

Growth of juvenile salema, *Sarpa salpa* (Teleostei: Sparidae), in the Kornati Archipelago, eastern Adriatic Sea*

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SUMMARY: Growth of juvenile *Sarpa salpa* from the Kornati Archipelago, eastern middle Adriatic Sea was analysed. A total of 1515 juveniles, ranging in length from 1.6 to 14.2 cm, were caught. Most individuals (94.65%) belonged to the 0⁺ cohort. The first settlers were aged 1.5-2.0 months, and probably entered shallow coves at the end of November. The relationship between total length and weight indicates positive allometric growth ($b = 3.284$). The condition factor, as a consequence of length-weight relationship, was $CF = 1.41$. The parabolic ($c = 0.023$ mm days⁻¹; $R^2 = 0.936$) and Gompertz ($c = 0.047$ mm days⁻¹; $R^2 = 0.897$) growth models seem to be the most appropriate for the description of young *S. salpa* growth.

Key words: juvenile growth, Sparidae, *Sarpa salpa*, Kornati Arhipelago, Adriatic Sea.

RESUMEN: CRECIMIENTO DE JUVENILES DE SALPA, *SARPA SALPA* (TELEOSTEI: SPARIDAE) EN EL ARCHIPIÉLAGO KORNATI, ADRIÁTICO ORIENTAL. – El crecimiento de juveniles de *Sarpa salpa* del archipiélago Kornati en el Mar Adriático oriental fue analizado. Un total de 1515 juveniles, de tallas comprendidas entre 1.6 y 14.2 cm, fueron capturados. La mayor parte de los individuos (94.65%) pertenecieron a la cohorte 0⁺. Los primeros individuos asentados tuvieron una edad comprendida entre 1.5 y 2.0 meses, y probablemente entraron en bahías someras a finales de noviembre. La relación entre la longitud total y el peso indica crecimiento alométrico positivo ($b = 3.284$). El factor de condición, como consecuencia de la relación talla-peso, fue $CF = 1.41$. Los modelos de crecimiento parabólico ($c = 0.023$ mm día⁻¹; $R^2 = 0.936$) y de Gompertz ($c = 0.047$ mm día⁻¹; $R^2 = 0.897$) parecen ser los más apropiados para la descripción del crecimiento de los juveniles de *S. salpa*.

Palabras clave: crecimiento juvenil, Sparidae, *Sarpa salpa*, archipiélago Kornati, Mar Adriático.

INTRODUCTION

The first year of life (0⁺) is a very sensitive period for most fish species, during which they are under intensive influence of abiotic and biotic factors that affect their growth, development and survival (Planes *et al.*, 1999). Growth is considered to be very sensitive to environmental conditions, and in temperate areas it is strictly dependent on season-

al changes (Weatherly and Gill, 1987). Further on, duration of the planktonic stage and the period that certain species spend in nursery areas is also related to seasonality (Macpherson, 1996). Data on juvenile fish growth rates are rather scarce in the literature, although they are crucial for a better understanding of species population dynamics (Lasker, 1985).

Using the analysis of size-frequency distributions (Barry and Tegner, 1989), juvenile growth can be estimated from the increase in the mean size of fish in a "cohort" within year-classes (Planes *et al.*,

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1999). A cohort is defined as a group of individuals of similar size that are assumed to be of a similar age. Different growth models from this perspective can be used to construct a growth slope.

Fish species belonging to the family Sparidae are widespread in the Mediterranean Sea and constitute an important fishery resource (Jardas, 1996). Results of previous studies indicate that the adult *Sarpa salpa* has rapid growth rates along the east coast of South Africa, with a maximum age of six years (van der Walt and Beckley, 1997), while off Canary Islands this species may reach a maximum age of eleven years (Méndez-Villamil *et al.*, 2001). Several biological aspects of juvenile *S. salpa* have been studied and it has been shown that this species predominantly inhabits *Posidonia oceanica* beds (Harmelin-Vivien *et al.*, 1995; Francour, 1997; Guidetti, 2000). It has an age-related mixed diet; larvae are planktivorous, while young, sub-adults and adults are herbivorous (Antolić *et al.*, 1994; Havellange *et al.*, 1997; Pinnegar and Polunin, 2000; Ruitton *et al.*, 2000). It is also known that this species undergoes a proterandrous sex change (van der Walt and Mann, 1998). The period of maximum spawning of *S. salpa* is from mid-September to mid-October and the period of intensive settlement is at the end of November (Bini, 1968; Tortonese, 1975; Quignard *et al.*, 1984). However, nothing is known about the growth of juvenile salema in the Mediterranean or elsewhere.

