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Age Growth and Mortality Estimates of Stout Whiting, *Sillago robusta* Stead (Sillaginidae), from Southern Queensland, Australia

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Abstract

Samples of the Stout Whiting, *Sillago robusta*, were obtained for ageing purposes during a bi-monthly survey of fishing grounds between Sandy Cape and Caloundra in Southern Queensland. Fish size ranged from 66 to 232 mm fork length and maximum age was estimated to be 5+ years. Ageing protocols were validated by 3 methods: 1) establishing a relationship between otolith weight and age; 2) determining a single annual change in marginal composition; and 3) confirming uniformity in position of first annulus for otoliths of various age. There was no significant difference in the estimated growth parameters between the sexes and the pooled growth parameter estimates were: L = 222 ± 4 mm, k = 0.479 ± 0.042 and t_0= -1.272 ± 0.142. Annual commercial catch data from 1991 to 1995 was examined to establish age-based catch curves. The average instantaneous rate of total mortality (Z) calculated from these curves was 1.24 ± 0.20. Natural mortality (M) was estimated at 0.7 ± 0.2 by a variety of methods. The catchability coefficient (q) was estimated at 0.00146 ± 0.00024. The use of these biological reference variables in the management of the Stout Whiting trawl fishery is discussed.

Introduction

Stout Whitings, *Sillago robusta*, are caught in a limited-entry trawl fishery in southern Queensland. The fishery has been monitored since 1991. Annual exploitation levels, as negotiated by industry and the managing authority, have been based on population assessment models since 1996. Accurate catch-at-age data and mortality estimates underpin most stock assessment techniques because of the need to establish the numbers of fish in each age-cohort for each previous year. Errors in ageing or mortality estimates can bias recruitment estimates and lead to over-estimation of productivity (Hilborn and Walters 1992). This can lead to the over-estimation of optimal fishing mortality and under-estimation of optimum standing stock biomass. Thus, accurate age growth and mortality parameters are fundamental to a sound fisheries decision making process (Morales-Nin 1992).

Age assessment, using annuli in anatomical hard tissues such as scales, and otoliths (whole, cracked and burnt, and sectioned) has been documented for a range of sillaginid species (Cleland 1947, Camp 1954, Radhakrishnan 1954, Mio 1965, Krishnayya 1968, Maclean 1969, Lenaton 1969, Krishnamurthy and Kaliyamurthy 1981, Hobday and Wankowski 1986, Smith et al. 1987, Jones et al. 1990, McKay 1992, Reddy and Neelakantan 1992, Hyndes and Potter 1996a 1996b and 1997, Hyndes et al. 1998, Fowler and Short 1998). In the absence of absolute age determination, by methods such as oxytetracycline mark-recapture, validating the relationship between otolith growth and fish age can be corroborated in several ways. There should be a positive relationship between fish age and otolith size, consistency in the location of otolith annuli, and periodicity in ring formation across all age groups (Manooch and Potts, 1997). Fowler and Short (1998) used these techniques, as well as some mark-recapture data, to validate their age estimates of *S. punctata* from South Australian waters.

Several authors (Hobday and Wankowski 1986, Reddy and Neelakantan 1992, Hyndes and Potter 1996b and 1997, Hyndes et al. 1998, Fowler and Short 1998) have used length-at-age data of sillaginid fish to estimate their von Bertalanffy growth parameters, L_{∞} k and t_0. Wankowski and Moulton (1986) used the ratio of biomass to commercial catch estimates to estimate total mortality (Z) of the sympatric species, *S. flindersi*, in southeastern Australian waters. This was later reviewed and revised by Smith et al. (1987). However, there are no published mortality estimates for *S. robusta*.

This paper reports on age, growth and mortality estimates of *S. robusta* from east coast Australian waters. These estimates have been applied in stout whiting stock assessments in Queensland waters to assist in the decision making process for managing the stout whiting trawl fishery since 1996.

Materials and Methods

Ageing protocols

Samples of *S. robusta* were collected from bi-monthly fishery-independent trawl surveys carried out in 1993-1994 on the stout whiting trawl fishery grounds between Sandy Cape and Caloundra (Fig. 1). In the laboratory, length frequency measurements were taken from each sample after which five fish were randomly selected from each 5 mm size class and individually weighed (± 0.01g) and measured (±1 mm FL). Otoliths were collected from these fish, cleaned in alcohol and air dried. After a drying period of 2-3 weeks, the otoliths were individually weighed (±0.001g) then stored in marked 5 ml vials. All terminology used to describe the otoliths is based on Secor et al. (1995).

Otolith preparation

Preliminary investigations were conducted to examine the suitability of various interpretive techniques for estimating age from otoliths. A random sample of 47 otolith pairs was chosen from the fishery independent survey collection. A thin (~300μm) slice through the nucleus was taken from the left otolith of each pair, using a Buhler© Isomet saw, and mounted on a slide for polishing. Each whole otolith and section pair were aged in random order and the resulting ages for each compared.

