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Growth and reproduction of *Xyrichthys novacula* (Pisces: Labridae) in the Mediterranean Sea*

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SUMMARY: Mediterranean razorfish, *Xyrichthys novacula,* were collected between July and December in a sandy bay of Ponza Island (Central Mediterranean Sea) to investigate the effects of reproduction and growth patterns on sexual inversion processes and haremic territoriality. The minimum body size of males decreased from 17 cm in July to 15 cm (T.L.) in October as a consequence of the sexual inversion after reproduction. Females showed a reproductive peak in August using both the Holden and Rait scale and the gonodosomatic index. The gonads of males were small, on average only 0.14% of total body weight. The proportion of body weight devoted to gonads did not change with male size. This is probably a consequence of the haremic mating system of the species which reduces sperm competition between males. A new coloration phase for females was introduced in addition to the three already described in the literature. Individuals of each age class are characterised by different coloration patterns. This chromatic feature of the species allows dominant males to recognize the age of females and consequently to choose during harem formation the older and larger specimens able to produce a larger number of offspring.

Key words: Xyrichthys novacula; proterogyny; growth; wrasses reproduction.

INTRODUCTION

The Mediterranean razorfish *Xyrichthys novacula* (L., 1758) is a benthic wrasse found on sandy bottoms at depths ranging from 1 to 50 m. It is the only Mediterranean species distributed along both the eastern and western Atlantic coasts (Tortonese, 1975). Sordi (1967) used histological analysis to confirm the Oliver and Massuti (1952) hypothesis that the species is a protogynous hermaphrodite. A recent histological gonad study has related the sexual inversion process with both chromatic change and increase in length (Bentivegna and Rassotto, 1987). Ethological studies on the social system of the genus *Xyrichthys* were conducted by Nemetzov (1985) and Victor (1987).

Among labrid species, protogynous sequential hermaphroditism, with sexual inversion from female to male, is the most common reproductive pattern (Reinboth, 1962; Robertson, 1973; Robertson and Warner, 1978; Randall and Bruce, 1983). Most of the species are characterised by a strict territorial organisation: we can distinguish between lek species, in which territorialism is temporary, occurring only in the spawning season, and haremic species in which it is permanent. In haremic species, females mate almost exclusively with the dominant male. A feature common to many wrasse species is the presence

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of a far larger number of females than males among the reproductive population. A species with a population structured in this way is defined as polygynous. In such a species, as Victor (1987) stated, a dominant male can monopolise females in two different, but not mutually exclusive ways: keeping other males away from the resources of his territory essential to females (resource defence polygyny) or merely defending the females of his territory from males (female defence polygyny). Ethological studies on *Xyrichthys novacula* (Terao *et al.*, 1991; Marconato *et al.*, 1995) have indicated that the Mediterranean razorfish is a haremic species in which dominant males defend the females of their territory from the mating attempts of others males.

The purpose of this study was to examine some aspects of reproduction and growth patterns of *X. novacula* as influenced by the sexual inversion process and haremic territorial organisation in an area of the Central Mediterranean Sea.

MATERIAL AND METHODS

The study area was located in a sandy bay of Ponza Island (Italy) (Fig.1). The bottom features are rather homogenous in the central area of the bay, characterised by well sorted fine sand up to a depth of 18m, while *Posidonia oceanica* meadows cover the area from 18 to 25 meters. The two sides of the bay have a rocky bottom. In order to cover the whole bathymetric range of the species (usually present between 1 and 25 meters), sampling stations were also located slightly outside the limit of the sandy area down to 25 m deep. *Xyrichthys novacula* was sampled from July to December 1994 using fishing lines. Three surveys were carried out each month and a total of 54 hours of fishing were completed. Total fish length (T.L.), measured to the nearest 1 mm, and total body weight and gonad weight to the nearest 0.001 g, were recorded for all specimens collected. Sex and colour pattern were also recorded for each fish sampled.

