Age Validation in Tailor (*Pomatomus saltatrix*)

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OBJECTIVES:

1 To validate the age interpretation of tailor otoliths and establish protocols for age and growth determination in this species.

2 To evaluate available evidence for size segregation of tailor stocks between offshore and inshore waters of southern Queensland.

1 NON-TECHNICAL SUMMARY

OUTCOMES ACHIEVED TO DATE

An age determination protocol has been developed, on the basis of a validated ageing methodology for *Pomatomus saltatrix*, which will enable greater reliance to be placed on the results of ongoing age-based stock monitoring programmes. There is now less uncertainty about the accuracy of the age-composition estimates from these monitoring programmes, and a more reliable estimate of the species' growth rate (at least on the east coast). We have found no substantive evidence of a significant 'sub-population' of old fish in offshore southern Queensland waters. This will give the relevant fishery managers a greater degree of confidence in the validity and justification for the current management arrangements.

This project was the result of concerns raised about the possible over-exploitation of the east-coast stock of tailor (*Pomatomus saltatrix*), a species of particular importance to the recreational fishing industry in southern Queensland. Previous work had developed a basic technique for determining the ages of *P. saltatrix*, a necessary precursor to any age-structured stock assessment procedure. Estimates of the rate of survival of one age-class to the next provide an indication of the instantaneous rate of total mortality within the population. This is also a *de facto* indication of the degree to which deaths due to natural factors (e.g. disease, predation and old age) and human-induced factors (pollution, habitat loss, and harvesting pressure) are impacting the stock.

Previous estimates of total mortality rates were high, indicating an annual survival rate of only about 13%. However there was some uncertainty about the reliability of the ageing methodology, which could potentially have a serious impact on the accuracy of the mortality estimates. From previous experience in Australia and elsewhere in the world (*P. saltatrix* is one of a very small number of exploited fish species with a circumglobal distribution), it is known that age determination in this species is not at all straightforward. If the ageing technique we had developed was biased in such a way as to underestimate the ages of (particularly older) fish, our estimates of mortality could be significantly overestimated, and the perceived threat from overexploitation may be rather less than current analyses suggest. It has often been suggested that, because of behavioural changes, larger (and older) fish are under-represented in our age-structure analysis samples which have been collected mainly from the ocean beach recreational angling fishery. If this is true, it would also have had the effect of overestimating total mortality rates.

This project was designed to address both these issues – (i) of potential ageing error and (ii) of the possible under-representation of older fish in the fishery samples. We investigated the first principally through a series of tag-release experiments with fluorescent otolith marking, and the second through a survey of various sectors of the fishery.

There have been several previous *P. saltatrix* tagging projects in Queensland, but because they weren't directed towards age-determination there are no other comprehensive age data sets available. These projects did, however, provide useful information about the recapture rates that might be anticipated. Most involved tagging *P. saltatrix* during the peak of the angling season on the ocean beaches (principally on Fraser Is.) prior to the introduction of the seasonal-spatial closure. For this reason recapture rates were high, and most recaptures occurred within a short time of release. Using fluorescent otolith marking techniques as a means of validating ageing methods requires the tagged and marked fish to be at liberty for a relatively long time (preferably more than 1 yr). To avoid having our marked fish recaptured too soon to be of value, we chose to tag and release during the closure period. Given the possibility that long-term recapture rates may be low, we also established (as a fallback position) a population of marked *P. saltatrix* in the Sea World Ski Lake, with the very considerable goodwill and assistance of Sea World management and staff.

Recaptures from the September 2000 Fraser Is tagging operation were so low during the following year that (for reasons of cost-benefit) we relocated the 2001 operation to the southern coastal beaches. The recapture rate from this operation was also extremely low. A tank experiment indicated minimal intrinsic tag loss and there were reported instances where tagged fish had been re-released by recreational fishers.