Otolith reading

A sample of 1320 whole otoliths from all fish collected during the fishery independent survey were immersed in vegetable oil and examined under a low power microscope using natural and artificial illumination. Each otolith was read separately by two readers and assigned an absolute age, according to the number of discernible annuli, and a relative readability index (r.i.) ranging from 1 to 5 (Table 1). Both readers read all samples a second time after an interval of 4-10 weeks. At each reading the reader was provided with no information other than the sample's coded identification number. A discriminant analysis of the ageable versus non-ageable fish, examining depth at capture, length, weight, sex, gonad weight, gono-somatic index and otolith weight, was conducted to examine if there were any differences between these two populations.

Validation of age estimate interpretations

To investigate the relationship between otolith size and fish age, we used a sub-sample (n=708) of fish whose otoliths were unambiguous (r.i. >2). To obtain a relative age estimate, all aged fish were assigned a nominal birth-date (Jan 1) coinciding with the period of peak spawning activity. Relative ages were calculated by adding the time difference between nominal birth-date (decimal years) to the number of

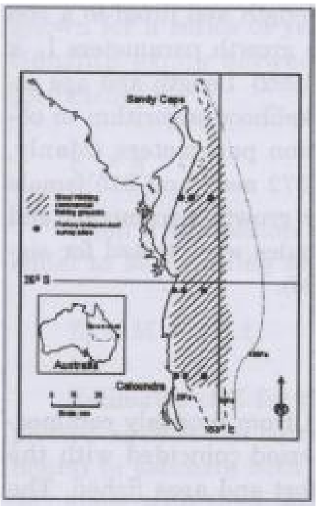

Fig. 1. Location of the commercial stout whiting trawl fishery: southern Queensland, Australia, with fishery-independent survey sites marked in black.

Table 1. Readability index (r.i.) for ageing *Sillago robusta* otoliths

r.i. Value	Definition
1	Internal Structure Visible, but no interpretation possible
2	Internal Structure Visible, but multiple interpretations possible
3	Internal Structure Visible, several interpretations possible, but confident that only one is plausible
4	Internal Structure Visible, little chance of mis-interpretation
5	Internal Structure Visible, only one interpretation possible

annuli. A range of polynomial models were then fitted to the otolith weight - relative age data to find the best fit.

We also investigated the distance from nucleus to the first annulus for a range of age groups (1+ to 4+). A random sub-sample (n = 332) of unambiguous otoliths (r.i. >2) was chosen from the collection. These were selected from all months in the year, and were examined under a light microscope linked to a computer with the image analysis package Optimas®. Measurements were then taken from the nucleus to the middle of the first annulus to establish the level of consistency in our protocols for ageing otoliths of various thicknesses/ages.

Finally, we analysed the temporal patterns of deposition of opaque or translucent material at the margin of the otolith to determine the periodicity of these structures. A sub-sample (n = 685) of otoliths with r.i. >2 was examined under a dissecting microscope at low power (10X) and a record was made of whether the margin was opaque or translucent. These were plotted as a proportion of the total bi-monthly sample against the time of year. Average monthly sea surface temperature data for Southeast Queensland waters ($26^0$30' S $153^0$30'E), obtained from the Australian Bureau of Meteorology, were plotted against the bi-monthly marginal increment data to determine whether there is a link between growth-check deposition and ambient water temperature.

Growth

Relative age estimates were plotted against fork length and fitted to a von Bertalanffy growth curve to obtain an estimate of the growth parameters L, k and t_0 using the software package PC-Yield II (Punt, 1992). Length and age estimates were then bootstrapped using a maximum likelihood algorithm to obtain 95% confidence intervals for the growth function parameters (Manly, 1997). The fork lengths and relative estimated age of 372 male and 215 female *S. robusta* were analysed separately to estimate their growth parameters and variances. The resulting estimates for males and females were tested for significance using the likelihood method of Kimura (1980).

Mortality

Length-frequency measurements were obtained from monthly commercial catch samples between 1991 and 1995. This period coincided with the era of expansion in this fishery, both in terms of effort and area fished. The total annual catch (t) from each vessel was also recorded. The data from these two sources were then used to build up an annual length-frequency distribution. Samples were also kept from the commercial catch for ageing as per the methods above. A random sub-sample (n = 400) of commercial sourced otoliths was examined each year to construct an annual age-frequency key, which was then applied to the length-frequency data to create a catch-at-age matrix. A weighted regression (by numbers caught) of catch-at-age was used to calculate annual estimates of the instantaneous rate of total mortality (Z) along with 95% confidence intervals (Beverton and Holt,1957).

