

Reproductive biology of the marbled goby, *Pomatoschistus marmoratus* (Pisces, Gobiidae), in a northern Aegean estuarine system (Greece)

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Received 19 February 2007; Accepted 29 May 2009

A b s t r a c t. The reproductive biology of the marbled goby, *Pomatoschistus marmoratus* (Risso, 1810), was studied in the Strymon River estuarine system (northern Greece) between September 1997 and August 1999. Samplings were conducted on a monthly basis at the mouth of the river using a bag seine net and overall a total of 4 563 individuals were collected. The total length of males ranged between 2.5 and 6.0 cm and that of females between 2.8 and 5.7 cm, while that of unsexed individuals ranged between 1.2 and 2.9 cm. Sex ratio was 1.54:1 in favour of the females and statistically different from unity. The spawning of the species was extended, occurring between February and May. Mean absolute fecundity (F) was 1 386 (SE=8) oocytes and showed a significant positive exponential relationship with total length ($F=14.387TL^{2.92}$), and total weight ($F=1351TW^{0.83}$) of the fish. The relative fecundity ranged between 878 and 3 444 oocytes/g of total weight. Mean size at first maturity was estimated at 3.82 cm for the females and 4.66 cm for the males.

Key words: sex ratio, fecundity, spawning, maturity

Introduction

The attraction of marine and freshwater fish species to estuaries and coastal lagoons distinguished estuarine habitats as important transition zones connecting the freshwaters with the sea. Although lagoon and estuarine habitats are important feeding grounds for fishes, fishes do not use lagoons for spawning except for very few exceptions (see K o u t r a k i s et al. 2005). Indeed, the majority of fish inhabiting Mediterranean estuarine systems undertake spawning migrations and breed at sea (e.g. grey mullets: K o u t r a k i s 2004) or into freshwater (e.g. the shad *Alosa fallax*: B o b o r i et al. 2001) as a result of the hostility of estuarine conditions to egg and larvae development (D a n d o 1984). Among the minority of estuarine fishes that spend their entire life cycle in coastal lagoons and estuaries in the Aegean is the south European toothcarp, *Aphanius fasciatus* (L e o n a r d o s & S i n i s 1999), and the marbled goby, *Pomatoschistus marmoratus* (K o u t r a k i s et al. 2005). Other species such as the sand smelt, *Atherina boyeri*, either enter lagoons for spawning in early spring and move again to the marine waters at the end of summer (B a r d i n & P o n t 2002, M a t i ć - S k o k o et al. 2007), either spend their entire life cycle in estuaries or lagoons (Camargue: F o c a n t et al. 1999, Vistonis estuarine system: K o u t r a k i s et al. 2004).

The marbled goby is a typical estuarine species (M a r i a n i 2001) and its distribution includes the east Atlantic coast, the Mediterranean, the Black and the Azov Seas and the Suez Canal (M i l l e r 1986). The presence of the marbled goby in Greece has been reported in the Porto-Lagos lagoon (K o u t r a k i s et al. 2005), in Rihios and Strymon estuarine systems (K o u t r a k i s & T s i k l i r a s 2003), in the recently re-flooded Drana

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lagoon (Koutrakis et al. 2009), and along several coastal areas of the Aegean Sea (Economidis 1973, Papaconstantinou 1988). Its status is safe in Greece, the reason for that being its low economic importance and the limited presence of predators in these estuarine systems that are commercially exploited (Koutrakis et al. 2007).

Literature on the reproductive biology of the marbled goby is available for the Mediterranean (Maccagnani et al. 1985, Fouda et al. 1993, Mazzoldi & Rasotto 2001, Mazzoldi et al. 2002), while no information exists for the species in Greek waters. The congeners sand goby, *P. minutus* and common goby, *P. microps* are well studied in Europe (Claridge et al. 1985, Maes et al. 1998, Pampoulie et al. 1999), including the Mediterranean Sea (Bouchereau & Guelorget 1998, Pampoulie et al. 2000). Information on the biology of the Gobiidae in Greek waters only exists for the estuarine goby *Knipowitschia caucasica* (Kevrekidis et al. 1990). The present work aims to study the reproductive biology of the marbled goby in the Aegean; more specifically to study the sex ratio, time of spawning, fecundity, and size at maturity of the marbled goby at the Strymon estuarine system, in the northern Aegean Sea.

