Preliminary consideration of the biology of several of South Australia's marine fish species that have conservation or management interest

Report to the Department for Environment and Heritage

R.J. Saunders, S.R. Bryars[1] and A.J. Fowler

[1]Nature Conservation, Conservation Policy and Programs,
Department for Environment and Heritage

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1.0 EXECUTIVE SUMMARY

1. There are many marine fish species that inhabit South Australian waters for which there is no or limited understanding of the population biology. There are management issues for some such species that are taken as by-catch in various line and net-based fisheries. This study aimed to provide some preliminary biological information for nine such species and to assess their vulnerability to fishing based on their life history characteristics.

2. Specimens of nine species were collected across 13 months from South Australia's marine waters, with some also from Western Australia. Fish age was determined from transverse sections of otoliths. A vulnerability index was calculated using an Excel macro using the age-based parameters, maximum age, the von Bertalanffy growth parameter K, and maximum length.

3. The ageing work was highly successful for western blue devils and harlequin fish, which indicated that both species were surprisingly long-lived. They were both assigned relatively high vulnerability indices.

4. Some individuals from the congenerics, red snapper and swallowtail, were also successfully aged, although the otoliths from the latter species were more difficult to age. Both species were relatively long-lived. The red snapper was assigned the highest vulnerability due to its high estimated longevity.

5. For the bluethroat wrasse, sea sweep and blue morwong the sample sizes were limiting. Nevertheless, the study demonstrated the tractability of ageing these species from their otoliths. The assigned vulnerability indices were similar to each other, and lower than for several of the other species.

6. For the red mullet and silver trevally the sample sizes were extremely low, whilst there was minimal success at ageing any specimens. No vulnerability index could be calculated for red mullet.

7. The vulnerability indices of the eight species were all relatively high, as a consequence of their high maximum ages, relatively slow growth rates and for some species their large maximum sizes. They represent a useful first measure for future management discussions.

2.0 INTRODUCTION

There are over 600 species of marine fishes recorded from southern Australia, many of which are endemic to this region (Gomon *et al.* 2008). Most of these species have little commercial value although some are targeted on a small scale (Knight *et al.* 2005), whilst many are captured incidentally as by-catch (Fowler *et al.* 2009; Currie *et al.* 2009). Most research effort for finfish species in South Australia has focussed on the larger, commercially-valuable species such as snapper (*Chrysophrys auratus*) and King George whiting (*Sillaginodes punctatus*). Unfortunately, there have been few resources available to study the biology or the impacts of fishing, environmental change or habitat destruction for the majority of the other species. This has culminated in there being only a very poor understanding of the basic biology and life history of most finfish species from the marine coastal waters of South Australia. Such paucity of biological information makes it difficult for informed and effective management or conservation planning for such species.

It is well known that different species of fish vary in their vulnerability to exploitation depending on their life history characteristics. For example, many shark species that are over-fished are long-lived, slow-growing, late maturing and low in fecundity. Recognising this, Cheung *et al.* (2005) developed a fuzzy logic model for calculating an index of intrinsic vulnerability to fishing for marine fishes that would be useful for fishery management and marine conservation planning. The index is based on key life history parameters and ecological characteristics of the different species. The model was validated against empirical datasets and later used to assess the intrinsic vulnerability of many of the species that contribute to the global fish catch (Cheung *et al.* 2007). A relatively high intrinsic vulnerability index would indicate the susceptibility of a species to over-exploitation. The index can range from 1 to 100, but in practise the lowest and highest values recorded by Cheung *et al.* (2007) were 10 and 90, respectively, whilst the average value across all fished species was 47.

This study considered a number of fish species that inhabit the coastal marine waters of South Australia for which concerns about conservation and/or management have been expressed (Table 1.1). The objectives with respect to these species were: to assess the tractability of ageing fish from their otoliths and to provide some age-based information for the different species; and to use the age-based data, as well as other information from the literature, to assess the vulnerability of these species to fishing using the intrinsic vulnerability index. Each of the nine fish species considered are either targeted occasionally or are taken as by-catch by commercial and/or recreational fishers in South Australia (Table 1.1). As yet, for several of these species, there are no restrictions on the numbers or size of fish that can be taken. Two species, i.e. the western blue devil (*Paraplesiops meleagris*) and the harlequin fish (*Othos dentex*) are of particular interest here because of concerns expressed by various community groups and conservation organisations. For eight of the nine species the intrinsic vulnerability index of Cheung *et al.* (2005) was successfully calculated. The biological data derived and the vulnerability indices provide a useful first step toward the sustainable management of these species.

Table 1.1. Summary of the taxonomic information for the species considered in this study. Also presented is the habitat type commonly inhabited as well as the recreational size, bag and boat limits. R = reef; P = pelagic, S = seagrass. * Note that bag and boat limits are combined across all *Centroberyx* spp.

Family	Species name	Common name	Habitat	Size limit (TL) cm	Bag (Boat) limit
Berycidae	*Centroberyx gerrardi*	Red snapper	R	30	10(30)*
Berycidae	*Centroberyx lineatus*	Swallowtail	R,P	30	10(30)*
Cheilodactylidae	*Nemadactylus valenciennesi*	Blue morwong	R	38	5(15)
Labridae	*Notolabrus tetricus*	Bluethroat wrasse	R	-	-
Serranidae	*Othos dentex*	Harlequin fish	R	-	-
Plesiopidae	*Paraplesiops meleagris*	Western blue devil	R	-	-
Carangidae	*Pseudocaranx georgianus*	Silver trevally	R, P	24	20(6)
Kyphosidae	*Scorpis aequipinnis*	Sea sweep	R	24	20(60)
Mullidae	*Upeneichthys vlamingii*	Red mullet	S,R	-	-

3.0 METHODS

3.1 Sample collection and processing

The fish considered in this study were obtained from three sources:

1. the SAFCOL fish market or at ports of landing;
2. recreational fishers and fishing clubs;
3. charter boat operators.

Most fish were collected from South Australian waters but some western blue devils and harlequin fish were collected from south-west Western Australia.

Samples were provided either as fish frames or whole fish. They were collected during the period of June 2008 to July 2009, although most were collected in March - April 2009. At the time of processing, fish were thawed, measured to the nearest mm for total length (TL) and standard length (SL) and, when possible, caudal fork length

(CFL). Whole fish were weighed to the nearest gram. A ventral incision was made in the body cavity. The gut was removed and notes on stomach contents were recorded. The gonads were examined and the sex was determined where possible. Gonads were weighed to the nearest 0.1 g and reproductive condition classified according to a 5-stage scale for females and a 3-stage scale for males (Table 3.1). Gonadosomatic indices also provide a measure of sexual development and were calculated using the equation:

$$GSI = \frac{G}{W} \times 100 ,$$

where GSI is the gonadosomatic index, G is the gonad mass (g) and W is the gonad-free fish mass (g).

The sagittae, i.e. the largest pair of otoliths for each species were removed, washed, dried and stored in small, snap-lock plastic bags for later processing.

Table 3.1. Summary of the descriptions of the different macroscopic stages that the fish gonads were assigned to during fish processing.

Sex	Stage	Condition	Description of gonads
Males	1	Immature	Testes were flattened, narrow, dark and thread-like
	2	Developing	Clearly visible and light in colour but opaque
	3	Active	Milt visible when cut
Females	1	Immature	Ovaries were rounded, narrow, translucent but very thin
	2	Developing	Larger, easily visible, pink in colour, translucent
	3	Developed	Oocytes visible
	4	Hydrated	Large, translucent (hydrated) oocytes visible
	5	Spent	Ovary flaccid and bloodshot

3.2 Determination and interpretation of fish ages

To determine fish age, a transverse section was prepared from one sagitta from each fish. The otolith was first embedded in resin and then cut to produce a thin section of ~300 µm in thickness, using a Gemmasta™ saw with a diamond impregnated blade. The section was then mounted on a glass slide with Selley's Superglue™.

Otolith interpretation and quality

The otolith sections were examined under transmitted light using low power microscopy (6 to 60x magnification). One experienced otolith reader (RJS) counted the number of opaque zones in all otolith sections on two occasions that were separated by at least 10 days. The clarity and interpretability of the incremental structure of the otoliths varied amongst individuals and between species. As such, each otolith section was assigned a readability index of 1 to 5, which related to the ease of interpretation and the level of confidence in the resulting count (Table 3.2).

Table 3.2. Definitions of the readability indices assigned to otoliths during the counting process.

Readability index	Description
1	No difficulty in interpreting otoliths structure as opaque zones were clear and interpretable
2	Some difficulty, particularly at edge OR first increment
3	Some difficulty, particularly at edge AND first increment
4	Considerable interpolation required throughout
5	Structure uninterpretable

An age in years was assigned to each fish after the second set of otolith counts. In the absence of data on time of spawning or timing of first increment formation, age in years was assumed to be a one to one relationship with the number of opaque zones.

Undertaking two independent readings of the same otoliths provided a measure of precision of otolith interpretation. The index of average percent error (IAPE) was used to quantify this variation and was calculated using the equation:

$$IAPE = \frac{100}{N}\sum_{j-1}^{N}\left[\frac{1}{R}\sum_{i-1}^{R}\frac{\left|x_{ij}-x_j\right|}{x_j}\right]$$

where *N* is the number of fish aged, *R* is the number of times fish are aged, x_{ij} is the *i*th determination for the *j*th fish , and x_j is the average estimated age of the *j*th fish (Beamish & Fournier 1981).

Age-bias plots were used to provide a visual representation of the variation in interpretation between the first and second readings. IAPE estimates and age-bias plots were presented to assess the precision between the first and second otolith counts.

Growth curves

Von Bertalanffy (VB) growth curves were fitted to length-at-age data using the non-linear least squares method. The VB growth equation is:

$$L_t = L_\infty \left(1 - e^{-k(t-t_0)}\right)$$

Where L_t is length at age t, L_∞ indicates the mean asymptotic length (mm), k represents the growth constant and t_0 is the theoretical age at length zero.

3.3 Vulnerability index

Intrinsic vulnerability indices were calculated using a Microsoft Excel macro program supplied by Dr William Cheung from The University of British Columbia (Cheung *et al.* 2005). For each species the calculation requires input of estimates for one or more life history and ecological parameters. Cheung *et al*. (2005, 2007) used the following parameters in their assessments of vulnerability: maximum length, age at first maturity, the von Bertalanffy growth parameter K, natural mortality rate, maximum age, geographic range, fecundity, and spatial behaviour strength. A minimum of one parameter entry is required to run the model. For this study, the parameters used were; maximum age, maximum length, and the von Bertalanffy growth parameter K. These were chosen because: (1) values for these three parameters were available from our work or the literature, and; (2) sensitivity analyses by us indicated that the program outcomes were highly sensitive to these three parameters. The model operates such that species with relatively high values for maximum age and/or maximum length, and/or a relatively low value for K will result in a higher overall vulnerability index. Where more suitable data were available from the literature, they were used rather than those from our results.

To test that the Excel program was functioning correctly, data for two of the three parameters, i.e. maximum age and maximum length, as derived from the literature, were entered for three species. The species were: the Australian herring (*Arripis georgianus*) a short-lived and small-sized species; the orange roughy (*Hoplostethus atlanticus*) a long-lived and small-sized species of fish; as well as the bronze whaler shark (*Carcharinus brachyurus*) a long-lived and large-sized species. The resulting vulnerability indices were then compared with the published values from Cheung *et al*. (2007) for the same three species. Both sets of results were reasonably close (maximum difference = 8) and related well to the life history parameters for each species (our results: Australian herring = 37, orange roughy = 66, bronze whaler = 85). Thus, we were confident that the computer program could be used for the nine species we were investigating. Some discrepancies between the results from Cheung *et al*. (2007) and our results were inevitable because the life history parameters and their values that were used by Cheung *et al*. (2007) were unknown to us. In the discussion section of our report, we have also compared the indices from our target species against seven other southern Australian species that were assessed by Cheung *et al*. (2007). Again, we are unsure of the parameters and values used by Cheung *et al*. (2007).

4.0 RESULTS

In total, 334 specimens were collected from across a wide size range for the nine species (Table 4.1).

Table 4.1. Species considered in this study, with number of fish sampled and size range of specimens considered.