Natural mortality (M) was calculated using the empirical methods of Rikhter and Efanov (1976) and Pauly (1980), as well as the regression method of Paloheimo (1961). Rikhter and Efanov (1976) demonstrated a strong correlation between natural mortality 'M' and 'T_{m50}', the size at which 50% of the population are mature, known as the age of massive maturation:

$$M = 1.521 / (T_{m50}^{0.720}) - 0.155 \text{ year}^{-1}$$

Pauly (1980) used a regression of 175 different fish stocks to derive an association between natural mortality 'M", the theoretical maximum size 'LÂ ',the Brody growth rate coefficient 'k' and the average seas surface temperature 'T' in degrees centigrade:

$$\ln M = -0.0152 - 0.279 \ln L\hat{A} + 0.6543 \ln K + 0.463 \ln T$$

Paloheimo (1961) investigated the relationship between fishing effort and Z. His method was based on the total mortality equation:

$$Z = F + M$$

where Z is total mortality, F is the fishing mortality and M is natural mortality. When annual estimates of total mortality Z_y and fishing effort f_y are known for a series of years 'y', and assuming that the following simple relationship exists between fishing mortality, effort and the catchability coefficient 'q':

$$F_y = q * f_y,$$

Then a regression of Z_y on f_y will have a slope of q and an intercept equal to M according to the relationship:

$$Z_y = M + q * f_y$$

Estimates of Z for the first 5 years of commercial fishing (1991-95) were plotted against the corresponding logbook derived annual fishing effort (in hours) to estimate both the catchability coefficient 'q' and natural mortality 'M', along with their 95% confidence intervals.

Results

Otoliths

A total of 1320 fish ranging from 66 to 232 mm (FL) and 2.55 to 108.70 g weight were examined in this study. Their otolith weights ranged from 0.032 to 0.197 g. The otoliths of *S. robusta* (Fig. 2) are similar to those of other sillaginids, having an identifiable nucleus, surrounded by a core of densely opaque material. In some otoliths irregularly spaced annuli were visible within the core. Likewise, several distinct opaque annuli were visible along the ventral anterior and posterior portions of the otolith. These annuli are visually enhanced when the otoliths were tilted towards the dorsal and ventral surface.

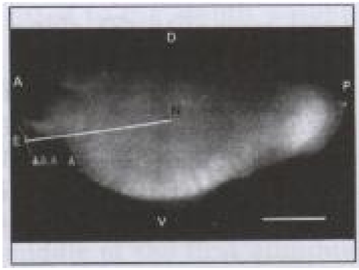

Fig. 2. Photograph of otolith from a large *Sillago robusta* (Fl: 207mm), showing the position (arrows) of four opaque (white) annuli. The line between N and E is the line used for 1st annulus analysis. A; anterior, D; dorsal, E; edge, N; nucleus, P; posterior, V; ventral. Scale bar = 1mm

Otolith preparation

Otoliths ranging in age from 0+ to 4+ years were used to compare the sectioned and whole otolith ageing techniques (n = 47). The estimated ages of sectioned otoliths were plotted against those from the corresponding whole otolith (Fig. 3). There were 10 cases where the ages derived from the two techniques disagreed and although the number of disagreements per age class increased with age, the difference was never greater than one year. Within each age-class, age estimates tended to be progressively lower for sectional otoliths than from whole otoliths as fish-length approached the maximum length for estimated age. Given the time involved in preparing sections, and the lack of any clear evidence that sections yielded more accurate age estimates than whole otoliths, a decision was made to age *S. robusta* using readings of whole otoliths.

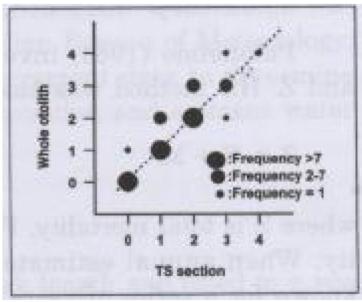

Fig. 3. Comparison of age estimates from whole and transverse section (TS) of sagittae from a sample of 47 *Sillago robusta* (*dotted line*; line of equal counts).

Otolith reading

The whole otolith pairs were read and assigned an age and a readability value. Over 65% (n=860) of these otolith pairs were assigned a r.i. >2 by both readers after the first reading with 86% agreement between the two readers. After a second reading, the level of agreement increased to >95% for the readable otoliths (r.i. >2). However, the level of agreement was <45% for unreadable otoliths (r.i. <3). A discriminant analysis of unambiguous age fish (r.i. >2) versus ambiguous age fish (r.i. <3) indicated a high degree of homogeneity between the two groups with respect to the population characteristics of depth at capture, length, weight, sex, gonad weight, gono-somatic index and otolith weight (Table 2). The maximum number of annuli observed on any otolith was five. Most (86.5%) had fewer than 3 annuli with 34.5% with none, 32% with 1, 20% with 2, 10% with 3, 3% with 4 and 0.5%

with 5. The average length-at-age for the estimated age groups is given in Table 3. There is a large confidence interval for the first age class as this included fish from 66 to 165 mm (FL), and in reality probably includes juveniles down to post-metamorphosis size.