Despite the small number of recaptures of fish that had been at large for more than a year, we were able to detect fluorescent marks (as a result of the application either of oxytetracycline or calcein) in enough of the otolith sections to validate our ageing technique. A simple examination of the position of the fluorescent mark (under ultraviolet light) in relationship to the previous and subsequent supposed growth checks provided conclusive evidence of the annual periodicity of the checks. One fish which had been injected with the marking compound on two occasions about 19 months apart showed a single growth check between the two fluorescing bands, providing further evidence of the checks' annual periodicity.

Radial measurements of the distance from the nucleus to the various internal growth-related structures in the otolith showed that the distances between successive annuli were consistent across individuals. This suggests some temporal alignment in otolith growth structure. In other words across all samples the periodicity is close to 12 months (on the reasonable assumption that there is one and only one check laid down each year). We investigated the possibility of predicting the actual date of deposition of the adjacent check(s) from knowledge of the fluorescent mark date and the relative distances between the check(s) and the fluorescent mark. However, the assumption of constant growth throughout the year was inconsistent with the predicted check dates, as these varied over the 12-month period. To determine whether this inconsistency was due to the constant growth assumption we incorporated a seasonally-oscillating function in the model. This gave a slight improvement in the predictions, but still failed to indicate that the growth checks are laid down during a relatively discrete (e.g. 2-3 month) period. The reason for this apparent anomaly is unclear. One explanation may be that the checks are not growth-related in the usual sense, but are related to spawning activity. Historically there has been a widely-held opinion that *P. saltatrix* spawn off Fraser Is in late September-October at the end of the northward spawning migration. However recent DPI research has revealed *P. saltatrix* eggs and larvae in plankton samples from many locations in southern Queensland coastal waters and throughout most of the year (albeit with a peak in spring), suggesting that spawning occurs over a much wider area and over a much longer period than earlier believed.

The consistency of age estimates has been improved very significantly by the development of a set of age-determination protocols for this species. These protocols were developed in collaboration with staff at WA Fisheries working on *P. saltatrix*-related projects, and staff from the Central Ageing Facility. This improvement in consistency (or precision) means that greater reliability can be placed on the results of the Long Term Monitoring Programme's annual fishery-dependent age-based sampling surveys in Queensland, and of similar stock monitoring programmes in Western Australia. As a result of the application of the ageing protocols, the relative proportions in of age 0 and age 1 fish have changed moderately, resulting in a slight downward revision of the total mortality estimates.

Surveys of a number of anglers, charter-boat operators and commercial beach net fishers, together with the results of our own Project fishing/tagging operations did not revealed any clear size-related division of the *P. saltatrix* stock between shallow and deep coastal waters. We found no evidence of a population of large, old fish in offshore waters that are less vulnerable to the typical inshore angler. Larger fish *are* caught, but mainly by specialised anglers fishing at night, either by casting further off the beach or from rocky headlands. Commercial beach haul-netters also occasionally capture a small school of large tailor when shooting a school of mullet from the beach. While total mortality may be marginally overestimated because of size-related differences in vulnerability, we have no evidence to indicate that the catch from the beach fishery is not representative of the available population.

KEYWORDS: Age validation, tailor, bluefish, elf, *Pomatomus saltatrix*, otolith, otolith growth, tagging, tag recapture, recreational fishing, charter boat fishing