Therefore, the objective of the present work was to describe growth of juvenile *S. salpa* from the Croatian waters, and to test different models for estimating juvenile fish growth.

MATERIAL AND METHODS

The Kornati Islands, with the most irregular coastlines of any Mediterranean islands, constitute one of eight Croatian national parks. This archipelago (147 islands, islets and reefs) lies along the central part of the eastern Adriatic coast, between the cities of Zadar and Šibenik. Sampling was conducted on a monthly basis from November 1991 to December 1992 at five coves: Šipnata, Lojena, Studena, Lavsa and Žakan (Fig. 1). The sampling was done on hard, sandy, sandy-clay and sandy-mud substrates that were laterally overgrown by meadows of *Posidonia oceanica* and/or *Cymodocea nodosa*. Sites were carefully selected to encompass a closed recruiting system: a small bay limited by a

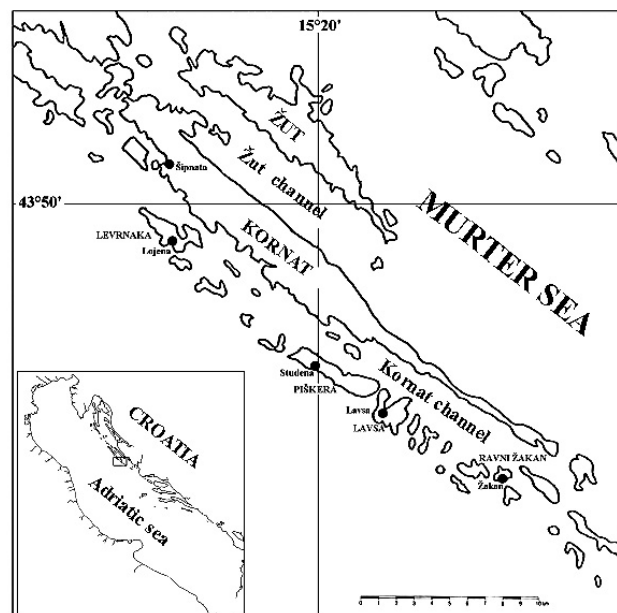


FIG. 1. – Location of the sampling stations in the Kornati Archipelago.

deeper water area with a drop-off, according to the recommendations of Planes *et al.* (1999). Analysing composition and temporal fluctuations of inshore juvenile fish populations at the same five stations in the Kornati Archipelago, Dulčić *et al.* (1997) found significant correlation coefficients of species composition between all stations that indicate similar hydrological conditions and great closure of this archipelago and enable the combination of data. The structure of the investigated coves precludes the possibility of migration, so juveniles were restricted to shallow inshore habitats and did not migrate to deeper water before recruitment (Harmelin-Vivien *et al.*, 1995; Garcia-Rubies and Macpherson, 1995; Planes *et al.*, 1999).

Fish samples were collected using a 50 m long beach seine. Net depth at the beginning of wings was 30 cm, while at the central part together with the sac the depth was 250 cm. The outer wings were of 8 mm mesh size and the central sac of 4 mm (Dulčić *et al.*, 1999). The net was always hauled from the entrance of the cove (max. 2 m depth) to its inner end (Kraljević and Jug-Dujaković, 1987). Collected juvenile individuals of salema, identified according to Šoljan (1975) and Jardas (1996), were preserved in 4% formaldehyde (pH from 8.5 to 9.0). Specimens characterised as juveniles, with already formed scales and no older than 14 months, were taken for the length analysis.

Due to the time of spawning and the period of intensive settlement, together with the duration of the

larval stage of life (Raventos and Macpherson, 2001), which varies between one and two months, October 1 was assumed to be the birth date of salema. Age in months was determined as the difference between the date of capture and the birth date. In the present paper, the term “cohort” was used to describe groups of salema of similar size that we identified monthly in each length-frequency distribution.