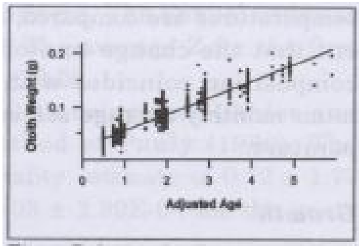

Fig. 4. Relationship between *Sillago robusta* otolith weight and adjusted age. Line of best fit is expressed as; otolith weight = 0.03*(adjusted age) + 0.02 (r^2 = 0.83. n=708).

Validation of age estimate interpretations

The correlation (Fig. 4) between *S. robusta* otolith weight and relative age was best explained by a linear equation (r^2=0.83). From a sample of 708 fish we found that otolith weight increased in proportion to relative age at the rate of:

$$\text{Otolith weight} = 0.03 * \text{relative age} + .02$$

Three hundred and thirty-two randomly chosen otoliths were examined to analyse the consistency of interpreting the radial distance to the first annulus. The estimated ages of these otoliths ranged between 1+ and 4+ (Fig. 5). The average position of the 1st annulus of the 1+ age group had the largest confidence interval, reflecting the extended spawning chronology of stout whiting. The average of all four year classes was 2.68 mm and there was no significant difference (P>0.99) in radial distance between age-classes.

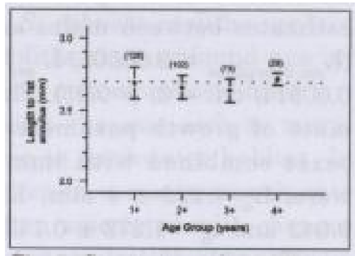

Fig. 5. Comparison of the distance from the nucleus to the 1st annulus on otoliths from *Sillago robusta* of various age classes. Sample size (n) is given in brackets above each data point.

The translucence of the marginal growth zone for age classes 0+ to 3+ (Fig. 6) showed a distinct seasonal trend. Older age classes (>4+) were not examined because of their small representation in each bi-monthly sample. Throughout the year, the otolith margin was predominantly translucent except in October when it was predominantly opaque. When the temporal patterns of marginal luminance and average southern Queensland sea surface

Table 2. Means and 95% confidence intervals for various population characteristics of *Sillago robusta* examined to investigate biological influence on readability.

Population Characteristic	r.i. >2	r.i. <2
Depth at capture (m)	21 ± 7	22.7 ± 7
Fork Length (mm)	171 ± 23	180 ± 23
Whole Weight (g)	51.7 ± 19.6	58.8 ± 19.6
Sex	1.45 ± 0.15	1.46 ± 0.15
Gonad weight (g)	1.07 ± 0.78	1.37 ± 0.78
Gonosomatic index	0.019 ± 0.01	0.02 ± 0.01
Otolith Weight (g)	0.09 ± 0.05	0.10 ±0.05

Table 3. Average length at age and confidence interval of *Sillago robusta*, derived from ageing whole otoliths.

Age class	Average length (mm) ± 95% Confidence Interval
0+	143 ± 22
1+	173 ± 15
2+	190 ± 14
3+	200 ± 17
4+	206 ± 10
5+	212 ± 3

temperatures are compared, it is apparent that the change in otolith margin composition coincides with the minimum monthly average sea surface temperature.

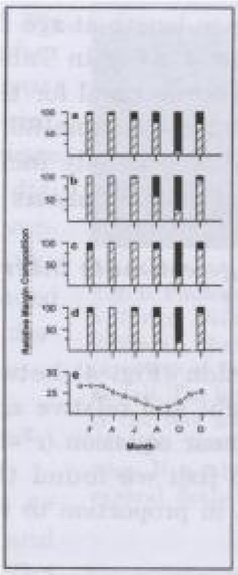

Fig. 6. *Sillago robusta* relative otolith margin composition between February and December: **a** formation of first opaque zone; **b** formation of second opaque zone; **c** formation of third opaque zone; **d** formation of fourth opaque zone; **e** mean sea surface temperature (^{0}C) at 26^{0}30' S, 153^{0}30'E (1994). Solid bar = opaque margin, hatched bar = translucent margin, (n = 685).

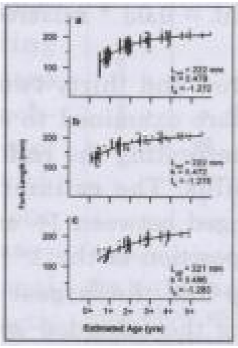

Fig. 7. Length-at-age data for, a; combined adults and juveniles (n = 708), b; males (n = 372), females (n = 215) *Sillago robusta*. Line represents optimum von Bertalanffy growth curve. Data were obtained from fishery independent survey samples.

