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REDBAIT (*EMMELICHTHYS NITIDUS*): A SYNOPSIS OF FISHERY AND BIOLOGICAL DATA.

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Executive Summary

A mid-water trawl fishery targeting small pelagic fishes was developed off Tasmania in 2001. A large proportion of the catch from this fishery consisted of redbait (*Emmelichthys nitidus*). To aid in management of this fishery and to develop priorities for future research, this report reviews and summarises available fishery and biological data.

Information was drawn from three main sources:

- A review of the available literature relating to redbait and other species in the family Emmelichthyidae.
- Fishery and biological data for redbait derived from the purse seine fishery (1984-94), research trawling (1985-90) and commercial mid-water pair-trawling (2001-02), off the coast of Tasmania.
- An examination of otolith structure of fish sampled from 1984-2001 to provide preliminary estimates of age and growth.

Redbait is a geographically widespread pelagic fish, distributed over the continental shelf break of Africa, Australia and South America. They are also found in association with seamounts, islands and mid-oceanic ridges in the south-west Atlantic, Indian and south Pacific Oceans. Despite being fished commercially throughout its range, for human consumption, bait and for fish meal, little is known of the biology and ecology of the species.

Emmelichthyids in general have distinct spawning seasons of one to two months' duration, generally coinciding with increasing water temperatures in spring. Redbait school by size and by depth, with smaller fish being captured in shallower water. Studies of the diet of redbait reveal a heavy reliance on large planktonic crustaceans, particularly krill. In turn, they are known to be an important prey species for seabirds, seals and tunas in Tasmanian waters.

Studies of the interactions between small pelagic species, such as jack mackerel, and the complex oceanography of the east coast of Tasmania show changes in behaviour and availability with changes in water temperature and productivity of planktonic food webs. The ecology and biology of redbait suggests that it will be no different to jack mackerel in this respect.

Available size composition information for redbait from Tasmanian waters was spread unevenly between months and years, with the purse seine fishery limited to the capture of fish schooled near the surface during spring, summer and early autumn. Similarly, too few samples were collected from research trawling and mid-water pair-trawling to be considered representative of population size structure. Nevertheless, a similar range of sizes of redbait was taken by all fishing methods, with fish from 100-300 mm FL making up the greatest majority of the catch.

Seasonal patterns of gonad development indicated an apparent peak of spawning activity around October-November, though no running ripe fish have been examined to date. Based on gonad maturity stage, 50% of females were judged to be sexually mature at about 240 mm FL, implying that commercial purse seine and mid-water trawl catches were dominated by immature fish.

An ageing protocol was developed for redbait, based on translucent and opaque zones visible in thin transverse otolith sections. Otolith microstructure from small redbait, including micro-increments, was investigated to infer the position of zones representing seasons of rapid and slower growth, and hence allocate fish to putative year classes. Assuming one opaque and one translucent zone was deposited each year (this was not validated), maximum age was estimated as 8+ years. Growth models based on size at age were generated using the von Bertalanffy growth function. Growth in redbait was rapid, with mean sizes at 1, 3 and 5 years old estimated as 155, 245 and 273 mm FL respectively. No sex based growth differences were evident.

To further explore patterns of seasonal otolith growth, marginal increment analysis was attempted. No clear pattern of otolith growth was evident, potentially due to small sample sizes and absence of samples from the colder months of the year. Consistency of otolith interpretation was compared within and between readers, and generally resulted in a high level of agreement between age estimates. The largest discrepancies were found in the oldest fish, indicating that careful interpretation of the narrow zones formed at the otolith margins by older fish was necessary for redbait ageing.

From the analysis of the literature and available data, it was evident that several directions of future research were essential for the furthering of our knowledge of redbait ecology and biology, with a view to stock assessment and management of the fishery. These included:

- Analysis of size and age distribution of catch data, with regard to geographic position, time of day, season, and habitat variables such as water temperature, and depth.

- More detailed characterisation of the reproductive biology of redbait, in particular information on fecundity and better estimates of timing of spawning and maturity.

- Development of a validated ageing method, refinement of growth models, and generation of estimates of age-class strengths and mortality rates.

- Investigation of the diet of redbait, with a view to understanding the role of redbait in the pelagic food web and how redbait interact with predators and prey.

- The distribution, growth and development and diet of early life stages of redbait and their contribution to dynamics of the fished population.

- A method to produce robust biomass estimates of the Zone A redbait stock, with a view to evaluating the appropriateness of current output controls. Contingent on the description of the reproductive biology and early life history of redbait, the egg production method may be the most appropriate method to produce biomass estimates for this species in a relatively short time frame.

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1. Literature review

1.1 Biology

1.1.1 Taxonomy and distribution

The family Emmelichthyidae comprises sixteen described species in three genera (Heemstra and Randall 1977; Parin 1991). Emmelichthyids are widespread, found throughout tropical and temperate waters in both hemispheres. They are generally found in schools over continental shelf breaks, seamounts and submarine ridges. They inhabit depths from the surface to in excess of 800 m, though they are mostly recorded from mid-water trawls in 100-400 m water (Heemstra and Randall 1977; Markina and Boldryev 1980; Last *et al.* 1983; Nor *et al.* 1985; May and Maxwell 1986; Smith and Heemstra 1986; Mel'nikov and Ivanin 1995; Parin *et al.* 1997).

Redbait (*Emmelichthys nitidus* Richardson, 1845) are one of two species of emmelichthyid reported off Tasmania, the other being the rubyfish (*Plagiogeneion rubiginosum*) (Last *et al.* 1983; May and Maxwell 1986; Gomon *et al.* 1994). Redbait are also widely distributed throughout the southern hemisphere, with the species reported from Tristan da Cunha in the southern Atlantic, the south-western coast of South Africa, St Paul and Amsterdam Islands, mid-oceanic ridges and seamounts through the Indian Ocean, the Great Australian Bight and south-eastern Australia, New Zealand, submarine ridges in the south-eastern Pacific, and the southern coast of Chile (Heemstra and Randall 1977; Markina and Boldryev 1980; Meléndez and Céspedes 1986; Oyarzún and Arriaza 1993; Parin *et al.* 1997).

1.1.2 Reproduction and early life history

Reproductive parameters have been reported for redbait from seamounts in the Indian Ocean (Roschin 1985). Spawning is apparently brief, with running ripe fish only present in August, and restricted to only a portion of the mature population each year. Sex ratios were approximately 1:1. Analyses by Roschin (1985) did not include any determination of size at maturity.

Rubyfish, a southern hemisphere emmelichthyid with a similar geographical distribution to redbait, is reported to spawn during winter-spring in the southern Indian Ocean, maturing at around 240 mm standard length (SL) (Mel'nikov and Ivanin 1995). *Erythrocles schlegelii,* an emmelichthyid from the subtropical west Pacific, reaches a maximum female gonosomatic index of approximately 9% of body weight during winter, and spawning occurs in several batches (Nor *et al.* 1985). Size at maturity in *E. schlegelii* is similar in both sexes, occurring at 210-220 mm (Nor *et al.* 1985).

Little is known about the early life history (i.e. eggs, larvae, post-larvae) of emmelichthyids in general, and no information is available on the early life history of redbait. Larvae of *E. schlegelii* are planktonic and have been reported in the waters off Taiwan during the northern hemisphere summer (Hsieh and Chiu 2002). Unspecified emmelichthyid larvae have been found to be associated with drift algae in coastal waters off northeastern New Zealand (Kingsford 1992).

1.1.3 Age and growth

The maximum reported size of redbait from Tasmania is 316 mm fork length (FL) (Williams *et al.* 1987), somewhat smaller than that recorded elsewhere throughout the distributional range. Redbait have been confirmed to grow to 335 mm FL off eastern Victoria (Furlani *et al.* 2000), 344 mm SL off the coast of Chile (Meléndez and Céspedes 1986) and individuals of 493 mm total length (TL) and possibly larger have been caught in South African waters (Heemstra and Randall 1977; Meyer and Smale 1991). Redbait are observed to school by size class, and also stratify by depth, with larger (>200 mm) redbait often found deeper and closer to the seafloor than schools of smaller fish (Markina and Boldryev 1980).

Estimates of growth for redbait, derived from either interpretation of scales (Roschin 1985) or whole otoliths (Williams *et al.* 1987), suggest that it is rapid in the first years of life. Williams *et al.* (1987) reported that redbait from Tasmanian waters reached a mean FL in excess of 200 mm in the first three years, with growth slowing thereafter. These authors also estimated a maximum age of at least seven years. A maximum age of 10 years old was estimated from otolith analyses of redbait captured in eastern Victorian waters (Furlani *et al.* 2000). The much larger redbait reported from Africa (e.g. Meyer and Smale 1991) indicate that maximum age in this species may be older than suggested from Tasmanian or Victorian samples, or that growth is highly variable regionally.

Unvalidated ageing of rubyfish in New Zealand, using thin otolith sections, has produced age estimates in excess of 80 years for fish over 400 mm (Paul *et al.* 2000), indicating that some emmelichthyids may be long-lived. However, as ageing methods have not been validated for any emmelichthyid species, current estimates of growth or maximum age may not be reliable.

1.1.4 Trophic interactions

A study of the diet of redbait in South African coastal waters indicated that the smaller size classes (136-280 mm) feed exclusively on small planktonic crustaceans, with euphausiids (*Nyctiphanes* and *Euphausia* spp.), hyperiid amphipods (primarily *Themisto gaudichaudi*), mysids and large copepods accounting for the entire diet (Meyer and Smale 1991). Larger individuals (281-493 mm) also feed for the most part on small planktonic crustaceans, but nekton such as cephalopods, carid shrimp, and small fishes including myctophids, also constituted a component of the diet (Meyer and Smale 1991). Redbait of unspecified size captured on the shelf off eastern Victoria had a varied diet, dominated by pelagic crustaceans and other pelagic invertebrates including gelatinous zooplankton (Bulman *et al.* 2000; Bulman *et al.* 2001).

The diet of redbait shows parallels with that of jack mackerel (*Trachurus declivis*) from Tasmania, with the krill *Nyctiphanes australis* representing the dominant prey item eaten by fish on the continental shelf (Young *et al.* 1993). Since redbait, jack mackerel and blue mackerel (*Scomber australasicus*) form mixed species schools in Tasmanian waters (Williams and Pullen 1993) it is likely that these species feed on similar prey species.