Empirical total size-frequency distributions were used to construct an age-length key with 3 mm

length intervals. The commonly used length-weight relationship ($W = a L_t^b$) was applied (Ricker, 1979). The condition factor ($CF = 100 * W * L_t^{-3}$) was calculated by cubic or Fulton's coefficient (Ricker, 1979). Several growth models were tested: linear ($L_t = a + c * t$), exponential ($L_t = a * e^{ct}$), logarithmic ($L_t = c * \ln(t) - a$), parabolic ($L_t = c * t^2 + b * t + a$), von Bertalanffy equation ($L_t = L_{\infty} * [1 - e^{-c(t-t_0)}]$), Beverton and Holt, 1957), the generalised Gompertz growth equation ($L_t = L_{\infty} * e^{-b e^{[exp(-c t)]}}$, Ricker, 1979) and

TABLE 1. – The length frequency distribution (with 3 mm intervals) of juvenile *S. salpa* in Croatian waters.

Length intervals (cm)	Months													Total
	Nov	Dec	Jan	Feb	Mar	Apr	Maz	Jun	Jul	Aug	Sep	Oct	Nov	
1.1-1.3														0
1.4-1.6	2													2
1.7-1.9	13	3												16
2.0-2.2	19	12	3											34
2.3-2.5	47	57	22	13										139
2.6-2.8	13	57	40	28	16									154
2.9-3.1		20	24	32	21	19								116
3.2-3.4		2	13	23	81	23	2							144
3.5-3.7			5	9	64	41	15							134
3.8-4.0			1	7	35	71	13	2						129
4.1-4.3				2	16	44	18	4						84
4.4-4.6					6	32	34	19						91
4.7-4.9						6	32	35	2					75
5.0-5.2						2	15	46	5					68
5.3-5.5							6	25	9					40
5.6-5.8							3	24	10					37
5.9-6.1							1	16	14	1				32
6.2-6.4								8	12	1				21
6.5-6.7								8	10	3				21
6.8-7.0								2	6	3				11
7.1-7.3									3	4				7
7.4-7.6									2	6	3			11
7.7-7.9									1	7	3			11
8.0-8.2									1	6	2	1		10
8.3-8.5									1	7	3	2		13
8.6-8.8									1	5	4	2		12
8.9-9.1										2	6	1		9
9.2-9.4										1	6	1		8
9.5-9.7										1	3	4	2	10
9.8-10.0											3	2	3	8
10.1-10.3											2	7	2	11
10.4-10.6											2	5	3	10
10.7-10.9											1	7	2	10
11.0-11.2												6	2	8
11.3-11.5												2	3	5
11.6-11.8												4	6	10
11.9-12.1													3	3
12.2-12.4													2	2
12.5-12.7													2	2
12.8-13.0													2	2
13.1-13.3													2	2
13.4-13.6													1	1
13.7-13.9													1	1
14.0-14.2													1	1
Total	94	151	108	114	239	238	139	189	77	47	38	44	37	1515
%	6.20	9.97	7.13	7.52	15.78	15.71	9.17	12.48	5.08	3.10	2.51	2.90	2.44	100
mean L(cm)	2.29	2.58	2.82	3.02	3.49	3.89	4.50	5.28	6.20	7.83	9.00	10.33	11.59	
SD L	0.264	0.268	0.364	0.366	0.403	0.459	0.53	0.61	0.792	0.82	0.879	0.967	1.213	
mean W(g)	0.1	0.17	0.21	0.26	0.4	0.59	0.99	1.85	3.27	6.84	10.66	16.27	19.11	
SD W	0.04	0.048	0.095	0.105	0.158	0.243	0.396	0.668	1.493	2.295	3.342	4.671	5.141	

the Laird-Gompertz equation ($L_t = L_0 * e^{[(a/c) * (1 - e^{-(exp - c * t)])}]$, Laird *et al.*, 1965). Abbreviations in the above equations are: L_t = total length (cm) at age t ; L_0 = total length when $t = t_0$; L_∞ = asymptotic length (cm) at the end of the first growth season (Katsuragava and Ekau, 2003); c = instantaneous growth rate when $t = t_0$; t = age (months from birthday or settlement); a , b = constants).

The equation was fitted (all individuals included) by an iterative method with a non-linear (user specified) subroutine (StatSoft, 1996). Calculation of the determination coefficient (R^2) provided a measure of goodness-of-fit (Sokal and Rohlf, 1981).