Growth

The fitted von Bertalanffy growth curves for males and females separately and combined are shown in Figure 7. The Kimura (1980) likelihood ratio test did not reveal any significant differences in the growth parameter estimates between males and females ($L_{sex\text{-}dependant}$ = 0.00505, $L_{sex\ independent}$ = 0.00514, d.f. = 3, p>0.05). The best estimate of growth parameters for both sexes combined with immature fish were; L_∞ = 222 ± 4 mm, K = 0.479 ± 0.042 and t_0= -1.272 ± 0.142.

The L_{max} observed during this study was 232 mm.

Mortality

The proportion of older fish (>2 years) declined (Table 4) as annual catches increased between 1991 and 1994. In each of these years nearly 80% of the catch came from the 0+ and 1+ age-classes. In 1995, Industry actively targeted larger fish with 11% coming from the 3+, 4+ and 5+ age classes, although 70% still came from 0+ and 1+ age classes. The first age group (0+) was excluded from the calculation of the slope of the regression (Z) because it was not fully recruited. The corresponding Z estimates between 1991 and 1994 reflect the degree of effort, and thus catch as the fishery expanded. The Z estimate for 1995 is significantly lower (P > 0.05) than the

Table 4. Estimated total catch (t), proportion in each age class, and corresponding Z estimate (± 95% C.I.) of *Sillago robusta* each year between 1991 and 1995. Data is derived from the commercial logbooks, commercial catch length-frequency data, and age-length estimates. The 0+ age group was not used in the calculation of Z as it was not fully recruited.

	Catch	% 0+	% 1+	% 2+	% 3+	% 4+	% 5+	Z ± C.I.
1991	528	23	54	18	5	1	0	1.23 ± 0.18
1992	893	35	42	16	6	1	0	1.06 ± 0.17
1993	1000	31	47	17	5	1	0	1.32 ± 0.16
1994	1984	34	49	14	3	0	0	1.59 ± 0.12
1995	1996	19	52	19	8	2	1	1.00 ±0.13

1994 estimate, reflecting the change in fishing patterns. The annual estimate of Z varied between 1.00 (1995) and 1.59 (1994). The average Z for the first 5 years catch-at-age data (1991-1995) was 1.24 ± 0.20.

Natural mortality estimates ranged from 0.48 using the Rikhter and Efanov (1976)) method to 0.87 using the method of Pauly (1980). The method of Paloheimo (1961) gave a natural mortality estimate of 0.72 ± 1.77 and a catchability coefficient estimate of 1.46E-03 ± 2.39E-04 for the years 1991-95.

Discussion

The otolith of *S. robusta* is typical of sillaginid sagittae, consisting of alternating opaque and translucent bands. Like other sillaginids (Camp 1954, MacLean 1969, Fowler and Short 1998), *S. robusta* otoliths contain transition zones in the inner regions of some otoliths that confound age interpretation. Kalish et al. (1995) attribute these to metamorphosis from larval to juvenile stages or during significant habitat changes such as movement from pelagic to demersal habitat or marine to freshwater habitat. In sillaginids, these have been attributed to changes in somatic growth rate (Camp 1954, Krishnayya 1968, Gauldie 1990) often associated with changes in feeding patterns and diet when the fish were juveniles (MacLean 1969). Burchmore et al. (1988) reported differences in feeding strategies between juvenile and adult *S. robusta*, which they attributed to habitat partitioning between the two age groups. Habitat partitioning was also observed by Hyndes et al. (1996) and in our fishery-independent surveys. This is probably the primary source of the transition zones in the inner otolith.

Like other sillaginid otoliths, *S. robusta* otoliths thicken with increasing age, making age interpretation difficult and increasing the probability of under-estimating age (Beamish, 1979, Hoyer et al. 1985, Morales-Nin, 1992). However, the maximum observed age of *S. robusta* (5+) was less than that observed in most other sillaginid species recorded in the scientific literature, and both the results of Hyndes and Potter (1996a) and this study indicate that for ageing *S. robusta*, there is no improvement in using other methods.

To minimise reader bias, all otoliths were examined in random order in the absence of any ancillary information. Although there was up to 95% agreement between multiple readings of unambiguous *S. robusta* otoliths, this ageable portion comprised only slightly more than 65% of all the otoliths examined. However, there does not appear to be any real difference between *S. robusta* that could be confidently aged and those that could not. Most of the *S. robusta* examined in this study came from inshore areas that are less exposed to the seasonal temperature fluctuations caused by the East Australia Current (Harris 1993a, 1993b). Kelley (1988) noted that continuous growth can occur over winter in warmer environments resulting in no distinct annulus formation. We believe that *S. robusta* otolith annuli are often indistinct because of the relatively stable water temperatures in southern Queensland (e.g. 26.5^{0}C Jan 94, 21.2^{0}C Aug 94).