Species name	Common name	n	Size range (mm)
Centroberyx gerrardi	Red snapper	107	204 to 499 CFL
Centroberyx lineatus	Swallowtail	59	116 to 277 CFL
Nemadactylus valenciennesi	Blue morwong	13	465 to 706 CFL
Notolabrus tetricus	Bluethroat wrasse	23	198 to 410 TL
Othos dentex	Harlequin fish	33	372 to 617 TL
Paraplesiops meleagris	Western blue devil	48	178 to 335 TL
Pseudocaranx georgianus	Silver trevally	28	263 to 475 CFL
Scorpis aequipinnis	Sea sweep	12	212 to 450 CFL
Upeneichthys vlamingii	Red mullet	11	179 to 219 CFL

The results for each species including notes from the literature are presented individually below.

4.1 Western blue devil, *Paraplesiops meleagris*

Preliminary observations

The western blue devil is distributed along the southern Australian coastline from Exmouth (WA) to Port Philip Bay (Vic). It grows to a maximum length of 360 mm TL (Hutchins and Swainston 2002). It is a strongly site-associated, cave-dwelling, carnivorous species that occurs on coastal reefs to depths of approximately 45 metres. Breeding pairs guard small batches of eggs on rock surfaces (Kuiter pers. comm. cited in Gomon *et al.* (2008)), which is in keeping with the biology of other members of the Plesiopidae (Heemstra and Randall 1999). There is currently no published data on age and growth for this species.

Most specimens were provided from the by-catch of charter fishers or commercial marine scale fishers who were long-lining or hand-lining in Backstairs Passage, South Australia. Some were accessed from the recreational sector of Western Australia. Many specimens had clearly suffered from barotrauma as their everted stomachs were protruding from their mouths. Retained stomach contents consisted of decapod crabs, gastropods and teleost fishes.

The ovaries of the sampled blue devils were at various stages of development. Some contained large oocytes but of a single size class suggesting that these fish produce a single batch of oocytes rather than spawning batches in short succession. This conforms to reports that individuals of this species guard eggs in caves (Gomon *et al.* 2008), as well as reports on the biology of other members of the Plesiopidae (Heemstra and Randall 1999). The general gonad staging used in this study (Table 3.1), was not appropriate for this species as it appears not to be a multiple batch spawner. No males contained large testes and the GSI for males was less than 1%. This observation is also in keeping with the reproductive strategy because single-batch, brooding species would require less milt to fertilise eggs than multiple batch, broadcast-spawning species.

Otolith interpretation and age information

The sagittae are large, dense and elliptical, with some increments visible prior to sectioning (Fig. 4.1a). Transverse sections of the sagittae revealed clear series of increments that were presumed to be annuli (Fig. 4.1b). Most sections were assigned the high readability indices of 1 or 2, with the remainder having indices of 3 or 4 (Fig. 4.2a). No otoliths were considered to be uninterpretable. The IAPE was exceptionally low at 0.63% and the age-bias plot indicated that the interpretation of the otoliths was consistent between readings (Fig. 4.2b).

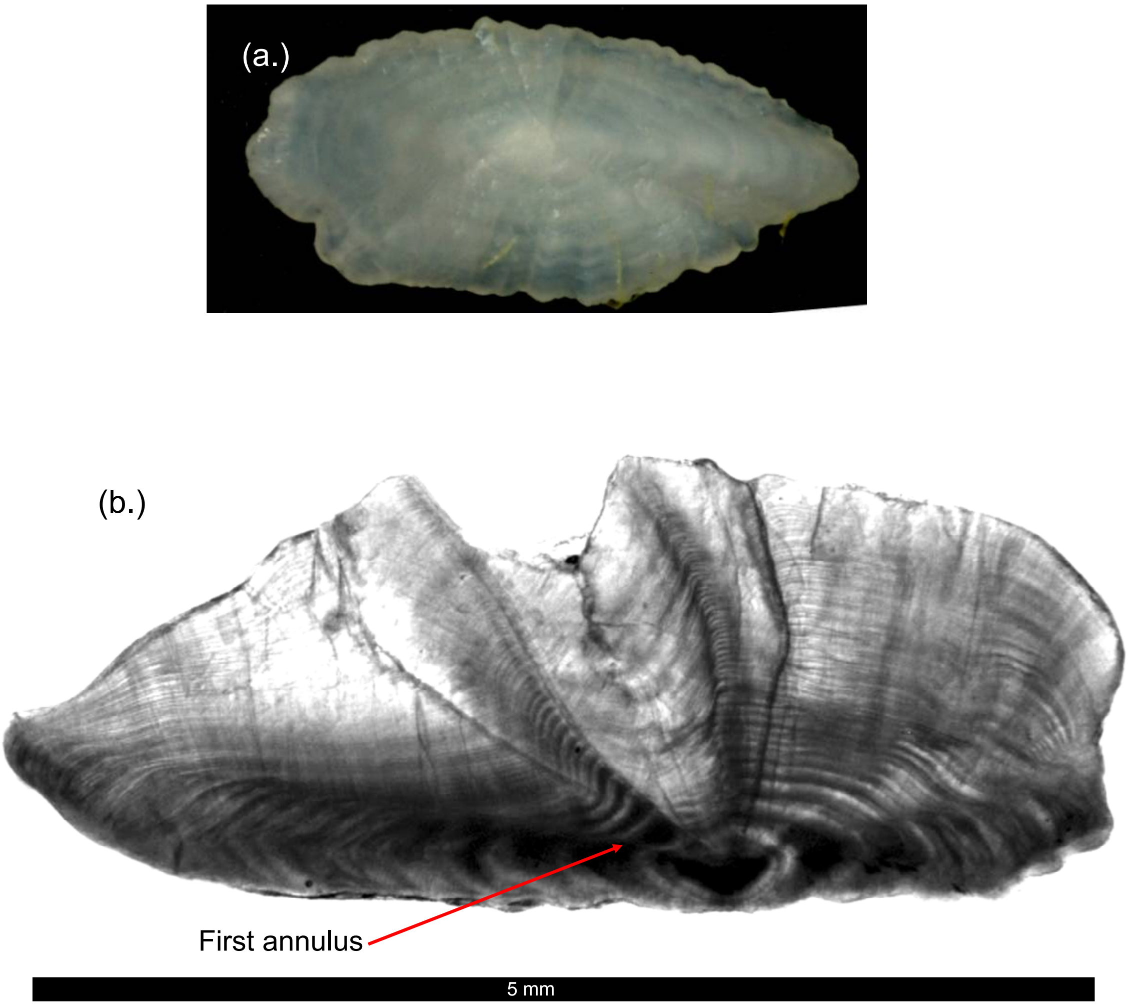

Figure 4.1. (a.) Whole sagitta from a blue devil illuminated with reflected light (otolith length = 18 mm). (b.) Transverse section of a sagitta from a blue devil illuminated with transmitted light displaying thin alternating opaque and translucent zones counted to estimate age.

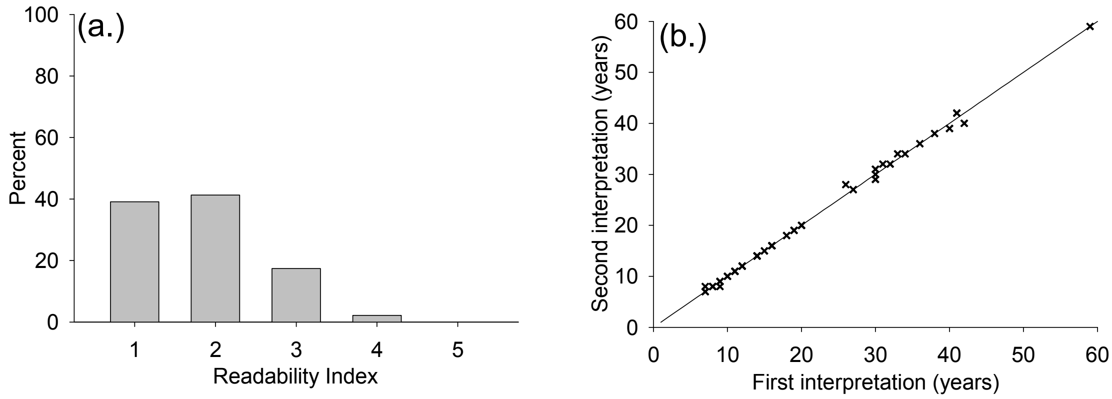

Figure 4.2. (a.) Frequency distribution of readability indices assigned to transverse sections of sagittae of the western blue devil. (b.) Age bias plot comparing between the first and second counts of 46 transverse sections of otoliths from western blue devils. Line is 1:1 ratio.

Those otoliths that were assigned a readability score of 3 or greater were exclusively from older fish (over 30 years), for which the outer increments were highly compressed. They required interpretation at x60 magnification on the dissecting microscope to differentiate the annuli. Those otoliths that were categorised to Class 2 were often the older ones for which the outer increments were challenging or for which there was some difficulty in distinguishing the first annulus. Most fish were aged from 7 to 42 years, but the oldest fish was a male that was 59 years old (Fig. 4.3). Most growth occurred before the age of 20 years before slowing dramatically, indicating indeterminate growth. There were no apparent differences in growth between males and females, or between the South Australian and Western Australian fish.

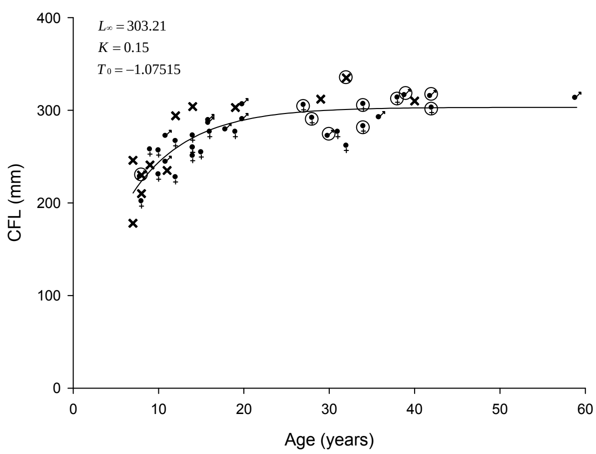

Figure 4.3. Relationship between size and age for western blue devils. The von Bertalanffy growth function fitted for all data points is indicated. Male and female symbols are used for the different genders, a cross is used when sex could not be determined. Symbols in circles represent fish sampled from Western Australia. n = 46. CFL = TL for this species.

4.2 Harlequin fish, *Othos dentex*

Preliminary observations

The harlequin fish was previously recorded from a distribution across southern Australia from Exmouth (WA) to Port Philip Bay (Vic), but is now thought to no longer occur in Victorian waters (Gomon *et al.* 2008). The species reaches a length of 760 mm TL (Hutchins and Swainston 2002). It occurs on shallow rocky reefs with drop-offs and caves to 30 m depth (Gomon *et al.* 2008). It is carnivorous and the body form and large canines are indicative of an ambush predator that most likely targets other fish species. No previous data are available on their reproductive biology or age and growth.

Specimens considered in this study were primarily collected from around southern Fleurieu Peninsula, western Eyre Peninsula and Kangaroo Island but some also came from southern Western Australia. Most specimens displayed signs of severe barotrauma with stomachs consistently everted. Those that were not everted were usually empty except for a few bait items (sardine cubes and squid pieces). One wrasse (Labridae) was retrieved from the gullet of one specimen. Reproductive biology could not be assessed with confidence as no specimens were at a stage of development greater than Stage 2.

Otolith interpretation and age information

The sagittae of harlequin fish are relatively thin, ovate with a pronounced rostrum and are strongly crenulated along both the dorsal and ventral margins (Fig. 4.4a). Transverse sections of the sagittae revealed series of opaque and translucent increments that were presumed to be annuli (Fig. 4.4b). Based on their interpretability, most sagittae were assigned readability indices of 2 to 4, whilst only a few were assigned the lowest index of 5 (Fig. 4.5a). The IAPE of 2.4% and the age-bias plot indicated that the first series of counts of the otoliths underestimated the second series of counts (Fig. 4.5b). Otolith sectioning was particularly difficult due to the fragile nature and the relatively small size of the otoliths. Some difficulty in interpretation was due to preparation problems such as missed cores and transverse sections that strayed from the vertical.

