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Life-history traits of the southern hemisphere eastern red scorpionfish, *Scorpaena cardinalis* (Scorpaenidae: Scorpaeninae)

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Abstract. Fishes of the family Scorpaenidae (scorpionfish/rockfish) are important to benthic rocky-reef communities and fisheries globally. The present study is the first to provide biological information for any species of the genus *Scorpaena* (*Scorpaena cardinalis*) in southern hemisphere waters, namely south-eastern Australia. Growth of *S. cardinalis* was estimated using size-at-age data from sectioned otoliths. Growth was slow, with fish attaining ~22 cm after 5 years and 26 cm after 10 years. The oldest fish sampled was estimated to be 33 years old. In contrast to similar-sized congeneric species, males increased in length significantly faster and attained larger sizes than females. Variable recruitment patterns were evident from the age composition of the sampled population. Males of *S. cardinalis* had mean gonadosomatic index levels (0.09%) an order of magnitude smaller than did the females (2.8–4%) during the March spawning peak. *S. cardinalis* possesses a cystovarian Type II-3 ovary, a highly specialised form associated with external fertilisation and the production of eggs in a floating gelatinous mass. Traits such as slow growth, substantial longevity, variable recruitment patterns and a highly specialised reproductive strategy may make this species vulnerable to over-exploitation as has occurred with other members of the family Scorpaenidae elsewhere.

Additional keywords: growth, histology, reproductive mode, Scorpaena.

Introduction

The genus *Scorpaena* (family Scorpaenidae: subfamily Scorpaeninae) is distributed throughout tropical and temperate seas of the world (Kuiter 1993; Gomon *et al*. 1994). Commonly referred to as scorpionfish, the genus is characterised by venomous glands associated with the dorsal, anal and pelvic spines. The genus is important to the ecology of rocky-reef communities (Russell 1983; La Mesa *et al*. 2005) and some species are targets of recreational and commercial fisheries. There are currently 62 valid species within the genus *Scorpaena* (Froese and Pauly 2009), yet relatively few species have been studied in terms of their basic biology. Furthermore, despite their global distribution, published studies on the biology of this large genus have been limited to northern hemisphere species. Those species that have been studied tend to be those that grow large and are important components of fisheries (e.g. *S. maderensis* (La Mesa *et al*. 2005), *S. guttata* (Love *et al*. 1987), *S. scrofa* (Ordines *et al*. 2005), *S. notata* (Whitehead *et al*. 1986), *S. porcus* (Bilgin and Çelik 2009), *S. elongata* (Ragonese *et al*. 2003)).

Scorpaenids exhibit variable longevity, with some species being relatively long-lived (up to 30 years; Ragonese *et al*. 2003), whereas others attain only 4–5 years of age (La Mesa *et al*. 2005). Information on age and growth within the genus *Scorpaena* is limited; however, La Mesa *et al*. (2005) reported a linear relationship between the maximum length and longevity for five species of the genus *Scorpaena* in the Mediterranean, with the largest species possessing the greatest longevities.

Reproduction within the Scorpaenidae is of particular interest because species within this family exhibit a range of reproductive modes (Koya and Muñoz 2007). Most genera within the Scorpaenidae are oviparous (spawning eggs); however, some are viviparous (giving birth to live young) and others intermediate between these two basic forms. Viviparity in scorpaenids is thought to have evolved from oviparity (Munoz *et al*. 2002). The intermediate reproductive mode, termed ovoviviparity, includes internal fertilisation and the spawning of fertilised eggs or embryos. Reproduction within the genus *Scorpaena* has previously been described as highly specialised, with the oviparous species examined (*S. porcus*, *S. guttata*, *S. miostoma* and *S. notata*) producing floating gelatinous egg masses (Koya and Muñoz 2007). This reproductive mode is thought to represent a shift from a primitive to specialised mode of oviparity (Wourms and Lombardi 1992) and has been used to infer evolution within the larger family Scorpaenidae (Koya and Muñoz 2007).

Scorpaena cardinalis, colloquially known as the eastern red scorpionfish, is one of 12 species of the genus *Scorpaena* recorded in Australian marine waters. *S. cardinalis* is distributed along the eastern coast of Australia, from southern Queensland (Noosa Heads ≈26°S) to eastern Victoria (≈39°S) and also

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occurs in New Zealand waters (Hutchins and Swainston 1986; Kuiter 1993). The species occupies various habitats from shallow estuaries to deep offshore reefs and is common on the rocky coastal reefs of New South Wales (NSW). The fishes of this species are a minor component of the catches of commercial line fishers and are well represented in the catches of offshore recreational fishers (Steffe *et al*. 1996). As with most scorpionfishes, *S. cardinalis* has a prominent head with spiny ridges, a large mouth and venomous fin spines. The species has cryptic and highly variable colouration, ranging from dull grey–brown to bright red. It is an ambush predator that feeds on small fish and crustaceans, which it swallows whole (Russell 1983).

