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REPRODUCTION, AGE AND GROWTH OF FOUR COASTAL FISH SPECIES IN THE NE ATLANTIC

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REPRODUCTION, AGE AND GROWTH OF FOUR COASTAL FISH SPECIES IN THE NE ATLANTIC

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iii) Abstract

The Archipelago of the Azores is the most remote and isolated group of islands in the Atlantic North. Given its insular conditions and biogeographic position, the Azorean fish populations undergo different environmental pressures than the continental ones. Life history traits of four fish species frequently found in the coastal areas of the Archipelago of the Azores are described in this study. The population structure, age and growth, and reproductive aspects of two wrasse - *Coris julis* and *Labrus bergylta*, and two scorpionfish - *Scorpaena maderensis* and *Scorpaena notata*, were studied. The results for the Azorean populations were then compared with published information on these species for the NE Atlantic and Mediterranean. *Coris julis* reproductive pattern involves protogynous diandric hermaphroditism, as described before for several Mediterranean populations. A clear distinction in biological traits between insular and continental populations was not found. Thus, local ecological conditions seem to be the major factor determining *C. julis* reproductive strategy. *Labrus bergylta* shows a reproductive pattern consistent with monandric protogyny. With a population structure where a very few large males dominate harems of females, *L. bergylta* is very susceptible to fishing pressure, since the removal of larger male individuals will lead to a drastic decline in the reproductive capacity of the population. Spawning season is determined by water temperature, taking place at about 16ºC. The age, growth and reproductive biology of Azorean populations of *S. maderensis* and *S. notata* present strong evidence of sexual dimorphism. Differences in sex ratio, maximum size and maximum age between Azorean and Mediterranean populations are evident.

Key words: *Coris julis*, *Labrus bergylta*, *Scorpaena maderensis*, *Scorpaena notata*, growth, reproduction.

iv) Resumo

O Arquipélago dos Açores é o grupo de ilhas mais remoto e isolado do Atlântico Norte. Devido às suas condições insulares e posição biogeográfica, as populações de peixes dos Açores encontram-se sobre pressões ambientais diferentes das populações continentais. Aspectos básicos da biologia de quatro espécies de peixes comuns nas zonas costeiras do Arquipélago dos Açores são descritas no presente estudo. Dois labrídeos - *Coris julis* e *Labrus bergylta*, e dois scorpaenídeos - *Scorpaena maderensis* e *Scorpaena notata*, foram estudados quanto à sua reprodução, estrutura populacional e idade e crescimento. OS resultados encontrados para as populações açoreanas foram comparados com a informação publicada existente para estas espécies no Atlântico Nordeste e no Mediterrâneo. O padrão reprodutivo de *C. julis* envolve hermafroditismo protogínico diandrico, da mesma forma que foi descrito para várias populações mediterrânicas. Não foi encontrada uma distinção clara a nível de aspectos biológicos entre populações insulares e continentais, sugerindo que as condições ecológicas de cada local parecem ser os principais factores que determinam a estratégia reprodutiva de cada população. *L. bergylta* apresenta um padrão reprodutivo consistente com protogenia monandrica. Com uma estrutura populacional em que poucos machos grandes dominam haréns de fêmeas, é uma espécie vulnerável a pressão de pesca, pois a remoção dos maiores indivíduos levará a um declínio abrupto da sua capacidade reprodutiva. O período reprodutor é determinado pela temperatura da água, ocorrendo quando esta atinge cerca de 16ºC. A idade, crescimento e reprodução das populações açoreanas de *S. maderensis* e *S. notata* apresentam fortes indícios de dimorfismo sexual. Foram ainda encontradas diferenças entre as populações dos Açores e do Mediterrâneo destas duas espécies a nível de proporções entre sexos e tamanhos e idades máximas.

Palavras-chave: *Coris julis*, *Labrus bergylta*, *Scorpaena maderensis*, *Scorpaena notata*, crescimento, reprodução.

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Chapter 1

General introduction

1. General introduction

1.1. The Archipelago of the Azores

At a distance of about 1300 km and 1700 km from the European and North American continents, the Archipelago of the Azores (36-40ºN, 24-32ºW) is the most extent and remote group of islands in the Atlantic North (Santos *et al*, 1995). The nine islands of the archipelago are the emergent parts of underwater volcanoes that rise steeply from an abyssal plain that has an average depth of about 4000 m (Morton *et al*, 1998). The area of the islands is about 1900 km^2, which is just a small fraction of the 1 million km^2 Exclusive Economic Zone (EEZ) of the Azores.

The unique biogeographic position of the Azores in the Atlantic Ocean is reflected in the dynamic and structure of its coastal communities. On one hand, Azorean ichtyofauna is quite dissimilar from that of Madeira, Canary Islands, West Africa and Cape Verde, at the genus level (Lloris *et al*., 1991). Environmental conditions and coastal habitats characteristics in the Azores allow for the co-occurrence of tropical species in their northern distribution limit and temperate species in their southern distribution limit (Santos *et al*., 1997). On the other hand, it is the group of islands that shows the highest degree of geographic isolation from the coastal waters of the nearest continents – North America, Europe and North Africa. This geographic isolation is thought to limit genetic fluxes between populations in some fish species (Aurelle *et al*., 2003; Aboim *et al*., 2005; Ball *et al*., 2007), which depend mostly on the circulation pattern of water masses and on intermediate habitats such as seamounts that may act as stepping stones (Santos *et al*., 1995).

1.2. Why study fish coastal communities in the Azores?

Two major reasons justify studying the ecology of the fish communities of the coastal area of the Azores. One reason is that baseline studies on the ecology of these insular communities allow us to understand their evolutionary history in the biogeographic context in which they are found. Furthermore, with these studies we can also identify the influence of biotic and abiotic environmental factors on the structure and dynamics of these insular communities (Morato *et al*., 2003). Another reason is that this knowledge, together with the evaluation of the human impact in these communities, has an essential role in establishing future scenarios such as global warming. Thus, this is a fundamental tool for the creation of adequate strategies for the management and conservation of the natural resources and the marine biodiversity of the Azores (Santos *et al*., 1995).

The life-history traits of a fish population, such as growth and reproduction, can be strongly influenced by ecological factors such as population structure, food availability and predation, and by environmental factors like regional patterns of temperature, salinity, currents and oxygenation (Gibson, 1994). Since these conditions can vary considerably between insular and continental coastal habitats, comparative studies between populations from these regions may reveal some plasticity in biological traits as a product of different environmental pressures (Morato *et al*., 2003). This, in turn, may allow us to simulate the effects of possible climate changes on fish species (Quinn and Adams, 1996).

1.3. Objectives of the present study

Most published work on Azorean coastal species is the result of the CLIPE project, in which studies were undertaken on the biology, ecology, genetics and physiology of coastal fishes from all the Portuguese national territory (Mainland, Azores and Madeira). In this project, a comparative database between the different Portuguese regions was created, in order to establish a basis for quantifying the impact of climate changes on the structure of coastal fish communities, by associating geographic and seasonal patterns of thermal regimes. Most work was developed by the Azorean team based in the Oceanography and Fisheries Department of the University of the Azores, while some modules were carried out in the Mainland and Madeira. An ambitious sampling design, aimed to collect biological data on coastal fishes from these areas, was put into practice from April 1997 to September 2000. Based on those biological data, several studies have been published, regarding weight-length relationships (Morato *et al*., 2001), first-records (Morato *et al*., 2004), reproduction and recruitment (Morato *et al*., 2003a; Morato *et al*., 2003b), feeding biology (Morato *et al*., 2000; Barreiros *et al*., 2003; Figueiredo *et al*., 2005), genetics (Guillemaud *et al*., 2000a; Guillemaud *et al*., 2000b; Aurelle *et al*., 2003) and mating behavior (Carvalho *et al*., 2003).

Although fish populations have been studied in the Azores, the biological features of some key species remain unknown. This is the case of the four species studied in the present work – two wrasse, the mediterranean wrasse *Coris julis* (Linnaeus 1758) and the ballan wrasse *Labrus bergylta* (Ascanius 1767), and two scorpionfish, *Scorpaena maderensis* (Valenciennes, 1833) and *Scorpaena notata* (Rafinesque, 1810). Although these species have low commercial value, they are some of the most representative and

typical species of the different components of Azorean coastal ecosystems. Thus, in the present work, biological aspects such as reproduction, age and growth for these four fish species in the Azores were studied based on samples collected by the CLIPE project, and the results compared with published information available for continental populations.

1.4. Review of the biology of the studied fish species

1.4.1. The wrasse *Labrus bergylta* and *Coris julis*

As for most species of the family Labridae, there is evidence that these two wrasse - *Labrus bergylta* and *Coris julis* - are protogynic hermaphrodites, where part of the females of a population turn into males (Dipper *et al*., 1977; Quignard, 1966; Bentivegna and Rassotto, 1983; Bruslé, 1987; Lejeune, 1987; Reinboth and Bruslé-Sicard, 1997). According to the *size advantage hypothesis* proposed by Warner (1988), protogynic hermaphroditism is associated to haremic mating systems in which a few males dominate reproduction. This way, since bigger and older males present higher reproductive success compared with smaller males, selection favors the individuals that change sex from female to male at a certain body size.

The ballan wrasse *Labrus bergylta*

Life-history traits of *L. bergylta* have only been published for the Northeast Atlantic populations. In these populations, *L. bergylta* is 'long-lived' species, with individuals being of more than 20 years of age (Dipper *et al*., 1977; Costello, 1991). Its monandric protogynic nature has been confirmed for this area, since all studied males presented

secondary testicles, derived from functional ovaries by sexual inversion (Quignard, 1966; Dipper and Pullin, 1979). Male individuals were rare, with reported sex ratios between 8.3 and 12.5 females for each male (Quignard, 1966, Dipper *et al*., 1977). The unbalanced sex ratio reflects the harematic reproductive behavior described for *L. bergylta*, with one male dominating several females in a territory that it actively defends, and in which it builds a nest in the rock during the reproductive period (Costello, 1991).

According to Dipper and Pullin (1979), sexual inversion in *L. bergylta* occurs by oocyte atrophy and the gradual development of spermatogenic cysts throughout the gonad. The age at which sexual inversion occurs seems to be extremely variable, since in the same population intersexed individuals (undergoing sexual inversion), with ages ranging from 5 to 14 years, were found (Dipper *et al*., 1977). The age at which the females reach sexual maturity appears to vary between areas, since although Quignard (1966) estimated it as 2 years old for the Atlantic French coast, Dipper and Pullin (1979) determined an age at first maturation for females in the Isle of Mann between 6 and 9 years old. The spawning season varies slightly in the Atlantic coasts, mainly when it comes to its extent. In the coasts of Sweden, Hillden (1984 *in* Costello, 1991) describes a short spawning season taking place from late May to late June, while in lower latitudes spawning takes place during spring and summer, from April to August (Quignard, 1966; Dipper and Pullin, 1979). Histological analysis of the ovaries of *L. bergylta* revealed that it is a synchronous spawner, with spawning taking place only once during the reproductive period (Dipper and Pullin, 1979).