Age validation is essential to accurate age estimation and for accurate age interpretation, both otolith and fish growth must exhibit a continuous relationship (Fowler and Short 1998, Manooch and Potts 1997). However, the relationship between otolith growth and somatic growth is often complicated by factors such as ambient temperatures and available food resources. Slower growing fish often have larger otoliths than their faster growing cohorts (Schirripa and Goodyear 1997, Sirois et al. 1998). Three methods of age validation were examined in this study. Firstly, a simple linear regression best explained the relationship between *S. robusta* otolith weight and relative age, indicating a continuous relationship between the two. Secondly, interpretation of the position of the first annulus was constant among the first four age groups, indicative on a consistent interpretive protocol. Thirdly, a single annual cycle in marginal accretion was observed, coinciding with the spring months of the year in 0+ to 3+ age classes. Krishnamurthy and Kaliyamurthy (1981) reported similar otolith marginal patterns in *S. sihama* from tropical Indian waters. Hyndes and Potter (1996a) reported annulus formation on the otoliths of *S. robusta* and scales of *S. flindersi* from temperate West Australian waters (>31^0S) in summer. We conclude that increasing ambient water temperature and perhaps day lengths have a strong correlation with the time of annulus formation in *S. robusta*.

The growth parameter estimates obtained by Hyndes and Potter (1996a) and this study both indicate that *S. robusta* has no significant sexual dimorphism. However, there are differences in growth patterns between sub-tropical east-coast and temperate west-coast populations. Most of the *S. robusta* examined in both studies were <3 years old, and about 80% of growth had occurred by the third year. However, the maximum observed age, fork length, and k parameter in this study was 5 years, 232 mm and 0.479 respectively, whereas in Western Australia, these parameters were 6 years, 200 mm and 1.0. Hyndes and Potter (1996a) attributed their high growth rate estimate to the fact that *S. robusta* from Western Australian waters have four sympatric sillaginids. To decrease resource competition, west coast *S. robusta* do not use any inshore nursery areas and thus do not have a major off-shore migration in their life-cycle (Hyndes et al. 1996). In our fishery independent survey, most of the small *S. robusta* (<120 mm FL) were taken in shallow waters less than 0.5 nautical miles (nm) from the beach which would indicate that they are using the nearshore shallows as a nursery area before migrating offshore. Also, along the southern coast of Queensland, *S. flindersi* and *S. ciliata* are sympatric species. Each has a different peak spawning period (Kailola et al. 93), presumably to minimise resource competition. Hobday and Wankowski (1986) cited a maximum predicted size (L_∞ = 239 mm), and growth rate (k = 0.46) for *S. flindersi* from southeastern Australia. These parameters for temperate water *S. flindersi* are similar to those of subtropical *S. robusta* from Southeast Queensland waters. Hobday and Wankowski (1986) also estimated t_0 for *S. flindersi* at 0.5, compared to our predicted value of -1.2 for *S. robusta*. This difference may be a function of the disparate proportion of juvenile fish presented in each survey, as both species appear to have similar growth rates and maximum predicted sizes.

Estimates of Z change over time when variations in age structure occur. Usually this relates to changes in either F or M, although M is thought to be fairly constant through time unless there are major impacts on feeding guilds. Nevertheless, age structured catch curves are recognised as the least biased method for estimating Z (Hilborn and Walters 1992, Pauly et al. 1995) because they remove the seasonal influence of growth. As expected, the estimates of Z derived from the first four years of stout whiting fishery data obtained reflect the annual changes in F. By 1994 the fishery was spatially fully developed and the corresponding Z estimate was the largest recorded. However, in 1995, the fishery actively targeted larger fish and one of the impacts of this was the lowest Z estimate. Even if it is assumed that M is relatively stable over time, and that changes in Z reflect changes in F as a fishery develops, and to a lesser degree the dynamic influences of recruitment, consciousness of the impact of directed fishing activity on Z is very important. Wankowski and Moulton (1986) also used catch curve analysis to estimate total mortality of temperate water *S. flindersi*. Their estimates ranged from 1.2 when using fishery-independent survey data to 1.7 from commercial landing data. They attributed for this difference to the higher proportion of juveniles in their fishery-independent survey data.