There has been no biological information collected for *S. cardinalis* or any other member of the genus *Scorpaena* from southern hemisphere waters. To address this knowledge gap, we tested hypotheses regarding the life-history and biology of *S. cardinalis*. Hypotheses examined included whether the longevity, growth and reproductive mode of *S. cardinalis* were similar to those reported for members of the genus *Scorpaena* from the northern hemisphere waters.

Materials and methods

Commercial catch sampling

Samples of *S. cardinalis* were obtained from commercial catches between December 2004 and December 2005. These fish were sampled throughout the region between the ports of Yamba (~29°S) and Narooma (~36°S) on the NSW coast. The protocol was to sample at least 20 fish individuals each month for biological assessment and to measure all other fishes in those catches to the nearest centimetre below the true length. Additional individuals smaller than those generally retained by commercial fishers were obtained on an *ad hoc* basis from recreational fishers. For biological assessment, the total length (TL) of each fish was measured to the nearest millimetre, and each fish was weighed to the nearest 0.1 g.

Age estimation and growth modelling

Estimates of age were made by examining sections of sagittal otoliths. The pair of sagittal otoliths was removed from each fish and one otolith embedded in resin before being sectioned transversely through the core with a diamond saw (Shell-Lap Supplies, Mile End, SA, Australia). The resulting sections, ~350 μm thick, were mounted on glass microscope slides and covered with glass coverslips. Sections were viewed with a compound microscope using reflected light against a black background. Opaque zones visible in the otolith sections were counted, and measurements were made from the core to each opaque zone and to the edge of the otolith. To limit the potential of counting false (not annual) checks, only opaque zones that were present on both sides of the sulcus were counted. All measurements were made along the dorsal edge of the sulcus by using a microscope-mounted video camera, interfaced with a computer running image-analysis software (Image Pro Plus, Media Cybernetics Inc., Bethesda, MD, USA).

Marginal increment (MI) analyses were used to examine the periodicity of opaque-zone formation. The MI was defined as the distance from the most recently completed opaque zone to the otolith edge as a proportion of the last completed increment. Plots of the monthly mean MI values were used to demonstrate a pattern that was consistent with annual periodicity of opaque-zone formation (i.e. only one increase and decrease in mean MI during a 12-month period). All otoliths were re-read to estimate the precision of opaque-zone counts. The coefficient of variation (CV) for the two readings for each otolith was calculated and averaged across all otoliths aged (Kimura and Lyons 1991; Campana 2001). Growth was described by fitting the von Bertalanffy growth function (VBGF) to the size-at-age data. To overcome the lack of young (<2 years old) fish in commercial catches and to provide more biologically meaningful growth curves, the size-at-age zero was constrained to pass through a TL of 2.3 mm (the size-at-hatching of the related *S. porcus* – Jug-Dujakovic *et al*. 1995). We tested the null hypothesis of no differences in growth between the sexes by comparing the growth curves, fitted across equal size and age ranges, by using the analysis of residual sums of squares (ARSS) method (Chen *et al*. 1992).

The age structure of *S. cardinalis* in the commercial fishery was estimated by applying an age-length key (by using only those fish that were sampled from the fishery) to the length–frequency data from the commercial catch.

Reproduction

Fish were assessed as being either female or male, the gonads removed and weighed to the nearest 0.01 g, and a gonadosomatic index (GSI) was calculated (gonad weight as a percentage of the whole bodyweight). Monthly mean GSI values were used to identify the period of peak reproductive activity. A further three *S. cardinalis* individuals were sampled during March 2009 for histological assessment of their ovarian structure. The gonads were fixed in a 10% formalin–acetic acid–calcium chloride (FAACC) solution for at least 1 week, before being transferred to 70% alcohol for storage. Histological sections were prepared by using the process detailed in Hughes *et al*. (2008) and were stained with Mayer's haematoxylin and eosin. The sections were examined with a compound microscope using reflected light and the structures were described according to the terminology used in McMillan (2007).

Results

Commercial-catch sampling

The lengths of *S. cardinalis* individuals in commercial landings ranged between 14 and 41 cm in TL (Fig. 1). The majority (~67% of landings) of fish individuals were between 19 and 26 cm in TL and the most abundant length classes were between 20 and 22 cm in TL (~35% of landings).