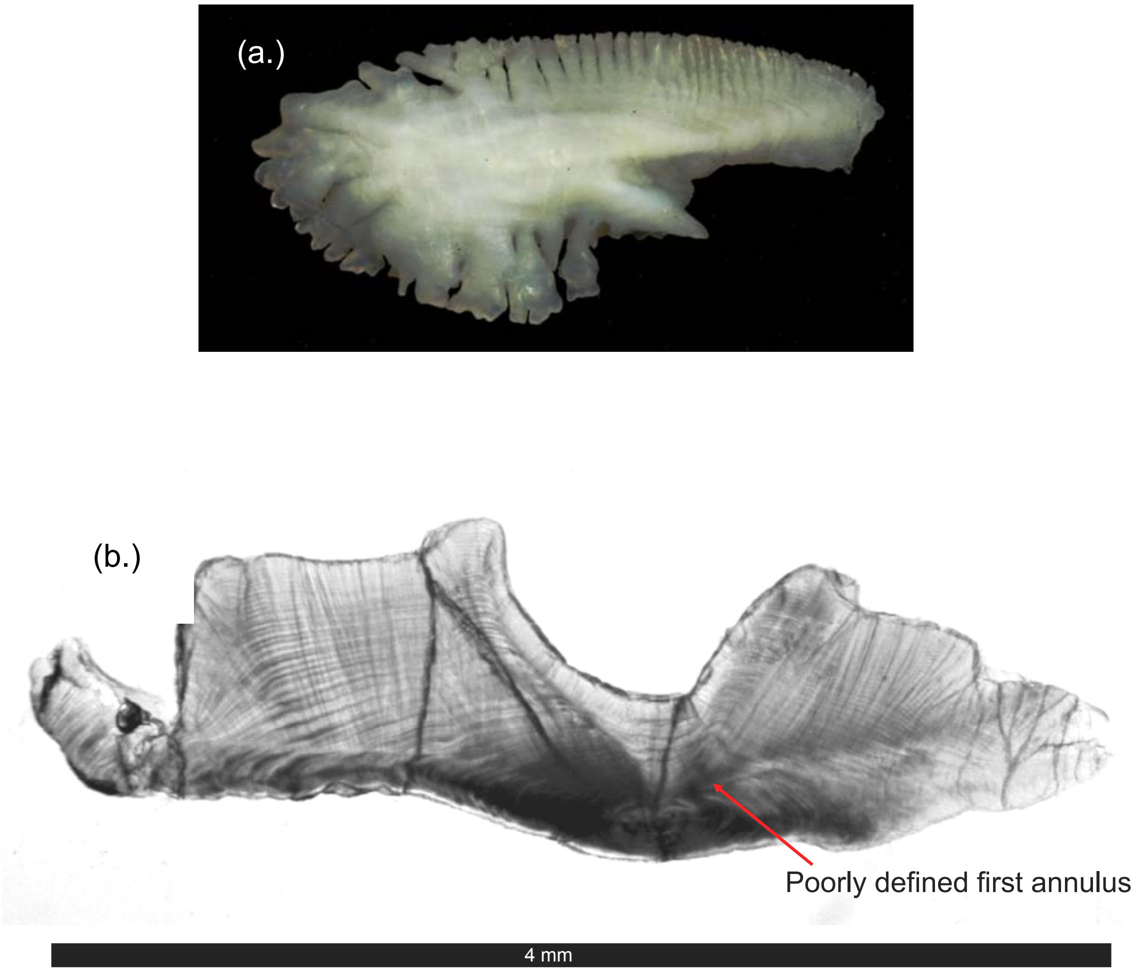

Figure 4.4. (a.) Whole sagitta from a harlequin fish illuminated with reflected light (otolith length = 12 mm). (b.) Transverse section of a sagitta of a harlequin fish illuminated with transmitted light, illustrating poor clarity of first increments in contrast to outer increments.

Of 27 fish that were successfully aged, the estimates of age ranged from 7 to 42 years. Most growth occurred before the age of 20 years, with only an extremely low growth rate apparent after this age (Fig. 4.6). There was considerable overlap in the sizes of the males and females, throughout the size range of fish considered (Table 4.1). Western Australian fish were indistinguishable from the South Australian ones in terms of age and growth.

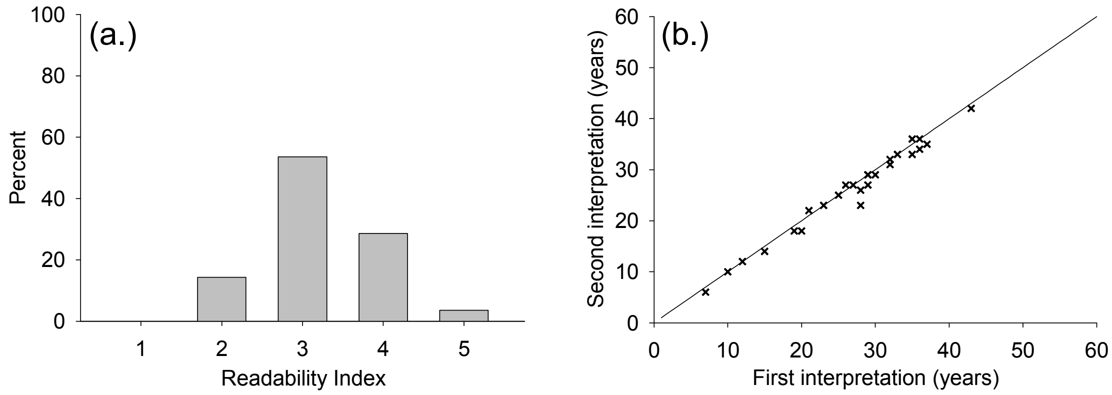

Figure 4.5. (a.) Frequency distribution of readability indices assigned to transverse sections of sagittae of the harlequin fish. (b.) Age bias plot comparing between the first and second counts of 26 transverse sections of otoliths from harlequin fish. Line is 1:1 ratio.

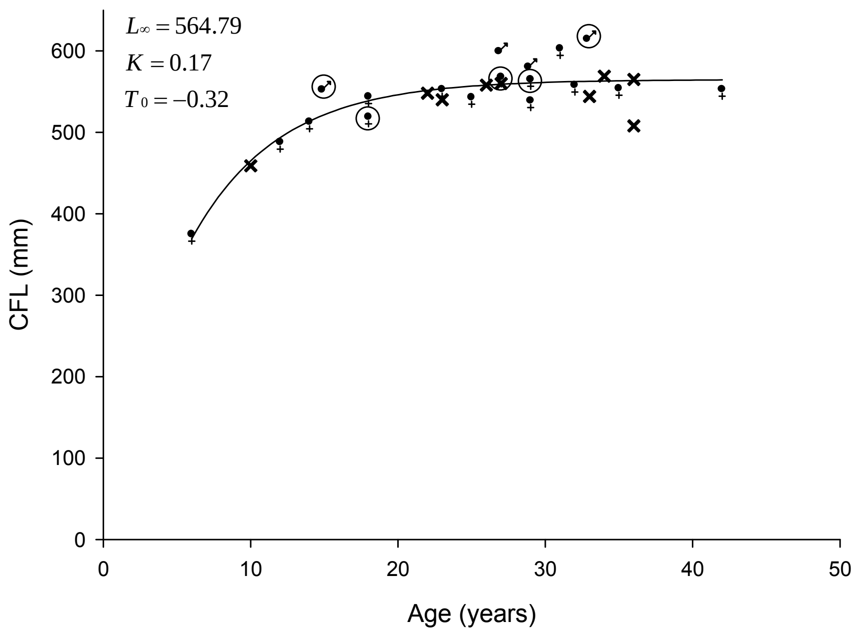

Figure 4.6. Relationship between size and age for harlequin fish. The von Bertalanffy growth function fitted for all data points is indicated. Male and female symbols are used for the two sexes and a cross indicates when sex could not be determined. Symbols in circles represent fish sampled from Western Australia. n= 27. CFL = TL for this species.

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4.3 Red snapper, *Centroberyx gerrardi*

Preliminary observations

The red snapper is distributed throughout southern Australia from Perth (WA) to Bermagui (southern NSW), and Tasmania. It grows to 660 mm TL (Hutchins and Swainston 2002). It is a demersal species that inhabits deeper reefs from 11 to >500 m (Gomon *et al.* 2008; Froese and Pauly 2009). They have been recorded as occurring in caves singly or in pairs (Gomon *et al.* 2008), but are also caught in large numbers in the Great Australian Bight trawl fishery. Previous research has indicated that red snapper are multiple batch spawners with asynchronous oocyte development (Brown and Sivakumaran 2007). In the Great Australian Bight, spawning occurs in summer with the monthly average GSI highest in February (Brown and Sivakumaran 2007). Age and growth of red snapper has been previously described, with the oldest recorded age of 71 years (Stokie and Krusic-Golub 2005).

Most fish considered here were sampled in March and April from Investigator Strait, although some were from near Pearson Island in the eastern Great Australian Bight. No fish had gonads that were at a late stage of development, i.e. no males were found with milt and all but two females were at Stage 1 or 2. The highest GSI for females was 0.5% and for males 0.02%. Such values are low compared to the high values observed in a previous study in the Great Australian Bight where GSI averaged ~4.0% in February (Brown and Sivakumaran 2007). Clearly, the fish sampled here were not in spawning condition, which is most likely due to the restricted period over which they were sampled.

Otolith interpretation and age information

The sagittae of red snapper were nearly circular in shape with a small rostrum and relatively smooth margins (Fig. 4.7a). In most transverse sections a series of alternating translucent and opaque bands, presumed to be annuli, were evident (Fig. 4.7b). The otoliths varied widely in the clarity of their incremental structure, but most were interpretable (Fig. 4.8a). No otoliths were classified to Class 1, as there was always some ambiguity in their interpretation as the increments compressed rapidly at around the fifth increment. Most otolith sections were classified to readability indices of 3 and 4, although some were considered uninterpretable. The IAPE was 3.6%, which is a small error given the limited sample size. The age-bias plot indicated no systematic bias between first and second readings, although variation of up to three increments was recorded (Fig. 4.8b). Previous studies have indicated that otoliths were generally of good quality, but they were from fish sampled from the trawl fishery in the Great Australian Bight (Brown and Sivakumaran 2007).

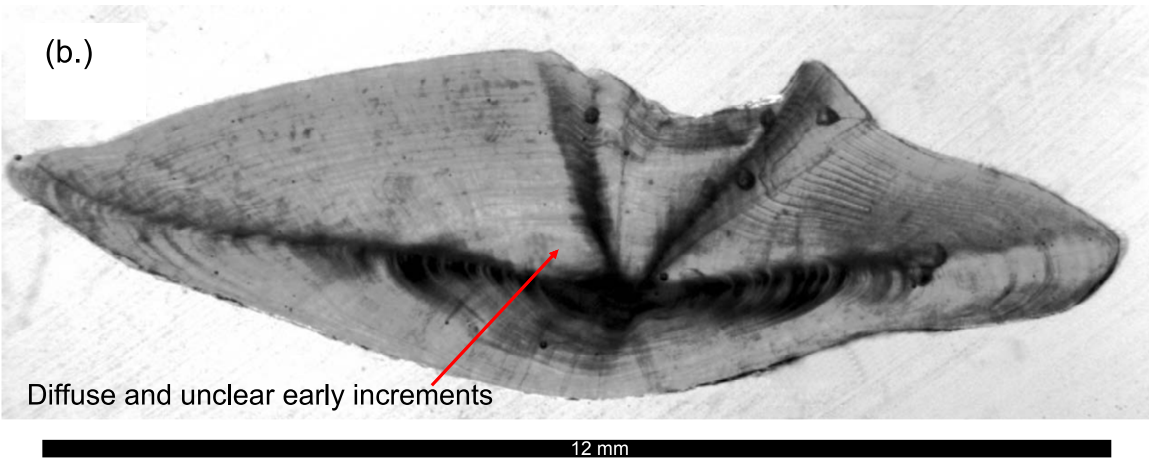


Figure 4.7. (a.) Whole sagitta from a red snapper illuminated with reflected light (otolith length = 32 mm). (b). Transverse section of a sagitta from a red snapper illuminated with transmitted light.