The mediterranean wrasse *Coris julis*

Life history traits of *C. julis* have only been described for Mediterranean populations. Unlike the ballan wrasse, *C. julis* is a relatively short-lived species, with a maximum estimated age of 7 years for the Catalan Coast (Gordoa *et al*., 2000). Its reproductive strategy is also different from that of ballan wrasse, and has been thoroughly studied (Bentivegna and Rassotto, 1983; Bentivegna and Cirino, 1985; Bruslé, 1987; Lejeune, 1987; Reinboth and Bruslé-Sicard, 1997). *C. julis* has been described as a protogynic diandric species, with two developmental pathways for males. Thus, two types of males are found in its populations – a primary male, morphologically similar to females, derived directly from larval/juvenile phase, and a secondary male with bright colors, derived from females by sexual inversion (Lejeune, 1987; Reinboth and Bruslé-Sicard, 1997). A significant correlation between the color pattern and the sexual phase of the gonads has been confirmed for this species (Bentivegna and Cirino, 1984; Reinboth and Bruslé-Sicard, 1997). Both primary and secondary *C. julis* males contribute to the reproductive process (Duchac *et al*., 1982), although Lejeune (1987) has reported that primary males only reproduce by interfering in the mating process of female-secondary male pairs. According to this author, however, the reproductive success of secondary males is much higher than that of primary males.

Bentivegna and Cirino (1984) studied population conditions in which sexual inversion is triggered. They found that in groups consisting only of females, sexual inversion of only the largest specimen took place, while this was not a rule in groups where a male was introduced. The presence of males, however, did not stop the inversion of some females. Only secondary males have been reported to be territorial (Lejeune, 1987). Besides the unbalanced sex-ratio, Lejeune (1987) considered the territorial availability

for secondary males an important factor to consider in the sexual inversion of *C. julis*. Smaller territories of secondary males appear to be associated to higher densities and to an early sexual inversion, increasing the number of secondary males in the population.

1.4.2. The scorpionfishes *Scorpaena maderensis* and *Scorpaena notata*

Life history traits of both *Scorpaena maderensis* and *Scorpaena notata populations* in the Atlantic are poorly studied, as most published information on these species concern Mediterranean populations.

S. notata shows a specialized mode of oviparity, since some unusual features in the gonadal morphology and in oogenesis and spermatogenesis processes have been described (Muñoz et al., 2002a, 2002b). The eggs are released within a gelatinous mass that is segregated by an internal epithelium of the ovarian wall. The annual reproductive cycle and fecundity of *S. notata* have been described for its population in Costa Brava, Mediterranean NW (Muñoz et al., 2005). No studies on the age and growth of *S. notata* were found.

Unlike *S. notata*, the reproductive biology of *S. maderensis* remains unknown, while its age and growth have been studied both for Mediterranean (Mesa et al., 2005) and Atlantic populations (Santos, 2000).

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Chapter 2

Biological traits of two common wrasse in the Azores: *Coris julis* and *Labrus bergylta*

Biological traits of two common wrasse in the Azores: *Coris julis* and *Labrus bergylta*

Abstract

Life history traits of two common wrasse in the Azores, *Coris julis* and *Labrus bergylta*, were studied. *Coris julis* reproductive pattern involved protogynous diandric hermaphroditism, although primary males were scarce. Maturation of females occurs during the first year, at 8.65 cm T_L, and spawning season extends from May to the end of July, when temperatures range between 17 and 19ºC. A comparison between this Atlantic population and others previously studied in the Mediterranean shows that there is no clear distinction between them regarding reproductive biology. *Labrus bergylta* shows a reproductive pattern consistent with monandric protogyny, with an unbalanced sex ratio of 1 male: 12.2 females. The population structure revealed few large males dominating harems of females. The removal of larger males by fishing may lead to a drastic decline in the reproductive capacity of the population. Spawning season is conditioned by water temperature, occurring at about 16ºC, which in the Azores takes place between January and March, in plain wintertime, whereas in higher latitudes of the North Atlantic these temperatures occur during summertime, at the same time as *L. bergylta* spawning season. Maturation occurs at the age of 2.6 yrs, with 25.35 cm T_L.

Key words: *Coris julis*, *Labrus bergylta*, reproduction, growth.

Introduction

Wrasse are common and abundant fish of the family Labridae that inhabit rocky and algal inshore areas (Costello, 1991). Two species of wrasse are particularly common in the rocky coasts of the Azores islands: the Mediterranean wrasse *Coris julis* (Linnaeus 1758) and the ballan wrasse *Labrus bergylta* (Ascanius 1767) (Porteiro *et al*., 1996). Besides the Azores islands, these two species are common throughout the NE Atlantic, including other Atlantic archipelagos like Madeira and Canarias (Quignard and Pras 1986; Costello, 1991). *C. julis* is also found in the Mediterranean Sea where it is the most common and abundant wrasse (Gordoa *et al*., 2000).

Managing fish populations requires increasing understanding of their behaviour, life history strategies and reproductive patterns (Alonzo and Mengel, 2005). Given that these two wrasse show life history patterns that may involve protogynous sex change (Reinboth, 1957; Quignard, 1966) their population dynamics and responses to fishing and management measures should differ from those of separate sex fishes (Alonzo and Mengel, 2004). This may be the case of *L. bergylta*, which is targeted by sport and small scale fishermen (rod and line and spear) in the NE Atlantic (Costello, 1991; Treasurer, 1994) and also in the Azores (Figueiredo *et al*., 2005). However, although several studies on *L. bergylta* growth and reproduction have been carried out in the NE Atlantic (Dipper *et al*., 1977; Dipper and Pullin, 1979; Costello, 1991; Treasurer, 1994), only its feeding ecology has been studied in the Azores (Figueiredo *et al*., 2005).

In the Mediterranean, sex-inversion (Bentivegna and Rassotto, 1983; Bruslé, 1987; Lejeune, 1987; Reinboth and Bruslé-Sicard, 1997), social behaviour (Bentivegna and

Cyrino, 1984; Lejeune, 1987), age and growth (Gordoa *et al*., 2000), population genetics (Mandrioli *et al*., 2000) and recruitment (Raventós and Macpherson, 2001) of *C. julis* have been thoroughly studied. In contrast, the Atlantic populations have only been studied as for length-weigh relationship (Morato *et al*., 2001). A recent population genetics study (Aurelle *et al*., 2003), however, has shown that there is evidence of some genetic differentiation between Atlantic and Mediterranean populations of *C. julis*. Since biological and environmental pressures differ substantially, the less well studied Atlantic populations are expected to differ from the Mediterranean populations in terms of life history traits.

In this study, biological traits such as reproduction and age and growth of the Azorean populations of *C. julis* and *L. bergylta* were studied. The results were compared with previous studies from other regions.

Material and methods

Coris julis and *Labrus bergylta* individuals were collected in the Azores archipelago between August 1997 and October 1999. Sampling was undertaken on a monthly basis in the island of Faial and once each summer in the years 1997, 1998 and 1999 at the islands of Corvo and Santa Maria (Fig.1). A total of 407 *C. julis* and 344 *L. bergylta* individuals were caught by spear fishing, hook-and-line and scuba hand netting. Samples gathered in 1997-1999 were pooled in order to improve sample sizes.

Total length (L_T) measurements were recorded to the nearest millimetre, and total weight (W_T) and eviscerated weight (W_E) were recorded to the nearest milligram.

Gonads (W_G) and livers (W_L) were removed and weighed. Each individual had its sex determined by macroscopic observation of the gonads using a scale adapted from Buxton (1990). Both ovaries and testes were then staged as either immature (stage 0), resting (stage I), developing (stage II), pre-spawning (stage III), spawning (stage IV) or spent (stage V). It was not possible to determine the sex of *C. julis* individuals below 6 cm L_T. Individuals of both species showing evidence of hermaphroditism were classified as intersex and colour pattern (female, male and transition) was recorded for *C. julis* individuals.

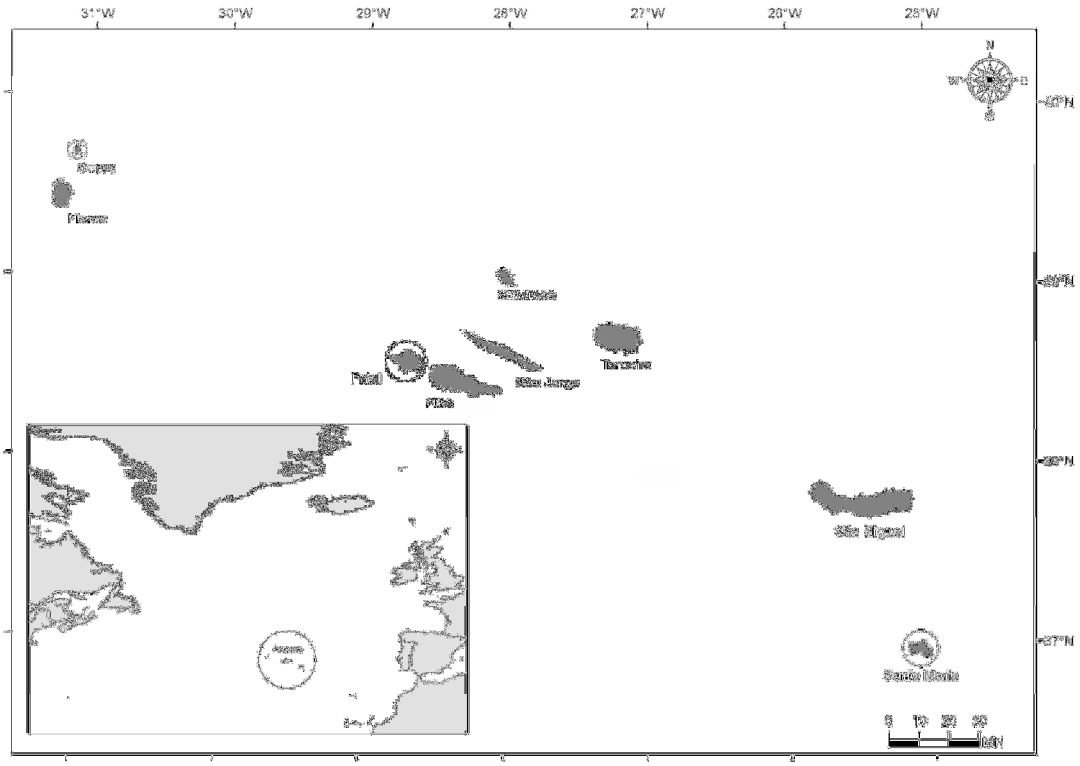

Fig. 1. Location of the Archipelago of Azores, showing the sampled islands of Corvo, Faial and Santa Maria

Sex-ratio (male:female) was analysed for *L. bergylta* for the whole sampling period and also by reproductive season. Since *C. julis* display sexual dichromatism, spear fishing and hand netting sampling may be biased towards one sex. Thus, the analysis of *C. julis*

sex ratio was based on underwater visual census (50x5 m strip transects) during the same period of sampling (1997-1999). Individuals were sexed based on their colour dimorphism (Porteiro *et al.*, 1996). The χ^2 goodness-of-fit test ($\alpha = 0.05$) was used to compare the sex ratio with a hypothetical 1:1 ratio (Zar, 1999). Length-frequency distribution was determined for each sex. Differences in mean lengths between sexes were tested using a t-test, after insuring that the total lengths of each sex followed a normal distribution with a Kolmogorov-Smirnov test (Zar, 1999). Even though the length-frequency distribution does not represent the true population distribution of *C. julis*, it is suitable for testing inter-sexual differences.