Redbait comprise a large component of the diets of some larger marine animals. Together with jack mackerel and arrow squid (*Nototodarus gouldii*), redbait formed the bulk of the diet of southern bluefin tuna (*Thunnus maccoyi*) caught on the Tasmanian continental shelf (Young *et al.* 1997). Redbait also constitute a significant part of the diet of albatross (*Thalassarche cauta*) (Hedd and Gales 2001), gannets (*Sula serrator*) (Brothers *et al.* 1993) and Australian fur seals (*Arctocephalus pusillus*) (Gales and Pemberton 1994).

1.1.5 Climatic and oceanographic interactions

The oceanography of the east coast of Tasmania is complex, with temperature, salinity and nutrients showing large fluctuations in space, by season and between years (Harris *et al.* 1987; Harris *et al.* 1988; Harris *et al.* 1992). In this region, the East Australian Current (EAC), a shallow tongue of warm, stratified, nutrient poor water from the northeast meets cooler, nutrient rich water from the southwest forming the subtropical convergence (STC). The position of the STC varies seasonally, with the EAC generally intruding further south in summer and autumn and retreating north in the cooler months (Harris *et al.* 1987). Further variability in the position of the STC is brought about by the climatic cycle of El Niño/Southern Oscillation (ENSO) events (Harris *et al.* 1987). During El Niño years, high westerly wind stress through spring and summer occurs, resulting in a greater influx of cooler, nutrient rich waters on the continental shelf and increased vertical mixing of the water column, prolonging the spring bloom (Harris *et al.* 1991; Harris *et al.* 1992). Conversely, during La Niña years, reduced westerlies and stronger EAC influence may result in the STC reaching further south. This results in nutrient poor warm water flooding the shelf, significantly reducing inshore phytoplankton productivity (Harris *et al.* 1991).

These climatic and oceanographic phenomena propagate through the food web to affect the behaviour of small pelagic fishes and their availability to the fishery. For example, the La Niña year of 1988-89 saw decreased primary productivity inshore due to the intrusion of EAC water onto the shelf (Harris *et al.* 1991; Harris *et al.* 1992). Surface swarms of krill (*Nyctiphanes australis*) did not form and so few surface schools of jack mackerel were available to the purse seine fishery (Harris *et al.* 1991; Harris *et al.* 1992; Young *et al.* 1993). This resulted in a landed catch of less than 9,000 t, down from nearly 38,000 t the previous year (Pullen 1994a). Furthermore, jack mackerel are thought to rely on krill to generate large fat reserves that are mobilised during the following spawning season to produce gametes (Williams and Pullen 1986). These fat reserves peak in autumn (Williams and Pullen 1986; Jordan *et al.* 1992), concurrent with peaks in krill swarms on the surface (Young *et al.* 1993). A likely result of the failure of krill swarms to form in 1988-89 was the subsequent and dramatic reduction in jack mackerel egg production in 1989-90 relative to previous years (Jordan *et al.* 1995).

The relationships between fluctuations in the pelagic habitat and redbait biology and behaviour has not been quantified. However, due to the parallels between the biology of redbait and jack mackerel, it is likely that redbait stocks may exhibit large fluctuations in abundance, behaviour and availability, tracking variations in oceanographic conditions and food availability at a range of spatial and temporal scales.

1.2 Emmelichthyid fisheries

1.2.1 Worldwide fisheries

Emmelichthyids support commercial fisheries throughout their geographic range, being used for human consumption, bait or fishmeal. They are targeted by trawling operations, with the majority of catch taken by vessels from states formerly in the USSR (Russian Federation, Georgia and Ukraine), South Africa, Australia and New Zealand (Anon. 2001). Redbait are the dominant species reported, with annual catches in the range of 1,800 – 3,000 t between 1995-1999 (Anon. 2001).

Catches of 250 – 600 t per year of rubyfish are taken by demersal trawl off northeastern New Zealand, about one third as a result of targeted fishing operations and the remainder as by-catch in other mid-water and bottom trawl fisheries (Paul 1997; Annala *et al.* 2002). Rubyfish are managed within the New Zealand quota management system, with the total allowable commercial catch currently set at 577 t (Annala *et al.* 2002).

To the authors' knowledge there are no formal stock assessments or biomass estimates for any emmelichthyid species with the exception of a yield estimate based on prior catch history for New Zealand rubyfish (Paul 1997).

1.2.2 The Tasmanian jack mackerel fishery

The Tasmanian jack mackerel purse seine fishery developed through the mid- to late 1980's, becoming the largest fishery in Australia by weight (Kailola *et al.* 1993), before dramatic reductions in catches in 1988-89[1] and resultant financial problems for the industrial fishery (Pullen 1994a). Large-scale purse seine operations for jack mackerel continued up to 1999-2000, with landings showing large year-to-year fluctuations, but an overall downward trend in production from the late-1980s (Fig. 1). The majority of the jack mackerel catch, along with a bycatch of redbait and blue mackerel, was processed at plants in Triabunna (mid east coast of Tasmania) for fish meal and oil for aquaculture feed, with small quantities frozen for rock lobster bait, processed for human consumption or canned as pet food (Pullen 1994a). In 1992-93, a consignment of jack mackerel was frozen and used as feed for farmed southern bluefin tuna in South Australia (Pullen 1994a).

In 2001-02 a fishing trial involving a mid-water pair-trawl operation was established to target subsurface schools of jack mackerel. Catches were in fact dominated by redbait, with a total of 4,600 t of redbait taken between December 2001 and April 2002. On the strength of this trial, a multipurpose 50 m mid-water trawler/purse seiner was brought to Tasmania to target small pelagic species, including redbait, with fishing operations commencing in late 2002. The primary market for redbait is currently as whole frozen

[1] The Tasmanian pelagic fishing season is defined as August to the following July.

fish for the southern bluefin tuna aquaculture industry and secondarily for use as fish meal.

Management of the small pelagic fishery off the central west, south and east coasts of Tasmania (Zone A) is currently under review, though it is intended to establish a joint management authority between Tasmania and the Commonwealth and manage the fishery under Tasmanian law. Current interim management arrangements involve a total allowable commercial catch of 34,000 t of small pelagics in Zone A for the 2002-03 season.

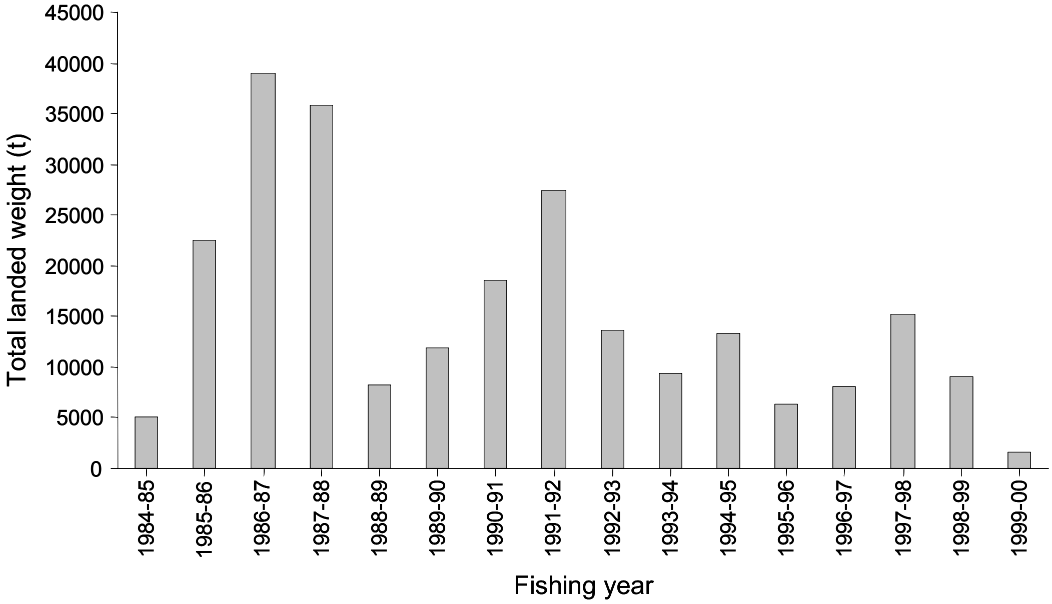

Fig. 1. Annual landings of all small pelagic species reported from the Tasmanian jack mackerel fishery, from the 1984-85 to the 1999-2000 fishing year.

2. Summary of data derived from sampling of redbait in Tasmania

2.1 Data sources

Commercial operators participating in the purse seine fishery have been required to complete logbooks recording catch and effort since the fishery commenced (1984). The initial logbook comprised a shot by shot record of fishing operations, including species breakdown. This was replaced for the 1990-91 fishing year with a trip catch return, in which catch composition was not routinely reported. Pair-trawl operations (2001-02) were reported in the Commonwealth South East Fishery trawl logbook, providing a shot by shot record of catch and effort, including catch composition.

As an adjunct to research attention directed at jack mackerel, fishery dependent length frequency and biological data on redbait was collected opportunistically between 1984 and 1993 by the then Department of Sea Fisheries (DSF). Biological information was also collected from samples of redbait collected from demersal research trawling conducted by CSIRO and DSF between 1985 and 1990. Length frequency data consisted of samples of fish measured for fork length (FL) rounded down to the nearest centimetre. More detailed biological data was collected from individual specimens and included FL (to the nearest millimetre), total weight (to the nearest gram), sex, gonad developmental stage (following the macroscopic staging criteria described in Marshall *et al.* 1993) and gonad weight (to the nearest 0.1g). Otoliths were also extracted, with a small sub-sample used for age estimation and growth modelling (Williams *et al.* 1987).

Between 1994 and 2001 there was effectively no scientific catch sampling of the purse seine fishery. Following the commencement of pair-trawl operations in 2001, the Australian Fisheries Management Authority (AFMA) provided observer coverage of operations, and some redbait, jack mackerel and blue mackerel length frequency data and biological specimens were collected.

Commercial logbook information, length frequency and biological data collected over the period 1984-95, along with information collected during the recent pair-trawl fishing trial (2001-02), were available for the present review. In addition, as part of this review otoliths from the archive housed at the Marine Research Laboratories were sectioned and interpreted to produce un-validated estimates of age and growth.

