only in *A. minuta* by means of a marking procedure (Iglesias *et al.*, 1997). Because *C. linearis* is highly related to *A. minuta* both in the pelagic mode of life and in the otolith growth ring pattern, it was assumed that the microincrements were laid down daily in this species too. Furthermore, in the calculation of hatch-dates, the time elapsed between hatching and first increment deposition was considered negligible and then ignored (Iglesias *et al.*, 1997).

In comparison with *A. minuta* (La Mesa, 1999), the otolith reading in *C. linearis* was more easily carried out as the increment pattern composed of dark and light zones was clear and continuous on the whole otolith surface. Overall, 167 otoliths were examined and only 19 were discarded (11 %). The ageing was carried out on a whole size range of fish sampled, namely on 71 females ranging from 15 to 32 mm TL and on 77 males ranging from 14 to 41 mm TL. Age-length keys were calculated for both

TABLE 2. – Age length key of females

TL (mm)	Age classes (months)					
	II	III	IV	V	VI	VII
15	1					
16		1	1			
17		1	1			
18		4	1			
19		2	1			
20		2	2			
21		4	1			
22		2	2			
23		2	2			
24			3	1		
25		3	2			
26		1	4			
27			2	1	1	
28				2	3	
29			2	1	2	
30				4	1	
31					2	1
32			1	2	2	
<i>n</i>	1	22	25	11	11	1
<i>mean</i>	15	20.8	23.6	29.1	29.5	31
<i>std</i>		2.8	3.9	2.3	1.7	

TABLE 3. – Age length key of males

TL(mm)	Age classes(months)					
	II	III	IV	V	VI	VII
14	2	1				
15						
16	1					
17		1				
18		1	1			
19		4				
20		2	1			
21			2	2		
22			1			
23		1	3			
24			4			
25			2	2		
26						
27			1			
28			2	2		
29			1	2		
30				3	1	
31			1	2	1	
32			1	1	1	
33				1	3	
34				3		
35				1	3	
36					3	
37					1	2
38					3	
39				1	1	
40					1	
41						4
<i>n</i>	3	10	20	20	18	6
<i>mean</i>	14.7	18.8	24.6	29.9	35.3	39.7
<i>std</i>	1.1	2.3	3.6	4.5	2.8	2.1

sexes and are reported in Tables 2 and 3. The growth model which best fits on our age-length data pairs was a simple linear regression (Fig. 3), and the

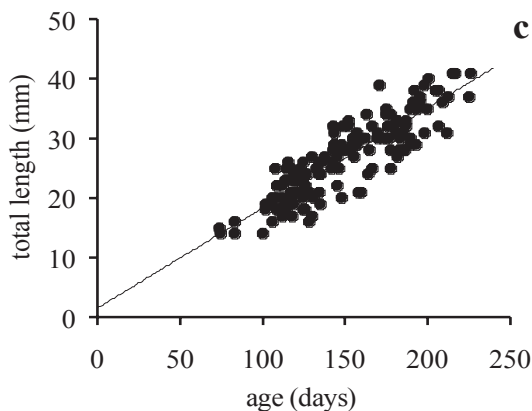
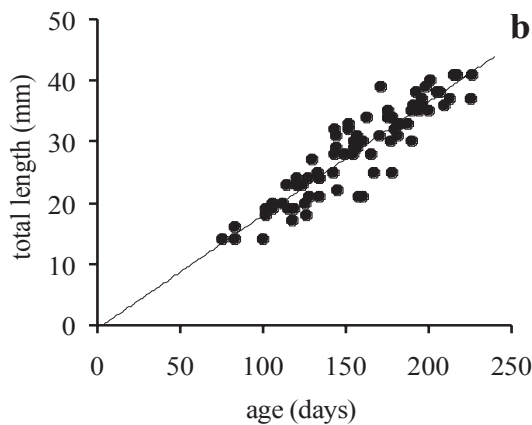
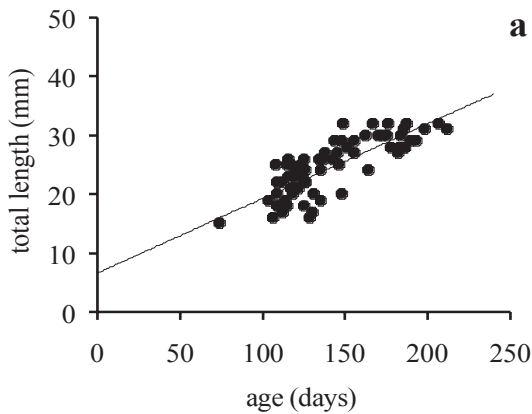