Accurate estimates of M are notoriously difficult to obtain (Hilborn and Walters, 1992 Etim et al. 1999) because they rely on pre-fishery data that is often impossible to obtain. We examined a variety of methods to estimate M. However, none account for the targeting by fishers of particular size ranges. Rikhter and Efanov's (1976) relationship between size at first maturity and natural mortality has been found to be more appropriate for species from higher latitudes. Pauly's (1980) empirical formula of natural mortality fails to account for reproductive, ecosystem or behavioural changes such as schooling. Paloheimo's (1961) Z based regression method assumes that effort is always proportional to fishing mortality. While providing estimates of both M and q along with confidence intervals, its accuracy requires a substantial variation in effort data. It does not take into account the improvements in gear technology through time, nor migration of target species. Clearly, between 1991 and 1995, there has been substantial development in fishing effort, skipper experience and size-range targeting in the stout whiting fishery. However, as no single method of estimating M stands out from the others, it is prudent to use a combination of several to provide an indicative starting point. For stock assessment purposes, M was set at 0.7 ± 0.2.

Conclusion

The establishment of key management reference points for a fishery depends on industry expectations and adequate biological data with which to begin stock assessment modelling (Caddy and Mahon, 1995). In this paper, we have presented some biological reference variables for the stout whiting fishery during its developmental phase. They have had practical application in establishing initial management target reference points in this fishery.

These are expected to change as the fishery progresses and further data becomes available. The importance of these changes will be in understanding the underlying biological and economic causes.

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References

Beamish, R.J. 1979. Difference in age of Pacific hake (*Merluccius productus*) using whole otoliths and sections of otoiths. Journal of the Fisheries Board of Canada 36,141-151.

Beverton, R.J.H and S.J. Holt. 1957. On the dynamics of exploited fish populations. Chapman and Hall. Fish and Fisheries Series 11.

Burchmore, J.J., D.A. Pollard, M.J. Middleton, J.A. Bell and B.C. Pease. 1988. Biology of four species of whiting (Pisces: Sillaginidae) in Botany Bay, New South Wales. Australian Journal of Marine and Freshwater Research 39,709-727.

Caddy, J.F. and R. Mahon. 1995. Reference points for fisheries management. FAO Fisheries Technical Paper No. 347. Rome FAO. 83p.

Camp, M. 1954. Occurrence of growth rings on the otoliths of the Indian Whiting, *Sillago sihama* (Forskål). Current Science 6,196-197.

Cleland, K.W. 1947. Studies on the economic biology of the sand whiting (*Sillago ciliata* C & V). Proceedings of the Linnaeus Society of New South Wales LXXII,215-228.

Etim, L., P.E. Lebo and R.P. King. 1999. The dynamics of an exploited population of siluroid catfish (*Schilbe intermidius* Rupell 1832) in the Cross River, Nigeria. Fisheries Research 40(3),295-307.

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

Gauldie, R.W. 1990. How often is the von Bertalanffy-type length-at-age curve in fishes related to weight change artefacts interpreted as age rings in otoliths? Comparative Biochemistry and Physiology 96A (4),451-8.

Harris, P.T. 1993a. Near-bed current measurements from the continental shelf off Fraser Island, obtained during November-December, 1992. Ocean Sciences Institute, Technical Report No. 28.66p.

Harris, P.T. 1993b. Near-bed current measurements from the continental shelf off Fraser Island, obtained during June-July, 1993. Ocean Sciences Institute, Technical Report No. 30.53p.

Hilborn, R. and C.J. Walters. 1992. Quantitative Fisheries Stock Assessment: choice, dynamics and uncertainty. Chapman and Hall.

Hobday, D.K. and W.J. Wankowski. 1986. Age determination and growth of school whiting. Victorian Department of Conservation, Forests and Lands, Marine Sciences Laboratory internal report No. 130. 29p.

Hoyer, M.V., J.V. Shireman and M.J. Maceina. 1985. Use of otoliths to determine age and growth of largemouth bass in Florida. Transactions of the American Fishereis Society 114,307-309.

Hyndes, G.A. and I.C. Potter 1996a. Comparisons between the age structures, growth and reproductive biology of two co-occurring sillaginids, *Sillago robusta* and *S. bassensis*, in temperate coastal waters in Australia. Journal of Fish Biology 49(1),14-32.

Hyndes, G.A. and I.C. Potter 1996b. Relationships between the movements, growth, age structures and reproductive biology of the teleosts *Sillago burrus* and *S. vittata* in temperate marine waters. Marine Biology 126,549-558.

Hyndes, G.A. and I.C. Potter 1997. Age, growth and reproduction of *Sillago schomburgkii* in south-western Australia, nearshore waters and comparisons of life history styles of a suite of *Sillago* species. Environmental Biology of Fishes 49,435-447.

Hyndes, G.A., I.C. Potter and R.C.J. Lenanton. 1996. Habitat partitioning by whiting species (Sillaginidae) in coastal waters. Environmental Biology of Fishes 45,21-40.

Hyndes, G.A., M.E. Platell, I.C. Potter and R.C.J. Lenanton. 1998. Age composition, growth, reproductive biology and recruitment of King George whiting (*Sillaginodes punctata*) in south-western Australia. Fisheries Bulletin 96, 258-70.