Age estimation and growth modelling

Otoliths were examined from 275 *S. cardinalis* individuals. Of these, 162 were caught by bottom-set line methods and 113 were caught with demersal fish traps. Sectioned *S. cardinalis* otoliths were relatively easy to interpret, with opaque and translucent zones being easily discernable and counted (see Accessory Publication to this paper, available on the web). The core was a largely opaque region, followed by a translucent region and then

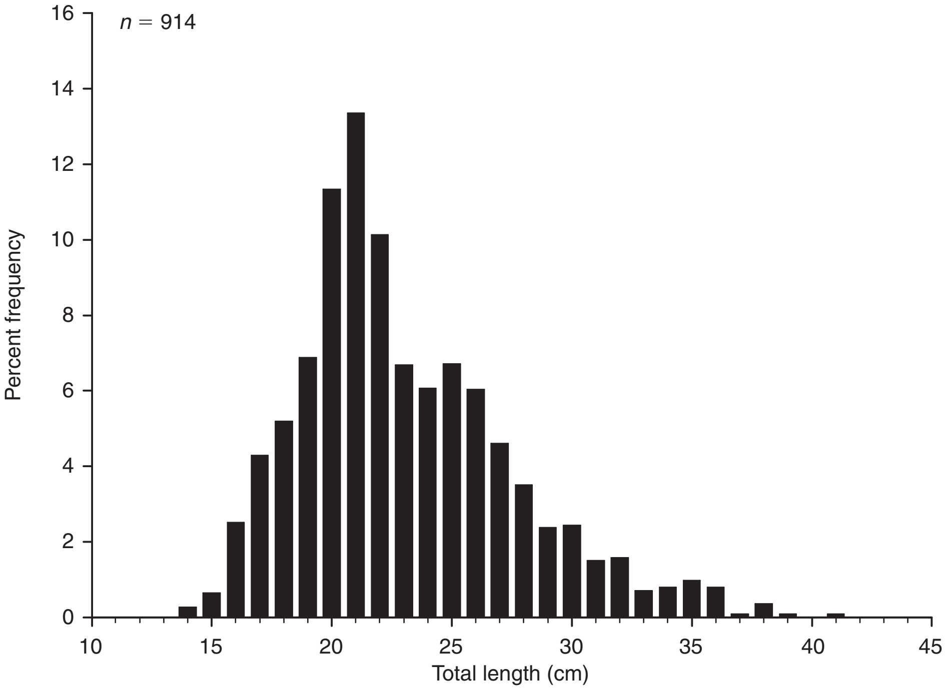


Fig. 1. The length–frequency distribution of *Scorpaena cardinalis* landed by the New South Wales commercial fishery during 2005/06.

a very distinct opaque zone, which was scored as the first annulus (see Accessory Publication). Subsequent opaque zones became progressively finer and closer together, the further out from the core they occurred. The maximum number of opaque zones counted was 33 and the CV averaged across all ages was 0.066.

The MIs for *S. cardinalis* showed considerable variation each month (Fig. 2), although with a seasonal pattern of the highest values occurring in summer (December to January) and the lowest values in autumn (March to April). This pattern was consistent with the annual periodicity of opaque-zone formation and it was therefore concluded that the number of opaque zones counted in otolith sections could be used to estimate the age in this species.

The growth of males and females was significantly different (ARSS $F_{3,255} = 8.86$, $P < 0.001$) in *S. cardinalis* and separate growth curves were fitted to size-at-age data for each sex. A general growth curve for *S. cardinalis* was also fitted by combining the data from both sexes and including the size-at-age data from 10 fish individuals that had gonads too small to determine their sex from. Males grew faster in terms of absolute length, lived longer and attained larger sizes than did females (Fig. 3). Overall, *S. cardinalis* grew slowly, attaining on average ~22 cm after 5 years and 26 cm after 10 years. The oldest fish collected (33 years) was a male that measured 33.5 cm in TL. The oldest female fish was estimated to be 23 years old and measured 21.8 cm in TL. The two largest fishes collected were males (40.5 and 39.9 cm in TL) and both were estimated to be 23 years old. The two largest females collected were 34.5 and 34.4 cm in TL and were estimated to be 7 and 16 years old, respectively.

The length–weight relationship for *S. cardinalis* was described by the following function:

$$\text{Weight (g)} = 0.0111 \times \text{TL (cm)}^{3.206} \ (R^2 = 0.98).$$

The age composition of *S. cardinalis* in commercial landings was characterised by many age classes, with >40% being greater than 10 years old (Fig. 4). The age composition provided evidence of variable year-class strength, with the relative abundance of age classes not declining in a constant manner.