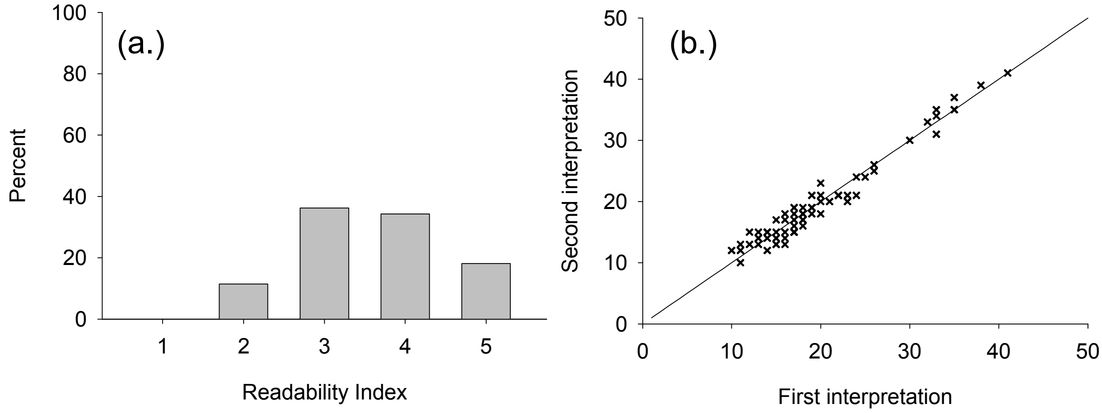


Figure 4.8. (a.) Frequency distribution of readability indices assigned to transverse sections of sagittae of red snapper. (b.) Age bias plot comparing between the first and second counts of 75 transverse sections of sagittae from red snapper. Line is 1:1 ratio.

Most fish were aged from 8 to 25 years, however there were a number of older fish that were up to 41 years old (Fig. 4.9). The estimated von Bertalanffy growth parameters varied subtly between males and females. Despite the considerable variation in estimates of size-at-age, males grew faster but reached a smaller asymptotic size than females. The von Bertalanffy growth curve for all fishes combined is provided in Fig. 4.9b.

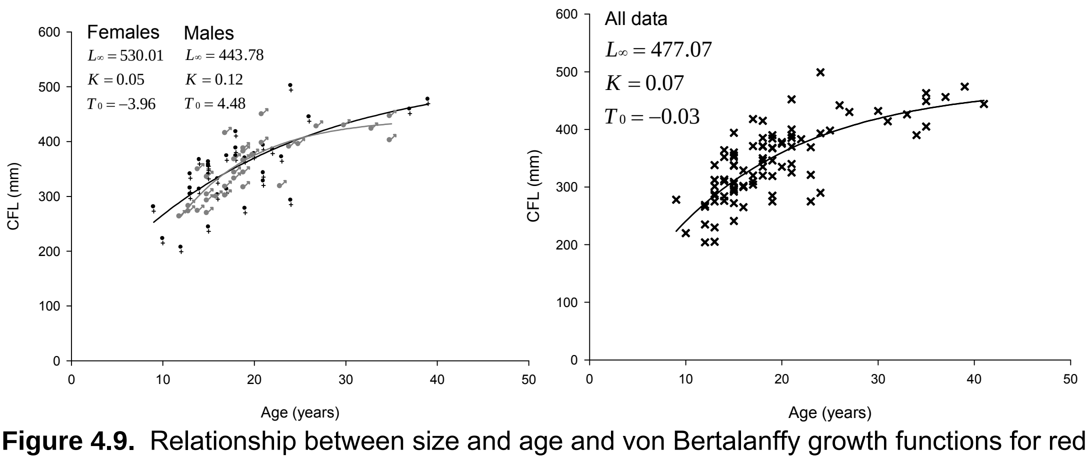


Figure 4.9. Relationship between size and age and von Bertalanffy growth functions for red snapper. (a.) Data for males and females separately, as indicated by symbols. Females, n = 34; males, n = 32 (grey line for males, black line for females). (b.) Data for both sexes combined. n = 90.

4.4 Swallowtail, *Centroberyx lineatus*

Preliminary observations

Swallowtail are distributed throughout the waters of southern Australia from Shark Bay (WA) to Eden (NSW) and Tasmania. The species grows to 450 mm TL (Hutchins and Swainston 2002). It is a schooling species that is found on deeper reefs from 12 to at least 157 m (Gomon *et al.* 2008). Swallowtail are a benthopelagic species, i.e. they live and feed near the bottom as well as in mid-water or near the surface (Gomon *et al.* 2008). No studies have previously reported age, growth or reproductive information for this species.

Sampling for this study occurred over a restricted period during autumn and no fish were found to be in spawning condition. No females had ovaries at Stage 3 or greater, whilst there were no males at Stage 2 or greater.

Otolith interpretation and age information

The sagittae of swallowtail were thick, near circular with an indistinct rostrum and relatively smooth margins (Fig. 4.10a). The transverse sections of the sagittae from this species were difficult to interpret. Some otoliths demonstrated complete series of alternating translucent and opaque zones, and could be interpreted with some difficulty to estimate age (Fig. 4.10b). However, the higher percentage of sectioned sagittae were considered uninterpretable (Fig. 4.11a). In such otoliths there was usually an area near the centre where the opaque and translucent zones could not be differentiated but rather consisted of a broad translucent zone (Fig. 4.10b). The edges of most otoliths displayed several clear increments. The age-bias plot indicated some under-ageing with the first set of counts, with the differences for individual otoliths as high as three increments (Fig. 4.11b). This accounts for the IAPE of 3.8%.

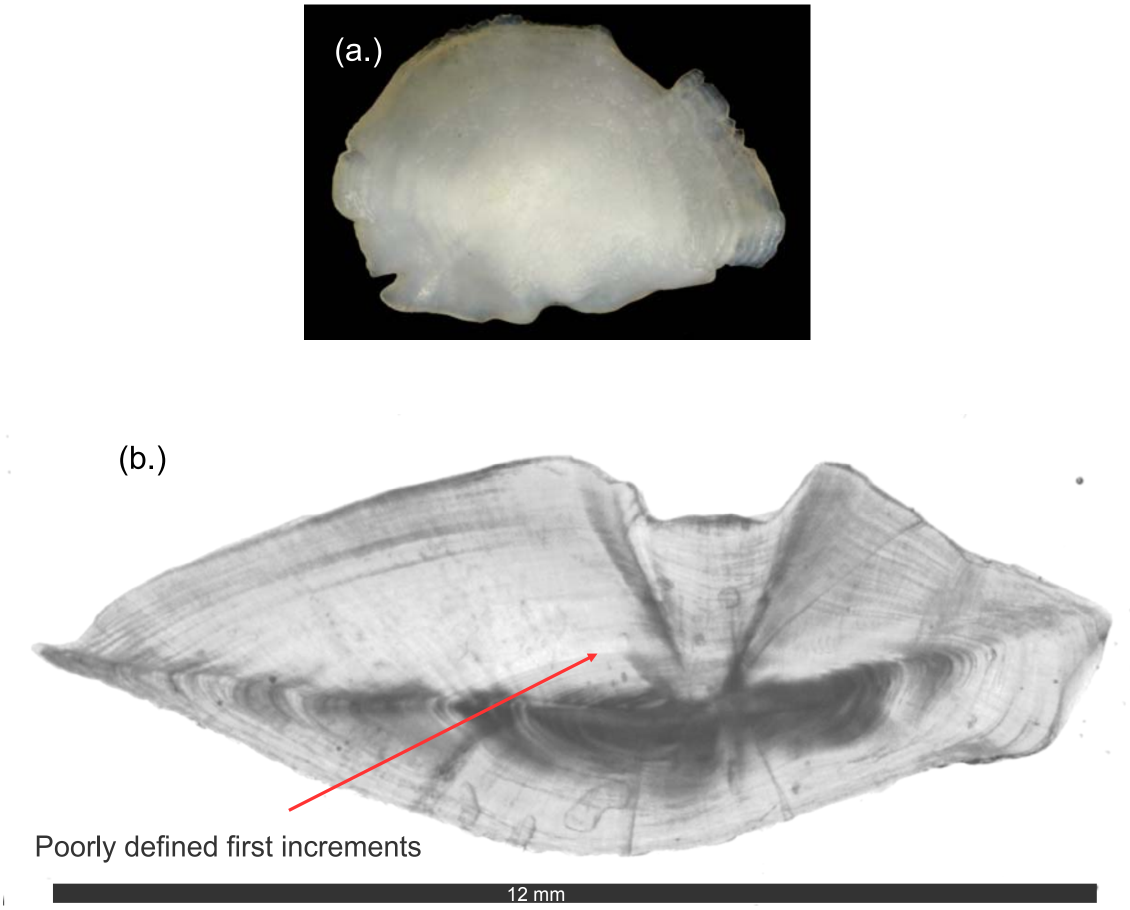


Figure 4.10. (a.) Whole sagitta from a swallowtail illuminated with reflected light (otolith length = 27 mm). (b.) Transverse section of a sagitta from a swallowtail illuminated with transmitted light.

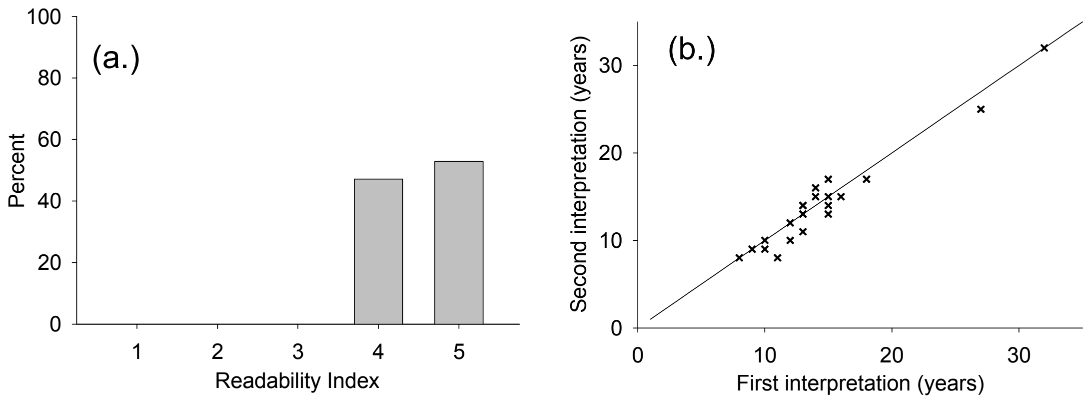


Figure 4.11. (a.) Frequency distribution of readability indices assigned to transverse sections of sagittae of swallowtail. (b.) Age bias plot comparing between the first and second counts of 22 transverse sections of otoliths from swallowtail. Line is 1:1 ratio.

Age estimates were obtained for 25 of the 59 specimens, although there was limited confidence in the age estimates. Most ages were from 8 to 20 years, whilst the oldest fish was 32 years. The estimates of size-at-age varied widely. The von Bertalanffy growth curve was fitted by minimising the sum of squares, but had to be constrained (i.e. L_0=0) to provide realistic estimates of L_∞ and K (Fig. 4.12). The growth curve indicated that most growth occurred before the age of 20 years, after which subsequent growth was very slow.

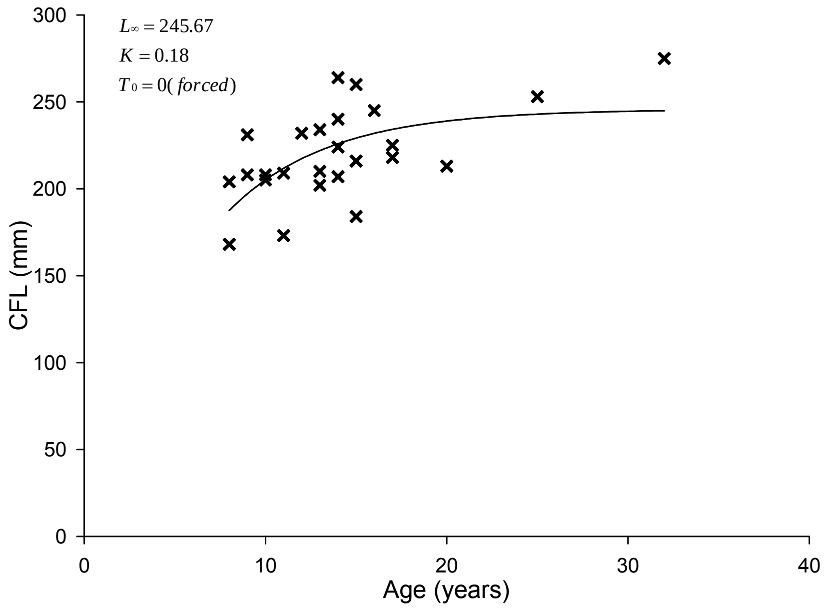


Figure 4.12. Relationship between size and age for swallowtail. The von Bertalanffy growth function fitted through all data points is indicated. n = 25.