Total length at first maturity (L_{T50}) and age at first maturity (Age_{50}) were estimated by fitting the logistic curve to the relative frequency of mature individuals by 1 cm L_T classes and by age: $P_X = [1 + e^{-a(X-b)}]^{-1}$, where P_X is the proportion of mature fish at length or age X, a is the slope of the curve and b is the length or age at which 50% of the fish are mature. Non-linear least squares regression was used to estimate the parameters of the logistic curve. Only females were used in this analysis because both species might be protogynous and no immature males were caught. Size at which sex inversion occurs was estimated either by analysing intersex individuals or by estimating the median value of the size range in which males and females overlap (Shapiro, 1984).

The gonado-somatic index (I_G), where $I_G = W_G / W_E * 100$, and the hepato-somatic index (I_H), where $I_H = W_H / W_E * 100$, were determined on a monthly basis. Spawning period was determined by combined analysis of monthly mean I_G and monthly variation in gonad maturity stages.

Sagittal otoliths were removed from 389 *C. julis* and 343 *L. bergylta* over the whole size ranges. Whole otoliths of both species were fully immersed in ethanol and read under reflected light. First of July was taken as the birthdate for *C. julis* since it is approximately the time for annulus formation (Jorge Fontes, pers. com.). Estimated ages used in *C. julis* analysis were given in months in order to produce more accurate results, because this seems to be a short-lived species (Gordoa *et al*., 2000). For *L. bergylta*, the counts were converted into ages, in years, assuming the first of January as the designated birthday (Williams and Bedford, 1974). The von Bertalanffy growth equation $L_t = L_\infty\ [1 - \exp(-k(t-t_0))]$, where L_∞ is the asymptotic mean length, k is the growth rate and t_0 is the hypothetic age at zero length, was fitted with least squares procedures by means of a non-linear regression using the Quasi-Newton algorithm included in the STATISTICA© 6.0 software. To account for individual growth variability, models were fitted to individual length-at-age data. Given that these species may be protogynous hermaphrodites, involving sex-inversion of some individuals at some point of their life cycle, the von Bertalanffy growth parameters were estimated for both sexes pooled together.

At the three islands and throughout the entire study period, water temperature was measured at 30 min intervals by means of underwater dataloggers. These were placed at 25 m depth on exposed rocky shores, in conditions that resemble the habitats and average depth distribution of these species in this region. Water temperature was averaged by month for each island, and again averaged for all islands over the entire period, so that it would give an approximation of the annual thermal regime of the Azores. A Spearman rank order correlation (r_S) was used to test the measure of relation between I_G and water temperature.

Results

Coris julis

C. julis individuals ranged from 2.7 to 24.2 cm L_T. Colour patterns were different between sexes. Two types of males were caught: primary males, with the same colour pattern as that of females, ranging from 10 to 15 cm L_T; and larger secondary males with bright colours, ranging from 15 to 24 cm L_T. Length-frequency distributions were clearly different between sexes, showing distinct modal size for males and females (Fig. 2). Average L_T was significantly different between sexes (t-value=21.3, df=315, p<0.001). Females dominated size classes < 17 cm L_T, with a mean L_T of 14.0 cm, while males dominated the larger size classes, with a mean L_T of 19.4 cm. No females larger than 18 cm were caught. Only 32 individuals (7.9%) with intersexed gonads were caught, with a mean L_T of 13.7 cm and ranging from 9.8 to 20.1 cm L_T. Most of these intersexed individuals were caught between August and September, soon after the reproduction season had finished, and showed a transitional colour pattern, which is characteristic of the intersexual phase (Reinboth and Bruslé-Sicard, 1997).

Sex-ratio estimation based on visual census for the whole period was significantly different from 1:1 and in favour of females, with 1 male to 3.7 females (n = 20046; P < 0.01) (Table 1). The sex ratio varied with season, from 1:3.1 during spawning to 1:4.3 during the recovering and resting stages. Significant differences between sexes were found in all seasons (Table 1). Only 4 primary males were caught, consisting in 1% of the sample size. Although this proportion may be slightly underestimated, it gives us an indication that the number of primary males in the population is very low.

Length and age at first maturity of females were difficult to estimate given the small number of individuals of less than 11 cm L_T in the sample. L_{T50} and Age_{50} were estimated as 8.50 (±0.006) cm L_T (r=1; p<0.01) and 0.67 (±0.0005) years old (r=1; p<0.01) (Fig. 3).

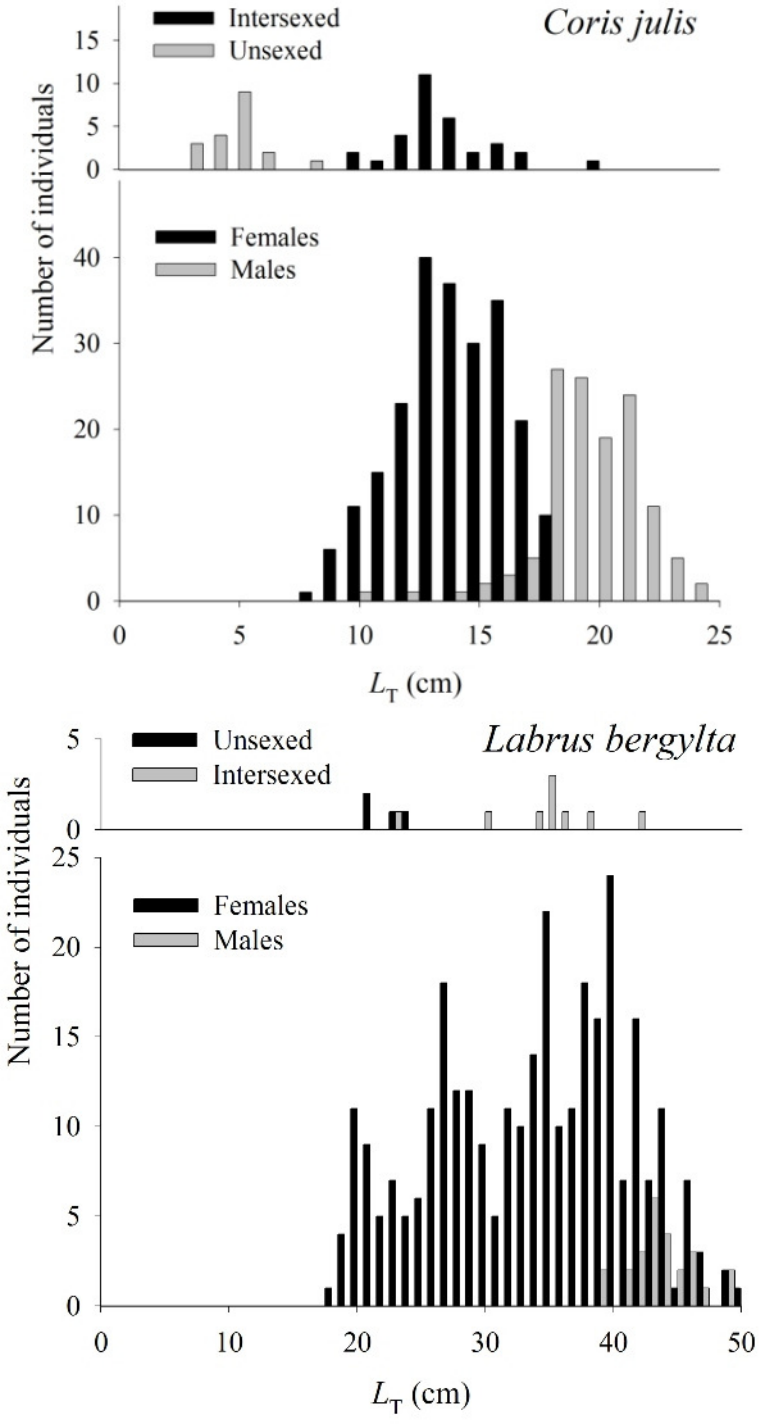

Fig. 2. Length frequency distribution of *Coris julis* (a) and *Labrus bergylta* (b) in the Azores, for the period 1997-1999.

The monthly proportion of gonad maturity stages varied along the year and was associated with monthly mean I_G and water temperature (Fig. 4). In fact, a significant correlation between monthly mean I_G and water temperature was found (r_S = -0.87, n = 17; P<0.00). Pre-spawning and spawning individuals first appeared in May, when the water temperature was > 17ºC, causing a sudden increase in mean I_G. The proportion of maturity stages III and IV and mean I_G both reach a peak in June, decreasing afterwards until the end of July, when water temperature increased to > 20ºC. Spent individuals could also be observed from May on, but it was only in August that they comprised most of the maturity stages. From September to November, as the temperature remained > 19ºC, all individuals were in a resting phase and I_G dropped to low values. Developing individuals were first observed in February, while I_G remained low and water temperature had decreased to low values, reaching a winter minimum of *c*. 15ºC. However, the timing at which *C. julis* gonads begin to develop is uncertain due to the absence of individuals in the samples from the months of December and January. I_H remains fairly constant through the year and it is not correlated to I_G (r_S = 0.37, n = 10; P = 0.29). During the spawning and pre-spawning period female I_G was consistently higher than male I_G, indicating that ovaries were larger than testes.

C. julis otoliths showed a rather clear pattern of ring deposition, with opaque rings alternated with thinner hyaline rings. Individuals caught varied from age class 0 to 5.7 years old. Von Bertalanffy growth parameters estimated for the whole sample (n = 381) were L_∞ = 22.2 cm (±1.07), k = 0.40 (±0.06) yr^{-1} and t_0 = -0.65 (±0.16) (R^2=0.79) (Fig. 5).

Table 1. Total and seasonal sex-ratio (M:F) of *Coris julis* and *Labrus bergylta* in the Azores, for the period 1997-1999.

Coris julis					
Season	Maturation stage	Sex-ratio (M:F)	*n*	χ^2	*P*
Total period		1 : 3.7	20046	6608.8	<0.01
February-April	Developing	1 : 4.0	2156	774.2	<0.01
May-July	Spawning	1: 3.1	8847	2357.6	<0.01
August-November	Recovering and resting	1 : 4.3	9043	3531.3	<0.01
Labrus bergylta					
Season	Maturation stage	Sex-ratio (M:F)	*n*	χ^2	*P*
Total period		1 : 12.2	331	238.6	<0.01
November-December	Developing	1 : 8.3	37	22.7	<0.01
January-March	Spawning	1 : 34.7	107	95.3	<0.01
April-October	Recovering and resting	1 : 9.4	187	121.9	<0.01

Labrus bergylta

L. bergylta individuals caught in this study ranged from 17.9 to 50 cm L_T and from 85.9 to 1821.8 g M_T. While females could be found throughout the whole size range, only males larger than 39 cm L_T (n = 25) were captured (Fig. 2). Average L_T was significantly different between sexes (t-value=-6.68, df=329, p<0.001). Females greatly outnumbered males during the entire study period, with an overall sex-ratio of 1 male:12.2 females (Table 1), significantly diverging from 1:1 (n=344, p<0.01). Sex-ratio also varied with season, showing a peak of 1:34.7 during the first trimester, when spawning seems to occur, but remaining around 1:9 through the rest of the year (Table 1). Few intersexed individuals were caught (n = 9) ranging from 23 to 42 cm L_T with an average of 32.3 cm L_T.

Length at first maturity (L_{T50}) and age at first maturity (Age_{50}) estimated for females were 25.35 (±0.34) cm L_T (r = 0.97; p < 0.01) and 2.62 (±0.08) years (r = 0.99; p < 0.01) (Fig. 3).