Reproduction

Elevated female GSIs were observed from December to April; however, the major peak occurred in March (Fig. 5). The mean female GSI (±s.e.) during March 2005 was 2.8 ± 0.9 and during March 2009 was 4.0 ± 1.4. During the peak spawning period (i.e. March), the mean GSI value for female *S. cardinalis* was approximately nine times that during their non-spawning period. The mean GSI values for males were an order of magnitude smaller than those for females, and during the spawning season, they were 1/40 of the weight of the female values (Fig. 5). Male *S. cardinalis* exhibited a monthly pattern of mean GSI values similar to that in females, with higher values during the austral summer/autumn and low values during late winter/spring.

Histological sections of the ovaries of *S. cardinalis* revealed them to be of the cystovarian Type II-3 (Takano 1989; McMillan 2007). This ovarian type is characterised by paired lobes that are fused at the caudal end. Each ovary contains an artery and veins that run through the spongy, vascular ovigerous stroma at its centre (Fig. 6*a*, *b*). Oocytes are produced from the epithelium

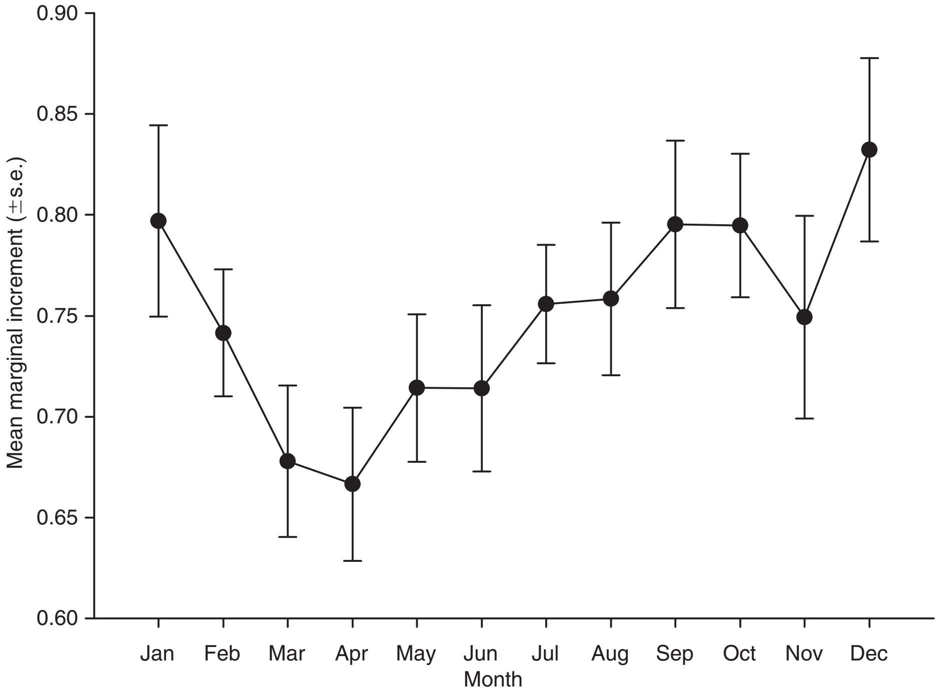
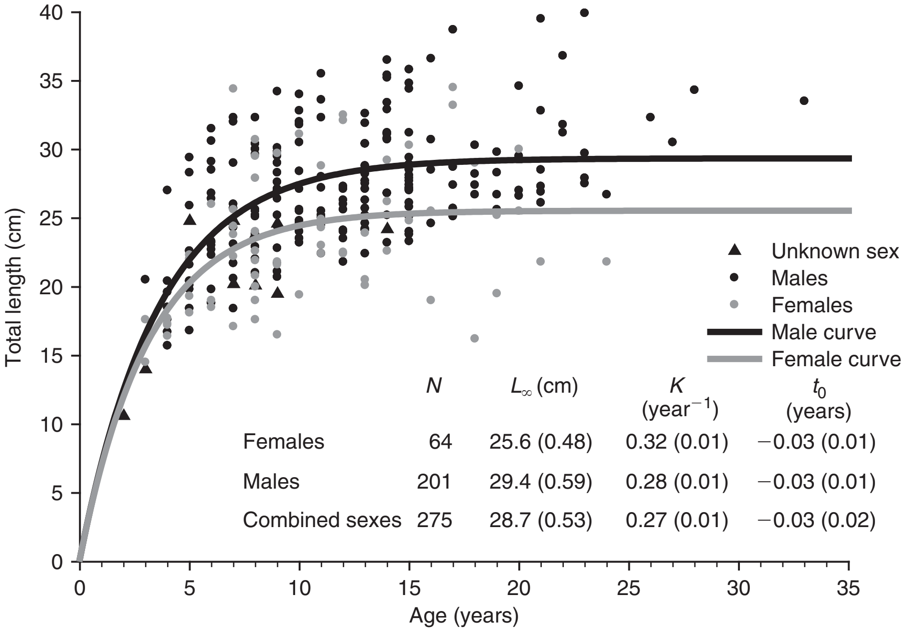