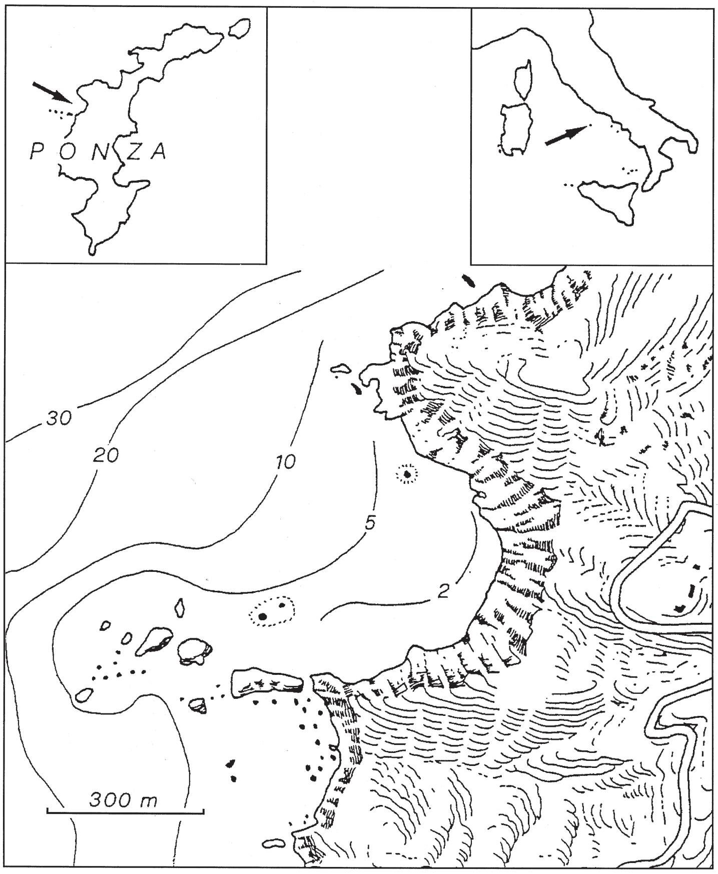

FIG. 1. – Study area

In order to study the growth of the species, the length-frequency distribution (LFD) calculated for each 1-cm size class was analysed each month. Otoliths of 122 specimens were drawn and prepared using abrasive paper and xylol. Successively otoliths were read with a stereomicroscope, and a non-linear calculation of the von Bertalanffy growth parameters (least squares method) was carried out using the FISAT software program (Gayanillo *et al.*, 1994). The method estimates the growth parameters in such a way that the sum of the differences between the observed and expected values is minimised. The modal lengths of the cohorts calculated through otolith analysis were then compared with those obtained decomposing LFD of collected fish with the Batthacharya method (Bhattacharya, 1967).