2.2 Catch history

Catch statistics from the Tasmanian small pelagic fishery, reported by species, were only available between 1984-85 and 1989-90. Species-specific catch composition was not routinely recorded after 1990, and hence catch history for redbait is incomplete.

Purse seine catches of redbait peaked at about 1,300 t in 1986-87 (Fig. 2), in the same year that record quantities (almost 40,000 tonnes) of jack mackerel were landed. Redbait represented the primary by-catch species taken by the purse seine fishery, though as a small proportion of the total landed catch, rarely exceeding 5% of the catch by weight.[2] By contrast, mid-water pair trawling operations in 2001-02 yielded a total landed weight of just over 5,000 t, of which almost 90% was redbait. As such, the 2001-02 redbait catch represents the highest recorded for the species.

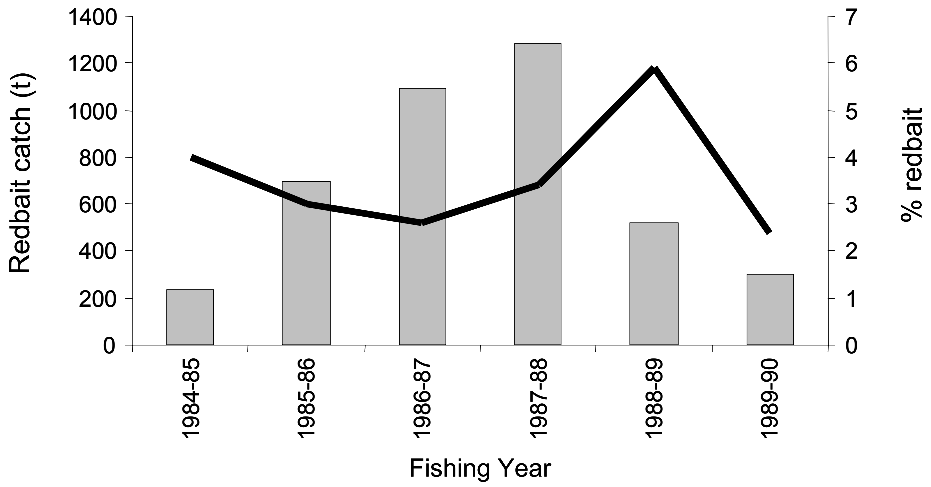

Fig. 2. Total landed weight of redbait (columns) and percentage of redbait in the total annual purse seine catch (line) from the 1984-85 to the 1989-90 fishing year.

During the purse seine fishing season, redbait catches peaked between February-June (Fig. 3), with a maximum of 592 t taken in a single month (April 1987) (Williams *et al.* 1987; Pullen 1994a;b). As a proportion of the overall purse seine catch, the redbait component peaked at about 5% in March, with lows in February and June of around 3% (Fig. 3). These observations do not provide strong evidence for seasonal variability in abundance; rather they more likely a reflection of the February to May period of peak purse seine activity.

[2] Purse seine vessels actively targeted jack mackerel surface schools and thus redbait catches reported for 1985-1990 only reflect the relative abundance of redbait in these surface schools.

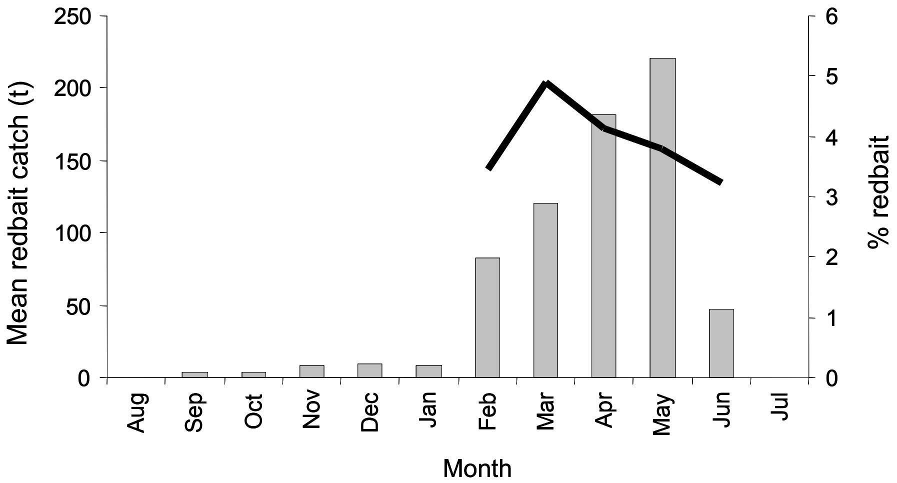

Fig. 3. Mean monthly catches of redbait (columns), and percentage of redbait in the combined monthly purse seine catch over the period 1984-85 to 1989-90 (lines). Catch proportions in months other than Feb-June have been excluded due to low overall catch levels.

2.3 Length frequency data

Data collected between 1984-85 and 1993-94 were derived from catch sampling during commercial purse seining activities and demersal research trawling. Data collected in 2001-02 result from commercial fishing using a mid-water pair-trawl. Sample sizes were generally small and samples were not available from all months within any given year (Tables 1 and 2). The majority of purse seine samples were restricted to between January-May across most years reflecting a lack of purse seine fishing effort during the colder months and reduced availability of schooling redbait to purse seining until late summer and autumn (Pullen 1994a).

Collection of biological specimens over the 2001-02 fishing season was undertaken on a small proportion of all trips (Table 2), so it is unlikely that the data from that year were fully representative of the redbait taken in the mid-water trawl fishery. Pair-trawling operations ceased in April 2002.

Table 1. Samples sizes (number of individuals) measured for length frequency distributions from the purse seine fishery (1984-94), broken down by calendar month within fishing years

X = months where redbait were landed, but no length frequency data was collected. No information on commercial redbait landings was available after 1989-90.

Fishing year	Aug	Sep	Oct	Nov	Dec	Jan	Feb	Mar	Apr	May	Jun	Jul
1984-85								×	200	146	16	
1985-86				50		50	150	50	247	200		
1986-87		×	68	50	100	5	84	201	138	150		
1987-88	100					×	100	194	50	263	100	
1988-89		100					27	55	×	100	×	
1989-90				100	×	×	×	×	×	×		
1990-91						20	150					
1991-92						96	148			329		
1992-93						20	170					
1993-94				90	100				100			

Table 2. Samples sizes (number of individuals) measured for length frequency distributions from research trawling (1985-86 to 1989-90) and commercial mid-water pair-trawl operations (2001-02), broken down by calendar month within fishing years.

X = months where redbait were landed but no length frequency data was collected.

Fishing year	Aug	Sep	Oct	Nov	Dec	Jan	Feb	Mar	Apr	May	Jun	Jul
1985-86									69	50	250	
1987-88							11					
1988-89	100	60	30	58				112				
1989-90										40		
2001-02					1685	×	×	165	×			

2.3.1 The purse seine fishery: 1984-1994

2.3.1.1 Length frequency by fishing season

The majority of redbait taken by the purse seine fishery measured between 150 and 300 mm FL, with individuals up to 310 mm FL (Fig. 4). Length frequency distributions were generally unimodal with the exception of 1988-89, when distinct modes of small (120-180 mm FL) as well as large (200-280 mm FL) fish were present (Fig. 4). Between 1984-85 and 1988-89 catches were characterised by fish in the 200-300 mm

FL size range, whereas between 1989-90 and 1993-94 few fish larger than 250 mm were recorded. Very small fish (less than 150 mm FL) were generally rare but did dominate catches in 1988-89 (Fig. 4).

Between 1988-89 and 1991-92 there was some evidence of a length mode that could be isolated and tracked through the length frequency data from one year to the next. That is to say there was evidence of modal progression from 150 mm FL in 1988-89 through to the mode at 175 mm, 210 mm and 220 mm FL in the following three fishing years (Fig. 4). However sample sizes were too small and unevenly spread through time within each fishing year (Table 1) to make any strong conclusions about growth by this method alone.

The causes of the observed shift in the size structure of catches to smaller fisher over the history of the purses seine fishery are unclear, but such a pattern may be consistent with the changes expected from exploitation of fish populations. However, any such conclusion is confounded since it is not possible to determine how representative the sampling was of the purse seine catch, nor how representative the purse seine catch was of the overall redbait population.

2.3.1.2 Length frequency by month

Length frequency data pooled by month did not reveal any evidence of modal progression that could be linked to growth (Fig. 5). There was a tendency for samples collected between August and February to be dominated by fish smaller than about 250 mm FL, whereas between March and June there was a greater representation of size classes >250 mm FL. Particularly small fish, of 150 mm FL and smaller were evident in September, February and March samples. The September data was however drawn from a single sample. The significance of the variability in size composition in relation to possible structuring processes within the redbait population (e.g. growth over a fishing season) is uncertain. A more robust sampling regime is required to address factors influencing stock structure or availability of redbait to the fishery.