Study Site

The River Strymon springs from Bulgaria and outflows in the north Aegean Sea, in the Strymonikos Gulf. A lagoon and numerous channels are formed at the mouth of the Strymon estuarine system. The discharge pattern of the River Strymon shows strong seasonal variability ranging from $18 \text{ m}^3 \text{ s}^{-1}$ in August to $122 \text{ m}^3 \text{ s}^{-1}$ in April (Mertzanis 1994). The river is dammed close to the border with Bulgaria and forms Lake Kerkini and as a result of the decreased flow during the summer, seawater intrudes as far as 7 km in the river (Haralambidou et al. 2005).

Material and Methods

Monthly samples were collected from the mouth of Strymon estuarine system between September 1997 and August 1999. For the collection of fish samples, a small bag seine net was used (length: 20 m, height: 1.5 m, mesh size: 2 mm bar length). Samples were immediately preserved in 8% formaldehyde solution buffered with seawater. In the laboratory, the samples were sorted and all the marbled goby individuals were measured (total length, TL, cm) and weighted (total weight, TW, 0.01 g). Sex was determined in a random sub-sample of 40 individuals per month or at all individuals when the sample size was less than 40. The gonad weight (GW, 0.01 g) was recorded for both sexes of the sub-sample. Sex and maturity stages were viewed macroscopically and the maturity stages were determined using the six stage key (I–VI) of Nikolskii (1963): immature (I: young individuals that have never spawned), resting (II: oocytes and sperm have not started to develop or have already been extruded; gonads of very small size; oocytes not visible macroscopically), maturing (III: oocytes visible macroscopically; gonad weight increases rapidly; testes' colour changes from transparent to pale rose), mature (IV: gonads have reached their maximum weight but oocytes and sperm do not run out when light pressure is applied), spawning (V: oocytes and sperm run out when light pressure is applied; gonad weight decreases rapidly from start to finish of spawning process), spent (VI: eggs and sperm extruded; gonad cavity swollen; gonad looks like an empty sac often containing a few oocytes or sperm). Mature individuals were

considered those at maturity stages IV, V and VI. Sex ratio was determined monthly (data were combined per corresponding month) and among size classes. A χ^2 goodness-of-fit test was undertaken to compare the sex ratios at each monthly sampling or within the size groups with the hypothesized sex ratio of 1:1. The gonadosomatic index (GSI), which describes the relative size of gonads and is used as an index of reproductive activity (Wootton 1990), was calculated as $GSI = (GW/TW) \times 100$.

Absolute fecundity (F) was determined in a sample of 176 female gonads collected in April. The female gonads were preserved in Gilson's fluid for 6 months and oocytes were then counted volumetrically under a microscope (Bagenal & Braum 1978) in four sub-samples. The diameter (mm) of 50 oocytes per female was calculated as the mean value of minimum and maximum diameter microscopic measurements. Relative fecundity (RelF) was considered as the number of oocytes per unit of weight or length (Nikolski 1963). The relationship between absolute fecundity and the length or the weight of a fish were determined according to the equation $F = ax^b$ (where F is absolute fecundity, x is the length or weight of the fish and a, b are constants).

The length at which 50% of individuals attained sexual maturity (L_m) was estimated by fitting a logistic curve to the relationship between the percentage of mature fish (P) per total body length class (TL):

$$P = e^{(v_1 + v_2 TL)} / (1 + e^{(v_1 + v_2 TL)})$$

The predicted length at which 50% of the fish were mature was estimated by:

$$L_m = -v_1 / v_2$$

The proportion of mature fish for each 0.2 cm total length class was calculated by sex and v_1 , v_2 were calculated using the method described by Petrakis & Stergiou (1997).