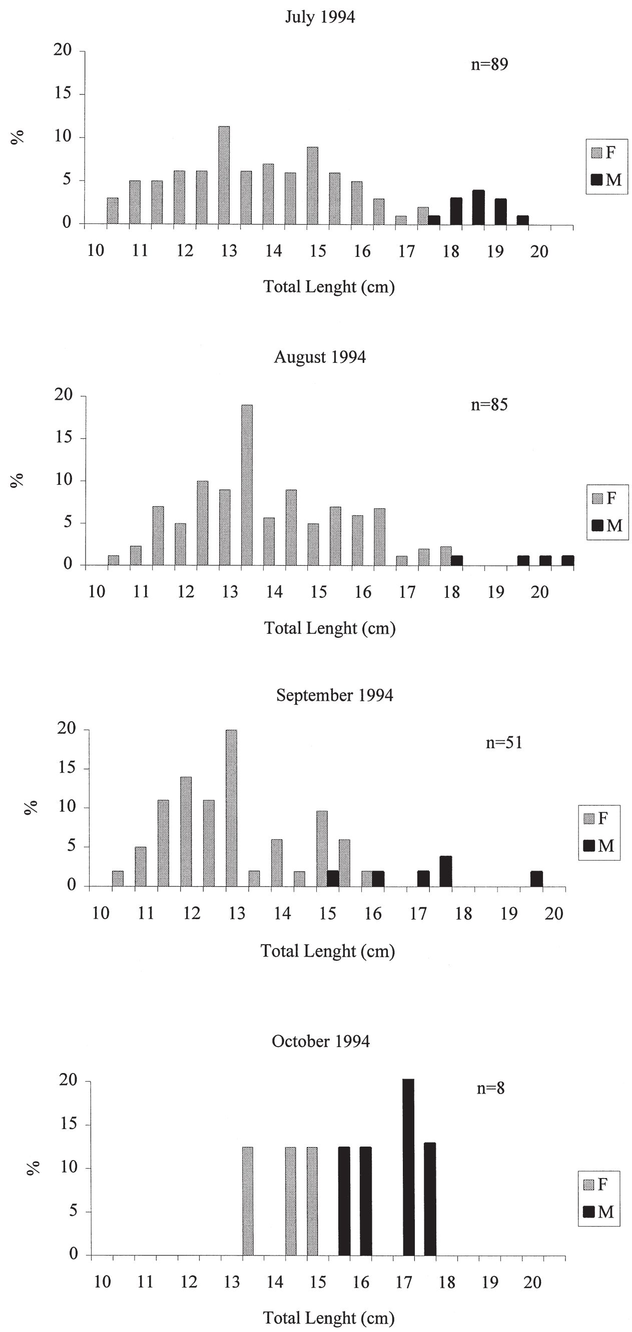

FIG. 2. – Monthly length-frequency distributions of *X. novacula* collected in the Central Mediterranean Sea

To provide information on the reproductive pattern of the species and to compare levels of gonadal activity, a gonadosomatic index (gonad weight/total body weight x 100) was calculated for both males and females during different sampling periods and each individual classified by maturity stage using the Holden and Raitt partial-spawner scale (1974). The gonadosomatic index (GSI) represents the percentage of gonad weight versus body weight; it is assumed that the period during which GSI is highest corresponds to the breeding season peak. It is considered the best indicator, lacking direct observations, of a species' reproductive activity fluctuations during different periods of the year (Stoumbodi *et al.*, 1993).

The mean individual size of fish was tested for differences between colour patterns using the analysis of variance (ANOVA) and the Tukey-Kramer test (Sokal and Rohlf, 1980). Correlation analysis was performed using the Pearson test.

RESULTS

Growth

A total of 231 specimens of *Xyrichthys novacula* of both sexes was caught from July to October. In November and December no razorfish were captured. The length-frequency distribution for July, August, September and October (Fig. 2) showed a clear-cut division between males and females of the species. The size range of females (10 - 18 cm T.L.) was smaller than the modal size of males. The smaller fish collected (10 cm T.L.) were present only in the first two months of sampling. Male size ranged from 15 to 20 cm, and the minimum body size of males decreased from 17 cm in July to 15 cm in October. Otolith analysis was used to determine the age of the razorfish. A recognisable pattern of broad opaque summer zones and narrow translucent winter zones appeared on the sagittae when observed under reflected light. Four cohorts aged between 1+ and 4+ were identified (r^2=0,89; n=122) (Tab.1) and the parameters of the von Bertalanffy growth curve determined: $L\infty$ =23.441 cm, t_0 = -0.591 andk = 0.289. The Bhattacharya method made it possible to distinguish four cohorts in the LFD of the collected fish that matched well with those calculated through otolith analysis (Fig. 3). The first population cohort (0+) was estimated from the growth curve equation but no individual

TABLE 1. – Mean total lenght (cm) and standard deviation of *X. novacula* age classes in the Central Tyrrhenian Sea.

Age	Mean total lenght	s.d.	n
1+	12.33	0.98	56
2+	15.18	0.76	37
3+	17.00	0.61	14
4+	18.95	0.93	6