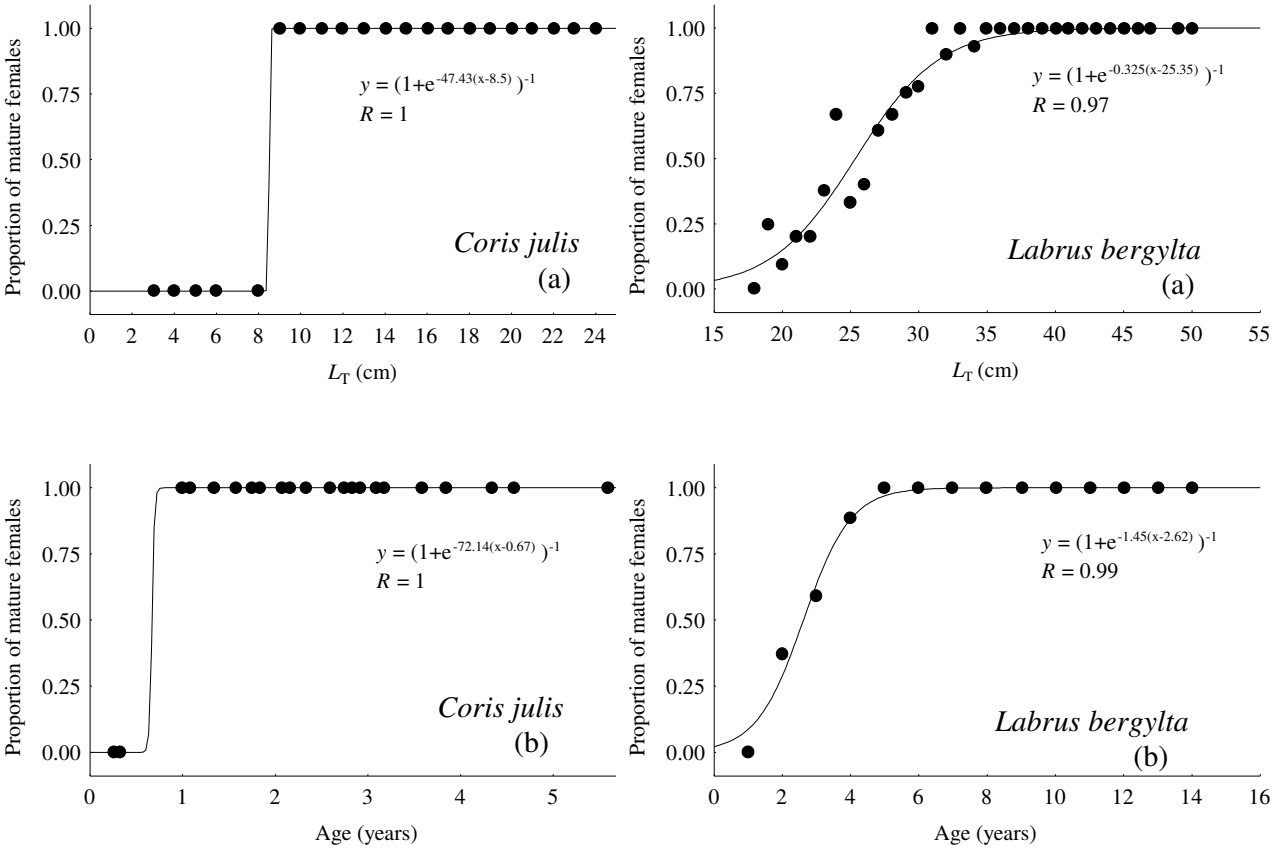

Fig.3. Maturity ogives of total length (a) and age (b) at first maturity for *Coris julis* and *Labrus bergylta* in the Azores for the period 1997-99.

L. bergylta monthly proportion of gonad maturity stages also varied throughout the year, and appeared associated with monthly mean I_G and water temperature (Fig. 4). *L. bergylta* monthly mean I_G was significantly correlated with the thermal regime of that region (r_S = -0.31, n = 338; P<0.001). Developing individuals became predominant in November, when water temperature began to decrease. By January most individuals

were either in developing or pre-spawning maturity stage. Between January and March, as the water temperature dropped to a winter minimum of about 15ºC, pre-spawning and spawning individuals became dominant while I_G reached its highest peaks. However, in April, as the water began to warm up, an abrupt decrease in I_G was accompanied by the predominance of spent individuals. From April to October almost all individuals caught were recovering or resting, and I_G remained constant and low. Differences in I_G between sexes could not be verified because very few males were caught during spawning and pre-spawning season. Regarding I_H, neither a seasonal pattern nor significant correlations with I_G were observed ($r_S = 0.19$, $n = 12$; P=0.56).

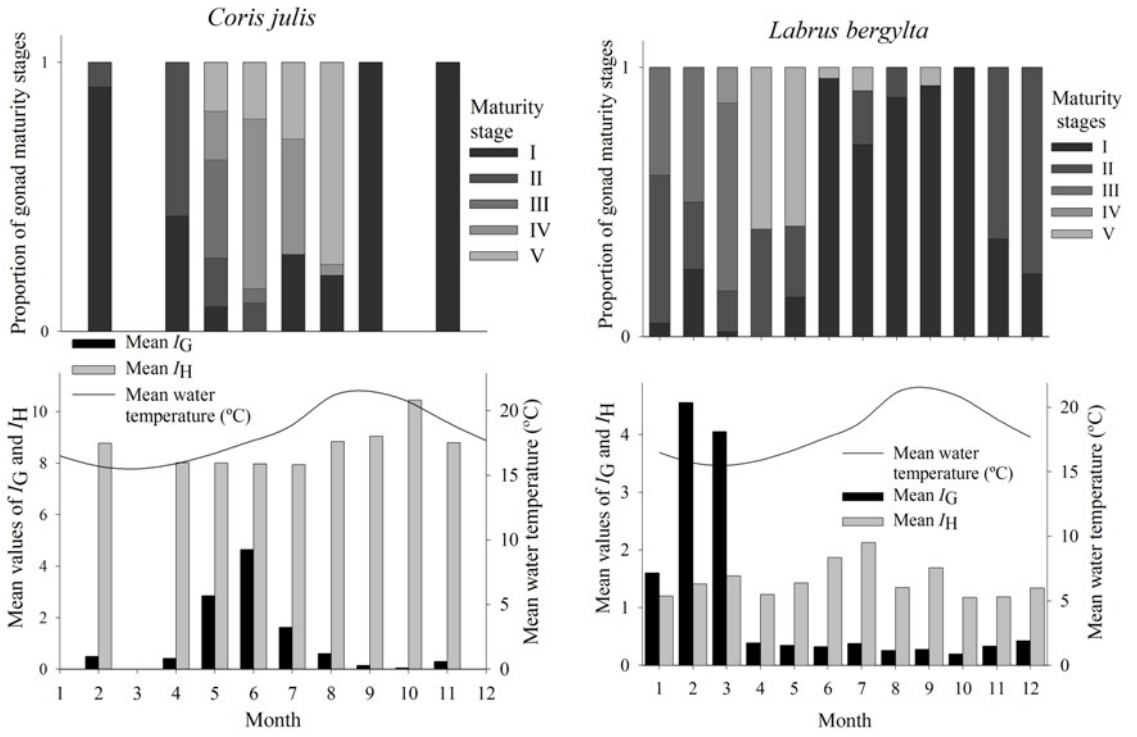

Fig.4. Proportion of gonad maturity stages and mean values of I_G and I_H by month of *Coris julis* and *Labrus bergylta* for the period 1997-99. Monthly mean water temperature is also given.

Age determination using ballan wrasse otoliths was possible given that a regular deposition pattern of alternating opaque and hyaline rings was visible. Maximum observed ages were 11 years for males (L_T = 39 cm) and 14 years for females (L_T = 40.5 cm). Von Bertalanffy growth curve estimated for both sexes (Fig. 5) shows rapid growth during the first two years, up to 11 cm year^{-1}, and a declining growth rate from the third year on. Estimated von Bertalanffy growth parameters for the whole sample (n = 343) were L_∞ = 44.9 cm (±0.8), k = 0.31 yr^{-1} (±0.03) and t_0 = -1.16 (±0.18) yr (R^2=0.91).

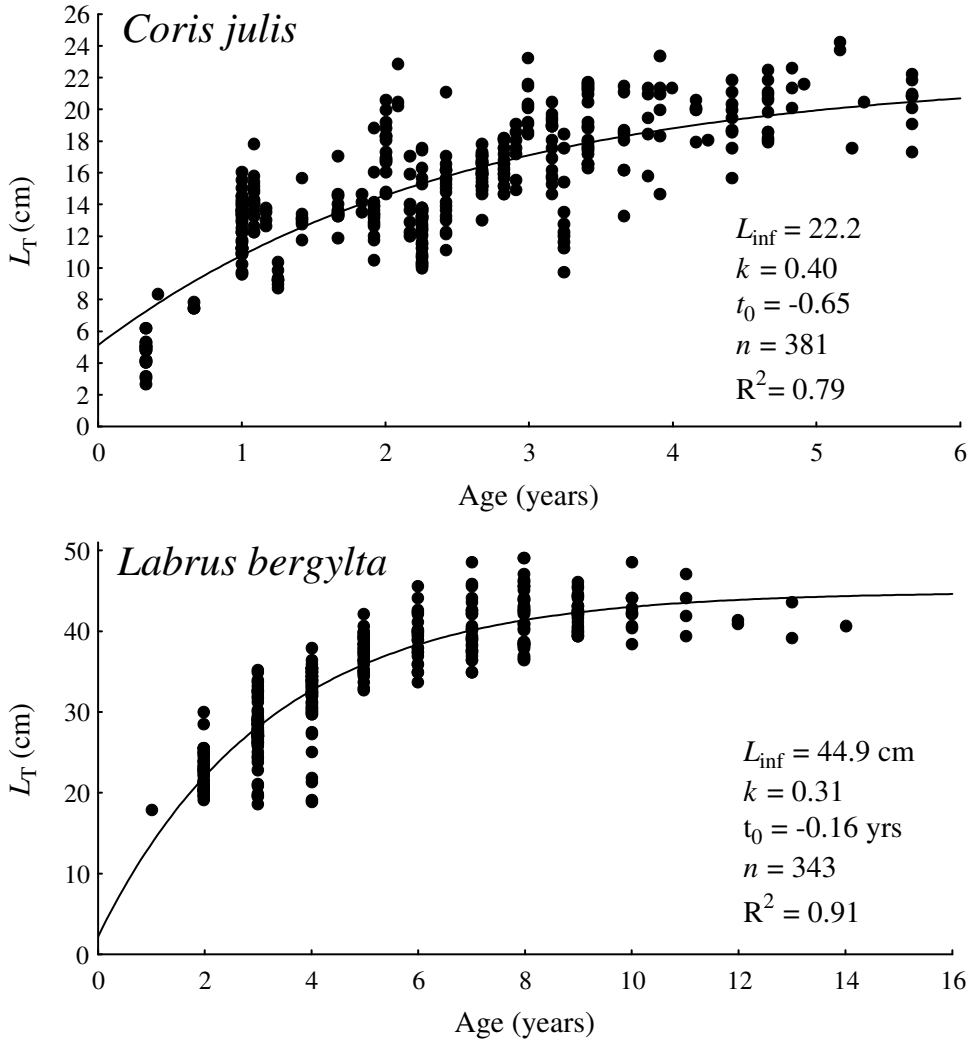

Fig. 5. Von Bertalanffy growth curves estimated for *Coris julis* and *Labrus bergylta* for the period 1997-1999.