FIG. 3. – Simple linear regressions fitted to age-length data of females (a), males (b) and whole population (c) of *C. linearis* from the Adriatic Sea.

results are summarised below:

Females: $TL = 6.601 + 0.127 \text{ age (days)}$
($r^2 = 0.65$; $n = 71$)

Males: $TL = -0.602 + 0.186 \text{ age (days)}$
($r^2 = 0.84$; $n = 77$)

Whole population: $TL = 1.515 + 0.168 \text{ age (days)}$
($r^2 = 0.77$; $n = 148$)

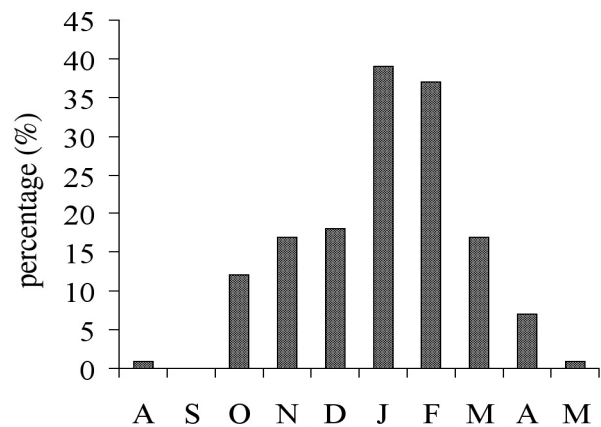


FIG. 4. – Monthly distribution of the birthdate of *C. linearis* back calculated from the ageing data and date of capture.

The growth rate (slopes) of females (0.127, confidence interval 0.105-0.149) and males (0.186, confidence interval 0.167-0.204) were statistically different ($F = 16.08$, $P < 0.01$), males growing faster and attaining a larger size than females.

The age at maturity (A50) was about five months ($\alpha = 6.06 \pm 1.31$ and $\beta = -1.17 \pm 0.25$) and the younger mature female was a little less than four months old and measured 18 mm TL. Up to the third month of life all females were immature, whereas all the specimens older than six months were mature. The maximum age calculated in our samples was 212 days for females and 225 days for males.

The backcalculation of the ageing data provides a wide hatch date distribution (at least from October to May) (Fig.4), showing one main peak in January.

Length-weight relationship

The relationship between fish length and weight was determined from 214 specimens, 114 females and 100 males. Females and males measured 15-33 mm and 14-41 mm and weighed 10-162 mg and 8-245 mg respectively.

The values of parameters a and b of the allometric power equations, derived from linear regression of the log-transformed length-weight data, are the following:

Females: $W = 0.00084 L^{3.44}$ ($r^2 = 0.93$; $n = 114$)

Males: $W = 0.00168 L^{3.19}$ ($r^2 = 0.97$; $n = 100$)

Whole population: $W = 0.00149 L^{3.24}$ ($r^2 = 0.95$; $n = 214$)

Positive allometric growth ($b > 3$) was observed in both sexes as well as in the whole population. The

F-test indicated significant difference between the allometric coefficient (b) of females and males ($P < 0.05$).

DISCUSSION

In the Mediterranean Sea, the crystal goby shows a wide distribution, being caught from the Spanish waters off Catalonia to the Greek waters off the Peloponnese (Relini Orsi and Fanciulli, 1977; Camiñas and Martorell, 1991). In Italian waters, the first data on this species were collected in the Gulf of Naples (Raffaele, 1895; Lo Bianco, 1909). More recently, the first record of *C. linearis* was reported from the Ligurian Sea (Relini Orsi and Fanciulli, 1977), where a small but profitable fishery is carried out off the small harbour of Camogli. In the central Adriatic Sea, the crystal goby lies mainly between 30 and 40 m depth and constitutes a by-catch species of the *A. minuta* fishery. The offshore distribution and the pelagic mode of life of this species has also been reported by other authors (Miller, 1973; Iglesias *et al.*, 1997). Larval and adult specimens of *C. linearis* were practically absent from the surface layer off the Catalan coast (NW Mediterranean Sea) and were almost exclusively collected at night (Olivar and Sabatès, 1997).