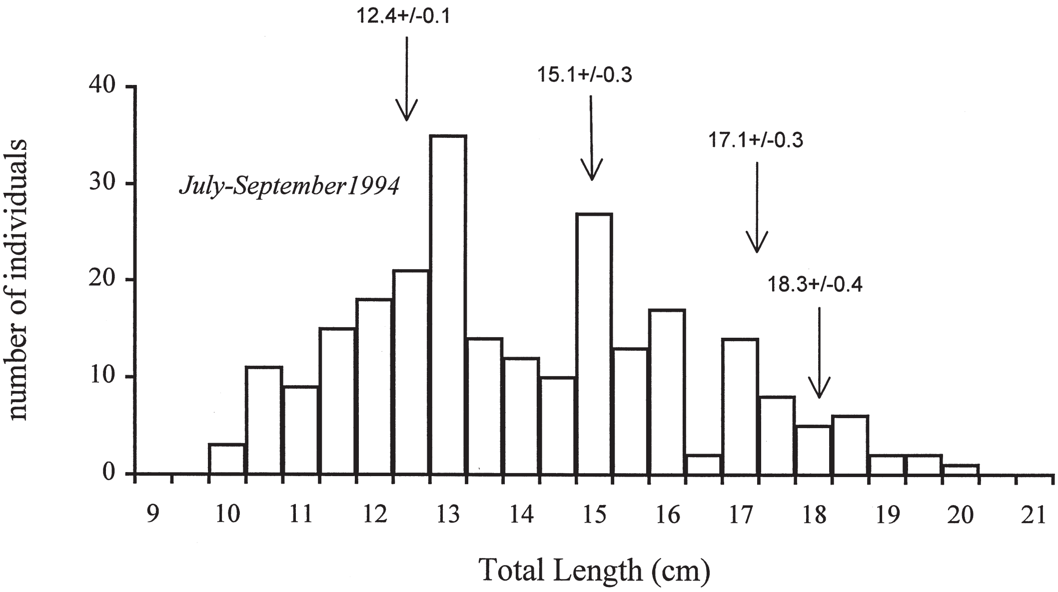

FIG. 3. – Overall length-frequency distribution of *X. novacula* collected in the period July-September 1994 showing the modal lengths of cohorts.

TABLE 2. – Characteristics of colour phases of *X. novacula* in the Central Tyrrhenian Sea

Phase 1 (Initial females)	- Body and head pinkish, a red patch around the anus; - thin, yellow vertical stripes on the scales; - a pearly white patch in the posterior region and beneath the pectoral fin; - anal and caudal fins yellow with light blue vertical tripes.
Phase 2 (Secondary females)	- Body pink -reddish, head yellow; - thin, light blue vertical stripes on the scales, anal and caudal fins; - a pearly white patch in the posterior region and beneath the pectoral fin.
Phase 3 (Transitional)	- Body and head grey-violet, reddish on the back. Dorsal fin orange; - violet-green vertical stripes thicker than in the females; - anal and caudal fins pink with blue stripes, a red-violet spot around the anus.
Phase 4 (Males)	- Body and head green, darker on the back, yellow-green on the sides; - marked blue stripes on the scales streaked with violet, the dorsal fin is orange; - anal and caudal fins orange or yellow with bright ligth blue stripes.

of this cohort was caught. Young of the year were only observed by visual census between 1 and 3 meters of depth at the end of the summer outside the reproductive harems of dominant males that were located deeper.

Reproduction

The sex-ratio is highly in favour of females, which constituted almost 90% of the individuals collected (S.r. =87.02%). The cohorts aged 1+ and 2+ were exclusively composed of females, 3+ fish were transitional and 4+ cohort was composed only of males. The minimum body size for mature females was 12 cm. Females with mature gonads (F4 in the Holden and Raitt scale) were observed from July to September. In July and in the first part of August mature and maturing females (F4+F3) made up almost 90% of specimens collected while mature females only (F4) reached its peak in the second part of August. In August and in September the percentage of spent females increased to 15% and 64% respectively (Fig.4). Gonodosomatic index was calculated for each month of sampling. According to the percentage of mature females trend, the mean GSI of females decreased rapidly from August (mean GSI=3.15; s.d.=1.76; n=199) to October (mean