RESULTS

A total of 1515 juveniles of *S. salpa*, ranging from 1.6 to 14.2 cm L_t , were analysed (Table 1). Most individuals (94.65%) belonged to the 0⁺ cohort, while 44 individuals (2.90%) and 37 individuals (2.44%) belonged to the 1⁰ and 1⁺ cohorts respectively. First juvenile *S. salpa* were sampled (94 individuals, 6.20% of the total sample) at the end of November (November 27), and ranged in length from 1.6 to 2.8 cm (2.29 ± 0.264 cm). The total weight of these individuals ranged from 0.02 to 0.20 g (0.10 ± 0.040 g). According to the spawning period of salema, their estimated birth date (October 1) and the duration of the larval stage, these individuals were probably 1.5-2.0 months old. Juveniles of *S. salpa* were caught throughout the year and they left shallow coves mostly in September. Older individuals (>1⁺) were again recorded in March.

The slope ($b = 3.284$; $R^2 = 0.996$) of the total length-weight regressions indicated positive allometric growth. The condition factor, as a consequence of the length-weight relationship, was $CF = 1.41$ ($R^2 = 0.991$). The results of using several different growth models are presented in Table 2. All tested models gave different results. Age length data

TABLE 2. – The results of using several different growth models for juvenile *S. salpa*.

models	K (mm days ⁻¹)	SE	R ²
von Bertalanffy	0.019	0.0010	0.741
Gompertz	0.048	0.0037	0.897
Laird-Gompertz	0.118	0.0074	0.510
exponential	0.055	0.0012	0.773
linear	0.203	0.0080	0.803
logarithmic	1.716	0.0894	0.557
parabolic	0.023	0.0015	0.936

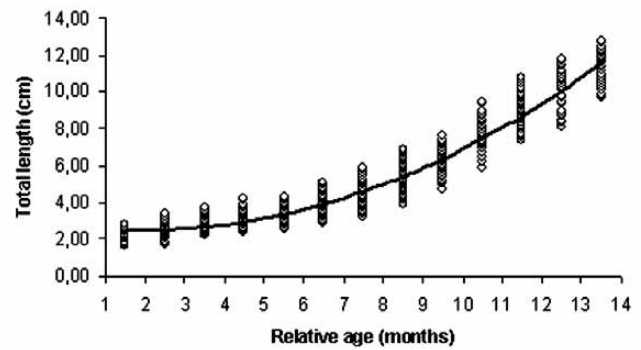


FIG. 2. – Parabolic growth curve of juvenile *S. salpa* from the Adriatic Sea ($L_t = 0.069 t^2 - 0.198 t + 2.658$; $R^2 = 0.936$)

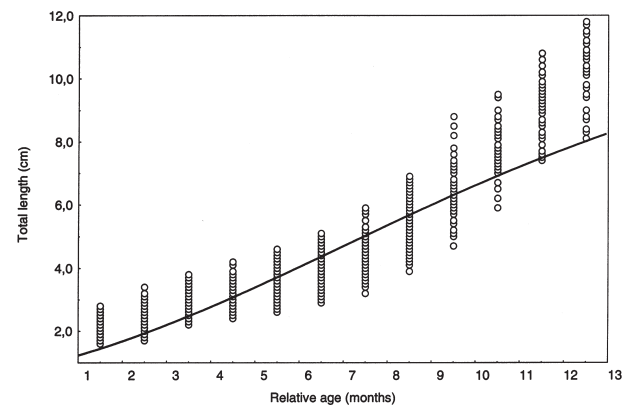


FIG. 3. – Gompertz growth curve of juvenile *S. salpa* from the Adriatic Sea ($L_t = 12.5 * e^{-2.674 * e^{(-0.144 * t)}}$)

of the juvenile salema were well described by the growth curve of the parabolic ($c = 0.023$ mm day⁻¹; $R^2 = 0.936$; Fig. 2) and Gompertz equation ($c = 0.048$ mm day⁻¹; $R^2 = 0.897$; Fig. 3).