4.5 Bluethroat wrasse, *Notolabrus tetricus*

Preliminary observations

The bluethroat wrasse is the most common wrasse in south-eastern Australia (Gomon *et al.* 2008). It is distributed from western South Australia to New South Wales and Tasmania and grows to a maximum size of 500 mm TL (Hutchins and Swainston 2002). This species is a protogynous hermaphrodite (Smith *et al.* 2003). It is generally reef-associated and occurs at depths of 1 - 50 m. Individuals have strong site fidelity to reef areas, and they generally move only short distances, with females having overlapping home ranges and males being territorial (Barrett 1995; Edgar *et al.* 2004). Although they are thought to be generally permanent reef residents living in defined home ranges, movement of up to 40 km has been recorded (Smith *et al*. 2003). Some information is also available on age and growth (Smith *et al*. 2003).

No fish in spawning condition or with developed testes or ovaries were recorded in this study. The most developed fish was a female at Stage 2 with a GSI of 0.4%. All males were at Stage 1 with GSI's of less than 1%.

Otolith interpretation and information

The sagittae of bluethroat wrasse were anvil-shaped with a narrow rostrum, small anti-rostrum and a post-rostrum considerably more pronounced than the rostrum (Fig. 4.13a). All otoliths showed series of alternating translucent and opaque bands that were presumed to be annuli (Fig. 4.13b). Approximately 30% of the otoliths were unterpretable (Fig. 4.14a). IAPE was high at 7.6% because there were differences of up to 2 increments between the first and second counts, despite the relatively low estimates of age (Fig. 4.14b). The differences were due to difficulties in interpreting the first and the marginal increments. The number of otoliths available was too low to develop a consistent approach to interpretation.

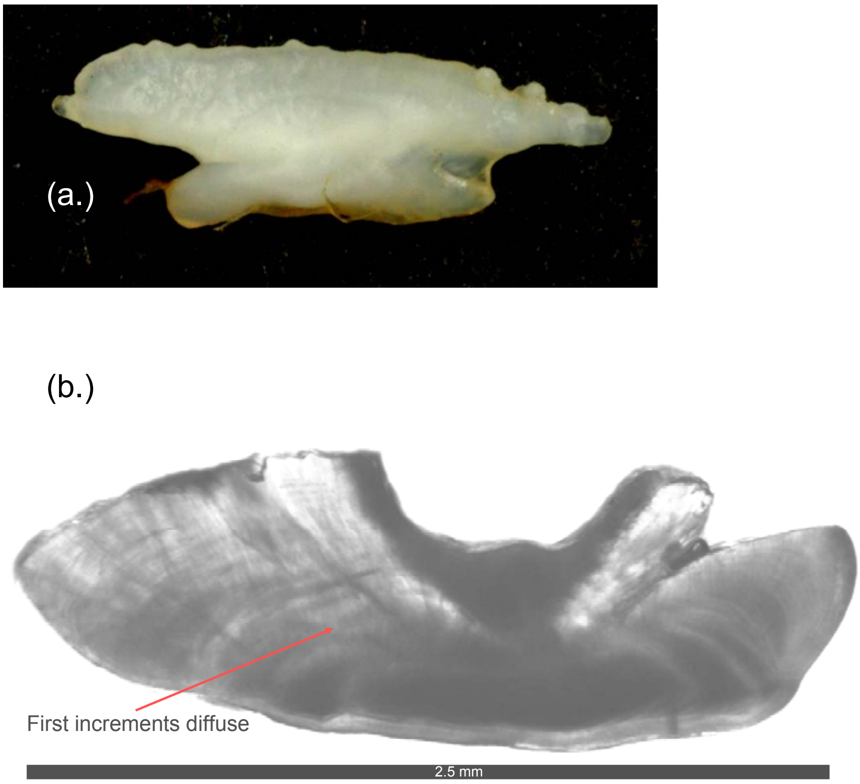


Figure 4.13. (a.) Whole sagitta from a bluethroat wrasse illuminated with reflected light (otoliths length = 8 mm). (b.) Transverse section of a sagitta from a bluethroat wrasse illuminated with transmitted light.

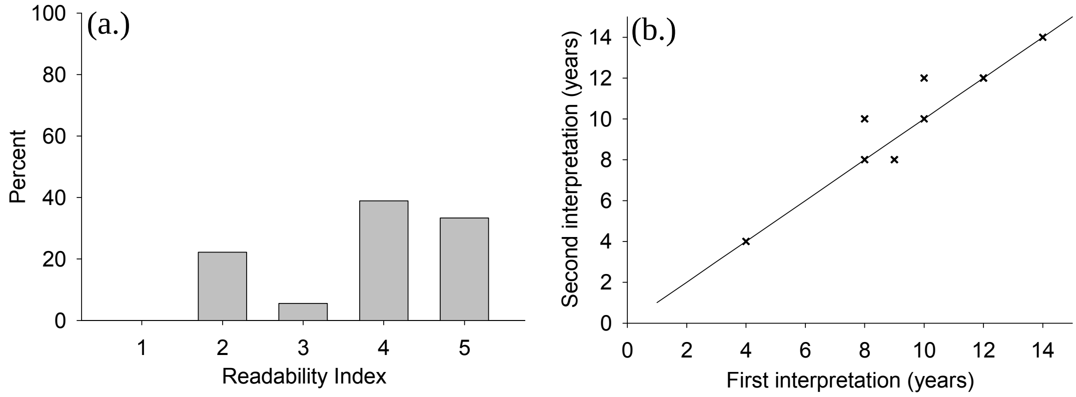


Figure 4.14. (a.) Frequency distribution of readability indices assigned to transverse sections of sagittae of bluethroat wrasse. (b.) Age bias plot for all transverse sections of bluethroat wrasse sagittae for which two interpretations were made. Line is 1:1 ratio. n = 9.

For 12 of the 23 specimens processed, estimates of age were obtained, which ranged from 4 to 14 years. These age estimates are considerably less than the 23 years recorded previously in a Victorian study (Smith *et al.* 2003). There was a dominance of males in the samples (Fig. 4.15). The growth conformed to an indeterminate growth pattern where size continued to increase considerably with age across the range of fish available.

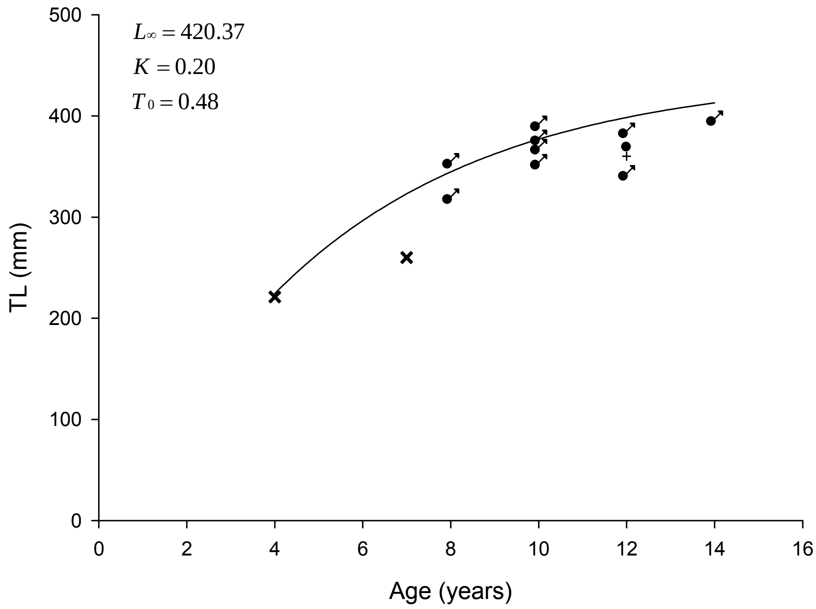


Figure 4.15. Relationship between size and age for the bluethroat wrasse based on the 12 estimates of age determined in this study. The von Bertalanffy growth function and parameters are indicated. The sex of each fish is indicated by the different symbols.

4.6 Sea sweep, *Scorpis aequipinnis*

Preliminary observations

Sea sweep occur in southern Australian waters from Shark Bay (WA) to Port Jackson (NSW), including Tasmania. The species reaches a maximum length of 610 mm TL (Hutchins and Swainston 2002). Sweep have been recorded from rocky reefs in shallow coastal waters to 25 m (Gomon *et al.* 2008), however, some specimens taken for this study were collected over rocky reefs that were greater than 40 m deep. Sweep are reputed to feed on zooplankton (Russell 1983; Gomon *et al.* 2008), but in Victorian waters were found to have a variable diet, exploiting both benthic and pelagic resources, and had irregular periods of selective carnivorous feeding (Newman *et al.* 2005). The specimens collected for this study had stomachs and intestines that were commonly full of red algae.

All females collected for this study were at Stage 1 or 2 and males at Stage 1, which means that none were in spawning condition. This was most likely due to the restricted sampling period over which the fish were collected. No other information is available on the reproductive biology of this species.

Otolith interpretation and age information

Sagittae of the sea sweep were thin, oval and sinuate with a pronounced but blunt rostrum (Fig. 4.16a). In all otoliths a clear series of alternating translucent and opaque zones, presumed to be annuli, were apparent (Fig. 4.16b). The otoliths were assigned the full range of readability indices (Fig. 4.17a), whilst the IAPE was high at 5.9%. Furthermore, the age-bias plot indicated that, in general, the second count gave higher estimates of age than did the first count (Fig. 4.17b). In spite of these difficulties the largest difference in ages between the first and second interpretation was still only 2 years. The major problem related to distinguishing the innermost increments (Fig. 4.16b). The otolith section from the oldest fish was the most difficult to interpret, primarily because the density of the opaque zones varied considerably and there was compression of increments toward the outer edge.

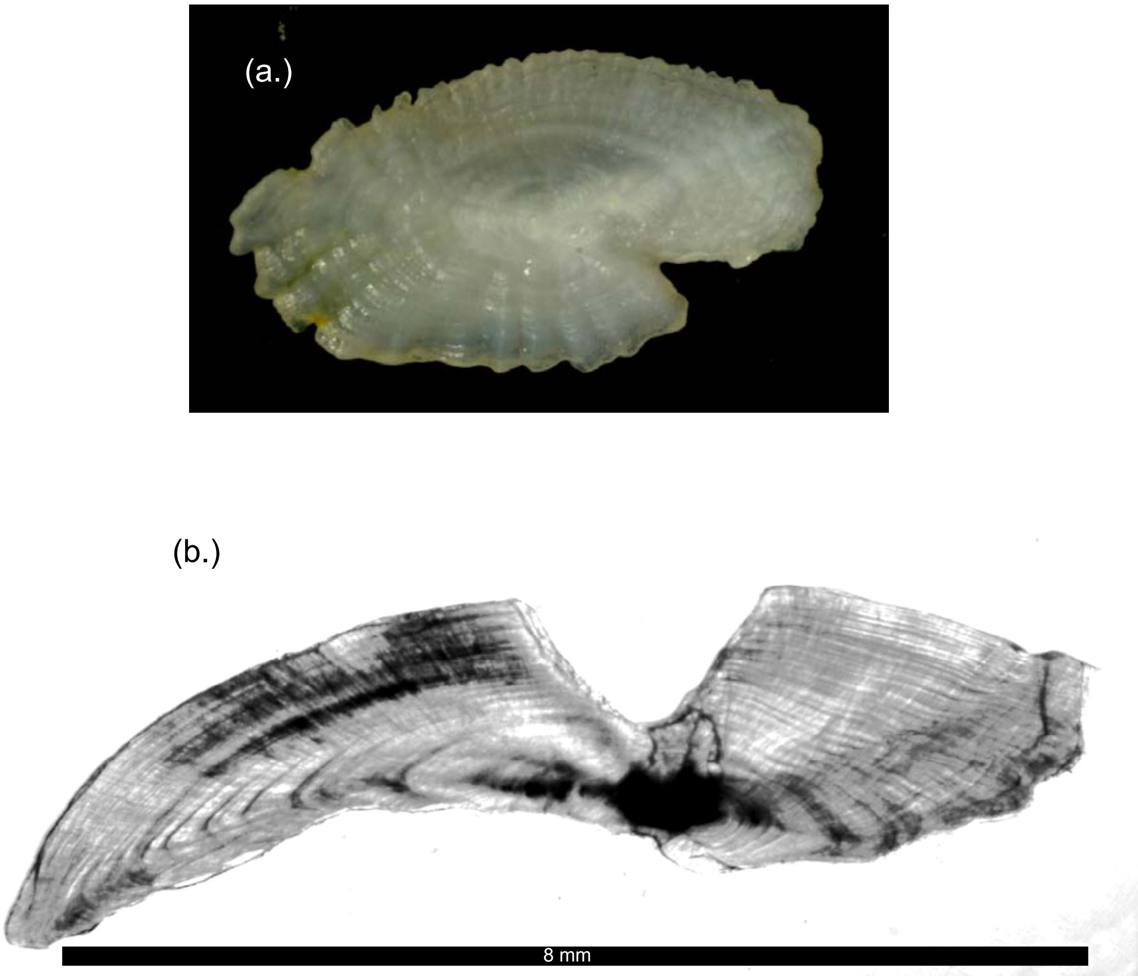


Figure 4.16. (a) Whole sagitta from a sea sweep illuminated with reflected light (otolith length = 14 mm). (b) Transverse section of a sea sweep otolith illuminated with transmitted light.