Fig. 2. Mean (±s.e.) marginal increment values for *Scorpaena cardinalis* ($n = 275$).



	N	L_∞ (cm)	K (year^{-1})	t_0 (years)
Females	64	25.6 (0.48)	0.32 (0.01)	−0.03 (0.01)
Males	201	29.4 (0.59)	0.28 (0.01)	−0.03 (0.01)
Combined sexes	275	28.7 (0.53)	0.27 (0.01)	−0.03 (0.02)

Fig. 3. Size-at-age data, with fitted von Bertalanffy growth curves for male and female *Scorpaena cardinalis* ($n = 275$). Note the size at hatching has been constrained at 2.3 mm TL.

surrounding the ovigerous stroma and are attached via vascularised peduncles that radiate from the stroma (Fig. 6*b*). These peduncles facilitate secondary oocyte development and increase in length as vitellogenesis proceeds. The ovarian lumen lies between the ovarian wall and the central stroma (Fig. 6*a*). The ovarian walls consist of the following three layers: an outer mesothelium, a layer of smooth muscle and blood vessels, and an inner layer of simple columnar epithelium (Fig. 6*c*). During the spawning season, these epithelial cells secrete a gelatinous material that fills the lumen. At ovulation, oocytes embed in this gelatinous material that stains lightly with haematoxylin (Fig. 6*d*).

Discussion

Age and growth

Sectioned otoliths of *S. cardinalis* were simple to interpret with the alternating opaque and translucent zones easily counted when viewed using reflected light. The degree of precision re-reading the otoliths (average CV = 0.066) was well within the range reported for many other species (Campana 2001) and was considered acceptable, given that 50% of fish individuals were estimated to be between 10 and 33 years old. The pattern in MI analyses was consistent with annual periodicity of opaque-zone formation. One opaque zone was formed in the otoliths of *S. cardinalis* each year during the austral spring/summer and was generally judged as being completed by autumn (March/April). This seasonal pattern of otolith opaque-zone deposition is consistent with that reported for numerous other reef-associated species in south-eastern Australia (Stewart and Hughes 2009).

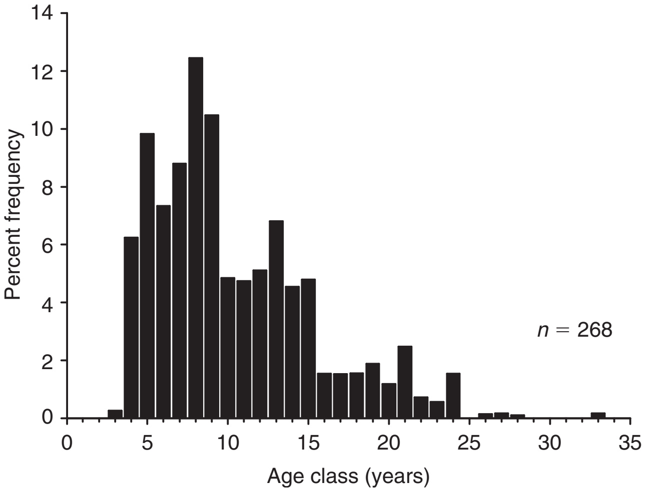


Fig. 4. Age composition of *Scorpaena cardinalis* in commercial landings during 2005/06.

Longevity of *S. cardinalis* was found to exceed that reported for other species within the genus *Scorpaena*. A maximum age of 33 years and a maximum TL of 40.5 cm were observed during the study. However, given that *S. cardinalis* reportedly attains a TL of 45 cm (Hutchins and Swainston 1986) and that the present ageing study was conducted during a relatively short period (12 months), we consider it probable that *S. cardinalis* can attain substantially greater ages than presented here. Nevertheless, growth in *S. cardinalis* is slow, with considerable individual variation in size-at-age. Similar slow growth and comparable longevity have also been reported for the northern hemisphere scorpaenids, i.e. *S. guttata* (a maximum TL of 43 cm and age of 21 years; Love *et al*. 1987), *S. elongata* (a maximum TL of 50 cm and age of 30 years; Ragonese *et al*. 2003) and *S. porcus* (a maximum TL of 37 cm and age of 18 years; Bilgin and Çelic 2009).