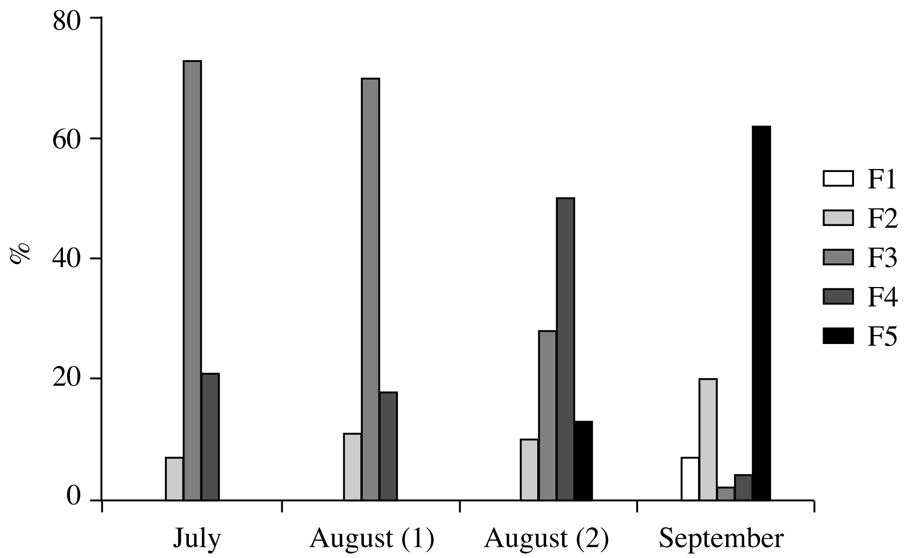

FIG. 4. – Percentage of maturity stages (Holden and Raitt scale) of females of *X. novacula* in different sample periods. Aug (1) = 1-15; Aug (2)=16-31. F1-F2 = immature; F3 = maturing; F4=mature; F5 = spent

GSI =0.35; s.d.=0.09; n=10) as shown in Figure 5. A decrease of GSI standard deviation for females from August to October was due to the presence in August of individuals belonging to all maturity stage except the spent one (Fig. 4). All females collected in September and especially in October, as the spawning season come to an end, were classified as spent or immature. The gonads of males were particularly small (mean weight = 0.0838 g; s.d. = 0.05; n=30) and the proportion of body weight devoted to gonads (GSI) was extremely low (mean GSI = 0.11; s.d. = 0.059; n=30). The GSI of males decreased from August (mean GSI = 0.15; s.d. = 0.06; n=30) to October (mean GSI = 0.03; s.d. = 0.01; n=6) (Fig. 5). The males sampled did not show gonads at the third or fourth stages of the Holden and Raitt scale and it was not possible quantify the percentage of mature individuals. There was no significant correlation (the slope did not depart significantly from zero, p>0,65) between GSI and body size of males (Fig. 6).

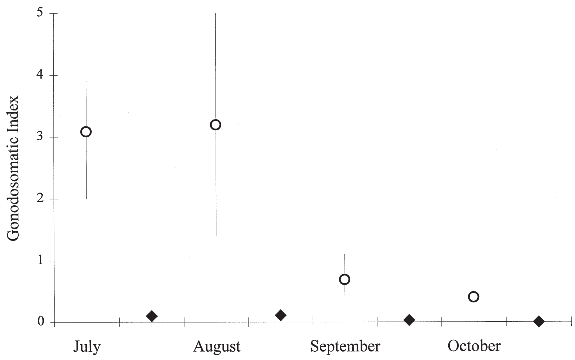

FIG. 5. – Gonadosomatic index trend (G.S.I.= gonad weight/body weight x100) of females (m) and males (u) of X. novacula

Coloration pattern analysis

The study of coloration patterns of *Xyrichthys novacula* revealed four different colour phases (Tab. 2), which showed significant differences in mean total fish length (F=239; d.f.= 3; p< 0.0001) (Fig. 7). The Tukey Kramer test indicated that colour phases were significantly correlated to mean total length (Table 3). The first two coloration phases are typical of females (an initial phase and a sec-

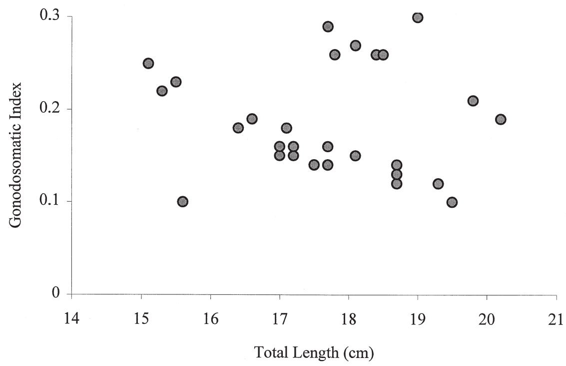

FIG.. 6. – The relationship between G.S.I. (gonad weight/body weight x100) and size (Total Length) of *X. novacula* males

ondary phase), the third is typical of a transitional phase and the last of adult males (terminal phase). The decrease in modal size of the terminal coloration phase from August to October and the presence of adult males in smaller size classes in the last two months' sample are shown in Figure 7.