Discussion

Coris julis

Protogynous sex change has been associated to a mating system in which male individuals show higher reproductive success when relatively large in size. This way, selection favours individuals that change sex from female to male above a certain body size, as predicted by the size advantage hypothesis (Warner, 1988). Diandry, i.e., the presence of two male developmental pathways in the same species, should evolve whenever small sneaker males are not completely excluded from breeding. In the Azores, *C. julis* presents a sexual pattern characterized by protogynous sex change and diandry, as described before for Mediterranean populations (Lejeune, 1987; Bruslé, 1987; Reinboth and Bruslé-Sicard, 1997). However, the way diandry is expressed differs between populations from both areas: in the Azores only a very small proportion of primary males was found comparing to those found by Bentivegna and Rassotto (1983) and Lejeune (1987) in the Mediterranean (Table 2). Other reproductive aspects such as the proportion of individuals undergoing sex inversion, sex ratio and number of primary males also seem to vary between studies (Table 2) but distinction between Atlantic and Mediterranean populations is not clearly visible. The spawning period, however, consistently occurs in late spring – early summer, showing strong correlation with regional thermal patterns, like other coastal fish species from the Azores (Morato et al., 2003), although its extent also varies between locations (Table 2). Ecological aspects such as social behaviour and territory availability have been shown to influence *C. julis* sex inversion dynamics and thus the entire community structure (Bentivegna and Cyrino, 1984; Lejeune, 1987). Local ecological conditions may explain the highly variable reproductive traits found between and within areas. As for age and growth, *C.*

julis appears to be a short-lived (5.7 years), fast growing fish, as also reported by Gordoa *et al*. (2000) in the Catalan Sea, although these authors estimated a slightly higher maximum age of 7 years.

Table 2. Summary of sex-ratio (M:F), spawning period and proportion of intersexed individuals and of primary males in different populations of *Coris julis*.

Coris julis						
Author	**Area**	***N***	**Sex ratio**	**Proportion of intersex**	**Spawning period**	**Proportion of primary males**
Present study	Atlantic (Azores)	407	1:3.7	7.6 %	May - July	1 %
Lejeune, 1987	Mediterranean (Corsiga)	210	1:2.57		End April – mid-September	14%
Bentivegna & Rasotto, 1983	Mediterranean (Napoli)	206		0.48 %		10%
Bruslé, 1987	Mediterranean (South of France)	136		11 %	July - August	
Gordoa et al., 2000	Mediterranean (Catalan Sea)	228			June (birthdate)	

Labrus bergylta

In the Azores, the *L. bergylta* population shows a number of biological traits similar to those found for North Atlantic populations, as it also exhibits a protogynous monandric sex-changing behaviour, with a sex-ratio consistently skewed towards females (Dipper et al., 1977; Dipper and Pullin, 1979) and the exclusive presence of large males in the population (Dipper *et al*., 1977; Treasurer, 1994). Sex-ratio, however, was not constant throughout the year, showing a peak of 1 male to 34.7 females during spawning. These differences may be due to behaviour patterns, since males are known to actively defend their nests during spawning and this way become less visible to divers. As a territorial fish, the selective removal of larger fish by sport fishing may affect this social structure and reduce egg survival by removing the nest-guarding males (Treasurer, 1994). *L.*

bergylta is thus a vulnerable species to fishing practices in the Azores because, according to Huntsman and Schaaf (1994), even moderate levels of fishing mortality may induce a drastic decline in the reproductive capacity of the population. These authors suggest the conservation of the numerical sex-ratio or of the male biomass - fecundity ratio as means to compensate the disadvantage of protogyny. Marine protected areas have the potential to mitigate some effects of fishing on sperm limitation in protogynous populations (Alonzo and Mengel, 2004).

L. bergylta's spawning season occurs during wintertime (January to March) in the Azores, whereas it is known to occur between late spring and early summer (May to August) in the North Atlantic (Dipper *et al*., 1977; Hillden, 1984 *in* Costello, 1991; Costello, 1991). Given that the water temperature associated to those geographical areas during those seasons is similar, even though it stands as a winter minimum in the Azores and a summer maximum in the North Atlantic, it is possible that the reproduction of *L. bergylta* occurs mainly at temperatures around 15-16ºC. Maturation occurs around the second year of life, in agreement with Dipper *et al*. (1977), and as observed by these authors growth rates start to decline afterwards. In the Azores, *L. bergylta* appears to be a slow growing and long-lived species, resembling North Atlantic populations (Dipper *et al*., 1977; Costello, 1991; Treasurer, 1994). However, the maximum observed age is far less in the Azores, with an estimated longevity of 14 years, compared to 29 years (Dipper *et al*., 1977) and 25 years (Costello, 1991) for North Atlantic populations. These differences, though, may be due to age reading methods, since in the Azores otoliths were read whole and this method is known to underestimate age in species with long life-span (White *et al*., 1998; Peltonen *et al*., 2002; Abecasis *et al*., 2006). Differences in age reading methods, however, produce

relatively small changes in growth rates estimates because the fish that are most prone to age determination errors are the older ones, and these present slower growth (Peltonen *et al*., 2002).

Sex-reversal dynamics of protogynous fish, such as *C. julis* and *L. bergylta*, appear to be highly influenced by social and ecological conditions of their habitats, such as size structure, sex ratio and density of local social groups (Munday et al., 2006). Fishing pressure or habitat degradation may alter these conditions and lead to drastic changes in the population structure of these species. However, protogynous fish appear to have compensatory mechanisms such as socially controlled sex reversal that maintains relatively constant sex-ratios (Platten et al., 2002; Muñoz and Warner, 2003). This seems to be the case of *C. julis*, since it shows high variability between populations and it has been shown that the removal of males from a group induces sex change in the biggest females (Bentivegna and Cirino, 1984). However, the same may not be true for *L. bergylta,* which is why its response to elevated male mortality or changes in sex ratio should be investigated and contemplated in the fishery management of protogynous populations.

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Chapter 3

Age, growth and reproductive biology of two scorpionfish from the Azores: *Scorpaena maderensis* and *Scorpaena notata*

Age, growth and reproductive biology of two scorpionfish from the Azores: *Scorpaena maderensis* and *Scorpaena notata*

Abstract

The age, growth and reproductive biology of Azorean populations of two common scorpionfish in the NE Atlantic, *Scorpaena maderensis* and *Scorpaena notata*, were studied. The results were compared with previous studies conducted for these species in the Mediterranean, and some differences between populations are evident. In contrast with Mediterranean populations, age and growth of both species in the Azores presented strong evidence of sexual dimorphism, with males growing bigger and longer than females. Von Bertalanffy growth parameters estimated for *S. maderensis* were L_∞=18.3 cm, k=0.22 cm.yr^{-1}, t_0=-3.08 yr for males, and L_∞=14.8 cm, k=0.31 yr^{-1} and t_0=-2.11 yr for females. Maximum observed age was 7 years for males and 6 years for females. Estimated growth parameters for *S. notata* were L_∞=22.3 cm, k=0.20 yr^{-1} and t_0=-3.18 yr for males, and L_∞=18.8 cm, k=0.37 yr^{-1} and t_0=-1.48 yr for females, with a maximum observed age of 8 years for males and 7 years for females. *S. maderensis* spawns between March and June, while *S. notata* appears to spawn in August. The first maturation of *S. maderensis* occurs at the length of 9.88 cm for males and 8.73 for females, at the age of 1.8 years. *S. notata* length and age at first maturation was 11.42 cm and 0.85 yrs for males and 10.77 cm and 0.86 years for females.

Key words: *Scorpaena maderensis*, *Scorpaena notata*, reproduction, growth.

Introduction

Scorpaena maderensis (Valenciennes, 1833) and *Scorpaena notata* (Rafinesque, 1810) are two common scorpionfish (family Scorpaenidae) that inhabit the shallow waters of the Eastern Atlantic. *S. notata* seems to be more widespread, being found from the Bay of Biscay to Senegal, in the Mediterranean and the Black Sea, and in the macaronesian archipelagos of Azores, Madeira and Canary Islands (Hureau & Litvinenko, 1986). On the other hand, *S. maderensis* presents a rather scattered distribution that includes all the macaronesian archipelagos (Azores, Madeira, Canary Islands and Cape Vert), the north-western coast of Africa from Morocco to Senegal, and several localities in the Mediterranean, such as the south-eastern coast of Spain, the coast of Lebanon, the eastern coast of Sicily (Mesa et al., 2005), the eastern Adriatic sea (Dulcic et al., 2003) and the waters off Greece (Ahnelt, 1983). Although widely spread, these species have poor commercial value, being caught mostly as by-catch of small-scale artisanal fisheries (Morato et al., 2001; Erzini et al., 2003; Mesa et al., 2005).

Basic aspects of the biology of these two *Scorpaena* spp. in the Atlantic are largely unknown, as most studies on these species were on Mediterranean populations. According to Muñoz et al. (2005), the reproductive biology in the family Scorpaenidae is particularly interesting because its species present a wide range of reproductive strategies, from basic oviparity to matrotrophic viviparity (i.e. internal fertilization of eggs with the mother providing some nutrition to developing embryos and with the young born as larvae). Specifically within the genus *Scorpaena*, a shift from a primitive to a specialized mode of oviparity seems to occur, since they deposit their eggs in a protective gelatinous matrix (Wourms & Lombardi, 1992). Muñoz et al. (2002a, 2002b)

described some unusual features in the gonadal morphology and in oogenesis and spermatogenesis processes in *S. notata*, reflecting this specialized mode of oviparity. The eggs are released within a gelatinous mass that is segregated by an internal epithelium of the ovarian wall, which provides mechanical protection and defence against predators, enables floatation and, above all, keeps the spawning together. This way, the abundant and viscous seminal fluid produced by the male will keep the sperms together so that when they are released onto the eggs within the matrix, fertilization is assured, allowing for a reduction in the egg production by the female (Muñoz et al., 2005). The annual reproductive cycle and fecundity of *S. notata* have been described for its population in Costa Brava, Mediterranean NW (Muñoz et al., 2005). No studies on the biology of age and growth were found for *S. notata*. In contrast, while the reproductive biology of *S. maderensis* remains unknown, its age and growth have been studied in the Mediterranean (Mesa et al., 2005) and in the Atlantic population of the Azores (Santos, 2000). Mesa et al. (2005) noticed that *S. maderensis* attains smaller sizes in the Mediterranean than in the Azores, suggesting that significant differences in growth may exist between Mediterranean and Atlantic populations.

In the present paper we describe the reproduction, age and growth biology of the scorpionfishes *S. maderensis* and *S. notata* in the Azores, and the results are compared with studies previously undertaken in the Mediterranean.

Material and methods

Overall, 220 *S. notata* and 516 *S. maderensis* individuals were collected between August 1997 and September 1999 in the Azores archipelago. Individuals were caught

by spear fishing, scuba hand netting and hook-and-line around the islands of Faial, Corvo and Santa Maria. Measurements of total length (L_T) to the nearest millimetre, and total weight (W_T) and eviscerated weight (W_E) to the nearest milligram were recorded for each fish. Gonads (W_G) and livers (W_L) were removed and weighed. Sex was determined by macroscopic observation of the gonads, which were then staged as immature (stage 0), resting (stage I), developing (stage II), pre-spawning (stage III), spawning (stage IV) or spent (stage V) (adapted from White et al., 1998).