Results of the growth increment analysis showed that growth rate increased during the first nine months of life. This rapid growth was recorded until the end of August when the maximal annual mean temperature (26.2°C) and maximal annual mean salinity (38.5‰) were recorded. The growth slope was highest in July and August. In the period after settlement, between December (mean 12.7°C) and February (mean 11.1°C), slower growth rates were noted. The growth rate of juvenile salema also slowed down at the beginning of autumn (after 7.5 cm L_t) (Fig. 4a). Therefore, few inflection points were evident, indicating the sigmoid growth of juvenile *S. salpa*. Salema reached the total length of over 9 cm after its first year. The Gompertz and von Bertalanffy models, as usually used, did not fit the data very well in the beginning (very low R^2), corresponding to the first two months of life, and at the end, the last five examined months of the real growth curve. In both cases, obtained growth slopes

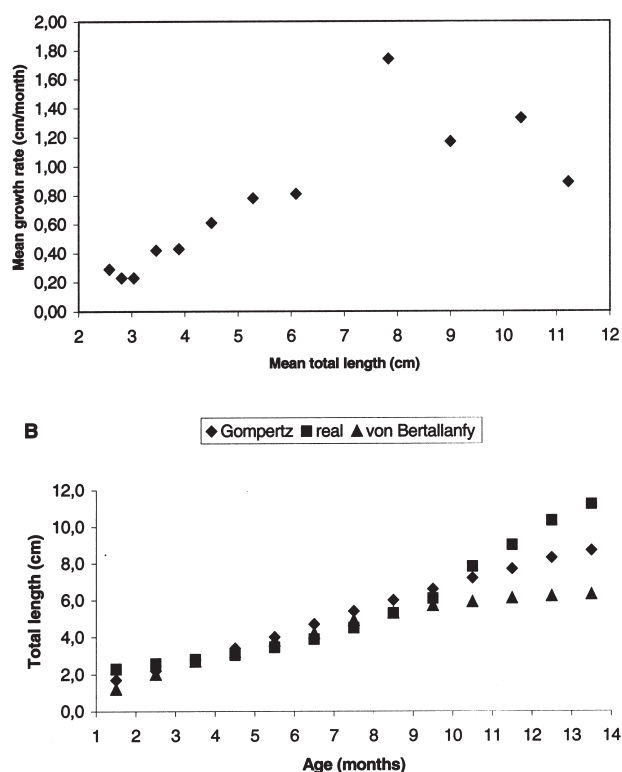


FIG. 4. – A. The monthly growth increment analysis of juvenile *S. salpa*; B. Comparison of the real (■) (by monthly mean length), Gompertz (◆) and von Bertalanffy (▲) growth curves of juvenile *S. salpa*.

underestimated growth in comparison with the real growth slope that was calculated according to monthly mean length values of the cohort (Fig. 4b). However, according to the analysis of residuals and R^2 , these two models described young salema growth more realistically than other tested models.

DISCUSSION

The potential for fish growth after settlement is intrinsically a product of their genotype, the effects of the individual's pre-settlement environment (food availability, temperature regime) (McCormick and Molony, 1992) and the characteristics of the post-settlement habitat (food availability, competitive regimes and risk of predation) (Ochi, 1986; Hixon, 1991).

The choice of an appropriate growth model depends on which species is being studied and also on the aims of the study (Gamito, 1998). There are numerous contradictory studies dealing with the use of appropriate models for estimating juvenile growth. The von Bertalanffy growth equation and its seasonal form (Ursin, 1963) are widely used for estimating growth of adult individuals. However, they have the disadvantage of not being accurate for

describing first growth years (Weatherley and Gill, 1987; Gamito, 1998), except for species whose estimated t_0 does not differ from zero, such as *Diplodus annularis* (Gordoa and Molí, 1997). This species remains in the same area throughout its life (Matić, 2001), so this fact may indicate that non-migratory species could maintain the same growth model in the juvenile and adult phase. For species with t_0 different to zero, Gordoa and Molí (1997) recommended using the exponential model. However, this growth model is not recommended for growth estimation of long-lived organisms (Cuenca *et al.*, 1985). Krebs (1994) considered that the logistic curve is an adequate description for species with simple life cycles, while Macpherson (1996) and Planes *et al.* (1999) suggested that juvenile's growth follows a linear model.

Analysing the results obtained by applying several growth models to juvenile salema, during the period after settlement in the littoral zone we found that the parabolic ($c = 0.023 \text{ mm days}^{-1}$; $R^2 = 0.936$) and Gompertz ($c = 0.047 \text{ mm days}^{-1}$; $R^2 = 0.897$) models best described juvenile growth of this species according to R^2 and its biology. This is in accordance with findings of some authors (Regner, 1980; Monteiro, 1989; Andrade, 1992; Gamito, 1998). The Laird-Gompertz model would probably be more appropriate for description of salema growth in a period before settlement (Dulčić, 1993; Nixon and Jones, 1997) and the seasonal von Bertalanffy model after the first year of its life. The lifetime growth of fish like salema, in relatively cold regions, such as the Adriatic Sea, is a mounting series of smaller sigmoids, each of which represents the course of a single year's growth (Weatherley and Gill, 1987). Therefore, a combination of the parabolic or Gompertz equation to describe the first year of growth, and the von Bertalanffy model to describe the following years, might be the solution for an adequate description of growth, as was recommended by Gamito (1998).