TABLE 3. – Mean total length and standard deviation of the four colour phases of *X. novacula*. Each mean is significantly different from the others (p<0.05). A,B,C and D are respectively the initial, secondary, transitional and terminal colour phase mentionated in the test.

	A	B	C	D
n. ind.	162	32	27	17
mean length (cm)	12.87	15.05	16.63	18.58
s.d. (cm)	1.16	0.91	0.76	0.62

DISCUSSION

The reproductive cycle of the Mediterranean razorfish *Xyrichthys novacula* is characterised by protogynous sequential hermaphroditism evidenced essentially by large differences between males and females in both coloration pattern and length composition (Bentivegna and Rassotto, 1987). Monandric wrasse species (in which males derived only by sexual inversion and are thus all secondary males) show a bimodal distribution of length: the size of females is smaller than modal size of males (Warner, 1975; Moyer and Nakazono, 1978; Shapiro, 1981), whereas in species with both primary and secondary males,

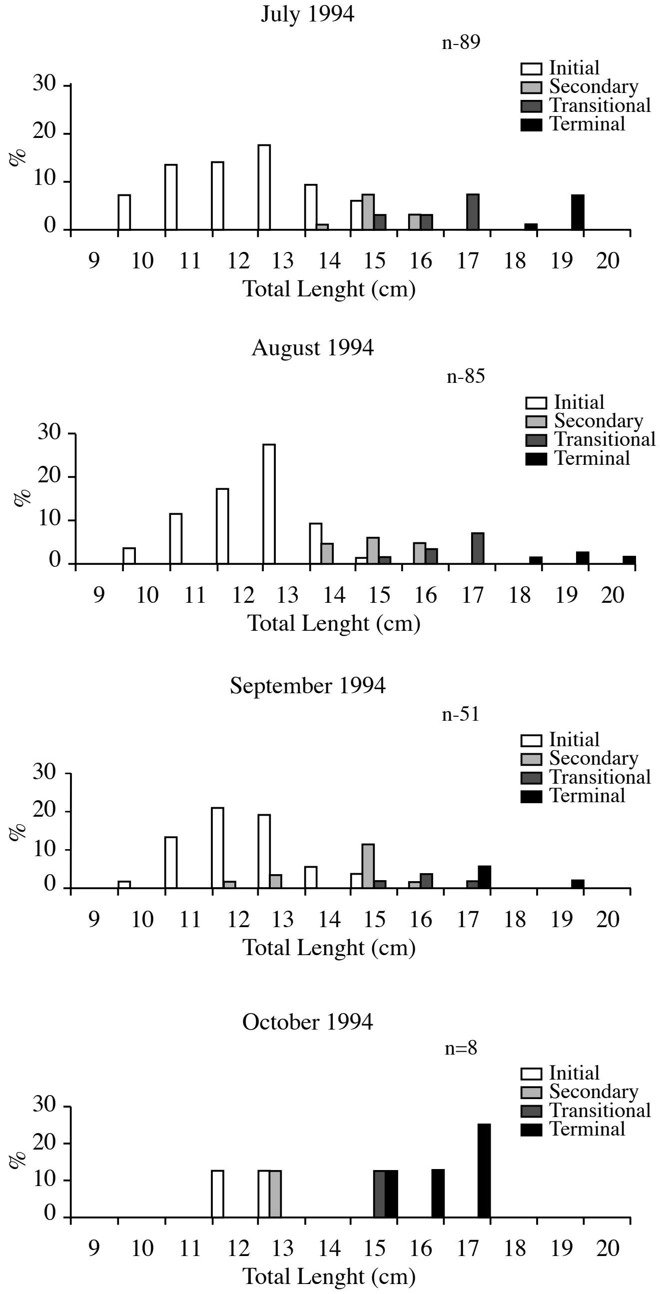

FIG.. 7. – Percentage of individuals of each colour phase (Initial, Secondary, Transitional, Terminal) of *X. novacula*.