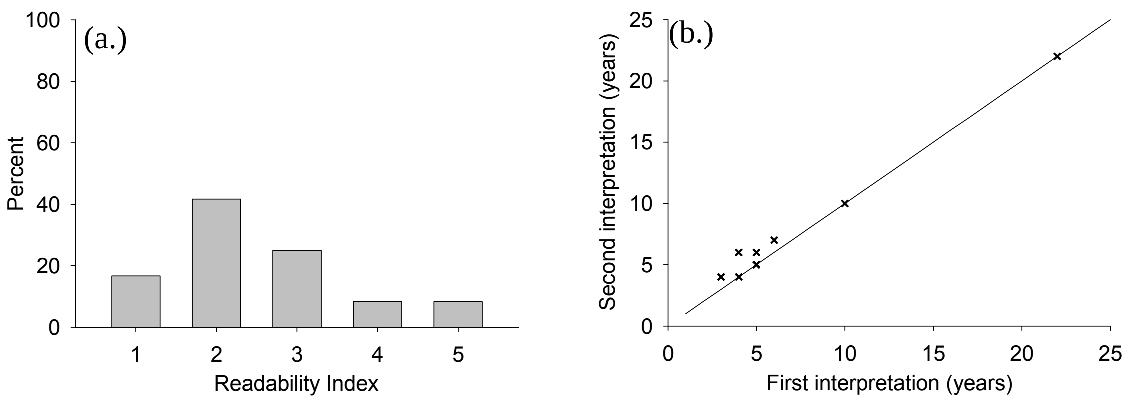


Figure 4.17. (a.) Frequency distribution of readability indices assigned to transverse sections of sagittae of sea sweep. (b.) Age bias plot for all transverse sections of sea sweep sagittae for which two interpretations were made. Line is 1:1 ratio. n = 11.

Estimates of age from otoliths were obtained for 11 of the 12 specimens of sea sweep. Most fish were between four and 10 years of age, but the oldest fish was aged at 23 years (Fig. 4.18). The size-at-age data, von Bertalanffy growth curve and parameters based on the 11 fish, regardless of sex or maturity, is presented in Fig. 4.18.

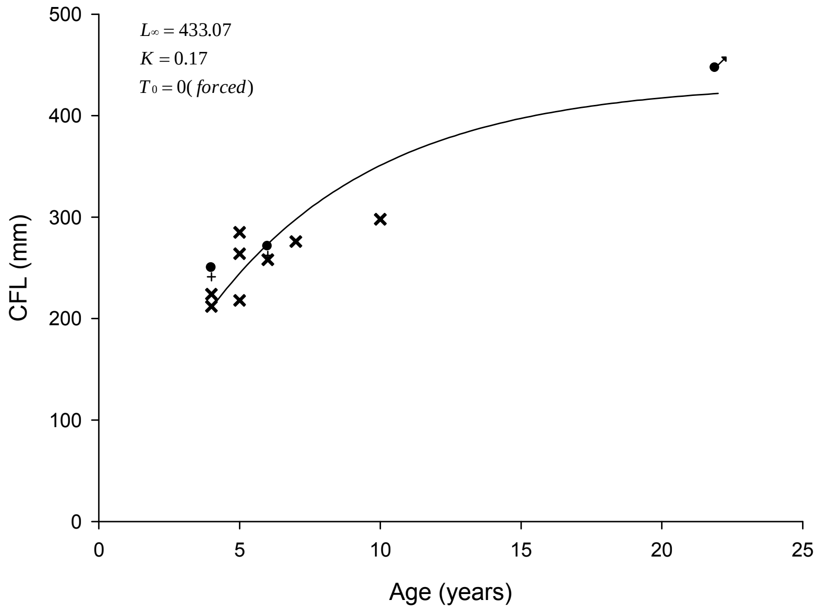


Figure 4.18. Relationship between size and age for the sea sweep based on the 11 estimates of age determined in this study. The von Bertalanffy growth function and parameters are indicated. The sex of some fish are also indicated.

4.7 Blue morwong, *Nemadactylus valenciennesi*

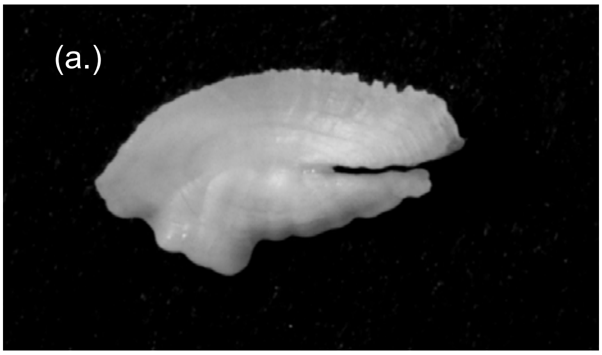
Preliminary observations

Blue morwong occur across southern Australia from northern New South Wales to Perth (WA), where they occur on deeper coastal reefs from 10 to 100 m (Gomon *et al.* 2008). They can grow to >1 m in total length. Previous research on age, growth and reproduction has been done in Western Australia (Coulson *et al.* 2007). Annual increments in otoliths were validated by marginal increment analysis and the maximum age reported was 20 years (Coulson *et al.* 2007). Gonadosomatic index peaked on the south coast of Western Australia in late summer to early autumn.

For the specimens processed here, all fish were provided either gutted or as frames. The blue morwong is a benthic carnivore, and here the stomachs contained a range of gastropods and bivalves.

Otolith interpretation and age information

Sagittae were strongly recurved, thin, ovate with a pronounced rostrum and anti-rostrum (Fig. 4.19a). In some otolith sections clear alternating translucent and opaque zones were evident (Fig. 4.19b). Most otoliths were interpretable and were assigned a readability index of 3 (Fig. 4.20a) and the IAPE was reasonably low at 3.4%. The age-bias plot suggested that the first series of counts under-estimated the second series by up to 2 increments (Fig. 4.20b). The major challenge was identifying the innermost increments, which were often diffuse and difficult to differentiate (Fig. 4.19b).



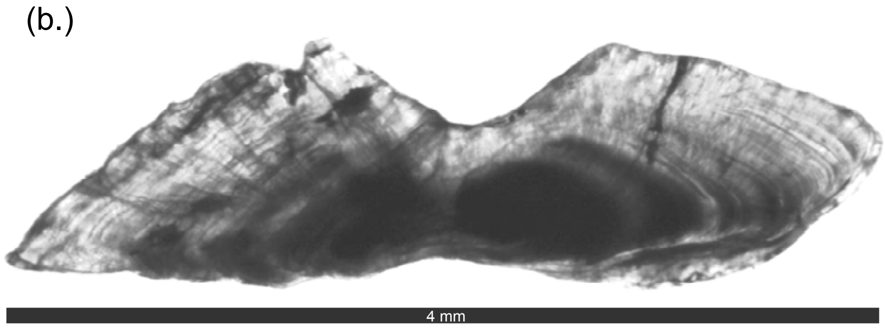
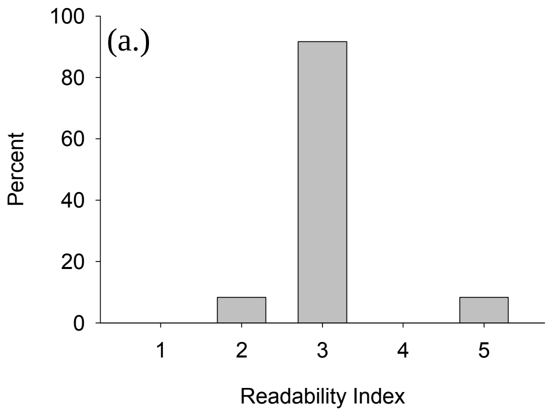


Figure 4.19. (a.) Whole sagitta from a blue morwong under reflected light (otolith length = 7 mm). (b.) Transverse section of a blue morwong otolith illuminated with transmitted light, showing some structure.



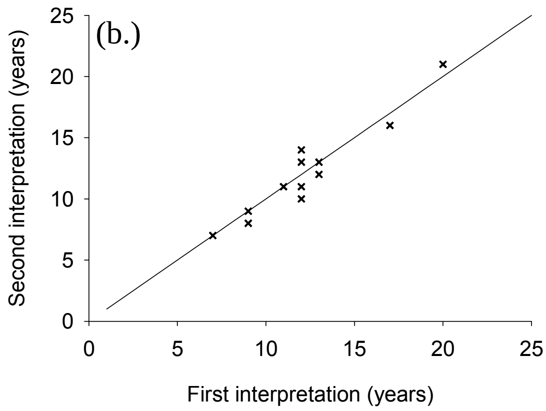


Figure 4.20. (a.) Frequency distribution of readability indices assigned to transverse sections of sagittae of blue morwong. (b.) Age-bias plot comparing between the first and second counts of the 12 blue morwong sagittae that could be interpreted. Line is 1:1 ratio.

For 12 of the 13 specimens collected, estimates of age were determined from the structure of the otoliths. The age estimates ranged from 7 to 21 years. Since the otolith from the largest fish collected was uninterpretable, the potential longevity is likely to exceed 21 years. There was considerable variation in the estimates of size-at-age, which prevented fitting a meaningful growth curve (Fig. 4.21).

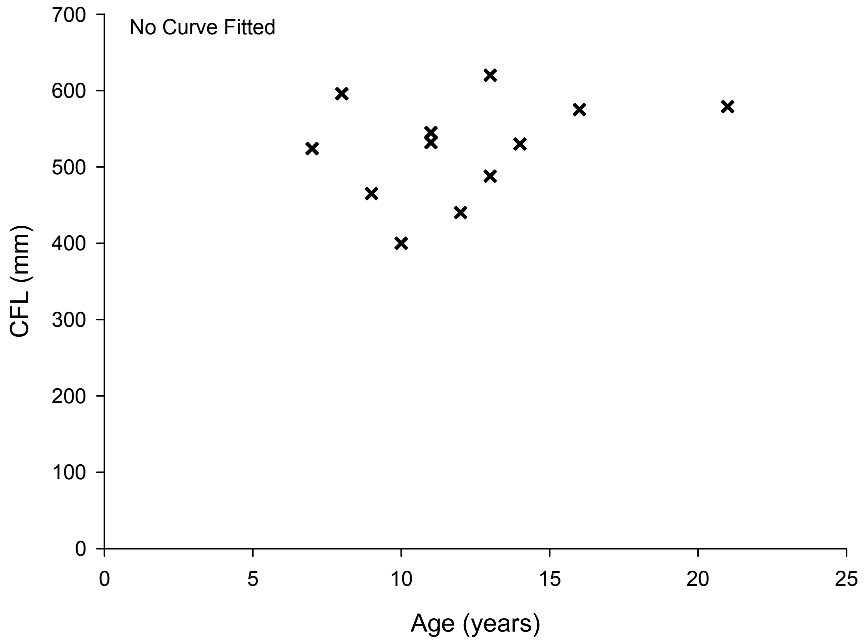


Figure 4.21. Relationship between size and age for the 12 blue morwong for which an estimate of age was determined.