La Mesa *et al*. (2005) reported a linear relationship between the maximum length and longevity for five species of the genus *Scorpaena* from the Mediterranean. Our estimates of maximum size and age for *S. cardinalis* do not fit the linear relationship well, individuals being considerably older at the maximum length than the age predicted by the linear relationship. Reasons for this discrepancy may relate to the different environmental conditions or exploitation levels experienced by *S. cardinalis* in the southern hemisphere. Alternatively, the inconsistency in methodology for estimating age within the genus *Scorpaena* may have been problematic given the bias that

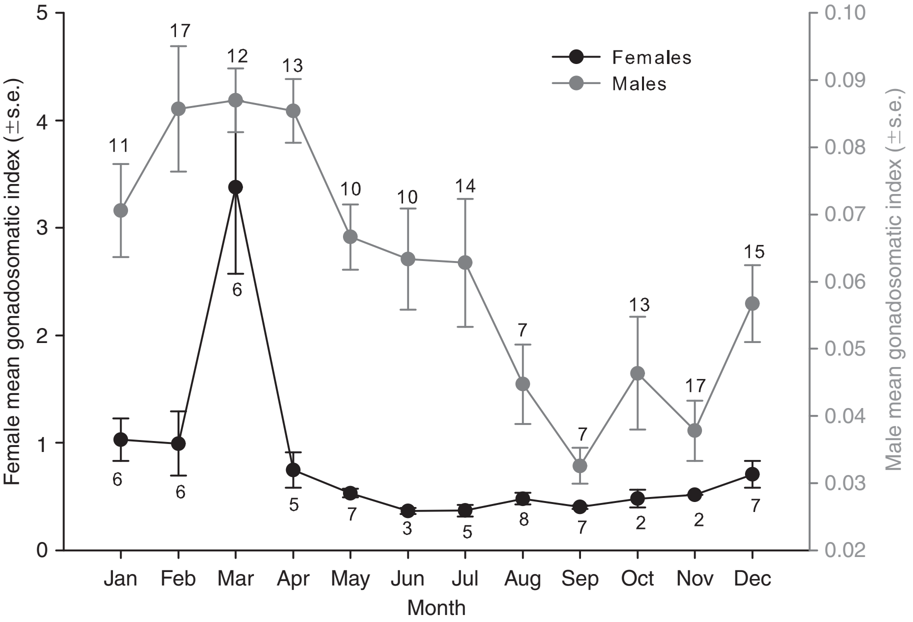


Fig. 5. Gonadosomatic indices (mean GSI ± s.e.) for male and female *Scorpaena cardinalis*. Note the different *y*-axis scales. The numbers represent sample sizes.

may be associated with under-estimation of age when making counts of opaque zones in whole otoliths (Beamish and McFarlane 1983, 1987). The age estimates summarised in La Mesa *et al*. (2005) for the species reported to have the shortest longevities (*S. maderensis* and *S. porcus*) were derived from counts of opaque zones in whole otoliths. The maximum age of 21 years for *S. guttata* was derived from sectioned anal pterygiophores (Love *et al*. 1987), and the maximum age of 30 years for *S. elongata* was derived from sectioned otoliths (Ragonese *et al*. 2003). The most dramatic examples of age under-estimation and resulting mismanagement have been reported for species within the family Scorpaenidae, specifically the genus *Sebastes* (Beamish and McFarlane 1987). Given this past history of problems in ageing of the members of the family Scorpaenidae, it is strongly recommended that future studies involving the estimation of age within the genus *Scorpaena* do so by using a consistent, validated method. The use of sectioned otoliths is the method most likely to produce the most accurate and precise age estimates (Campana 2001).

Previous authors have demonstrated substantial differences in growth between the sexes within the genus *Scorpaena*. The finding that males of *S. cardinalis* grow significantly faster in terms of length and attain greater sizes than do females is in contrast to the results for other similar-sized species within the genus. It is reported by Bilgin and Çelik (2009) and Love *et al*. (1987) that females grow larger, more quickly and have longer life spans than do males for *S. porcus* and *S. guttata*, respectively. In contrast, La Mesa *et al*. (2005) reported that females of the much smaller species *S. maderensis* attain smaller maximum sizes than do males. Despite this information, the biological advantages associated with either sex growing faster, living longer and attaining significantly greater sizes than the other within the genus *Scorpaena* has, up to this point, rarely been discussed.