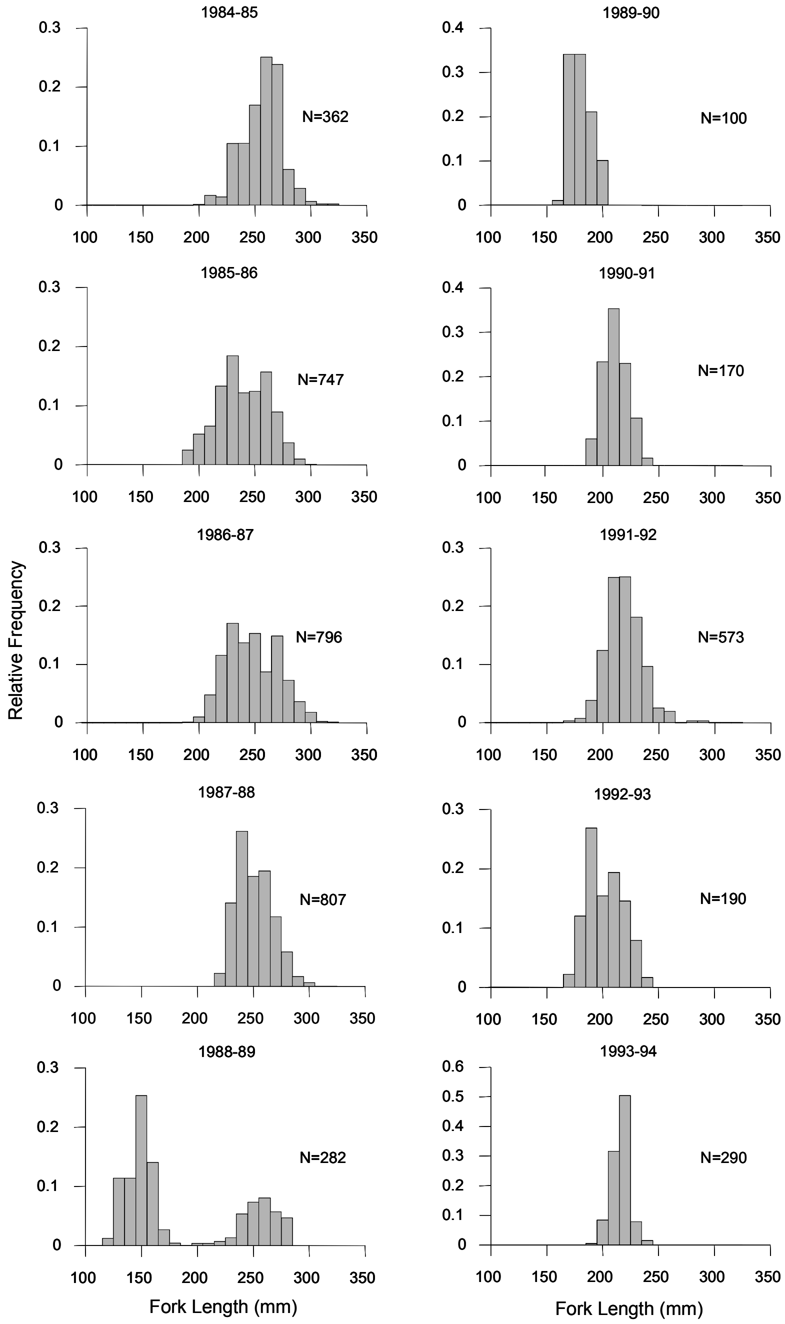

Fig. 4. Length frequency distributions of redbait captured by purse seine, 1984-85 to 1993-94. Frequencies are by 10 mm size classes (fork length, rounded down to the nearest size class), within fishing seasons (August - July). Distributions are adjusted to give equal influence to data from each sampling dates within a season, independent of sample sizes. N = total number of individuals measured within a fishing season.

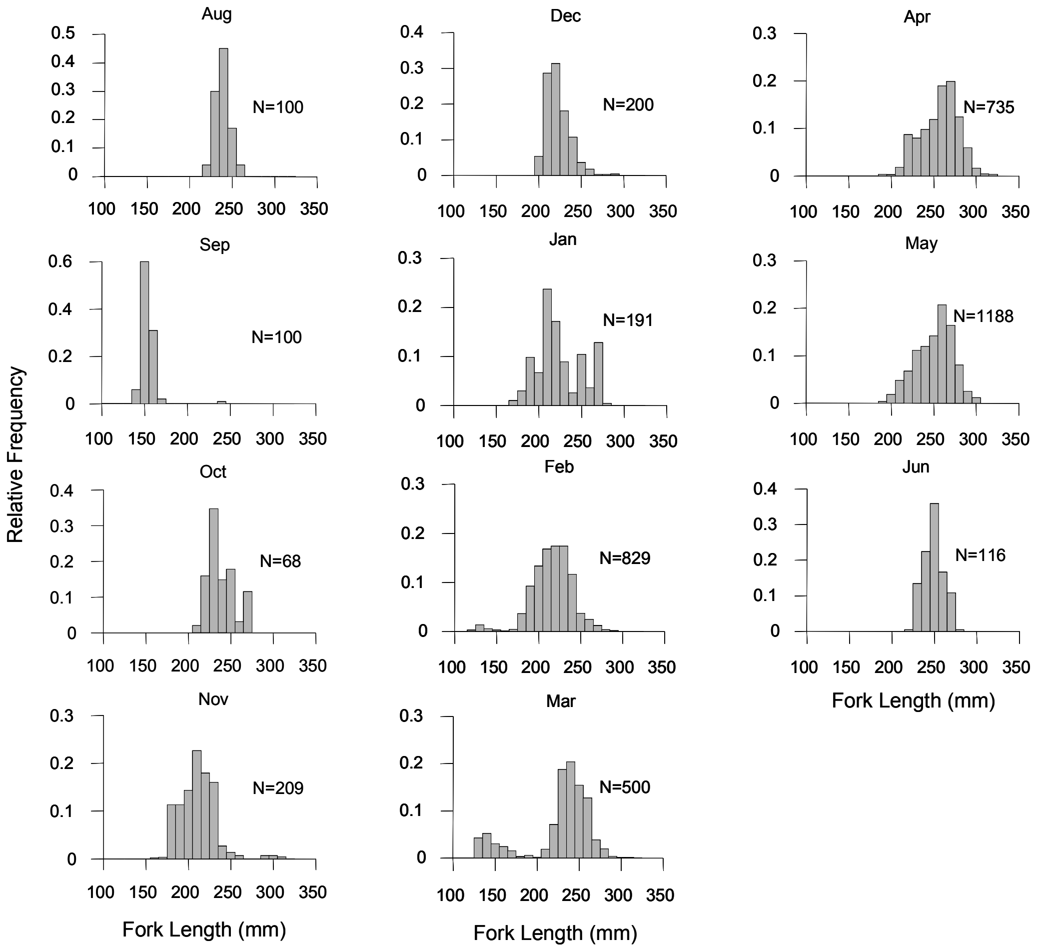

Fig. 5. Length frequency distributions of redbait captured by purse seine, by calendar month. Frequencies are by 10 mm size classes (fork length, rounded down to the nearest size class), pooled across fishing seasons 1984-85 to 1993-94. Distributions are adjusted to give equal influence to data from each sampling dates within a month, independent of sample sizes. July omitted due to lack of data. N = total number of individuals measured within a month.

2.3.2 Research trawling: 1985-1990

Only fishing years 1985-86 and 1989-90 produced sufficient data to warrant plotting length frequency distributions. Distributions showed considerable contrast between years, with two modes at 130 and 220 mm FL present in 1985-86, and a single mode at 150 mm FL in 1988-89 (Fig. 6).

Comparison with purse seine catches (Fig. 4) indicates some consistencies in the size of fish caught by the two methods in corresponding years, despite apparent differences in the segment of the population (surface verses subsurface) targeted by each method. For instance, the mode of larger fish evident in the 1985-86 trawl samples was also present in the purse seine catch in the same year (Fig. 4). Similarly, the mode of small fish present in 1988-89 was evident in both trawl and purse seine catches. Although based on limited information, these observations suggest gear selectivity effects on size structure were limited. However, as noted above, redbait school by size class and also stratify by depth (Markina and Boldryev 1980) and the influence of such factors also needs to be taken into account, along with fishing method, in determining size structure of catches.

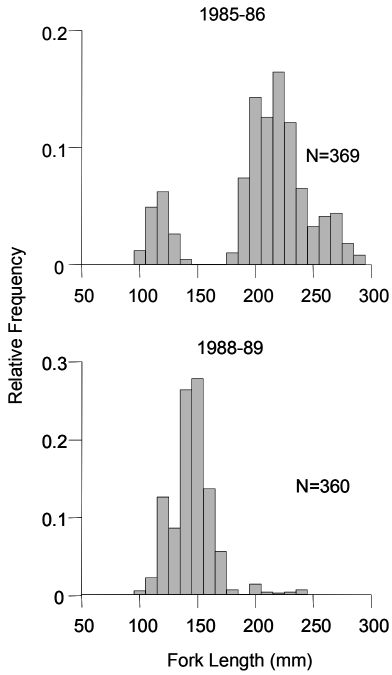

Fig. 6. Length frequency distributions of redbait captured by demersal research trawling. Distributions are adjusted to give equal influence to data from each sampling dates within a season, independent of sample sizes. N = total number of individuals measured within a season.

2.3.3 The mid-water trawl fishery: 2001-02

Size composition data were collected from pair-trawl operations in 2001-02 across three trips in December and one trip in March. The mid-water trawl fishery generally accessed slightly smaller fish than the purse seine fishery, with the majority of fish measuring between 120 and 200 mm (mode at 140-170 mm) and a secondary peak at around 240 –250 mm (Fig. 7). The size structure of the mid-water trawl samples were generally similar to the 1988-89 purse seine and demersal research trawl catches (Figs 4 and 6). Few inferences can be made from the mid-water trawl data given the limited temporal (and spatial) scale of sampling.

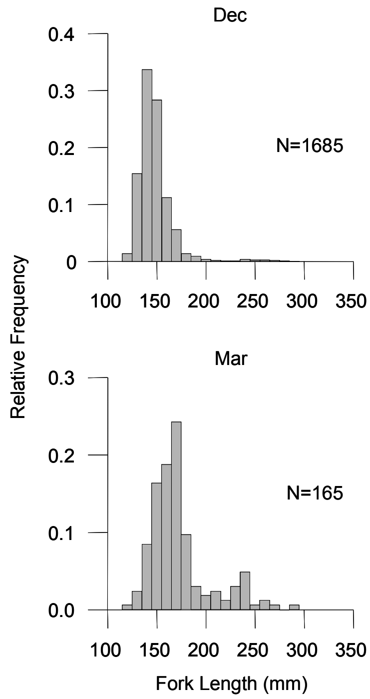

Fig. 7. Length frequency distributions of redbait captured by mid-water pair-trawl, by calendar month, for the fishing year 2001-02. Distributions are adjusted to give equal influence to data from each sampling dates within a month, independent of sample sizes. N = total number of individuals measured within a month.

2.4 Reproductive biology

2.4.1 Seasonal patterns of gonad development

All available data from the purse seine and mid-water trawl fishery on sex, total body weight, gonad weight and macroscopic gonad maturity stage were combined. The gonosomatic index (GSI), calculated as the proportion of total wet weight of an individual that is devoted to gonad tissue.