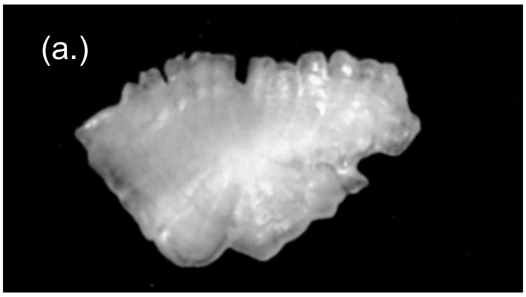
4.8 Red mullet, *Upeneichthys vlamingii*

Preliminary observations

Red mullet are found throughout southern Australia from the south coast of New South Wales to southern Western Australia, including Tasmania. They attain a maximum size of 420 mm TL (Hutchins and Swainston 2002). No previous studies have been done on the biology of this species. Specimens for this study were collected from Spencer Gulf, SA. None were in spawning condition.

Otolith interpretation and age information

The sagittae were thin, oval-shaped with an indistinct rostrum and lobed ventral margin (Fig. 4.22a). In general, otolith sections were uninterpretable because they were exceptionally thin, and the contrasting zones were difficult to differentiate (Fig. 4.22b). As such, there were no interpretable age data available.



(b.)

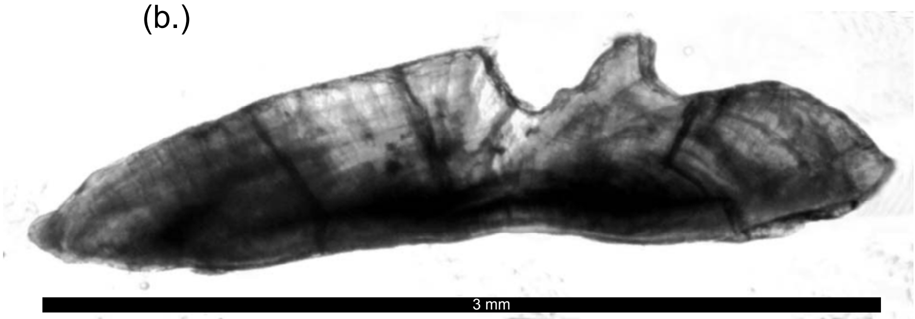


Figure 4.22. (a.) Whole sagitta from a red mullet illuminated with reflected light (otolith length = 4.5 mm). (b.) Transverse section of a sagitta from red mullet illuminated with transmitted light. Note the lack of a clear incremental structure.

4.9 Silver trevally, *Pseudocaranx georgianus*

Preliminary observations

The distribution of silver trevally is unclear due to taxonomic confusion but it occurs at least along southern Australia from the central coast of NSW to Perth (WA). It was regarded until recently as *P. dentex*, but was recently assigned to *P. georgianus*. The species is very likely to be the same as that in New Zealand (currently *P. dentex*) or at least very closely allied. Previous studies have been done on the biology of the silver trevally in New Zealand (Langley 2004), New South Wales (Rowling and Raines 2000) and Western Australia (Farmer *et al.* 2005). Maximum ages reported are 23 years for NSW (Rowling and Raines 2000) and 33 years for New Zealand (Langley 2004). Silver trevally are multiple batch spawners with "modest" egg production (Rowling and Raines 2000).

Most specimens considered for this study were collected from around Greenly Island and Investigator Strait in March and April 2009. Some were collected in March from Greenly Island and had large developed ovaries at Stage 3, but most were at Stage 2. Two females collected later from Investigator Strait in April also had ovaries that were at Stage 3.

Otolith interpretation and age information

The sagittae of silver trevally were thin and ovate with a pronounced rostrum and small anti-rostrum (Fig. 4.23a). Otolith sections were mostly uninterpretable. They were exceptionally thin and fragile, and contrasting zones were difficult to interpret. In some specimens up to 4 opaque zones were evident, whilst others appeared to have considerably more (Fig. 4.23b). Other studies have not reported such difficulty in interpreting the otolith structure (eg Rowling and Raines 2000; Farmer *et al.* 2005). No growth curve was fitted because only five estimates of age were available.

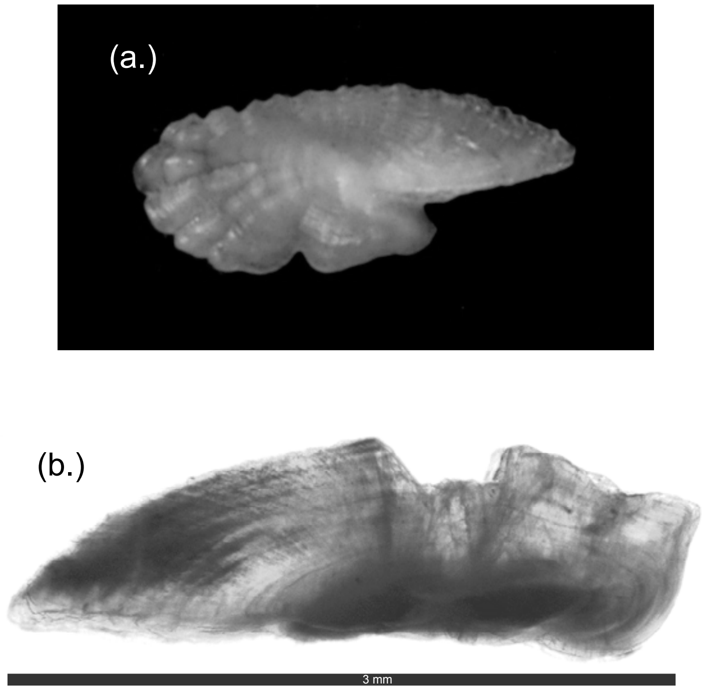


Figure 4.23. (a.) Whole sagitta from a silver trevally illuminated with reflected light (otolith length = 6.5 mm). (b.) Transverse section of a silver trevally otolith illuminated with transmitted light.

4.10 Vulnerability Index

Vulnerability indices were successfully calculated for eight of the nine species considered in this study using estimates of parameters that were either determined in this study or were taken from the literature (Table 4.2). Note that the value for K estimated in this study for the sea sweep was considered unreliable because of the small sample size and was excluded from the calculation of vulnerability index. Also, an estimate of K was not available for an Australian population of silver trevally.

The estimated vulnerability indices ranged from 57 for the sea sweep up to 72 for the red snapper (Table 4.2).

Table 4.2. Estimates of vulnerability indices and the values of the different parameters that were used in their calculations. * indicates those data from the literature rather than this study. K = von Bertalanffy growth parameter.

Common name	Max age	Max total length (mm)	K	Vulnerability Index	Reference
Red snapper	71*	660*	0.03*	72	Stokie & Krusic-Golub (2005); Hutchins & Swainston (2002)
Swallowtail	32	450*	0.18	61	Hutchins & Swainston (2002)
Western blue devil	59	360*	0.15	60	Hutchins & Swainston (2002)
Harlequin fish	42	760*	0.17	68	Hutchins & Swainston (2002)
Sea sweep	23	610*	-	57	Hutchins & Swainston (2002)
Blue morwong	21	1000*	0.22*	64	Coulson *et al.* (2007); Gomon *et al.* (2008)
Bluethroat wrasse	23*	500*	0.13*	60	Hutchins & Swainston (2002); Smith *et al.* (2003)
Silver trevally	23*	800*	-	62	Rowling & Raines (2000); Gomon *et al.* 2008)

5.0 DISCUSSION

The objectives of this study were to provide some age-based life history information for each of the selected nine species, and to subsequently provide a preliminary first estimate of the intrinsic vulnerability to fishing for each species. Whilst the red snapper is fished commercially, the remaining species are all taken as by-catch in line-fishing and in some net-fishing activities in South Australia. Each species has been recognised as having some significance from a management perspective. The tractability of ageing each species was assessed. The otoliths from the nine species considered demonstrated a wide range of characteristics that affected their usefulness in estimating fish age. Some otoliths demonstrated clear alternating opaque and translucent zones that were similar in appearance to validated annual increments described for other species (Fowler 1995, Fowler and Short 1998). As such, in the absence of any possibility of undertaking a validation study, these increments were also interpreted as being formed annually and so provided estimates of age in years. For several other species, the incremental structure was less clear, but nevertheless counts of annual increments were achieved for some specimens. For the remaining species, the otoliths proved extremely difficult to interpret and insufficient fish were successfully aged to confidently provide estimates of any age-based parameters.

Where possible the age-based information derived in this study or gleaned from the literature was used in the calculation of the vulnerability indices. The intrinsic vulnerability scores for most of our study species were relatively high, driven mostly by relatively slow growth rates and high estimates of maximum age. To place these indices in context, they are presented graphically along with estimates of indices for several other South Australian species for which the indices were presented in Cheung *et al*. (2007) (Fig. 5.1). The vulnerability indices for the eight species considered in this study were similar to those for southern bluefin tuna and orange roughy, which are two species that are now known to be significantly overfished. Furthermore, the vulnerability indices were considerably higher than for other fish species that are heavily exploited by commercial fishers, such as Australian salmon and Australian herring. To further place our results into context, Cheung *et al*. (2007) calculated a mean vulnerability index of about 47 for the 1,353 species that they considered, and a mean vulnerability index of around 60 for threatened species listed under the IUCN Red list.

A summary of the current understanding of the life history of each species, based on the recently derived age-based data and further information gleaned from the literature, is presented below.

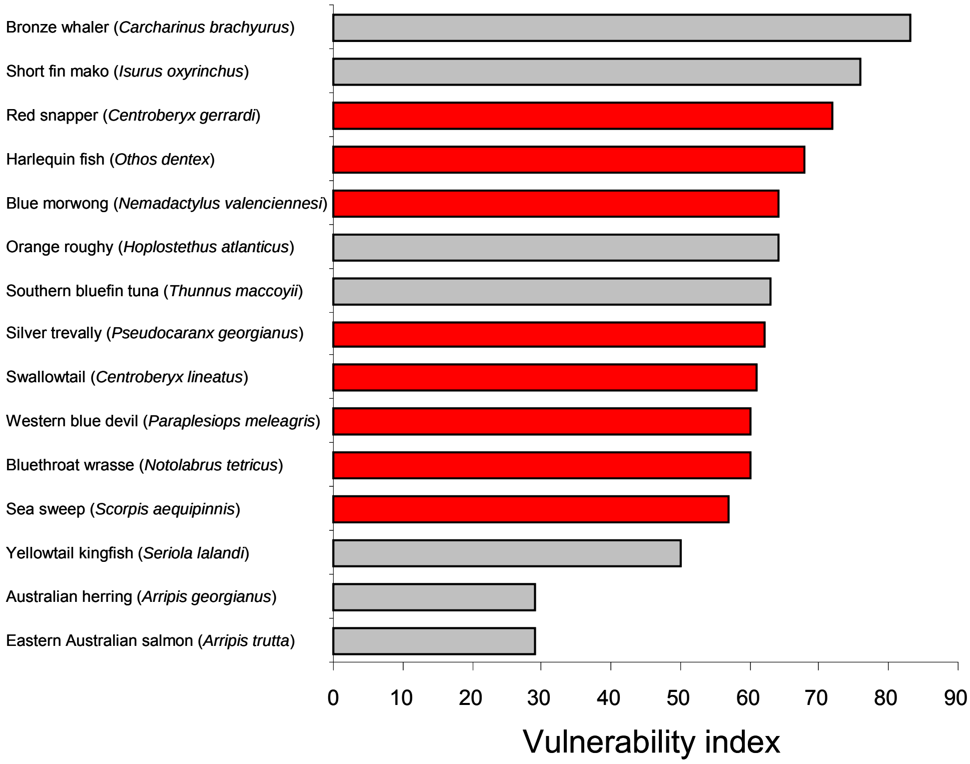


Figure 5.1. Vulnerability indices: species for which the vulnerability indices were calculated in this study are highlighted in red and those from Cheung *et al*. (2007) are presented in grey.

Western blue devil

This study presented the first estimates of age for this species of fish. Of the relatively small number of individuals considered, numerous fish were >30 years of age whilst the oldest was 59 years. As such, the western blue devil is a surprisingly long-lived, small reef fish species. Current understanding is that it is a strongly site-attached species that produces benthic eggs. Such life history characteristics make it particularly susceptible to local-scale environmental events. Understanding of the reproductive biology is poor, but the data on overlapping size and age ranges of males and females suggest that the western blue devil is not a sequential hermaphrodite, thus removing concerns about size-selective harvesting of the two sexes. As yet, there are insufficient data on size and age at maturity to determine an appropriate minimum legal size. Nevertheless, the everted stomachs that resulted from barotrauma, suggest that when captured and released from deep water, these fish would likely have low post-release survival. Despite these serious considerations, the vulnerability index for this species was relatively low compared to the other seven species. This is likely to be due to its small maximum size. Nonetheless, a score of 60 is still relatively high (Cheung *et al*. 2007).