2 ACKNOWLEDGMENTS

Many people have contributed to this project, and we are grateful for their generous assistance. We will mention a number of key people here, but apologise if any are inadvertently omitted. In particular, we would like to thank recreational anglers Mick O'Neill, Brad Zeller, Ken Tarlington, Martin Cowling, Michael Lapps, Alan Free, Don McCorkindale, Bill Johnston, Dan Willett, Ron Vine, Peter Nelson, Keith Chilcott, Edward Chilcott, Graeme Maiden, Phillip Williams, Tom Gallagher and Rodney McLean, all of whom volunteered their own time to assist with tagging *P. saltatrix* on Fraser Island in September 2000. Kathryn Tummon's photographic expertise during this trip was also appreciated. Several other fishers including Cliff Andreasson, Barry Hoare, David Trail, Bradley Smith and Daniel Holder provided invaluable assistance during other sampling work. In addition, members of the "Beach Bums" recreational fishing club and the North Brisbane, Bribie Island and Gold Coast Sportfishing Clubs volunteered their time to help us collect live *P. saltatrix* on several occasions. We acknowledge with particular thanks Platypus Fishing Lines for donating fishing goods to be used as rewards for the return of tagged fish and recapture information to the Project.

The staff at Sea World were extremely helpful, providing us with facilities, assistance with obtaining samples and advice on sampling in the Ski Lake, and of course allowing us to make use of the Ski Lake for holding tagged tailor for the duration of the project. We would like particularly to thank Marnie Horton, Michael Leibinger, and Trevor Long for their interest and tolerance.

Staff at the University of Queensland's Centre for Microscopy and Microanalysis willingly gave of their time and expertise in helping Project staff prepare, examine and interpret the SEM material. Thanks are also due to Richard Prankerd (School of Pharmacy, University of Queensland) for suggesting a convenient way to thicken up the calcein solution.

Ray Joyce was a notable help to this project, advising on survey design, introducing us to the some of the commercial charterboat community, and providing us with data collected from the charterboat catches. His enthusiasm was most appreciated. We would also like to thank the 77 recreational, commercial, and charterboat fishers who gave of their time to respond to our survey. Their honest opinions and observations were integral to the results of the second objective of this project.

Special thanks are due to Denise Whyte who examined 1200 pairs of otoliths for evidence of UV fluorescence, and to Sandra O'Sullivan who measured many radial otolith distances. Their perseverance made a valuable contribution to the project. Simon Robertson (Central Ageing Facility, Queenscliff), Mike Cappo (AIMS), and Richard Steckis, Suzy Ayvazian and Jason How (WA Fisheries) all provided substantial input to the ageing component of this project and their efforts were much appreciated.

Finally we acknowledge the anonymous independent reviewer, whose valuable comments improved the content and readability of this document.

3 BACKGROUND

P. saltatrix is one of southeast Queensland's premier sport-fish, with an estimated annual recreational catch of around 250 tonnes (Williams 2002). There is a significant seasonal ocean-beach angling fishery for *P. saltatrix*, particularly on Fraser Island, which attracts many thousands of fishers to the islands each year (Pollock 1984). This fishery makes an extremely important contribution to the region's economy because of the flow-on effects relating to accommodation, 4WD sales and service, ferry transport, and sales of fuel, bait and fishing gear.

A commercial catch of around 160 t p.a. makes it a moderately important component of the commercial ocean beach and estuarine net fisheries[1]. It was one of several species investigated by the Southern Fisheries Centre's integrated Stock Assessment and Monitoring Project (ISAMP; FRDC 94/161), which identified and tested appropriate methods for monitoring and assessing the status of south Queensland's major finfish stocks. *P. saltatrix* was identified as requiring investigation because of management concerns about exploitation levels and perceived declines in recreational sector catch rates.

Ageing is important because it underpins most productivity calculations - a most influential biological variable (Campana 2000). However, much of the age determination research can be divided into two categories, based on temporal scale of resolution; 1) either annually to support harvest/populations studies, or 2) daily to investigate recruitment patterns. Both scales are susceptible to similar error sources: process error in interpreting structures (under/over-estimating age) and interpretive error associated with the subjectivity of interpretation by different readers (Campana 2000).

Ageing error can affect accuracy, precision or both. Accuracy, the closeness of an estimated or computed value to its true value (Kalish *et al.* 1995), can be achieved by validation to confirm frequency of annulus formation and interpretation (Campana 2000). If it is not possible to validate age absolutely, the age at which the first growth check is deposited should be determined, then the periodicity of checks across the range of ages of interest should be verified.