Length-frequency distributions were determined for each sex. Differences in mean lengths between sexes were tested using a Student's t-test. Sex-ratio, expressed as male:female ratio, was analysed for the whole sampling period and compared with the hypothetical 1:1 ratio using a χ^2 goodness-of-fit test ($\alpha = 0.05$) (Zar, 1999).

Sagittal otoliths were removed from 218 *S. notata* and 380 *S. maderensis* and stored dry. Age and growth were studied by interpreting the growth structures of whole otoliths fully immersed in ethanol under reflected light. The rings were counted along the internal face, without previous knowledge of the individual length or sex. Although growth structures were easily identified in whole otoliths, calcareous accumulations at the edge did not allow the measurement of marginal increments or the determination of its opaque/hyaline nature. Thus, a marginal increment analysis as a means of validating the annual deposition of rings was not carried out. It should be mentioned, however, that for *S. maderensis* this otolith reading method has been validated and positively tested for precision (Santos, 2000).

The von Bertalanffy growth equation $L_t=L_\infty \cdot (1-\exp \cdot [-k \cdot (t-t_0)]$ (L_∞-asymptotic mean length; k–growth rate; t_0–hypothetic age at zero length) was fitted to length at age data obtained from the otolith readings by means of non-linear least squares parameter estimation using the Quasi-Newton algorithm included in the STATISTICA© 6.0 software. The von Bertalanffy growth equations were calculated for males and females separately and statistically compared using likelihood ratio (LR) tests (Kimura, 1980). To account for individual growth variability, models were fitted to individual length-at-age data.

The gonado-somatic index (I_G), where $I_G = W_G / W_E *100$, the hepato-somatic index (I_H), where $I_H = W_H / W_E *100$, and Fulton's condition factor K, where $K = 1000\ W_E\ L_T^{-3}$ were determined on a monthly basis. These indices were calculated as a function of W_E to avoid any variation that could arise from differences in the digestive tract contents or energy reserves. For *S. maderensis*, spawning period was determined by analysing the annual pattern of variation of mean I_G and gonad maturity stages. Given that *S. notata* was poorly represented in some months, its spawning season was determined by identifying the months when individuals showed stage IV gonads and the highest I_G values.

Total length at first maturity (L_{T50}) and age at first maturity (Age_{50}) were estimated by fitting the logistic curve to the relative frequency of mature individuals by 1 cm L_T classes and by age: $P_X = [1 + e^{-a(X-b)}]^{-1}$, where P_X is the proportion of mature fish at length or age X, a is the slope of the curve and b is the length or age at which 50% of the fish are mature. The parameters of the logistic curve were also estimated by means of non-linear least squares regression using the Quasi-Newton algorithm included in the

STATISTICA© 6.0 software. L_{T50} and Age_{50} were estimated for separate sexes and the results were statistically compared using likelihood ratio (LR) tests (Kimura, 1980).

Results

Of the 516 *S. maderensis* individuals caught, the gonads could only be macroscopically identified in 385. Of these 385 individuals, 184 (47.8%) were identified as males, 145 (37.7%) as females and 56 (14.5%) as unsexed immature. Since more males were caught than females, the sex ratio for the whole period was 1.27:1, diverging significantly from 1:1 (χ^2=3.25, d.f.=1, p<0.03). With regards to the 220 *S. notata* caught, 105 were males, 106 were females and sex could not be macroscopically identified in 9 immature individuals. The sex ratio was balanced (1:1, χ2=0.005, d.f.=1, p<0.95) for the whole period.

Age and Growth

S. maderensis individuals ranged from 8.4 to 17.8 cm L_t, while *S. notata* ranged from 5.1 to 22.8 cm L_t. Length-frequency distributions suggested that males were bigger than females for both species (Figure 1). In fact, significant differences in mean lengths between sexes were found for both *S. maderensis* (Mean male L_t = 13.0 cm; mean female L_t =11.8; t = 7.27, d.f.=327, p<0.01) and *S. notata* (Mean male L_t = 16.9 cm; mean female L_t =15.2; t = 4.68, d.f.=209, p<0.01).

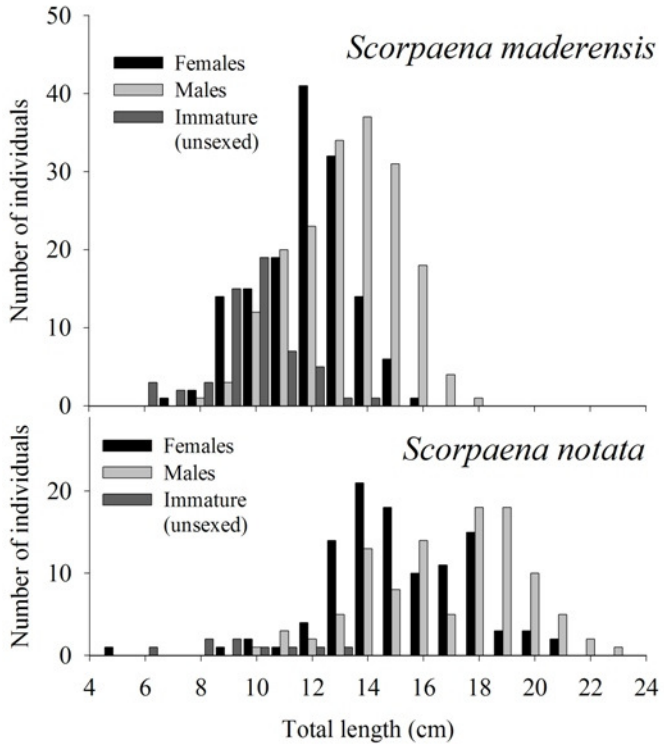

Fig. 1. Length frequency distribution of *Scorpaena maderensis* and *Scorpaena notata* in the Azores, for the period 1997-1999.

Sagittae otoliths from 380 *S. maderensis* individuals were interpreted. A regular pattern of deposition could be easily observed, especially in otoliths that presented fewer rings. Maximum observed age was 7 years for males and 6 years for females. The von Bertalanffy growth model was fitted to males and females separately (Figure 2). The estimated growth parameters were L_∞=18.3 cm (±1.3), k=0.22 yr^{-1} (±0.06) and t_0=-3.08 yr (±0.74) for males, and L_∞=14.8 cm (±1.0), k=0.31 yr^{-1} (±0.1) and t_0=-2.11 yr (±0.73) for females. Significant differences between sexes were found (LR, d.f.=3, $p<0.01$).

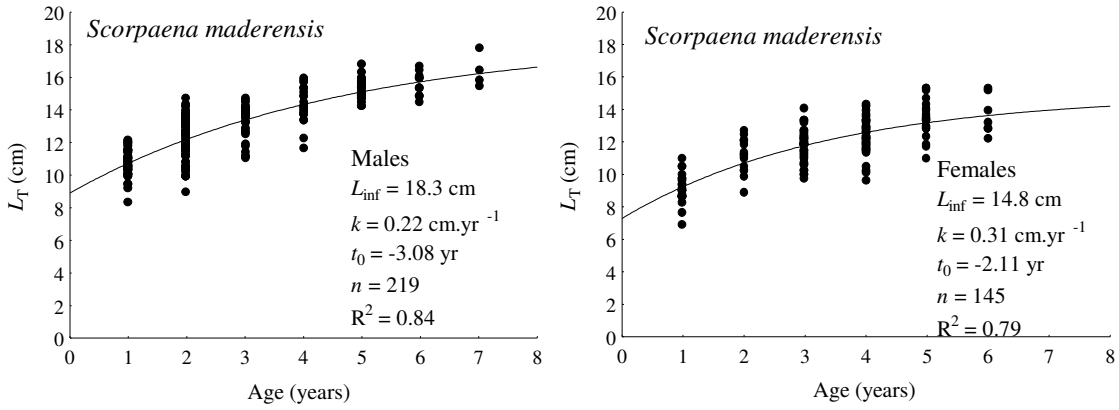

Fig. 2. Fitted Von Bertalanffy growth curves for males and females of *Scorpaena maderensis* for the period 1997-1999.

Age and growth of *S. notata* were studied by interpreting 211 sagittae otoliths. Maximum observed age was 8 years for males and 7 years for females. Significant differences between sexes were also found (LR, d.f.=3, $p<0.01$). The estimated growth parameters were L_∞=22.3 cm (±1.5), k=0.20 yr^{-1} (±0.06) and t_0=-3.18 yr (±0.82) for males, and L_∞=18.8 cm (±0.74), k=0.37 yr^{-1} (±0.08) and t_0=-1.48 yr (±0.53) for females (Figure 3).

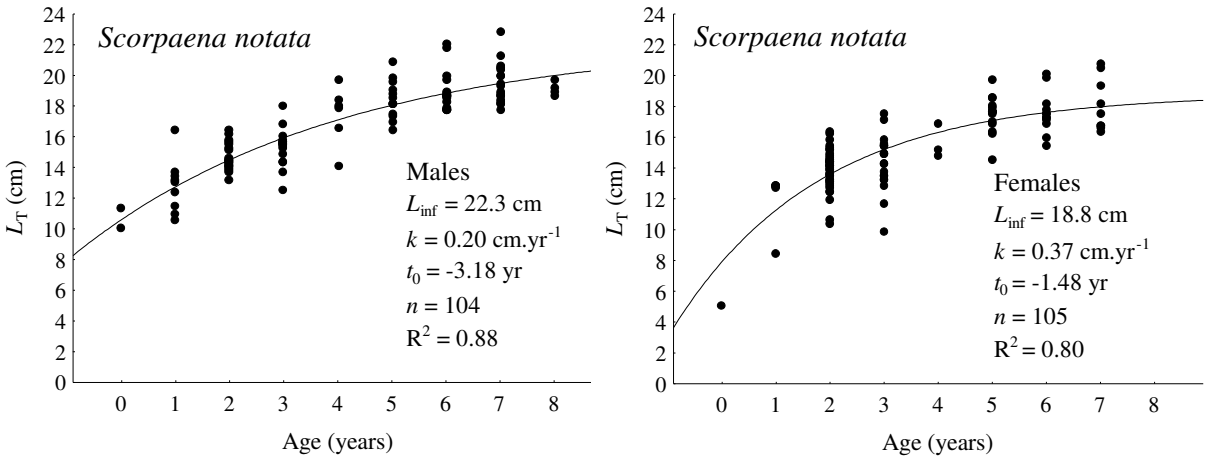

Fig. 3. Fitted Von Bertalanffy growth curves for males and females of *Scorpaena notata* for the period 1997-1999.

Reproduction

For *S. maderensis*, the combined analysis of the monthly mean I_G and the annual pattern of gonad maturity stages (Figure 4) revealed that spawning occurs between March and June, when the highest values of I_G are attained and maturity stages IV appear. By May, the first spent individuals (stage V) appeared, and these became dominant between June and August. From August to October only individuals showing stage I and II gonads appeared. Recovery and resting season was therefore defined between June and October. The development season seems to occur from November to March, as individuals started to show stage III gonads. I_G and I_H were inversely related. In June, at the end of spawning season, I_G suddenly decreased and remained low until the rest of the year. Meanwhile, I_H kept increasing, reaching a peak in November. From November to April, I_H experienced a sudden decrease while I_G slowly increased. Condition factor K remained fairly constant throughout the year, except for a sudden increase in August. Monthly mean water temperature and mean I_G were highly correlated (Spearman R=-0.79; $p<0.01$) for *S. maderensis* (Figure 5).