Although GSI values were unavailable for June to August a clear peak was evident between October and November implying that redbait actively spawn during these months and that spawning activity was completed by December (Fig. 8). However, even though the October-November peak in female GSI was distinct, mean GSI values of less than 3% are low by comparison with *Erythrocles schlegelii* and jack mackerel, where females may have as much as 9-10% of body weight as gonad tissue in the lead up to spawning (Roschin 1985; Williams *et al.* 1987).

Macroscopic staging indicated that fish with maturing gonads (Stages 3-5) were present between October – December and that spent fish (stage 7) were present from November to February, suggesting that spawning takes place through late spring and summer (Fig. 9). Since no running ripe (Stage 6) fish were sampled it is possible that spawning fish do not school at the surface, and hence were unavailable to the purse seine fishery. A similar observation has been made for jack mackerel, where running ripe fish move into deeper water to spawn on the shelf break (Jordan *et al.* 1995), and as consequence running ripe fish were not recorded from purse seine catches. It is possible that redbait exhibit similar behaviour. With the development of the present mid-water trawl fishery it is likely that further information will soon be available on redbait spawning behaviour.

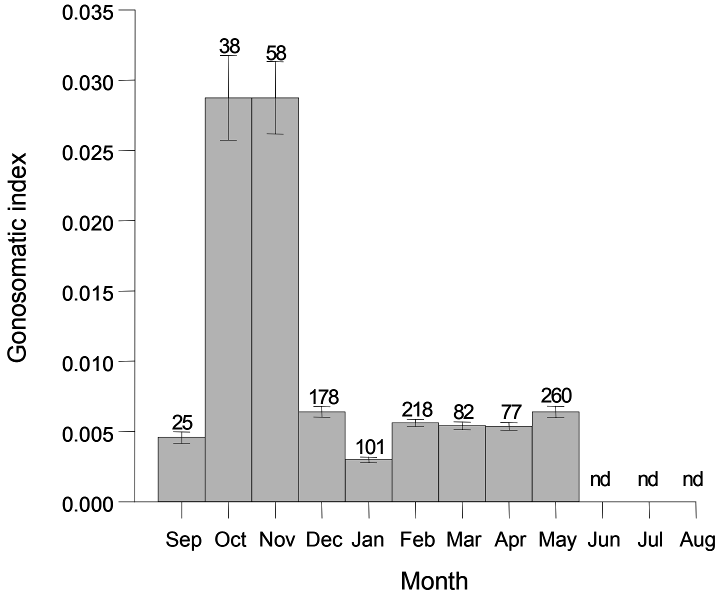

Fig. 8. Mean gonosomatic index (grams of gonad tissue per gram of total body weight) by month for female redbait. Error bars are standard error. Numbers above each bar are total sample size in each month. nd = no data.

2.4.2 Size at maturity

Size at maturity of female redbait was estimated by pooling all data across months where gonad development was most advanced i.e. October –December. As gonads with evidence of advanced sexual development (stage 4 and above) occurred in low numbers, fish having gonads of stage 3 or higher were defined as ‘mature’. Proportion of mature fish in 10 mm size classes increased steeply in fish above 220 mm FL, with greater that 50% mature in most size classes 240 mm FL and above, and all specimens above 280 mm FL having mature gonads (Fig. 10).

Based on 50% maturity at 240 mm FL, it is apparent that purse seine catch samples between 1989-90 and 1993-94 and the vast majority of the 2001-02 pair-trawl samples were based on immature fish. The impacts of selectively harvesting juvenile fish on redbait stocks is uncertain, but should be investigated as a matter of priority as further information about the life history and stock structure becomes available. Further, there is a caveat on patterns of gonad maturity and GSI data discussed above (Figs 8 and 9), as both are skewed by large proportions of immature fish in samples. Hence more accurate characterisation of the period and duration of spawning is pending the collection of samples focussing on the reproductively active portion of the redbait population.

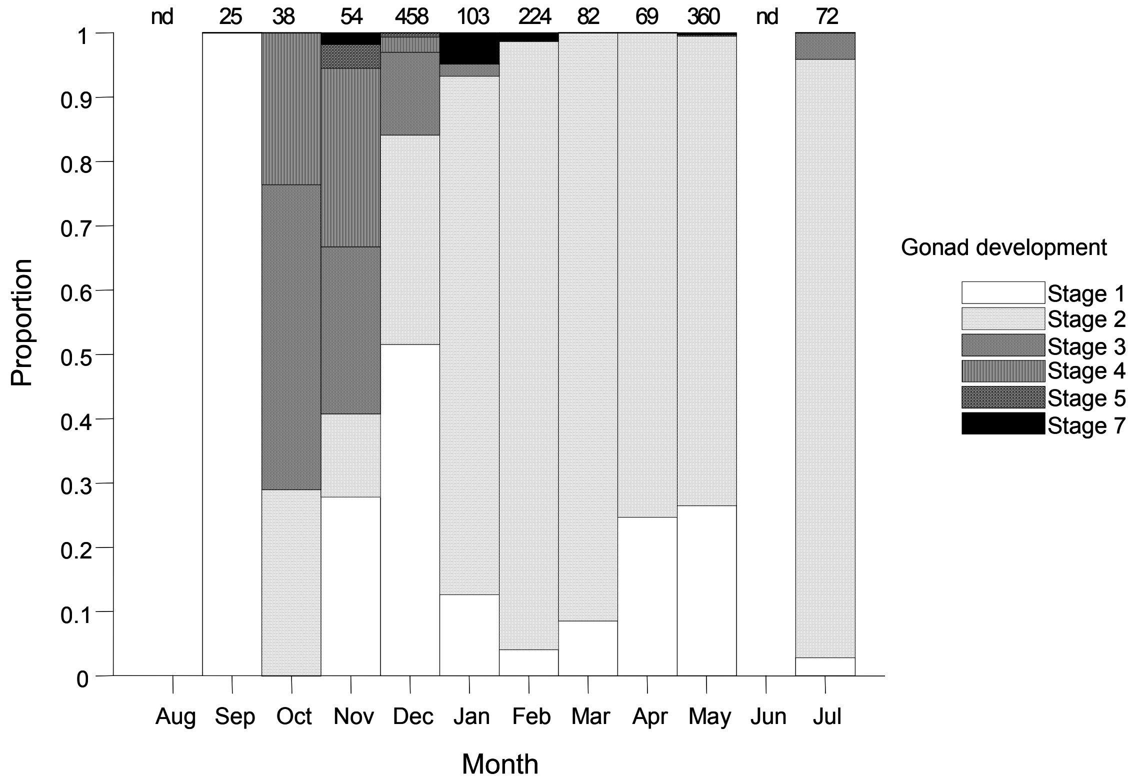

Fig. 9. Gonad developmental stages of redbait females, as proportion of monthly total. Gonad stages are derived from macroscopic inspection of whole gonads, following the 7 point scale of Marshall *et al.* (1993). Numbers above each bar are total sample size in each month. nd = no data.

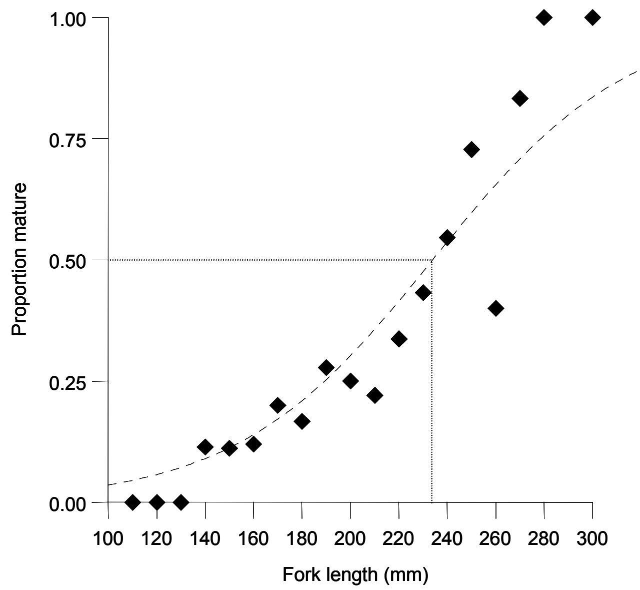

Fig. 10. Proportion of female redbait with mature gonads (gonad stage 3 or above) by fork length. Dashed curve is a logistic function, fitted by maximisation of a binomial likelihood function. Approximate position of the predicted 50 percent maturity in the 240 mm size class is indicated.

2.5 Age and growth

2.5.1 Preparation of otoliths

Otoliths derived from archived (1984-1994) and recent (2001-02) collections were mounted in polyester resin, and transverse sections (250-300 µm thick) cut through the primordium with a lapidary saw. Sections were mounted on slides and examined in transmitted light under a binocular microscope at ×25 magnification. Fifty-three otoliths, randomly subsampled from within strata defined by specimen length, were also weighed to the nearest 0.1 mg.

Sagittal otoliths were extracted from three small (< 70 mm FL) redbait found in the gut contents of jack mackerel captured in mid-water trawls in 2001-02. These otoliths were weighed and then attached to microscope slides with thermoplastic resin. Sagittae were then ground using 1200 grade wet and dry sandpaper until microincrements were clearly visible. If both sagittae from an individual were suitable, one was ground down in the transverse plane until a thin section through the primordium was produced (i.e. the same plane as otoliths sectioned for routine ageing) and the other was ground in the logitudinal plane until the primordium was clearly visible. The ground facets were polished with alumina powder wetted into a paste and spread on a synthetic felt surface. The polished facets were finally covered with a thin layer of thermoplastic resin and the otoliths inspected under transmitted light at ×100-400 on a compound microscope. Images of sections were digitised and measured using image analysis software.

To investigate seasonal patterns of growth in otoliths, a subsample of sectioned otoliths, stratified between months, were measured for marginal increment analysis. Sections were digitised under transmitted light using a compound microscope at ×100 magnification and key features measured using image analysis software. The analysis consisted of measuring the width between adjacent opaque zones, along the axis shown in Fig. 11. An index of completion was calculated as the width of the last annulus divided by the width of the second last annulus. This index represents a measure of how developed the last annulus is compared to the width of the previous full year's growth.