Following the estimation of L_m , a dimensionless ratio, important in the context of life history theory (Loughurst & Pauly 1987) was computed: the L_m / L_{max} , which expresses the proportion of the potential growth span of the species that is covered before maturation. This ratio was computed for comparative purposes for other goby populations based on the published L_m and L_{max} values at each location.

Results

The total length of males ranged between 2.5 and 6.0 cm and that of females between 2.8 and 5.7 cm, while that of unsexed individuals ranged between 1.2 and 2.9 cm. Overall, 346 (60.59%) out of the 571 individuals sexed were females and 225 (39.41%) were males. The female to male ratio of 1.54:1 was statistically different from unity ($\chi^2 = 26.10$, $P < 0.001$) and exhibited monthly variation from 0.27 (August) to 5.07 (April) (Fig. 1). The number of females was significantly higher in February (F:M=2.25, $\chi^2 = 8.86$, $P = 0.003$), April (F:M=5.07, $\chi^2 = 39.56$, $P < 0.001$), May (F:M=2.24, $\chi^2 = 9.19$, $P = 0.002$), September (F:M=2.84, $\chi^2 = 15.836$, $P < 0.001$) and October (F:M=1.95, $\chi^2 = 5.16$, $P = 0.023$) and that of males in December (F:M=0.51, $\chi^2 = 6.154$, $P = 0.013$). Sex ratio did not differ statistically from unity in January ($P = 0.23$), March ($P = 0.89$), July ($P = 0.13$), August ($P = 0.06$) and November ($P = 0.18$). In June of both years, the number of individuals caught was insufficient for sex ratio determination.

As far as size specific sex ratio is concerned, the number of females was greater in length classes 3.4 ($P < 0.05$) and 4.6-5.4 cm ($P < 0.05$). Female to male ratio did not differ from unity

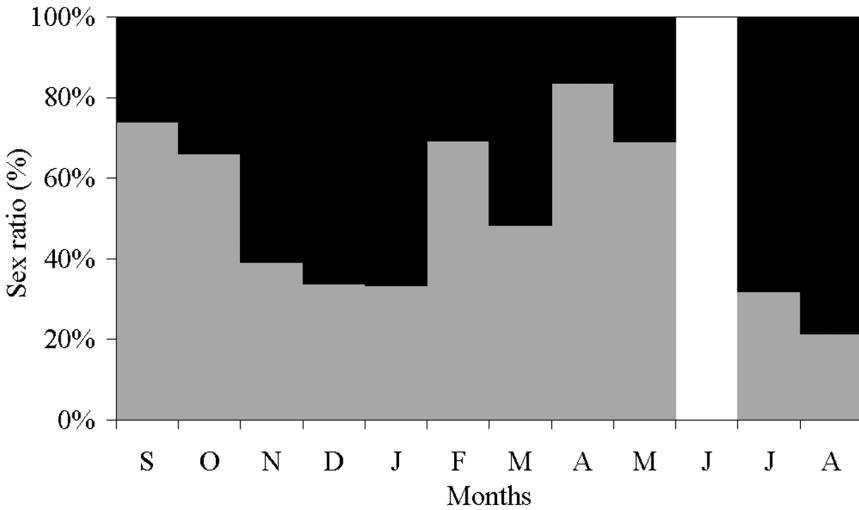


Fig. 1. Monthly variation of sex ratio for the marbled goby for the marbled goby between September 1997 and August 1999 (■: males, ■: females).

in all other length classes ($P > 0.05$). Insufficient number of samples did not allow for the estimation of sex ratio in lower than 2.6 cm and higher than 5.6 cm length classes (Fig. 2).