the proportion of secondary males is highly variable (Choat and Robertson, 1975; Warner and Robertson, 1978). Through the analysis of length-frequency distribution and percentage of individuals for each colour pattern in the various monthly samples, the size of sexual inversion was estimated between 15 and 17 cm of T.L. The decrease in modal size of males and terminal coloration pattern individuals were recorded from August to October. This feature is clearly related to the sexual inversion process, which occurs outside the breeding season, soon after spawning, in most hermaphroditic species (Shapiro, 1987). The presence, in September and October, of terminal phase males in smaller size classes is precisely the outcome of this process. The reproductive peak of the species is concentrated mainly in the second part of August as evidenced using both Holden and Raitt scale and gonodosomatic index. Oliver and Massutti (1952) hypoth-

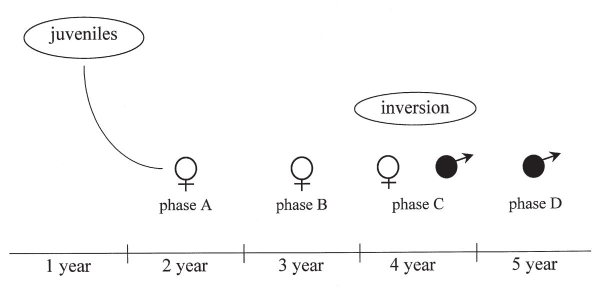

FIG. 8. – Life cycle of the razorfish in the Central Mediterranean Sea. A, B, C, and D are respectively the Initial, Secondary, Transitional and Terminal colour phases of the species.

esised that the species spends most of the time buried in the sand in the winter since no individuals were collected during the cold season. Furthermore the inability of *X. novacula* to survive in aquariums at temperatures below 13° C (Bini, 1969) could also support this hypothesis. Our study seems to confirm this theory. No fish were caught in winter in the study area, either by using traditional fishing methods (M.M.M, 1990) or our sampling gear. Moreover, the growth coefficient estimated using the von Bertallanffy growth curve was particularly low (k=0.289).

Reproduction showed a number of interesting and important analogies with two species of the genera already studied, both typical of tropical seas and sandy bottoms, *X. martinicensis* (Victor, 1987) and *X. pentadactilus* (Nemetzov, 1985). These two species are strictly haremic in their social and reproductive organisation which assumes the existence of a harem run by one male that mates exclusively with the females of his harem. *Xyrichthys novacula* is considered a haremic species as indicated in the ethological studies conducted by Terao *et al*., (1991) and Marconato *et al*., (1995). Biological features of this species such as polygyny and monandry showed by Bentivegna and Rassotto (1987) are considered characteristic of haremic species. Moreover some important aspects of the reproduction of *Xyrichthys novacula* evidenced by this study are also regarded as essential for defining a haremic species. Our data pointed out that the GSI did not increase with the size of *Xyrichthys novacula* males which showed one of the lowest GSI and relatively small gonad weight compared with other species of tropical wrasses studied. The lack of sperm competition between males as a consequence of the haremic mating system of this species is the cause of no selection for increased gonadal investment in different size classes or male types, as is typical of non-haremic wrasses (Warner and Robertson, 1978; Victor, 1987). Macroscopic evidence of this mating system is the scarce development of the males' gonads as evidenced by the low GSI, the lack of the third and fourth maturity stages using the Holden and Raitt scale, and low weight of male testis of *Xyrichthys novacula*.

The life cycle of the Mediterranean razorfish was plotted by age class, colour phase and period of sexual inversion of the species in Figure 8. We introduced a new coloration phase for females. Coloration pattern analysis showed four distinct colour phases although only three are described in the literature (Bentivegna and Rassotto, 1987). The four colour phases fit well with the four age classes estimated by otolith readings. This could means that individuals of each age class are generally characterised by different coloration patterns. In the absence of direct underwater investigations we hypothesised that this chromatic feature of the species allows dominant males of *Xyrichthys novacula* to recognise the age of females and consequently to choose older and larger females during their harem formation. This characteristic can be explained keeping in mind the Size-Advantage Model (Ghiselin, 1969, 1974), in which large females are typically favoured because large size increases fecundity, whereas male size is affected by sexual selection in contests for females and fertilisation (male-male competion). As a result, in order to achieve greater reproductive success, dominant males of *Xyrichthys novacula* tend to select such older females, recognisable by their colour pattern, which are able to produce a greater number of eggs and, therefore, to obtain a higher number of offspring. At the moment this hypothesis could represent a basis for development of further direct investigations on the *Xyrichthys novacula* social organisation system

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