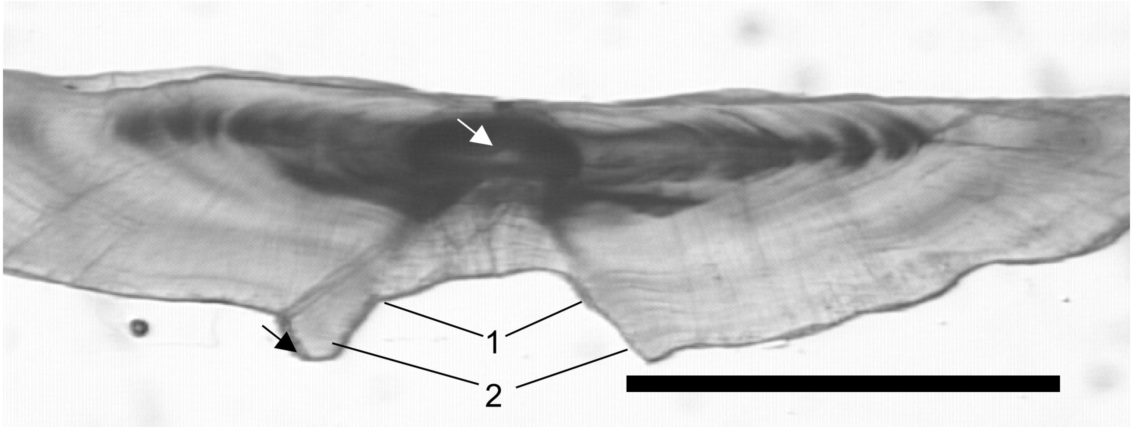

Fig. 11. Photomicrograph of a transverse section of a sagittal otolith taken from a 233 mm FL redbait, captured on the 27th May 1986. This specimen was estimated to have been spawned in 1984, based on the presence of the 2 indicated opaque zones visible on either side of the sulcus acusticus. The two arrows indicate the axis along which increment widths were measured. Scale bar = 500µm.

2.5.2 Interpretation of otolith structure

Clear micro-increments (similar to those formed daily in the larvae and juveniles of many fish species, e.g. jack mackerel larvae (Jordan 1994)) were evident encircling the primordium in transverse and longitudinal sections of otoliths prepared from small (<70 mm FL) redbait, (Fig. 12). Assuming these micro-increments are formed daily, total counts indicated back-calculated birth dates during the previous spawning season (refer section 2.4.1), and that these fish were only a few months old when captured (e.g. Figs 12 and 13B).

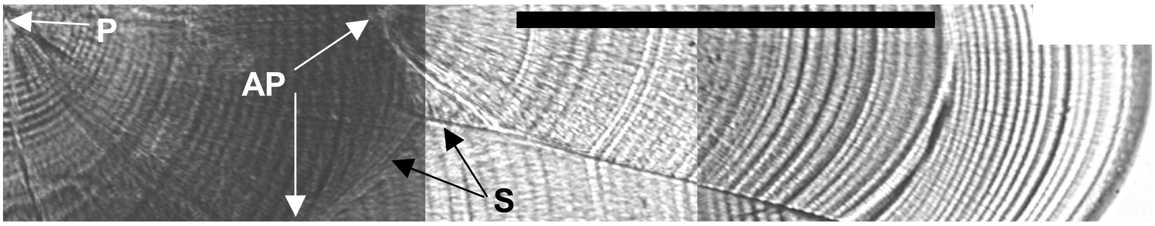

Fig. 12. Composite image of a 65 mm FL redbait sagittal otolith captured in mid January 2002, ground in the longitudinal plane, viewed at high magnification under transmitted light. Approximately 90 micro-increments are evident between the primordium and the edge of the otolith at the right hand side of the image. By assuming micro-increments are formed daily, this individual was spawned in mid November 2001. P = primordium, AP = accessory primordia, S = suture. Scale bar = 240µm.

At 40 to 50 micro-increments (approximately 250 µm radius) out from the primordium the otolith microstructure altered, with the presence of accessory primordia and sutures evident joining areas of otolith material formed around adjacent primordia (Fig. 11). The zone where accessory primordia were evident in longitudinal sections corresponded in radius and micro-increment count to a distinct suture seen in transverse sections of sagittae from small individuals (e.g. Fig. 13B). The same suture was also evident in transverse sections of otoliths from larger fish prepared for routine ageing (Figs. 11 and 13A). As these corresponding structures were identified, in both fish likely to be less than one year old, and in much larger individuals presumably 1+ and older, interpretation of the first and subsequent ‘annual’ zones could be made.

Since it is likely that fish < 70 mm FL are only a few months old, otolith and somatic growth is apparently initially rapid in redbait, with opaque material seen around the primordium formed during the first season of growth (presumably the summer/autumn after hatching). Translucent material surrounds this inner zone of opaque material (Fig. 13), suggesting that this zone forms over the first winter (presumably during a period of slower growth), and then subsequent opaque zones mark the subsequent seasons of rapid growth in each year of life. Hence opaque zones outside the initial core of opaque material were interpreted as (unvalidated) ‘annuli’ for the purpose of allocating individuals into putative year classes (e.g. Figs 11 and 13A).

2.5.3 Marginal increment analysis

Index of completion, plotted against the month individuals were captured, showed no clear pattern in otolith growth throughout the year (Fig. 14).

Several factors may have obscured any seasonal patterns of otolith growth in this study. Opaque zones were difficult to identify until translucent material has been formed on the otolith margin. This was most problematic in younger fish, where opaque zones were less clearly contrasted with translucent zones. Few samples were available from the colder months, when translucent material is likely to be formed (see section 2.5.2). Hence few otoliths were available from the period when the otolith margin was likely to be most readily interpreted. Further, as completed otolith annulus radii decreased sequentially, particularly between annuli 1-3 (Fig. 12A), a comparison of the widths between these annuli was not an accurate index of annulus growth, i.e. second annuli were never as wide as first annuli, so the index of completion for 1+ individuals approaching 2 years old would be always be lower than that of a 4+ individual approaching 5 years old. Hence individuals less with less than 2 opaque zones were not plotted, further reducing sample sizes within each month (Fig. 14). Future marginal increment analyses should rely on samples collected such that comparisons can be made within age classes and between individuals captured throughout the seasons of a single year to minimise these confounding effects.

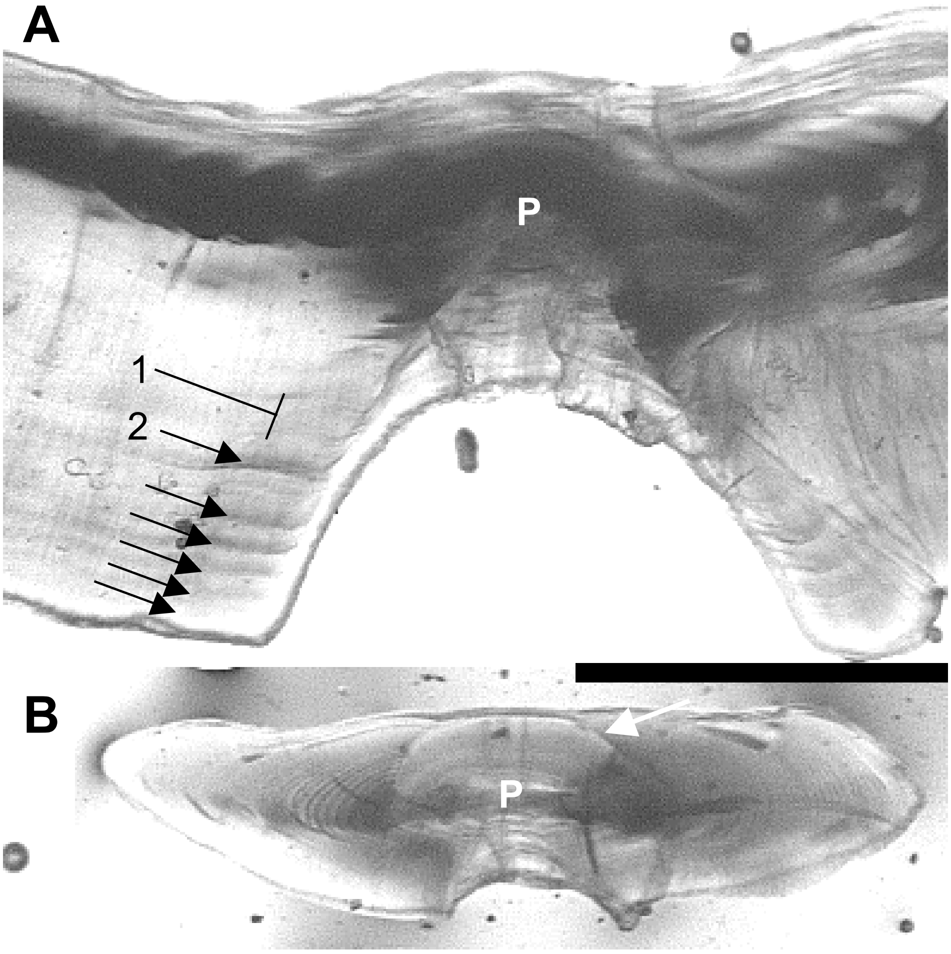

Fig. 13. Photomicrographs of transverse sections of sagittal otoliths from redbait, taken at the same magnification. P= primordium, scale bar = 500µm **A)** Otolith from a 316 mm FL redbait, captured on 17th April 1987. The first broad opaque zone, marking the boundary between the first and second year's growth is indicated (1), and the second (2) and subsequent narrower opaque zones are arrowed. This individual had 7 opaque zones, and was estimated to belong to the year class spawned at the end of 1979. **B)** Photomicrograph of a transverse section of a sagittal otolith from a 55 mm FL redbait, found in the gut contents of a jack mackerel captured on 3rd January 2002. By assuming micro-increments are formed daily, this individual was approximately 75 days old when eaten, giving a back-calculated spawning date of 20 November 2001. Arrow indicates position of the suture corresponding to the area of accessory primordia formation in Fig. 12.