The results of the combined analysis of the proportion of stage IV maturity stages through the year and the monthly mean I_G, I_H and K for *S. notata* were rather patchy because data were missing for the months January, July and October (Figure 6). It seems, however, that *S. notata* spawns in August, since individuals showed the highest values of I_G and stage IV gonads in this month. I_G and I_H were inversely related in the months of August and September, but their annual pattern of variation was not clear. The condition factor *K* appeared to remain constant through the year. A correlation between monthly mean water temperature and I_G was not found (Spearman R=-0.12; p=0.68). However, since data on *S. notata* I_G was missing for several months, these results are not conclusive.

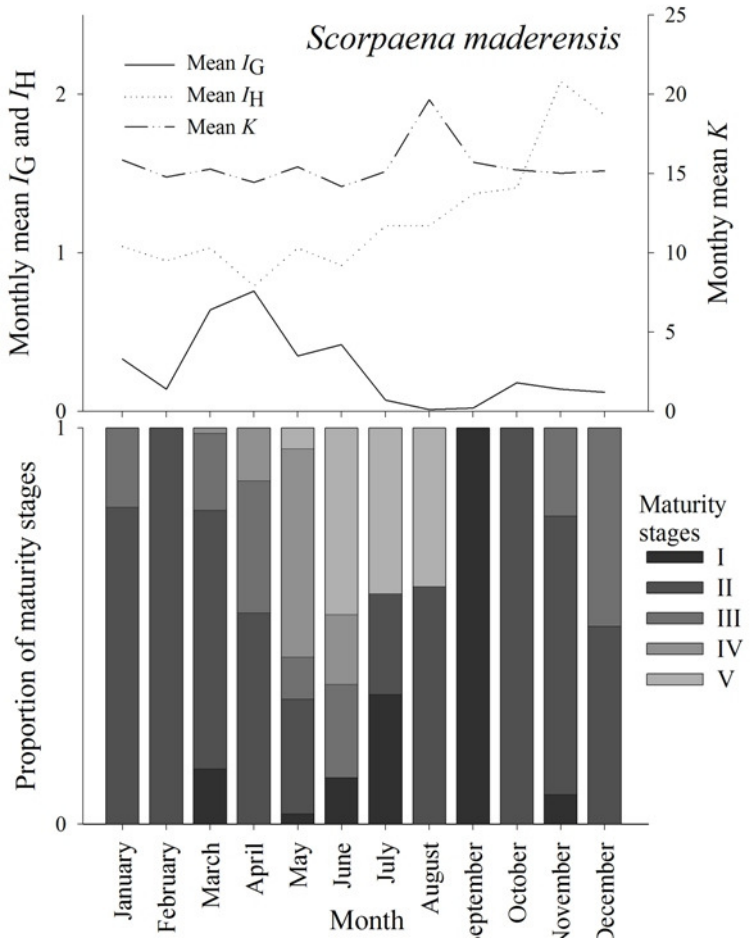

Fig.4. Monthly proportion of gonad maturity stages and mean values of IG, IH and K of *Scorpaena maderensis* for the period 1997-99.

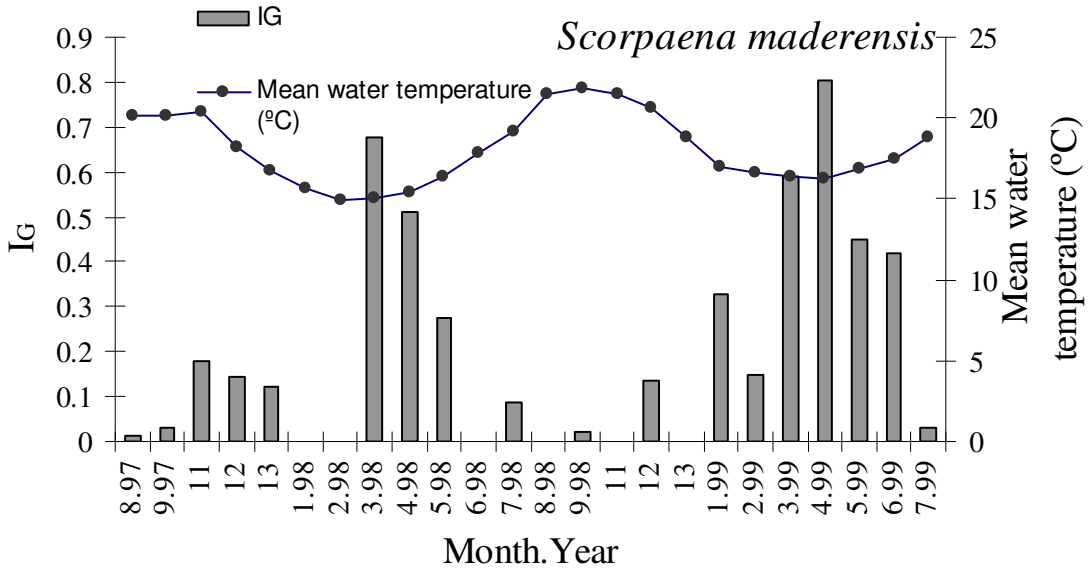

Figure 5. Monthly mean water temperature in the Archipelago of the Azores and monthly mean IG for *Scorpaena maderensis* for the period 1997-1999.

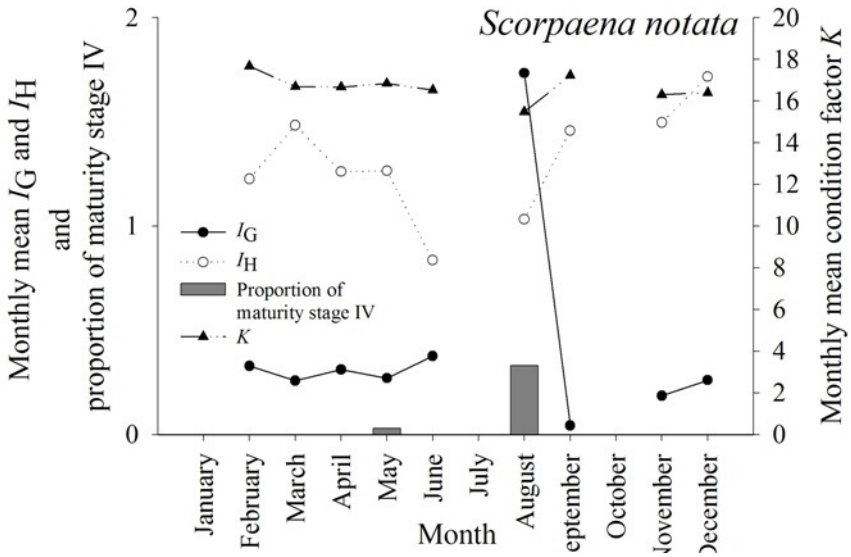

Fig.6. Monthly proportion of gonad maturity stages and mean values of IG, IH and K of *Scorpaena notata* for the period 1997-99.

For both species, length at first maturity estimated for each sex is shown in figure 7. Estimated L_{50} for *S. maderensis* was 9.88 (±0.56) for males and 8.73 (±1.70) for females. *S. notata* estimated L_{50} was 11.42 (±0.40) for males and 10.77 (±0.19) for females. Significant differences in L_{50} between sexes were found for both *S. maderensis* (LR, d.f.=2, $p<0.05$) and *S. notata* (LR, d.f.=2, $p<0.05$).

Since Age_{50} could not be estimated for separate sexes for *S. maderensis*, it was therefore estimated for sexes pooled and the results are shown in figure 8. For both sexes, first maturity of *S. maderensis* appears to occur at the age of 1.8 years (±0.1). Estimated age at first maturity for *S. notata* was 0.85 (±53.95) years for males and 0.86 (±0.07) years for females (Figure 9). No significant differences in Age_{50} between sexes were found (LR, d.f.=2, $p=0.15$).

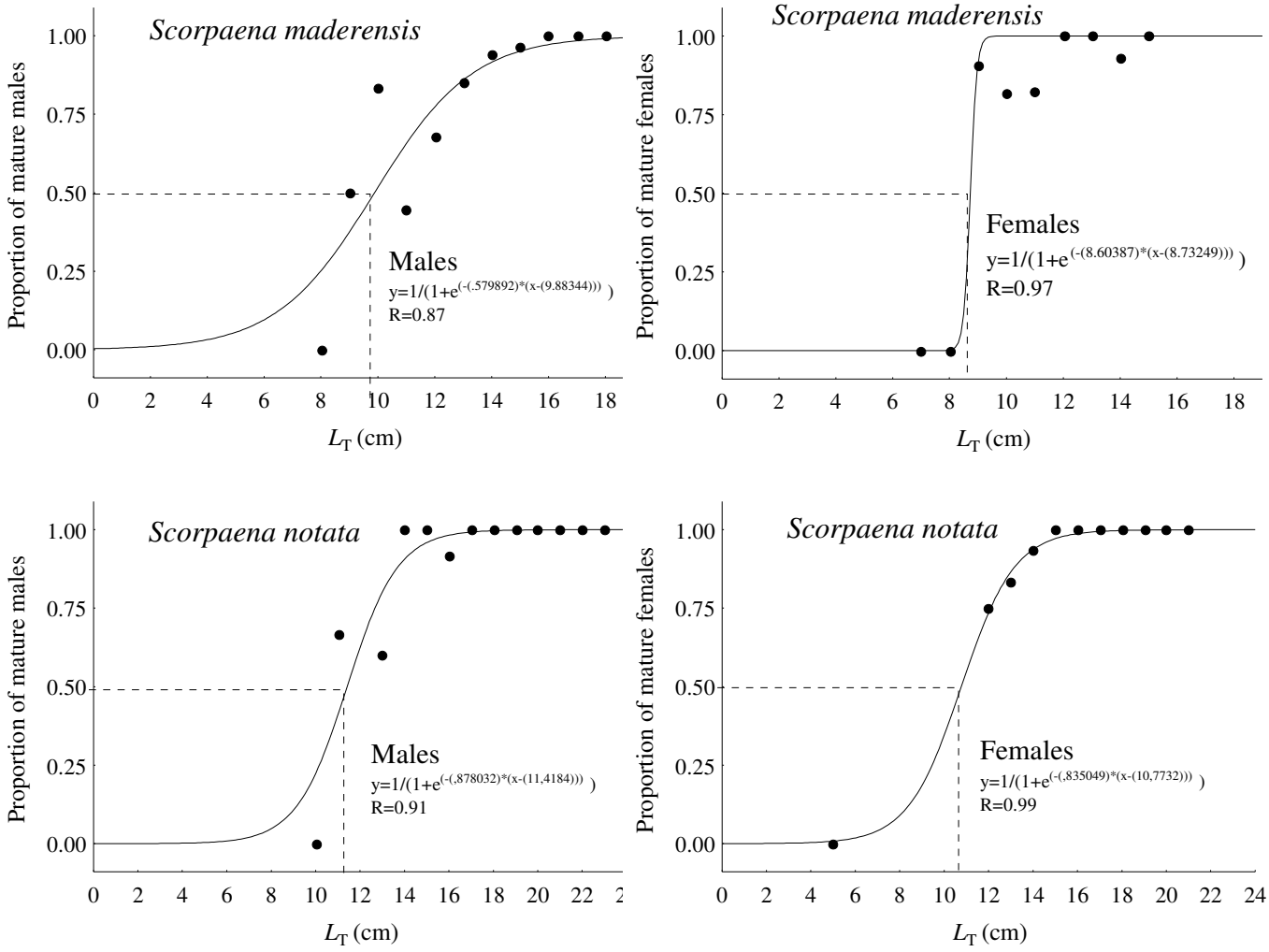

Fig.7. Maturity ogives of total length at first maturity for males and females of *Scorpaena maderensis* and *Scorpaena notata* for the period 1997-99.