Harlequin fish

The harlequin fish was also characterised as another long-lived, reef-associated fish species of southern Australia. Numerous individuals were aged to >30 years of age. This species is one of the very few representatives of the Serranidae in southern Australia, and no previous studies of its biology have been done. While many species of the Serranidae family are protogynous hermaphrodites, the overlapping size ranges and ages of males and females here suggest that this species is not a sequential hermaphrodite. Data on size at maturity are needed for the harlequin fish for which currently there is no minimum legal size limit. Nevertheless, the everted stomachs are a sign of barotrauma which suggest that fish captured and released from deep water may have low post-release survival. This species was classified as one of the more vulnerable of those considered here.

Red snapper

Some of the red snapper considered in our study were relatively old at >40 years, but nevertheless were still considerably younger than the 71 years of age reported for this species by Stockie and Krusic-Golub (2005). No fish of less than 7 years of age were either captured in our study or in previously reported research, suggesting a disjunct between the juvenile and adult habitat. As yet, the distribution and habitat of juvenile red snapper is unknown although previous studies have speculated that they are likely to occur in inshore regions (Brown and Sivakumaran 2007). This species was assigned the highest vulnerability index of those species considered in this study.

Swallowtail

For the swallowtail, less than 50% of the otoliths from the fish considered here had a structure that was clear enough to interpret in terms of age. This may relate to their benthopelagic habit where fish range across a broad range of depths and so are likely to experience rapid environmental changes that may prevent them from being exposed to the seasonal variation that is required for the development of clear increment formation. Some success in ageing fish was achieved, which provided estimates of age of around 30 years. As such, this demonstrates that this is a relatively long-lived species, similar to other members of the genus and the family. This species was assigned a moderate level of vulnerability compared to its congeneric the red snapper, which probably relates to the lower estimate of maximum age. Nevertheless, higher sample sizes would likely increase the estimate of maximum age and thereby influence the estimate of the vulnerability index.

<u>Bluethroat wrasse</u>

The bluethroat wrasse is a highly-abundant, reef-associated species of fish that can live to the moderate age of 23 years. This species is readily captured and their territorial nature may make them vulnerable to localised depletion. Fishing pressure in Victoria may have reduced the average fish size (Smith *et al.* 2003) and there is now some evidence that their populations are influenced by fishing pressure, particularly with respect to female size and sex ratio (Shepherd and Baker 2008). Populations of sequential hermaphroditic species are known to be sensitive to size-selective harvesting. Here the species was assigned a moderate vulnerability index.

<u>Sea sweep</u>

This study provided new basic biological information for the sea sweep. The transverse sections of their otoliths were interpretable and 11 of 12 specimens were aged providing estimates of age of up to 23 years. This largest and oldest specimen was from the most remote location sampled (west of Pearson Island, Great Australian Bight). The sea sweep is a good candidate for future research using otoliths-based ageing techniques. Of the species considered here, this one was assigned the second lowest vulnerability index, similar to that of the western blue devil. Nevertheless, the estimate of maximum age is likely to increase with sample size, thereby impacting on the estimate of vulnerability index.

<u>Blue morwong</u>

Only a small number of fish were available to this study, of which the majority were successfully aged. The oldest fish was 21 years, which is older than those aged in a much more extensive study that was undertaken in Western Australia (Coulson *et al.* 2007). This is despite that none of the specimens aged here were particularly large, i.e. none were approaching the maximum size of around 100 cm TL. It is clear from the small number of fish processed that size-at-age is extremely variable (Coulson *et al.* 2007). This species was assigned a moderate level of vulnerability index.

Red mullet

Little information was gained from our analysis of the 11 specimens considered for this species. The interpretation of otoliths proved very difficult and no confident estimates of age were obtained. Ageing from otoliths for this species may yet be possible but it is suggested that larger fish be considered in the future. The lack of age-based parameters and information from the literature prevented the estimation of a vulnerability index.

Silver trevally

Only medium-sized specimens were available to this study with none approaching the maximum size of 80 cm TL. The otoliths were found to be largely uninterpretable, although assessment of those from larger fish in the future is recommended. A moderate vulnerability index was determined based on the age-based parameter estimates available in the literature.

Conclusions

The strength of conclusions from this study differed amongst the nine species, depending on the usefulness of their otoliths and the sample sizes available. For the western blue devil and harlequin fish the first age-based data were provided from good sample sizes collected across many months. The resulting data were invaluable for demonstrating the long-lived nature of both species. Otoliths also proved to be extremely useful for the red snapper, with the data substantiating that this also was a long-lived species. The swallowtail, a congeneric of the red snapper, had otoliths that were more challenging to interpret, which resulted in more otoliths being rejected. For the bluethroat wrasse, sea sweep and blue morwong the sample sizes were extremely limited, but the study at least demonstrated the tractability of using the otoliths in population-based studies. Alternatively, the low sample sizes and poor clarity of increments in the otoliths of red mullet and silver trevally meant that no useful biological data were collected. If opportunity was to arise for further population-based work on these two species a more thorough examination of the otoliths from a broader size range of fish, as well as consideration of other hard anatomical structures for ageing work, would be warranted.

Vulnerability indices were determined for eight of the nine species, based on the age-based data from this study or from the literature. The indices for all species were relatively high, i.e. comparable to such species as the orange roughy and southern bluefin tuna. The long-lived nature, slow growth rates of the various species and the relatively large maximum sizes of some species caused their high vulnerability indices. Even based upon maximum age alone, fish species with longevities of >40 years are considered to have a very high intrinsic vulnerability to fishing (Fig. 1e in Cheung *et al*. 2005). As demonstrated in this study, each of the red snapper, western blue devil and harlequin fish have maximum ages that exceed 40 years. Overall, the vulnerability indices from this study provide an early warning about the conservation status of these species for consideration in future discussions about marine conservation planning and management. Nevertheless, there is obviously no complete understanding of the population biology for any of the species. Further research activity is warranted on the determination of age-based characteristics, as well as on the reproductive biology of each species.

6.0 REFERENCES

Barrett, N.S. (1995) Short- and long-term movement patterns of six temperate reef fishes (Families Labridae and Monacanthidae). *Marine and Freshwater Research* 46(5): 853-860.

Beamish, R. and Fournier, D.A. (1981) A method for comparing the precision of a set of age determinations. *Journal of the Fisheries Research Board of Canada.* 36, 1395-1400.

Brown, L.P. and Sivakumaran, K.P. (2007). Spawning and reproductive characteristics of Bight redfish and deepwater flathead in the Great Australian Bight Trawl Fishery. Final report to Fisheries Research and Development Corporation Project No. 2003/003. Primary Industries Research Victoria, Queenscliff.

Cheung, W.W.L., Pitcher, T.J., and Pauly, D. (2005) A fuzzy logic expert system to estimate intrinsic extinction vulnerability of marine fishes to fishing. *Biological Conservation* 124:97-111

Cheung, W.W.L., Watson, R., Morato, T., Pitcher, T.J., and Pauly, D. (2007) Intrinsic vulnerability in the global fish catch. *Marine Ecology Progress Series* 333: 1-12.

Coulson, P.G., Potter, I.C., Hesp.A. and Hall, N.G. (2007) Biological parameters required for managing Western Blue Groper, Blue Morwong and Yellowtail Flathead. Final report to Fisheries Research and Development Corporation. Project No. 2004/057.

Currie, D.R., Dixon, C.D., Roberts, S.D., Hooper, G.E., Sorokin, S.J. and Ward, T.M. (2009) Fishery-independent by-catch survey to inform risk assessment of the Spencer Gulf Prawn Trawl Fishery. Report to PIRSA Fisheries. SARDI Research Report Series No. 390.

Edgar, G.J., Barrett, N.S. and Morton, A.J. (2004) Patterns of fish movement on eastern Tasmanian rocky reefs. *Environmental Biology of Fishes* 70(3): 273-284.

Farmer, B.M., French, D.J.W., Potter, I.C., Hesp, S.A. and Hall, N.G. (2005) Determination of biological parameters for managing fisheries for mulloway and silver trevally in Western Australia. Final report to Fisheries Research and Development Corporation. Project No. 2002/004.

Fowler, A.J. (1995) Annulus formation in otoliths of coral reef fish – a review. In: Secor DH, Dean JM Campana SE (eds). Recent developments in fish otoliths research. University of South Carolina Press, Columbia, pp 45-63.

Fowler, A.J. and Short, D.A. (1998) Validation of age determination from otoliths of the King George whiting *Sillaginodes puncata* (Perciformes). Marine Biology 130: 577-587.

Fowler, A.J. and McGarvey, R. (2000) Development of an integrated fisheries management model for King George whiting (*Sillaginodes punctata*) in South Australia. Final report to Fisheries Research and Development Corporation. Project No. 95/008.

Fowler, A.J. Lloyd, M. Schmarr, D. (2009) A Preliminary consideration of by-catch in the Marine Scalefish fishery of South Australia. South Australian Research and Development Institute SARDI Publication No. F2009/000097-1 SARDI Research Report Series No. 365.

Froese, R., and Pauly, D. (Eds) (2008) FishBase. Available at www.fishbase.org, version (12/2008).

Gomon, M., Bray, D. and Kuiter, R. (2008) Fishes of Australia's Southern Coast. Reed, New Holland, Sydney.

Heemstra, P.C. and Randall, J.E. (1999) Serranidae: Groupers and sea basses (also, soapfishes, anthiines, etc.). In: Carpenter, K. and Niem, V. (Eds.) FAO Species Identification Guide for Fishery Purposes. The Living Marine Resources of the Western Central Pacific. Volume 4. Bony Fishes Part 2 (Mugilidae to Carangidae). FAO, Rome. pp.2442-2473.

Hutchins, B. and Swainston, R. (2002) Sea fishes of southern Australia. Complete field guide for anglers and divers. Swainston Publ., Perth.

Knight, M., Tsolos, A. and Doonan, A.M. (2005) South Australian fisheries and aquaculture information and statistics report South Australian Research and Development Institute Henley Beach 79 p. SARDI Research Report Series No.67

Langley, A.D. (2004) Length and age composition of trevally (*Pseudocaranx dentex*) in commercial landings from the TRE 1 purse–seine fishery, 2002-2003. New Zealand Fisheries Assessment Report 2004/39.

Newman, D., Jones, P. and Laurenson, L. (2005), A preliminary examination of the diet and feeding of sea sweep *Scorpis aequipinnis* (Pisces: Scorpididae) from coastal waters of south-western Victoria, Australia. *Hydrobiologia* 533: 175-186.

Rowling, K.R. and Raines, L.P. (2000) Description of the biology and an assessment of the fishery for silver trevally (*Pseudocaranx dentex*) off New South Wales, NSW Final Report to Fisheries Research and Development Corporation. FRDC Project No. 97/125.

Russell, B.C. (1983) The food and feeding habits of rocky reef fish of north-eastern New Zealand. *New Zealand Journal of Marine and Freshwater Research* 17(2):121-145.

Shepherd, S.A. and Baker, J.L. (2008) Reef fishes of lower Gulf St Vincent. In: Shepherd, S.A., Bryars, S., Kirkegaard, I.R., Harbison, P., and Jennings, J.T. (Eds.) Natural History of Gulf St Vincent. pp. 297-316. (Royal Society of South Australia Inc.).

Smith, D.C., Montgomery, I., Sivakumaran, K.P., Krusic-Golub, K., Smith, K. and Hodge, R. (2003) The fisheries biology of bluethroat wrasse (*Notolabrus tetricus*) in Victorian Waters. Final report to Fisheries Research and Development Corporation. Project No. 97/128.

Stokie, T.K. and Krusic-Golub, K. (2005) Age estimation of Bight redfish and deepwater flathead in the Great Australian Bight Trawl Fishery, 2004/05. Final report to the Australian Fisheries Management Authority Project No. R04/1098. 28pp. Primary Industries Research Victoria, Queenscliff.