Reproduction

We suggest that one potential advantage of males of *S. cardinalis* attaining larger sizes than females may be related to their reproductive strategy, whereby larger males are more likely to successfully compete for females. In *S. porcus* and *S. guttata*, where females grow larger than males, both sexes have similar GSI values (Bilgin and Çelik 2009; Love *et al*. 1987). *S. guttata* is known to form large spawning aggregations offshore (Love *et al*. 1987) where it may be advantageous to produce large quantities of sperm. In contrast, the mean GSI value for male *S. cardinalis* during the spawning season in the present study was 1/40 of the weight of the female values. A similar disparity

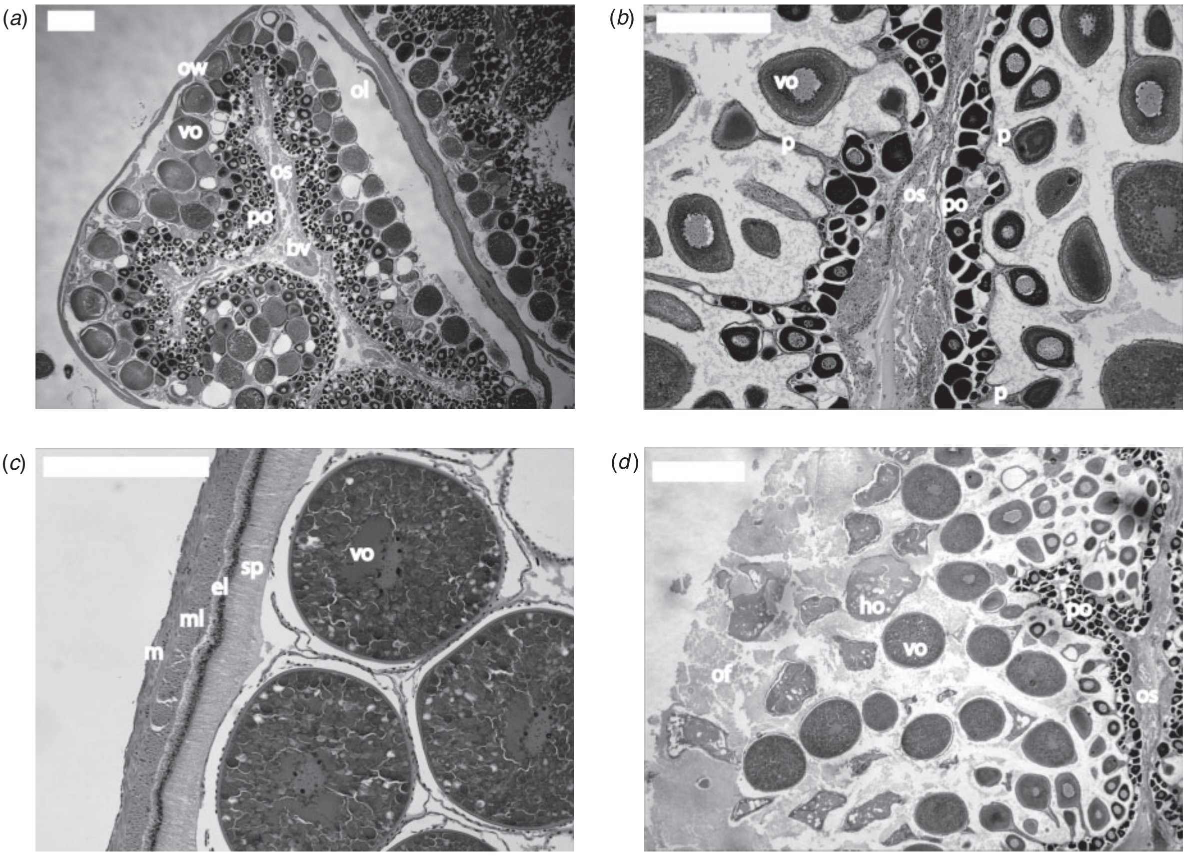


Fig. 6. The ovarian structure of *Scorpaena cardinalis*. (*a*) A cross-section of developing ovary; scale bar = 0.5 mm. (*b*) Inner ovarian structure; scale bar = 0.25 mm. (*c*) Structure of ovarian wall; scale bar = 0.25 mm. (*d*) Ripe ovary; scale bar = 0.25 mm. ow, ovarian wall; vo, vitellogenic oocyte; po, previtellogenic oocyte; os, ovarian stroma; bv, blood vessel; ol, ovarian lumen; p, peduncle; m, mesothelium; ml, muscle layer; el, epithelial layer; sp, secretory processes; ho, hydrated oocyte; of, ovarian fluid.