Because of other sources of error, however, accuracy does not necessarily result from the use of a fully validated ageing method. Many approaches to age validation have been reported, including

- release of known age and marked fish,
- radiocarbon
- mark-recapture radiochemical dating (isotope decay ratios),
- length frequency analysis
- natural date-specific marks
- marginal increment analysis
- captive rearing

[1] Recent (September 2003) changes to the Fisheries Regulations prohibit commercial net-fishing for tailor on Fraser Is.

Various techniques have been investigated as a means of validating ages of *P. saltatrix*. These range from tag-recapture experiments (Barger 1990; Govender 1999), marginal increment analysis (van der Elst 1976; Bade 1977; Wilk 1977; Krug and Haimovici 1989; Hoyle *et al*, 2000) and back-calculation (Hammer 1959 *not sighted*; Lassiter 1962 *not sighted*; Richards 1976; van der Elst 1976; Bade 1977; Krug and Haimovici 1989). Several authors (Ricker 1958; Campana 2000) have argued against the use of back-calculation as an age validation procedure because of the effect of Lee's phenomenon (see Ricker 1975) which typically underestimates the size of fish of younger age.

Ageing precision may be defined as the reproducibility of repeated measurements. Various indices have been used to measure the precision of age estimates of *P. saltatrix*, the most common being the percentage-agreement (van der Elst 1976; Krug and Haimovici 1989; Barger 1990; Hoyle *et al*, 2000; Sipe and Chittenden 2001; Lucena and O'Brien 2001). However, this technique does have inadequacies, especially when a sample of fish covers only a few age classes. Other measures include average percent error (APE) (Hoenig *et al*. 1995), coefficient of variation (CV) and Chang's (1982) D test (Hoyle *et al*, 2000; Wischniowski and Bobko 2000).

Campana (2000) recognised that APE was not particularly sensitive to variations in age composition, and CV was a more statistically robust measure of precision. He cited a maximum coefficient of variation value of 5% as a common reference point for production ageing of many fishes of moderate longevity and reading complexity.

He also identified four steps to developing a successful ageing program: (a) develop the ageing method, (b) validate age, (c) prepare reference collection – important for testing long-term drift and training, and (d) monitor quality control for short and long-term ageing consistency.

Routine ageing of *P. saltatrix* from Queensland waters was examined by Hoyle *et al*. (2000), who estimated age from samples of the recreational and commercial beach fishery using whole and sectioned otoliths. This enabled a preliminary estimation of the species' growth parameters and a first insight into instantaneous total mortality rates in the East Coast stock. The magnitude of the mortality estimate ($Z = 2.03$) was disturbing, as it indicated an annual survival rate of only 13%, suggesting that the stock may be under considerable pressure from natural attrition and fishery exploitation, and that stringent management measures may be required. Hoyle *et al*. (2000) also identified the possibility that the fishery was subject to hyperstability, as the bulk of the fishing effort (particularly in the recreational sector) is applied to the population when it is schooling or aggregating to spawn. A hyperstable stock may be in a state of contraction without this becoming evident in the catch-effort statistics.

Mortality may have been overestimated by Hoyle *et* al. (2000) because of a possible systematic underestimation of the age composition of the catch. Although their results from marginal increment analysis implied the deposition of a single annual band in December-January, the variability in increment width during the mid-year period was such that the possibility of subsidiary checks could not be ruled out. In other words there was some doubt that the techniques used to age *P. saltatrix* were providing an accurate picture of age composition.