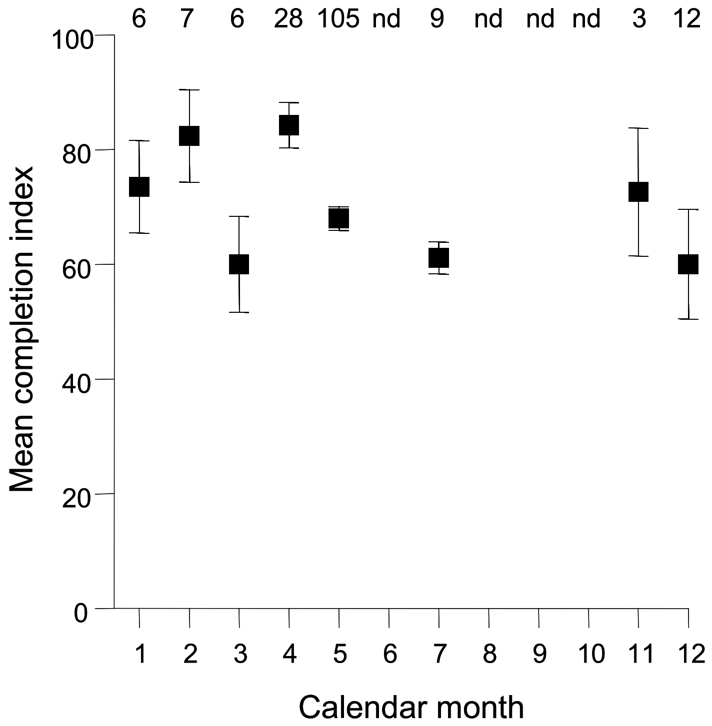

Fig. 14. Seasonal pattern of mean completion index of the last annulus forming in redbait otoliths. Only fish with 2 or more opaque zones are included. Numbers above data points are sample sizes. nd= no data. Error bars are ± 1 standard error.

2.5.4 Consistency and bias in ageing

To assess the consistency of readings of opaque zones, the primary reader (DW) read 282 otoliths twice, independent of length, capture date or other estimates of age. To assess the reproducibility of the ageing criterion between readers, a second reader (ST)[3], experienced with ageing of fish using sectioned otoliths, was instructed as to the ageing protocols to interpret redbait otoliths. The second reader then re-read 71 otoliths, randomly chosen from within all available age classes. Second readings were then compared using age bias plots (*sensu* Campana *et al.* 1995; Campana 2001).

Within reader age estimates showed a high level of consistency, with low levels of deviation from 1:1 correspondence between readings (Fig. 15). Between reader age estimates did not show as close correspondence, with a tendency for ST to underestimate the age of fish relative to DW age estimates (Fig. 16). This was most pronounced in the oldest age classes, where ST aged no individuals older than age class 6, whereas DW aged two individuals as 7 and 8. This under-ageing suggests that careful edge interpretation to detect narrow opaque zones laid down by older fish is an issue for redbait otoliths. This is exacerbated by the fact that the majority of redbait aged were from months when opaque zones are forming and, therefore, hard to detect (see section 2.5.3).

[3] Sean Tracey, TAFI.

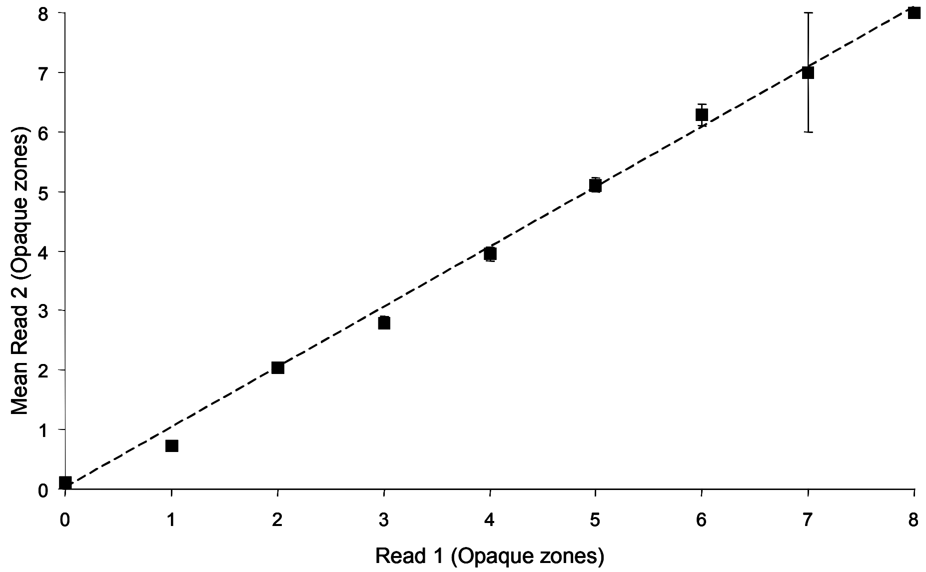

Fig. 15. Within reader bias plot for 282 redbait otoliths. Symbols are means of zone counts from second reads (Read 2), against initial estimates (Read 1). Dotted line is 1:1 correspondence line. Error bars are ± 1 standard error.

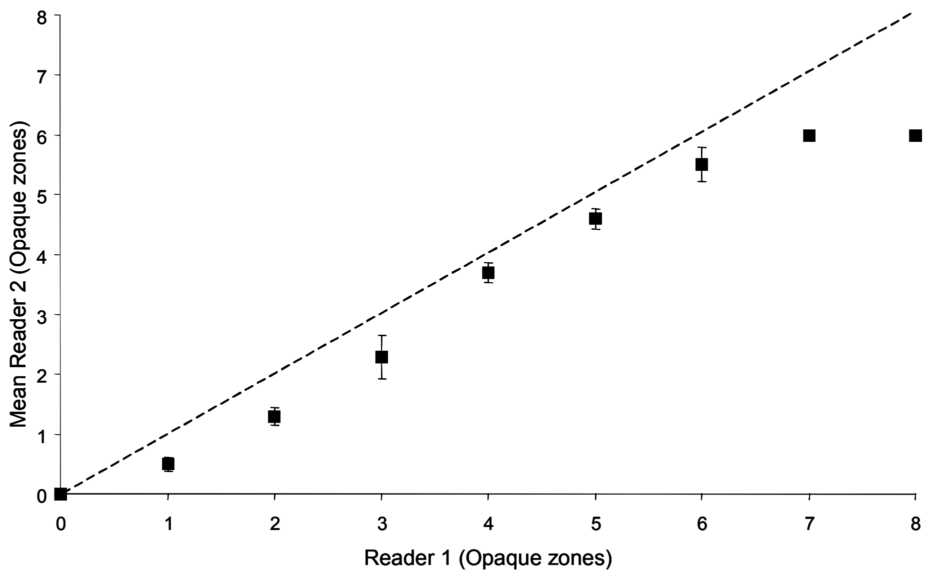

Fig. 16. Between reader bias plot for 71 redbait otoliths. Symbols are means of zone counts from Reader 2 (ST), against estimates from the first read by the Reader 1 (DW). Dotted line is 1:1 correspondence line. Error bars are ± 1 standard error.

2.5.5 Growth modelling

Growth modelling was conducted on the assumption that the number of opaque zones counted beyond the primordial opaque region was equivalent to the age class of redbait in years (see section 2.5.2). Decimal ages were then calculated for each individual, based on the age class, and proportion of the year between the arbitrary birth date (chosen as the 1st November, to reflect the apparent annual peak of reproductive activity) and the capture date. For example, the fish depicted in Fig. 13A, having 7 opaque zones and having been caught on the 17th of April, was estimated to be 7.46 years old at capture under this protocol.

A von Bertalanffy growth function was fitted to length-at-age data for 336 individuals (Fig. 17). The growth function was fitted by least squares, using the solver add-in in MS Excel 2000®. A likelihood ratio test (Kimura 1980) was used to determine if any differences existed between the sexes. Growth functions were fitted by sex to sexed fish pooled with juveniles, and then a third growth function was fitted to both datasets combined. The improvement in fit with the sexes modelled separately was not significant (χ^2=1.00, df =3, P=0.80), implying no significant size-at-age differences between sexes. On the basis of the von Bertalanffy growth function for combined data, mean lengths at ages 1, 3 and 5 years are 155, 245 and 273 mm FL respectively. On the basis of this model, age at 50% maturity in females is 2-3 years.

Considerable variability around the fitted growth function was evident from the distribution of size-at-age data in Fig. 17. Several factors may account for or contribute to this variation:

- **Variability in actual birth date.** More detailed characterisation of the reproductive biology of redbait, early life history, and components of otolith microstructure will lead to better understanding of the timing of spawning and how spawning date affects subsequent growth.

- **Seasonal and inter-annual variability in growth.** Fish species in Tasmanian waters show changes in growth rate as productivity and water temperatures vary within and between years. For example, growth is likely to slow over the cooler months, potentially reflected in the change in otolith material seen in Figs 11-13. As otoliths in the dataset were collected from different fishing years, including years classified as El Niño and La Niña climatic cycles, it is possible that growth rates of fish captured in different years were variable. The uneven spread of samples through time makes it difficult to examine for such effects in the otoliths processed to date.

- **Low precision in ageing estimates.** The majority of fish aged were captured during the summer months, when opaque zones are forming at the margin of the otolith and are difficult to discern. More samples from the cooler months (June – October) are required to refine age estimation and increase confidence in estimates of growth.

- **Growth variability between individuals**. Variability in size-at-age may also be brought about by differing individual growth potential in response to genetic and environmental influences.