Jones, G.K., D.A. Dall, K.L. Hall and A.J. Staniford. 1990. The South Australian Marine Scalefish Fishery. Green Paper p,58-85.

Kelley, D.F. 1988. Age determination in bass and assessment of growth and year-class strength. Journal of the Marine Biology Association of the United Kingdom 68,179-214.

Kailola, P.J., M.J. Williams, P.C. Stewart, A. McNee. and C. Grieve. 1993. Australian Fisheries Resources. BRR and FRDC. 422pp.

Kimura, D. 1980. Liklihood methods for the von Bertalanfy equation. Fisheries Bulletin 77(4),765-776.

Krishnamurthy, K.N. and M. Kaliyamurthy. 1981. Studies on the age and growth of sand whiting *Sillago sihama* (Forskål) from Pulicat Lake with observations on its biology and fishery. Indian Journal of Fisheries 25(1-2),84-97.

Krishnayya, C.G. 1968. On the use of otoliths in the determinations of age and growth of the Gangetic whiting, *Sillago panijus* (Ham. Buch.), with notes on its fishery in the Hooghly Estuary. Indian Journal of Fisheries 10(A),391-412.

Lenanton, R.C.J. 1969. Whiting fishery - Shark Bay. Western Australian Fishery Bulletin, FINS 2(1), 4-11.

McKay, R.J. 1992. FAO Species Catologue Vol.14. Sillaginid Fishes of the World. FAO Fisheries Synopsis No.125, Vol.14, 87p.

MacLean, J.L. 1969. A Study of the Biology of Winter Whiting, *Sillago maculata* (Quoy and Gaimard)in Moreton Bay. M.Sc. Thesis, University of Queensland.

Manly, B.F.J. 1997. Randomization, Bootstrap and Monte Carlo methods in biology. Chapman and Hall. 399 p.

Manooch, C.S. and J.C. Potts. 1997. Age, growth and mortality of greater amberjack from the southeastern United States. Fisheries Research 30,229-240.

Mio, S. 1965. The determination of the age and growth of *Sillago sihama* (Forskål). Bulletin of the Japan Sea Regional Fisheries Laboratory 14,1-18. (in Japanese with English summary)

Morales-Nin, B. 1992. Determination of growth in bony fishes from otolith microstructure. FAO Fisheries Technical Paper No. 322. 51 pp.

Paloheimo, J.E. 1961. Studies on estimation of mortalities. I. Comparison of a method described by Beverton and Holt and a new linear formula. Journal of the Fisheries Research Board of Canada 18(5),645-62.

Pauly, D. 1980. On the interrelationships between natural mortality, growth parameters and mean environmental temperature in 175 fish stocks. Journal du Conseil CIEM 39(2),175-92

Pauly, D., J. Moreau and N. Abad. 1995. Comparison of age-structured and length-converted catch curves of brown trout *Salmo truta* in two French rivers. Fisheries Research 22,197-204.

Punt, A.E. 1992. PC-Yield II User's Guide (versions 2.2). Benguela Ecology Programme, Report No. 26. 36p.

Radhakrishnan, N. 1954. Occurrence of growth rings on the otoliths of the Indian whiting, *Sillago sihama* (Forskål). Current Science 23(6),196-197.

Reddy, C.R. and B. Neelakantan. 1992. Age and growth of Indian whiting, *Sillago sihama* (Forskal) from Karwar waters. Mahasaga 25(1),61-64.

Rikhter, V.A. and V.N. Efanov. 1976. On one of the approaches to estimation of natural mortality of fish populations. ICNAF Res. Document 76/VI/8,12p.

Schirripa, M.J. and C.P. Goodyear. 1997. Simulation of alternative assumptions of fish otolith-somatic growth with a bioenergetics model. Ecological Modelling 102,209-223.

Secor,D.H., J.M. Dean and S.E. Campana.1995. Recent developments in fish otoliths research. University of South Carolina Press. 735p.

Sirois, P., F. Lecomte and J.J. Dodson. 1998. An otolith-based back-calculation method to account for time-varying growth rate in rainbow smelt (*Osmerus mordax*) larvae. Canadian Journal of Fisheries and Aquatic Science 55,2662-2671.

Smith, D.C., D. Huber and M.E. McGuren. 1987. Assessment of the New South Wales Redspot whiting Fishery. New South Wales Fishereis Department Internal Reprot No. 29,23p.

Sparre, P., E. Ursin and S.C. Venema. 1989. Introduction to tropical fish stock assessment. Part 1. Manual. FAO Fisheries Technical Paper. No. 306.1. Rome, FAO 337p.

Wankowski, J.W.J. and P.L. Moulton (1986) Distribution, abundance and biomass estimates of commerically important demersal fish species in eastern Bass Strait, Austalia. Victorian Department of Conservation, Forests and Lands: Marine Science Laboratory Internal Report No. 62. 57p.

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