An otolith exchange was arranged between project staff at the Southern Fisheries Centre and Mr Richard Steckis, who was undertaking a Ph.D. study on *P. saltatrix* in Western Australia. A sample of 100 sectioned *P. saltatrix* otoliths from south Queensland, which had already been read on two occasions by two independent and experienced otolith readers at SFC, were again read (independently) by Mr Steckis and another experienced otolith reader in WA. The results of this exchange programme provided confirmation of the difficulty of interpreting the internal structure of these otoliths. For example, the percentage concurrence in age estimates between readers in the two organisations ranged from 37% to as little as 14%. Concurrence of estimates between readers within States was better (Queensland: 85%, WA: 54%), but still indicative of considerable reader error or inconsistency in interpretation. Several estimates of *P. saltatrix* growth are available worldwide, but parameter estimates vary considerably. This indicated that *P. saltatrix* is not a straightforward species to age, and that different techniques and protocols may produce quite different results. For example, published K values from the von Bertalanffy growth function range from 0.096 (Barger 1990; U.S. South Atlantic coast) to 0.43 (Govender 1996; South Africa), with intermediate values reported from Queensland (Bade 1977), South Africa (Van der Elst 1976), the New York Bight (Chiarella and Conover 1990) and the Gulf of Mexico (Barger 1990).

An alternative explanation for the apparently high total mortality rate in this stock is the possibility that the age-structure of the ocean beach catch may not be representative of that in the whole population. A study by Steffe *et al.* (1996) on the recreational fishery in NSW revealed that *P. saltatrix* caught by ocean beach anglers tended to be smaller than those caught by boat-based anglers. The perception that larger *P. saltatrix* tend to stay slightly further offshore than the smaller fish has been voiced on a number of occasions by recreational and commercial fishers in Queensland. It has been borne out to some extent by reports of particularly large *P. saltatrix* being caught off headlands, and by individuals prepared to fish further out in the surf zone or at times considered unfavourable by the typical beach angler. This size segregation of *P. saltatrix* populations has also been reported from Western Australia (R. Steckis, pers. comm.) and the U.S. (Barger 1990).

4 NEED

The Integrated Stock Assessment and Monitoring Programme came to four important conclusions about *P. saltatrix*:

- There was no evidence of an overall reduction in average size of *P. saltatrix* caught by recreational club anglers between 1973 and 1991, although average size did vary considerably from year to year.

- The spatial distribution of *P. saltatrix* eggs and larvae was relatively even, suggesting that spawning may occur across the continental shelf and along the coast from Fraser Island to the Qld/NSW border, rather than being more concentrated at Fraser Island as previously thought.

- The size and age structure of *P. saltatrix* catches on ocean beaches may not be representative of the population as a whole. This situation has been reported in *P. saltatrix* fisheries in Brazil, North Africa, Western Australia, and possibly the United States.

- If beach-caught *P. saltatrix* are not representative, then the estimates of total mortality have been biased upwards.

An FRDC-funded Stock Assessment Review workshop (98/129) at the Southern Fisheries Centre in August 1998 examined monitoring and assessment processes and scrutinise data sets for selected species, including *P. saltatrix*. This workshop involved participants from the recreational and commercial sectors who had considerable experience fishing for *P. saltatrix*. It also included participants from the Queensland Fisheries Management Authority and the Subtropical Finfish Management Advisory Committee, as well as recognised stock assessment scientists from CSIRO (Hobart and Brisbane) and research biologists from Queensland and other States.

Further analysis and interpretation of the ISAMP age-estimation data (including the Qld-WA otolith exchange data) during the Workshop confirmed that there was both bias (between organisations) and considerable error in the age estimation process. However, in the absence of definitive validation data it was not possible to determine whether either data set was correct, and the Workshop concluded that additional research would be required to resolve the problem. It was recommended that otolith labelling with oxytetracycline (OTC) would be the logical first step, incorporated into a tag-recapture programme involving members of recreational tagging clubs affiliated with the Australian National Sportfishing Association (ANSA). It was also recommended that steps be taken, initially by interviews with a wide cross-section of boat and shore-based anglers, to determine whether the ocean beach angling catches are in fact representative of the entire *P. saltatrix* population in southern Queensland.