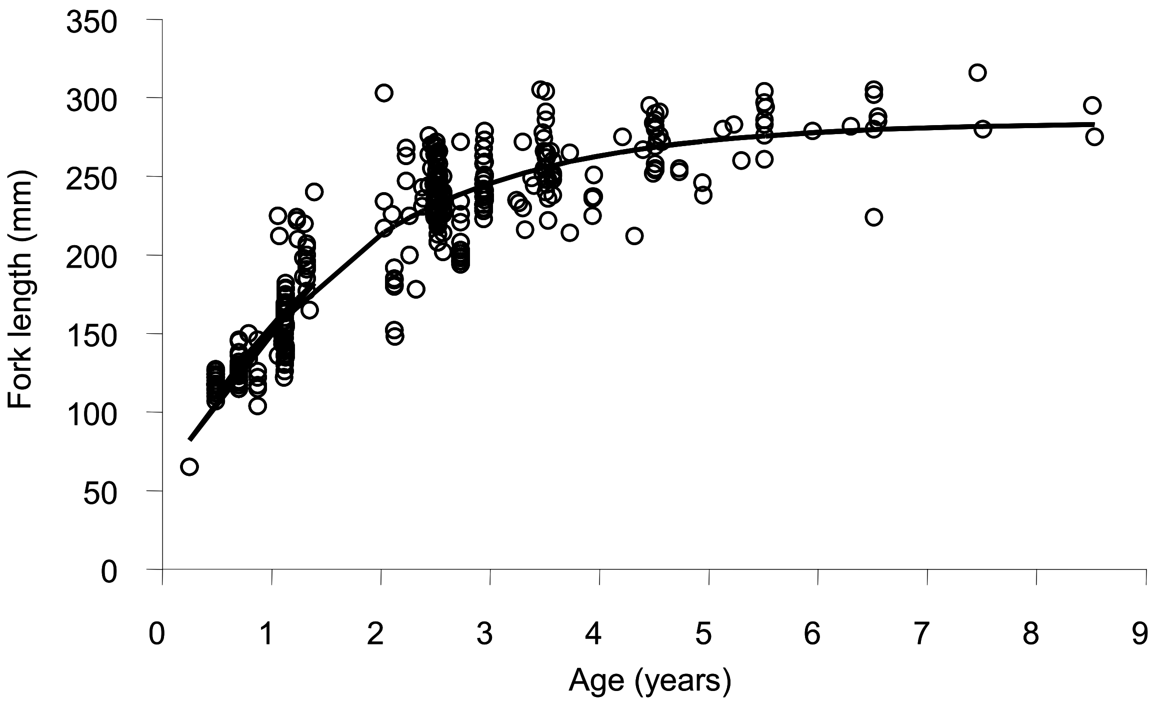

Fig. 17. Size-at-age data (symbols) and von Bertalanffy growth function (line) for 336 redbait, fitted by least squares regression. Solutions for the standard von Bertalanffy growth function parameters are L_{∞}= 287 mm, k = 0.56 yr^{-1}, t_0 = -0.36 yr.

2.5.6 Otolith weight

Otolith weight exhibited a rapid increase with age, particularly in the first three years (Fig. 18). This indicated that the bulk of otolith material was formed during this time, as was evident in otolith sections (refer Figs 11 and 13). Otolith weight also increases with fish length (Fig. 19). However, variability of individuals was too great to accurately predict length or age from otolith weight.

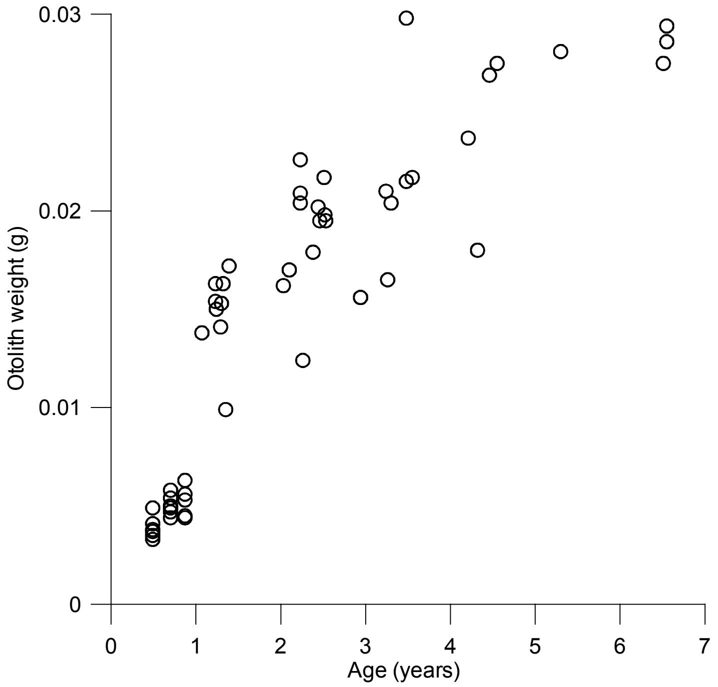

Fig. 18. Sagittal weight against decimal age for redbait (N= 53).

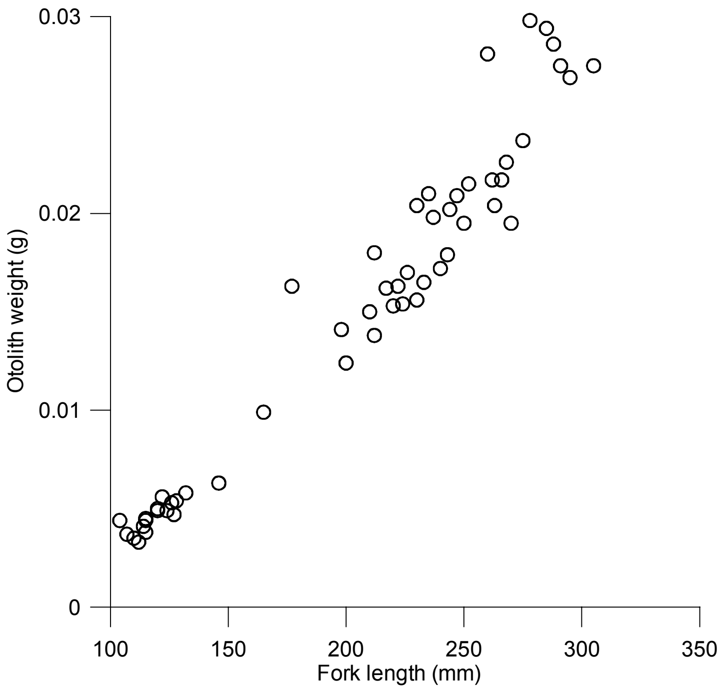

Fig. 19. Sagittal weight against fork length for redbait (N=53).

3. Conclusions

3.1 General

There is a general paucity of biological information in the scientific literature for redbait or related species. The majority of data available on redbait in Australia has been derived from purse seine fishing operations off the east coast of Tasmania, supplemented by some trawl catches. The information suggests that redbait are ecologically and biologically similar to other small pelagic species such as jack mackerel that are encountered in the waters off Tasmania.

Redbait consume mostly zooplankton, primarily crustaceans, and form an important part of the diet of large predatory fish, seals and seabirds. As such redbait are likely to be a key species in the pelagic ecosystem.

Given the ecological similarities with jack mackerel, redbait are likely to exhibit large fluctuations in abundance, behaviour and availability that may be linked to variability in oceanographic conditions that are a feature of the waters off eastern Tasmania.

Redbait school by size, with evidence of population structuring by depth such that larger fish school over deeper water. The spawning season is apparently restricted to about two months, peaking in October and November, though no running ripe fish have been examined to date. Although all size classes above about 100 mm appear vulnerable to purse seine and mid-water trawl methods, immature fish dominate commercial catches in most years. Growth appears to be rapid in the first few years of life and the maximum (unvalidated) age of redbait off Tasmania is about eight years. Females attain maturity at around 240 mm FL or 2-3 years of age.

3.2 Further research

Much of the fisheries biology of redbait is poorly defined. To characterise the current mid-water trawl fishery, and provide a scientific basis for management of the redbait stocks around Tasmania, research is required to address:

Spatio-temporal patterns of population structuring.

The size and age distribution of the redbait catch with respect to geographic position, depth, oceanographic conditions, time of day and season, in combination with effort data, is critical for any assessment of the redbait fishery.

Reproductive biology.

Due to small sample sizes and the lack of running ripe fish, size at maturity and seasonal patterns of reproductive allocation and spawning are poorly defined. Fecundity of redbait is unknown. Sampling prior to and during the likely spring-summer spawning season of redbait will provide better resolution on all these parameters, providing a basis for egg-per-recruit modelling as an input to stock assessments, and as an input to biomass estimation using the egg production method.

Age and growth.

Structures visible in sectioned otoliths show promise for the development of a protocol for ageing redbait. However, as discussed in detail above, much more ageing, conducted on samples collected on the broadest range of sizes and throughout the year will greatly enhance confidence in growth models based on size-at-age. Comparisons of size-at-age growth models with other methods of estimating growth, such as length-mode progression analysis, and further investigation of seasonal patterns of otolith growth, could also be used to test the hypothesis that opaque zones are formed annually. A validated ageing protocol has the potential to investigate age-class strength and mortality rates and lead to models of yield and turnover in the redbait population.

Trophic interactions.

Little is known about the diet of redbait. As seen with the jack mackerel, understanding the trophic position of redbait is critical to understanding the dynamics of the fished population; in addition to top down (i.e. predator related) or bottom-up (i.e. prey species related) processes in the pelagic food web.

Early life history of redbait.

The ecology and biology of redbait eggs and larvae are unknown. The distribution, growth and development and diet of early life stages of redbait are important inputs to understanding population dynamics. Developmental rates of eggs and larvae are also inputs to biomass estimation using the egg production method.

Biomass estimation.

The current TAC for the Zone A small pelagics fishery is not based on any scientific estimate of the available biomass of the target species. Hence robust estimates of biomass of redbait as soon as possible is a research priority for this fishery. Research is currently being conducted on applying the egg production method to produce biomass estimates for blue mackerel stocks in southeastern Australia. The egg production method is well established and is applied to small pelagic stocks worldwide to produce fishery independent biomass estimates. Inputs to the method include parameters such as sex ratios, batch fecundity, and the fraction of the mature population that is actively spawning during each season, as a well as the ability to identify eggs and larvae. With specimens likely to be available from the fishery soon to provide estimates of many of the reproductive parameters for redbait, the egg production method in particular shows promise for estimating biomass of redbait cost-effectively and in a relatively short time frame.

4. Acknowledgements

Much of the information used in this report was collected as part of the DSF jack mackerel purse seine fishery monitoring program and we particularly wish to acknowledge the efforts of Howel Williams and Grant Pullen in the collection of data. Thanks are also extended to Bob Stanley and Chris MacKinley of the AFMA Observer Program for providing catch and biological information for the pair-trawl fishing trials.

Seafish Tasmania and the crew of the F.V. *Ellidi* are gratefully acknowledged for assisting in the collection of some of the samples used in this report and allowing data on recent catch levels to be included. Thanks to Laurelle Weise, Graeme Ewing and Sean Tracey for assistance with processing of biological specimens, and Colin Buxton, Alan Jordan and Philippe Ziegler who extensively reviewed this report and suggested many useful improvements to the text.

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