The reproduction of the species in Strymon estuarine system lasts between March and May. According to the monthly variation of the GSI, the gonads start to develop in February and mature in April and May when the highest values of GSI were recorded (Fig. 3). The first mature females (stages IV and V) appeared in March and their percentage was highest in May (78%). During the remaining period of year, all females were resting (stage II).

Each spawning female produces an average of 1 386 (SE=8) oocytes. Absolute fecundity however exhibited high variability ranging between 336 and 3 052 oocytes. The total

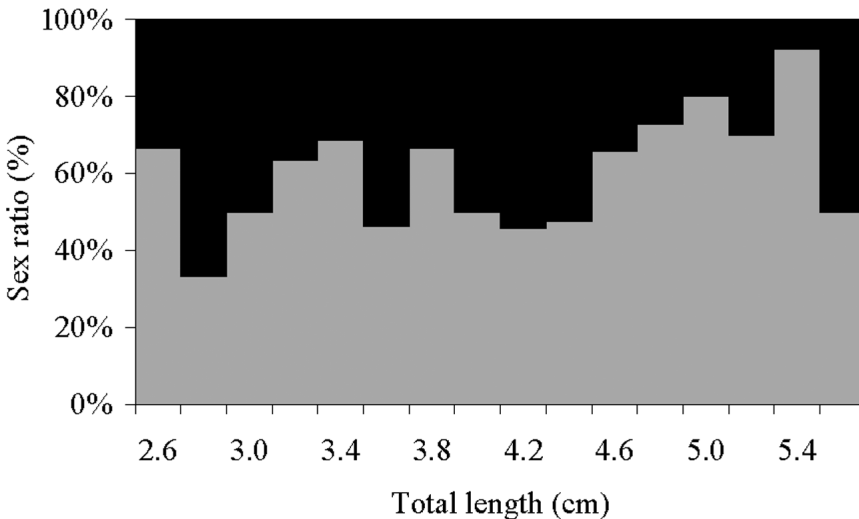


Fig. 2. Sex-ratio (%) as a function of total length (TL, cm) for the marbled goby between September 1997 and August 1999 (■: males, ■: females).

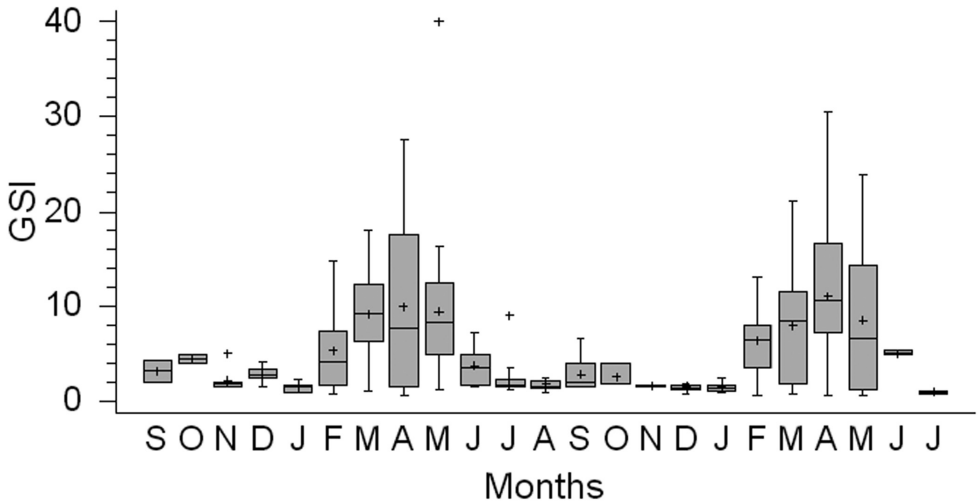


Fig. 3. Monthly variation of the gonadosomatic index (GSI) for female marbled goby, between September 1997 and August 1999. The rectangular part of the plot extends from the lower to the upper quartile; the centre lines within each box show the location of the sample medians; the crosses within each box indicate the location of the sample means; the crosses outside the box indicate outliers.