in GSI values between the sexes has been reported for *S. notata* (Muñoz *et al*. 2005; Ordines *et al*. 2009), where males attained greater sizes and ages than did females in the Mediterranean (Ordines *et al*. 2009). The disparity in the ripe gonad size between the sexes suggests that the males of *S. cardinalis* use their sperm more efficiently than do those of the congeneric species *S. porcus* and *S. guttata*, and so do not require the same level of sperm production. There is no evidence that *S. cardinalis* forms spawning aggregations as does *S. guttata*. Although it is clear that the reproductive ecology of *S. cardinalis* requires considerable further research, the evidence presented here suggests that males partition greater resources to somatic growth than to sperm production. A larger body size may be advantageous in competing for females (Ng *et al*. 2003) and so conducive to pair spawning when large amounts of sperm are not required. In highly efficient pair-spawning teleosts, males typically have small gonads compared with those of females (Sadovy 1996).

Reproduction within the genus *Scorpaena* is characterised by external fertilisation and production of eggs that are embedded in a gelatinous matrix (Wourms and Lombardi 1992; Koya and Muñoz 2007; McMillan 2007). Findings from the present study suggest that *S. cardinalis* has a similar reproductive strategy. The morphology of the highly specialised cystovarian Type II-3 ovary in *S. cardinalis* is consistent with that described for other species within the genus that produce gelatinous egg masses (Munoz *et al*. 2002; Koya and Muñoz 2007). The function of the vascularised peduncles that radiate from the central stroma and are attached to each oocyte is to facilitate ovulation of mature oocytes into the surrounding lumen (Munoz *et al*. 2002). The epithelium of each ovary wall secretes a gelatinous mass into the lumen around the mature oocytes, resulting in hollow, bilobed egg masses being produced. This gelatinous mass provides protection and floatation for oocytes (Koya and Muñoz 2007; McMillan 2007).

Scorpaena cardinalis spawns in the austral summer/autumn, with elevated GSI levels between December and April. Interestingly, very high GSI levels in females were observed only during March. It is not known whether this pattern is an artefact of our sampling protocol or whether it reflects a short period when spawning actually occurs. Published monthly GSI values in other *Scorpaena* congenerics (*S. notata*, *S. guttata* and *S. porcus*) indicate spawning periods of approximately 4 months during which mean GSI values range between ~3 and 5% (Love *et al*. 1987; Muñoz *et al*. 2005; Bilgin and Çelik 2009). The peak mean GSI values for female *S. cardinalis* of 2.8% during March 2005 and 4.0% during March 2009 were similar to those reported for other spawning female *Scorpaena* congenerics; however, the relatively low mean GSI values ($\leq$1%) that occurred for all other months do suggest that spawning may be restricted to a shorter period in *S. cardinalis*.

Implications for fisheries

Several aspects of the biology of *S. cardinalis* suggest, like for many other species in the family Scorpaenidae, that the species may be vulnerable to overexploitation. Growth is slow, the individuals have considerable longevity, commercial landings are dominated by fishes >10 years old and the age composition in landings strongly suggests variable recruitment patterns. *S. cardinalis* is presently largely a by-catch of commercial and recreational line fishing; however, as catches of traditionally more highly favoured species decline (Scandol *et al*. 2008), there exists the risk of increased targeting of *S. cardinalis* by fishers.

The species of Scorpaenidae have a long history of depletion through line-fishing methods (Mason 1998), with population resilience declining through the removal of larger and older fish (Leaman and Beamish 1984). It is recommended that landings of *S. cardinalis* be monitored (quantities, sizes and ages) closely for indicators of declines in abundance and age. Management to ameliorate declines of scorpaenids has proven difficult. Evidence from the Mediterranean suggests that refuges from fishing may allow protected spawning populations to supply sufficient recruitment to avoid stock collapse in areas of very heavy fishing pressure (Ribas *et al*. 2006; Gancitano and Ragonese 2008). Such refuges from fishing may include areas that are too rough to trawl (as in the Mediterranean) or no-take marine protected areas. Given that *S. cardinalis* is mainly caught by line-fishing, which can be carried out over any bottom type, no-take areas may be the most effective management tool for sustaining the fisheries for this species.

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