Despite its wide distribution, the life history of *C. linearis* has been scarcely studied to date. Considering the shrinkage of our specimens due to alcohol preservation (Fey, 1999), the maximum length of *C. linearis* recorded in the Adriatic Sea is rather close to the maximum length reported in the literature, i.e. 39 and 47 mm in females and males respectively (Miller, 1986). Consequently, because the maximum age estimated in our older specimens did not exceed seven months, and they probably die immediately afterwards, it could be hypothesised that there is more than one cohort per year.

Therefore, according to the literature (Collett, 1878), our data on longevity confirm that *C. linearis* is an annual fish and probably dies after its first breeding season. Indeed, histological analyses of some specimens (V. Caputo, pers. comm.) revealed a widespread degeneration of the intestinal epithelium that could partially explain their death, as reported in the related pelagic goby *A. minuta* (La Mesa, 1999). A loss of functionality of the digestive system seems, therefore, to occur in all the pelagic gobies of Mediterranean, such as *Aphia ferreri* (Fage, 1910), *A. minuta* (La Mesa, 1999) and *C. linearis*.

Unfortunately, the small number of *C. linearis* collected over a short period of the year (351 specimens in six months, of which 70% in June) did not allow the determination of the pattern of seasonal growth by analysis of the length frequency distributions, or the confirmation of the massive disappearance of the postspawning adult class.

The ability to reproduce at small absolute sizes, as part of the evolutionary decrease in body size, is an important feature of the adaptive radiation of the gobies (Miller, 1979). In nektonic aphyine gobies, such as *C. linearis*, early maturation at small size is associated with gonadal heterochrony (Gould, 1977). Our data on age at maturity confirm the early maturation of this species, whose females are already mature at four months of life. *C. linearis* seems, therefore, to be one of the most early-maturing species among gobies, whose age at first maturity ranges from a few months to at least three years (Miller, 1989).

The persistence of post-larval features of habit and anatomy in the adult of *C. linearis*, as well as probably the sudden death after spawning, could have influenced the growth pattern of this species. Indeed, the growth model that best fits our age length data was the linear regression, which is typical of larval fish development (Campana and Jones, 1992). In males, the growth rate remained constant, at least over the size range analysed, and, apparently, there was no tendency towards an asymptotic maximum length in larger specimens. In females the lower goodness of fit of the linear growth model was probably due to a decrease in growth rate of older specimens, most of which were in spawning conditions. The considerable reproductive effort of females, clearly evidenced by the abnormal development of the ovaries, requires energy mobilisation for gonadal anabolism to somatic growth disadvantage and is, most likely, the cause of a lower growth rate compared to males.

Finally, the hatch date distribution of *C. linearis*, obtained by the backcalculation of our ageing data, points out a long breeding season (at least eight months, i.e. from October to May), which is characteristic of several small epibenthic and nektonic gobids, such as members of the genus *Pomatoschistus* and the semelparous aphyines respectively (Miller, 1989). The long breeding season, along with the early maturation of gonads, seems to indicate that a fish could be born and reproduce in the same spawning season, supporting the presence of more than one cohort per year mentioned above. For

example, a fish hatched in January is probably able to spawn still in April-May and to live at least up to August. Unfortunately, the small number of specimens caught in a limited period (only six months) did not allow me to have monthly size frequency distributions in order to graphically support this hypothesis.

The life history of *C. linearis* therefore displays all the ecological and behavioural characteristics of most nektonic gobies (Collett, 1878; Tamura and Honma, 1969, 1970; Miller, 1973), such as a short life-span (one or two years), a high reproductive effort during a long breeding season and a probable postspawning death of the adult specimens just after breeding.

ACKNOWLEDGEMENTS

I am very grateful to E. Arneri for his valuable comments, as well as to E. Morello for the language improvement of the manuscript. I am much indebted to both B. Antolini and the crew of the vessel "Maria Madre" of Ortona for their valuable help in the fishing activities. This work was financially supported by the Italian MRAAF (Ministero Risorse Agricole, Alimentari e Forestali).

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Scient. ed.: H. Farrugio