length of the most fecund marbled goby was 5.5 cm. Each female marbled goby produces on average 1 978 eggs/g of total weight (SE=11). The relative fecundity ranged between 878 and 3 444 eggs/g of total weight and showed a strong positive linear relationship with total length (RelF=-29.81+1.217TL, $r^2= 0.957$, $P<0.001$). Oocyte diameter ranged between 0.198 and 0.816 mm, with an average value of 0.53 (SE=0.01). Oocyte diameter showed a marginal ($P=0.045$, $r^2=0.25$) negative relationship with absolute fecundity. Absolute fecundity increased exponentially with total length (Fig. 4) and total weight of the fish. The relationships of fecundity with total length and weight are expressed by the equations:

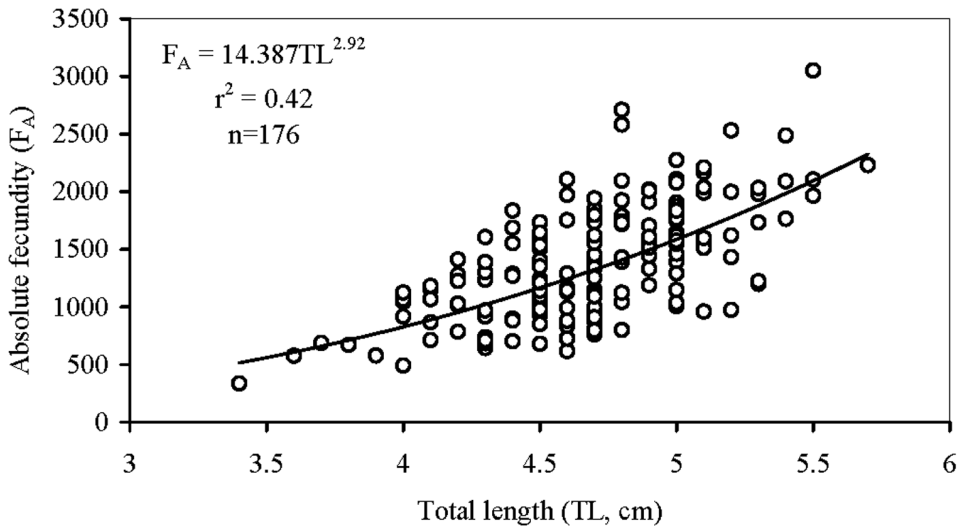


Fig. 4. Absolute fecundity (F_A) of the marbled goby as a function of length (TL, cm).

$$F=14.387TL^{2.92} (r^2= 0.42, n=176, P<0.05)$$

$$F=1351TW^{0.83} (r^2=0.39, n=176, P<0.05).$$

The L_m of males was higher than that of females. The mean length at which 50% of individuals are sexually mature was 3.82 cm for the females and 4.66 cm for the males (Fig. 5). The smallest mature female was 3.4 cm TL while the smallest mature male was 3.7 cm TL. The L_m/L_{max} was 0.67 for the females and 0.77 for the males.