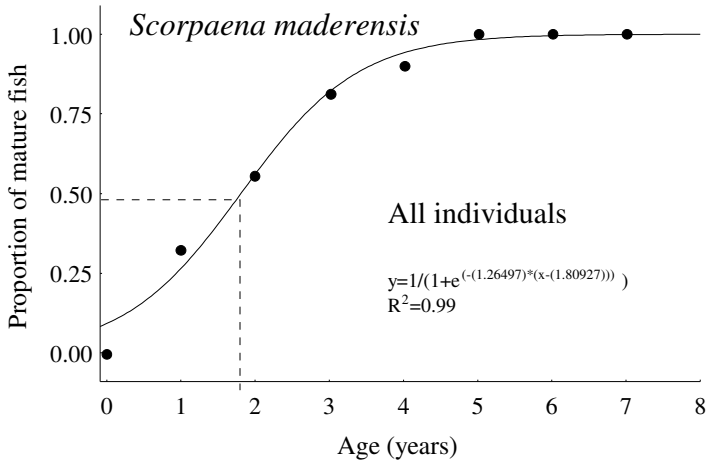

Fig.8. Maturity ogive of age at first maturity for both sexes pooled of *Scorpaena maderensis* for the period 1997-99.

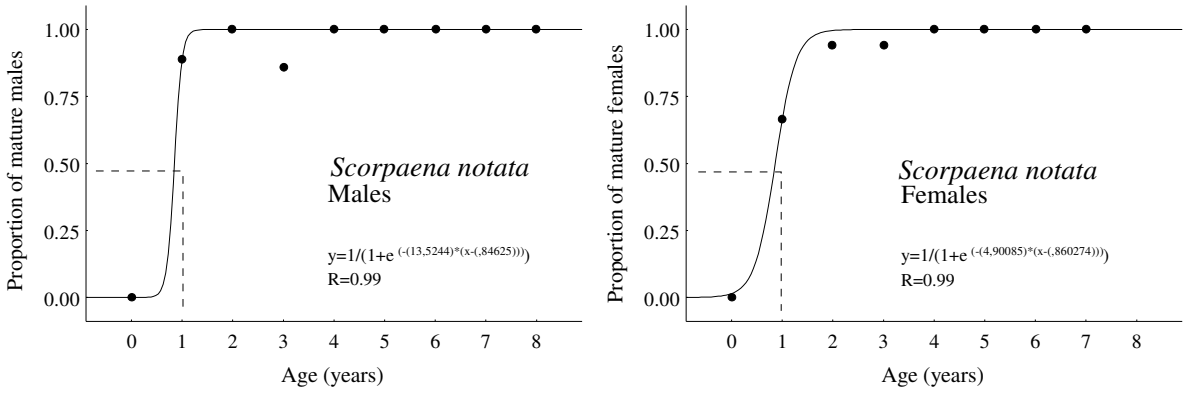

Fig.9. Maturity ogives of age at first maturity for males and females of *Scorpaena notata* for the period 1997-99.

Discussion

Sexual dimorphism is a fairly common feature among scorpionfish (Lenarz & Echeverria, 1991). Most differences between sexes in scorpionfish have been reported for fish size, reflecting different growth rates and longevity (Massuti et al., 2000; Mesa et al., 2005; Abellan et al., 2001; Kelly et al., 1999; Laidig, 2003), although they have also been found in other biological aspects such as morphometric measurements (La Mesa, 2005) maturation (Bradai & Bouain, 1991) and spawning period (Mendonça et al., 2006). The life-history traits of the two scorpionfish addressed in this study are characterized by distinct sexual dimorphism.

Significant differences in maximum size, growth rates and longevity were found for both species, with males living longer and attaining bigger sizes than females, although the females seem to grow faster and this way attain their maximum size earlier than males. In the Mediterranean, Mesa et al. (2005) also found higher growth rates in females of *S. maderensis* and that males attain bigger sizes. However, these authors estimated a maximum age of 4 years for males and 5 years for females, which are lower

than the 7 and 6 years found in this study for males and females, respectively, and the 9 years estimated by Santos (2000). These differences in longevity are probably due to different size ranges between Mediterranean and Atlantic populations, since Mesa et al. (2005) found a maximum L_T of about 13 cm, much smaller than the 17.8 cm L_T reported in the Azores (Morato et al. 2001). As for *S. notata*, sexual dimorphism in age and growth may not occur in the Mediterranean populations, unlike in the Azores, since Muñoz et al. (2005) found no differences in mean standard lengths between sexes.

Male dominance appears to be a characteristic of the Mediterranean populations of both species (Mesa et al., 2005; Muñoz et al., 2005), but in the Azores this is only true for *S. maderensis*, since *S. notata* showed a balanced 1:1 sex-ratio.

In the Azores, spawning of *S. maderensis* takes place between March and June, when water temperature increases, whereas based on preliminary data, Mesa et al. (2005) reported a winter spawning season, from December to February, in the Mediterranean. Further studies should be made to confirm these differences. The spawning season of *S. notata* takes place in August, which is coincident with the period recorded by Muñoz et al. (2005) for the Mediterranean, July to October, although its full extent could not be estimated in this study. For both species, the evolution of I_H and K along the year confirms the hypothesis, proposed by Shchepkin (1971) for *S. porcus* and Muñoz et al. (2005) for *S. notata*, that the liver plays a major role in storing and providing the necessary energy for maturation and spawning. For both species, sexual dimorphism in growth accounts for the differences found in the size at first maturation between sexes. Males start to mature at bigger sizes than females, which make them more vulnerable to fishing pressure.

The results of this study suggest that, even though published information on these two species is scarce, some differences between Atlantic and Mediterranean populations appear to exist. *S. maderensis* shows a bigger size range in the Azores than in the Mediterranean, but this is a common feature in many other fish species (Morato et al., 2001; Abecasis et al., 2006). The similar growth rates between the two populations indicate that different longevity may account for the different size ranges, which in this case may be due to different local ecological conditions, such as prey availability or community structure and composition. In the case of *S. notata*, it seems that mediterranean populations also show smaller size ranges than in the Azores, given that maximum reported size was 18.5 cm L_T for Croatian waters (Dulcic & Kraljevic, 1996) and 22.8 cm L_T in the Azores (Morato et al., 2001). However, in the Mediterranean there is no evidence of sexual dimorphism in growth rates (Muñoz et al., 2005), whereas in the Azores it is clear that males grow bigger than females. On the other hand, in the Mediterranean males are dominant while in the Azores the proportion between sexes is equal. Either way, an increase in the male biomass when compared to females is evident in both populations. Given the specialized mode of reproduction of this species, and knowing that spawning is multiple (Muñoz et al., 2005), one could speculate that male *S. notata* may be required to apply more energy in reproduction, perhaps in the production of the abundant and viscous seminal fluid that will be deposited onto the several egg masses that each female produces during one spawning season.

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Chapter 4

Final synthesis

4. Final synthesis

4.1. Life history strategies

Basic aspects of the biology of four coastal fish species in the Azores have been described in the present study. The two wrasse, *Coris julis* and *Labrus bergylta*, and the two scorpionfish *Scorpaena maderensis* and *Scorpaena notata*, are amongst the most common fish species in the coastal rocky shores of the Azores archipelago. In these islands they share a common biologic feature: males are bigger than females. The life-history strategies that allow them to express such a feature, however, are quite different. As for the two wrasse, males are bigger than females because they are protogynous hermaphrodites, *i.e.*, they undergo sexual inversion from female to male at a certain point of their life cycle. In the case of the two scorpionfish, however, this feature is a result of their growth strategy, as males live longer and attain bigger sizes than females.

In both cases, males are required to invest more in reproduction than what is commonly found for teleosts species. The two wrasse are known to be highly territorial, with males actively defending their territory and their brood (Lejeune, 1987; Costello, 1991). Furthermore, they show a harematic mating system in which a few males monopolize reproduction (Lejeune, 1987; Costello, 1991). This way, large male individuals show higher reproductive success than smaller ones, and therefore selection favours individuals that undergo protogynous sex inversion above a certain body size, as predicted by the size advantage hypothesis (Warner, 1988). As for the scorpionfish, it seems that males show some unusual features in the gonadal morphology and spermatogenesis that allow them to produce an abundant and viscous seminal fluid.

When released onto the eggs that are kept together within a gelatinous matrix produced by the female, the male special seminal fluid keeps the sperms together so that fertilization is assured (Muñoz et al., 2002a; 2002b; 2005).

The protogynous reproductive strategy of both *C. julis* and *L. bergylta* results in highly unbalanced sex ratios, in which females greatly outnumber males. These species are thus quite vulnerable to fishing pressures, especially *L. bergylta* which is known to be a sport fishing target (Costello, 1991; Treasurer, 1994; Figueiredo *et al*., 2005), because the removal of few large male individuals may cause a great reduction in the reproductive potential. Since these species are well known for their territorial behaviour (Lejeune, 1987; Costello, 1991), the recently established marine reserves in the Azores will play a key role in preserving a standing male biomass to assure the reproduction of these species (Huntsman & Schaaf, 1994).

4.2. Comparison between life history traits of Azorean, NE Atlantic and Mediterranean populations

The life-history traits described in the present study for the Azorean populations of these four coastal fish species were compared with those of populations from the Mediterranean and the NE Atlantic. Regarding *C. julis*, although Aurelle *et al*. (2003) suggested the existence of genetic differentiation between Atlantic and Mediterranean populations, the reproductive and growth strategies of these two populations were not clearly different. In fact, for this species, basic biological aspects were different in every location where they have been studied, suggesting that they are more related with the ecological conditions of each location, such as territory availability or predation, than

with environmental differences between insular and continental conditions. The Azorean and NE Atlantic populations of *L. bergylta* share most of their reproductive and growth features. Reproduction of *L. bergylta* appear to be highly influenced by the water temperature pattern, with spawning occurring when the water temperature is around 16ºC both in the Azores and in higher latitudes of the NE Atlantic (Dipper *et al*., 1977; Hillden, 1984 *in* Costello, 1991; Costello, 1991), although these temperatures occur at different times of the year in each location.

Differences between life history traits of Azorean and Mediterranean populations of both scorpionfish *S. maderensis* and *S. notata* were found. In the Azores both species show greater size ranges than Mediterranean populations, and males live longer and attain larger sizes than females, whereas in the Mediterranean growth rates and size distributions of males and females are equal (Muñoz et al., 2005). Genetic studies on Atlantic and Mediterranean populations of these two scorpionfish could show if there is a genetic basis for these differences and how the dispersal of these species was accomplished, especially in the case of the scattered geographic distribution of *S. maderensis*.

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