Growth, defined as the rate at which fishes increase in weight and length, is directly and indirectly very sensitive to temperature fluctuations (Weatherly and Gill, 1987). In the Kornati Archipelago, surface water reaches a maximum temperature in July and/or August (24–29°C) and a minimum in February (9–12°C). *Diplodus puntazzo* and *Diplodus vulgaris*, which belong to the same family as salema and spawn in the same period (Matić, 2001), exhibited lower growth than, for example, related species such as *Diplodus sargus* settling in May (Planes *et*

al., 1999). In addition, zooplankton abundance decreases during the winter season in the Adriatic Sea (Regner, 1985; Bojanić, 2001; Bojanić *et al.*, 2001) and is also a factor limiting the growth of *D. puntazzo* and *D. vulgaris*, which during early life stages feed on zooplankton (Kentouri and Divanach, 1982). After hatching, *S. salpa* feed on pelagic crustaceans (haracticoids, amphipods), then at about 2.5 cm they start feeding on epiphytic algae. When the individuals reach 13 cm they start feeding on macrophytes (Christensen, 1978). The ingestion of copepods by juveniles was reported also by Bini (1968), Tortonese (1975) and Lasiak (1986). Whitehead *et al.* (1986) indicate that young *S. salpa* are mainly carnivorous while Verlaque (1990) indicates that juveniles feed on epiphytic algae and the adults on macrophytes and seaweeds. However, since adriatic juvenile *S. salpa* feed on phytoplankton, benthic algae and marine phanerogam - *Posidonia oceanica* (unpublished data), similar to adult specimens (Antolić *et al.*, 1994), and taking into account that higher biomass of phytoplankton is recorded in the Adriatic Sea during winter (Mišeta, 1999), young salema probably do not suffer from starvation in a period after settlement.

There is a lack of information about growth of juvenile fish species based on parabolic or Gompertz models in the literature, so it was hard to compare our results with other studies. Using the Gompertz model, Pallaoro *et al.* (1998) estimated the growth rate of *Oblada melanura* to be 0.083 mm day⁻¹ and Gamito (1998) found that *Sparus aurata* has a growth rate of 0.003 mm day⁻¹. We supposed the reason for the relatively slow growth of *S. salpa* to be positive allometric growth ($b = 3.284$), or relatively lower condition ($CF = 1.41$), because salema is a high-depth and short-bodied species. Also, juveniles of *S. salpa* settled from ichthyoplankton in November and spent the whole winter in shallow coves with lower temperatures than the open sea. Planes *et al.* (1999) estimated growth rate of sparid juveniles of the genus *Diplodus* using a linear model and their values obtained for *D. vulgaris* (0.202 mm day⁻¹) and *D. puntazzo* (0.160 mm day⁻¹), which settled from ichthyoplankton after salema, were numerically very similar to the values obtained for *S. salpa* using the same model (0.203 mm day⁻¹). However, it is not recommendable to compare directly growth slopes of different species.

From our investigation in the protected area of Kornati Archipelago, it is evident that juvenile sparids do not compete with adults for habitat

because they recruit in very shallow water, 1-2 m deep along the coastline, forming a small number of monospecific shoals with a markedly clumped distribution. These monospecific shoals never mix with the shoals of adults present in the nursery area (Macpherson, 1998). Settlement intensity vary spatially, temporally and among species (Vigliola *et al.*, 1998), indicating a possible competition between different juvenile species in nearshore habitats. As the juveniles grow larger, the shoals fragment, showing a less clumped distribution over the nursery area, but some species like *S. salpa* remain gregarious even at the adult stage. Consequently, the increase in adult density in a protected area does not affect juvenile growth, as Planes *et al.* (1999) have hypothesised.

Future studies should attempt to determine to what extent habitat conditions modify the growth pattern of species in different stages of their development, as was already proposed by Gordoa and Molí (1997). It is also very important to incorporate juvenile growth into studies of adult population growth.

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