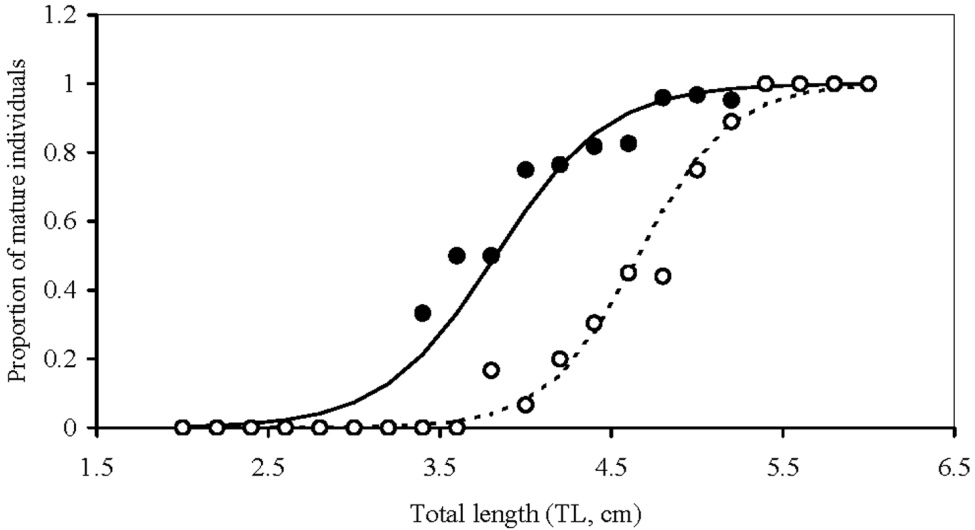


Fig. 5. Estimated (line) and observed (dots) proportion of mature at length (TL, cm) marbled goby (females: solid circles, males: open circles).

Discussion

A biased sex ratio towards the females was observed, overall and during the reproductive season. The overall biased sex ratio towards females has also been reported for the marbled goby in Suez Canal (F:M=1.27; Fouda et al. 1993) and for the common goby in Manguio Lagoon (F:M=2.80; Bouchereau et al. 1993). The differences observed in the size-specific sex ratio of marbled goby are most probably related to sexual differences in growth, mortality and energetic cost of reproduction. Competition for nests among males has been shown to decrease the longevity of male sandgobies and nest-guarding has been reported to exhaust their energy reserves (Lindström 2001). A similar cost was not found for females, suggesting that competition among males may result in higher male mortality (Lindström 2001). The parental care provided and the nest building by males may also contribute to the skewed sex ratios, with males possibly avoiding capture during spawning months (Mazzoldi et al. 2002). It has been argued however, that the female dominance throughout most of the year may be a specific character of the marbled goby (Fouda et al. 1993), as well as of some other goby species (Miller 1984).

The marbled goby, one of the few species that have been adapted in estuarine life and may spend its entire lifespan in lagoons and estuaries (Koutrakis et al. 2005), is characterised by short lifespan, opportunistic feeding strategy and the ability to tolerate extremes of heat and salinity (Fouda 1995). These characteristics allow its adaptability to

the extreme and often unpredictable estuarine conditions (Fouda 1995). Several gobies, including the marbled goby are able to reproduce in brackish waters (Claridge et al. 1985, Koutrakis et al. 2005). The presence of mature individuals in Strymon estuarine system indicates that this estuarine system is used for the reproduction of the species, while the presence of very small sized individuals shows that it serves as a nursery ground as well. According to the monthly GSI variation and the percentage of maturity stages, the reproductive period of the marbled goby in Strymon estuarine system is protracted and lasts three to four months. It seems that the extended spawning season is a common characteristic of the Mediterranean gobies, as the marbled goby spawns from February to August in Po River (Maccagnani et al. 1985) and from November to April in Suez Canal (Fouda et al. 1993). Two spawning peaks have been reported for the extended breeding season of the marbled goby in the Venetian lagoon, one between April and mid-July and one from mid-August to end of September (Mazzoldi & Rasotto 2001). The sand and common gobies in French waters spawn from December to April and from March to June, respectively (Bouchereau et al. 1990, 1993, Pampoulie et al. 1999, 2000). In order to avoid resource competition among their offspring, the two species may have selected sequential spawning. Similar response to potential competition with depth and substrate segregation between the sand and the common goby has been reported in Zeeschelde estuary, North Sea (Maes et al. 1998). The variability in the onset and duration of spawning among populations of gobies suggests a possible environmental effect that controls these traits (Mazzoldi et al. 2002). High phenotypic plasticity to environmental perturbations has also been reported for the common goby (Pampoulie et al. 2000).

Marbled goby is characterised by bimaturism since males and females mature at different size. In species with promiscuous mating and indeterminate growth, males are smaller and younger at maturity than females (Stearns 1992). In contrast, male marbled gobies matured later than the females probably because males are nest builders and provide parental care (Mazzoldi et al. 2002) to allow for greater rates of offspring survival (Sargent et al. 1987, Smith & Wootton 1995). It seems that early maturation is traded-off with parental care, which requires energetic resources and adequate size for the offspring protection in the sense that larger individuals are less likely to be preyed upon. In the case of females, the larger an individual at maturity, which coincides with cessation of growth, the higher its fecundity (Pampoulie et al. 2000). The advantage of delayed maturation for individuals that become parents is their larger size which can be positively associated with their ability to provide parental care and defend nest sites (Hutchings 2002). Size and age at first maturity primarily depend on environmental and genetic factors (Wootton 1990) but can be influenced by a number of other biological conditions (e.g. parental care; predation: Abrams & Rowe 1996). The marbled goby in Suez Canal reaches maturity at 2.4 cm SL (Fouda et al. 1993), while the common goby in Mauguio Lagoon (S France) at 2.7 cm TL (Bouchereau et al. 1993). In general, the L_m/L_{max} ratio is higher for the short-lived, fast-growing species and lower for the long-lived, slow-growing fish species (Beverton 1963, Longhurst & Pauly 1987). The L_m/L_{max} for the northern Aegean marbled goby is high for both sexes, even when compared to its conspecific in Suez Canal ($L_m/L_{max}=0.49$; Fouda et al. 1993) and its congeneric in France (*P. microps*: $L_m/L_{max}=0.57$; Bouchereau et al. 1993) indicating that a significant proportion of potential growth is achieved before maturation, especially for the males.

The absolute fecundity of the marbled goby exhibited high variability among individuals of the same size. The phenomenon is probably a result of either genetic differences among

the females, or environmental conditions (W o o t t o n 1990). Many fish reduce fecundity under food stress at high population densities and increase it when well fed and growing fast at low population densities (S t e a r n s 1992). The marbled goby produces more oocytes in the northern Mediterranean (Aegean and Adriatic) than does in the Suez Canal. Indeed, in Venetian lagoon (northern Adriatic Sea) the marbled goby produces on average 1 355 oocytes ranging from 412 to 2 904 (M a z z o l d i et al. 2002), while in Suez Canal, its fecundity ranges from 295 to 1 300 oocytes, with an average of 603 oocytes for similar size ranges (F o u d a et al. 1993). In contrast, the larger in size sand goby produces 998 to 5 100 oocytes per spawning act (B o u c h e r e a u et al. 1990). Thus, the size-dependent nature of fecundity seems to hold both within and among species that share common morphological and habitat characteristics such as gobies. The increase in the reproductive potential, as reflected on increase in absolute fecundity with size and mass and the increase of relative fecundity with length, shows that, despite its late maturation, the female marbled goby allocates more energy to reproduction as it grows. Part of the energy allocated to number of oocytes produced is traded-off with oocyte size (J o n s s o n & J o n s s o n 1999), which declines with fish length, i.e. as fecundity increases. In contrast, the Venetian lagoon population of marbled goby is reported to allocate the same energy (expressed as GSI) to reproduction regardless the female size (M a z z o l d i & R a s o t t o 2001), while the common goby in Veccarés Lagoon has been reported to increase both its fecundity and its oocyte size through time (P a m p o u l i e et al. 2000).

A c k n o w l e d g e m e n t s

The authors would like to thank E. E l e f t h e r i a d i s and V. P a p a n t o n i o u for their help throughout this work, which is part of the LIFE96ENV/GR/564/PAZ project entitled 'Concerted actions for the management of Strymonikos coastal zone' and was co-funded by the European Community, the Greek Ministry of Agriculture and the Greek Ministry of Environment and Public Works.

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