The need was identified for a comprehensive age-validation exercise to determine whether the existing ISAMP *P. saltatrix* age estimates were biased. If they were biased, adjustments could be applied to rectify the data and produce a more reliable mortality estimate.

If they prove to be unbiased, either the high Z value was correct, or older age-classes have been under-represented in the catch-at-age samples. In the latter case it would need to be demonstrated that the age composition of the ocean beach catch is different from that of the fully recruited sector of the entire population, in order to rule out the possibility that the fishery may be facing the danger of overexploitation.

5 OBJECTIVES

- To validate the age interpretation of tailor otoliths and establish protocols for age and growth determination in this species.

- To evaluate available evidence for size segregation of tailor stocks between offshore and inshore waters of southern Queensland.

6 MATERIALS AND METHODS

6.1 Overview of Methods

Verification of increment periodicity was approached via oxytetracycline (OTC) labelling of otoliths and analysis of daily rings. Both these techniques have been widely applied to confirming the annual periodicity of growth checks or bands in the otoliths of many species of fish (Gauldie 1987; Brothers 1990; Villanueva and Moí 1997; Campana 2000; Cappo *et al*. 2000; Hernaman *et al*. 2000; Al-Husaini and Dashti 2001; Waldron and Kerstan 2001). OTC labelling consisted of applying a fluorescent mark to the otolith, so that the timing of subsequent growth marks could be determined unequivocally. OTC labelling was achieved by tagging events, making use of the skill of ANSA-affiliated recreational tagging club members, as had been done in several previous studies of this type in Queensland. The main tagging operation was designed to provide an independent means of validating annual growth checks in fish encompassing the maximum range of ages possible. It was anticipated that each (annual) fishing/tagging operation would result in the release of 1500 fish of various sizes.

There are inherent risks in any tagging program, one of which is uncertainty surrounding the numbers or proportions of tags expected to be recaptured. Recapture rates from previous *P. saltatrix* tagging studies in southeast Queensland have been reported as ranging from 1.7% (Young *et al*. 1999) to 10% (Halliday 1988). We also recognised that not all recaptures would be reported correctly, and, despite our publicity efforts, some anglers would not retain the frames and otoliths. For the validation experiment to succeed, tagged and labelled fish should ideally be at liberty for periods exceeding 1 year. In previous studies on *P. saltatrix* in Queensland most recaptures were reported within the first 4 weeks after tagging and release (Bade 1977; Halliday 1988; Morton and Halliday 1993).

To maximise the probability of obtaining tag returns from as long a period as possible, we conducted two tagging operations; one based on the wild population (mainly targeting the stock at its most concentrated on the Fraser Island ocean beach (25° 01’S, 153° 20’E)), and the other based on a ‘semi-captive’ population in a large saltwater Ski Lake at Sea World on the Gold Coast (27° 55’S, 153° 25.1’E) (Fig. 6.1). Previous *P. saltatrix* tagging conducted at Fraser Is during the spawning run made use of recreational anglers to capture the fish for tagging, but the disadvantage of this approach was that on release the fish were immediately exposed to a very high level of fishing activity, which greatly increased the likelihood that they would be recaptured within days (sometimes hours). To allow the fish at least a short period to disperse before being exposed to recreational angling, we chose to carry out the tagging during the spatial/seasonal closure (Fig. 6.1) which at the time extended from 1 to 30 September in the area between 400 m north of Waddy Pt and 400 m south of Indian Hd and extending 400 m offshore.

A second, semi-captive, marked and tagged population was established in the Sea World Ski Lake, with the great generosity of Sea World management and staff. These fish were sourced partly from the resident population in the lake, but primarily by wild fish caught from adjacent waters in the Southport Broadwater and offshore from the Gold Coast

Seaway. Some of the fish were double-tagged to provide an independent measure of tag loss rates. It was originally intended that this population would be resampled after periods of 1, 2, 4, 8 and 12 months, either by angling or (if necessary) netting, at times when the

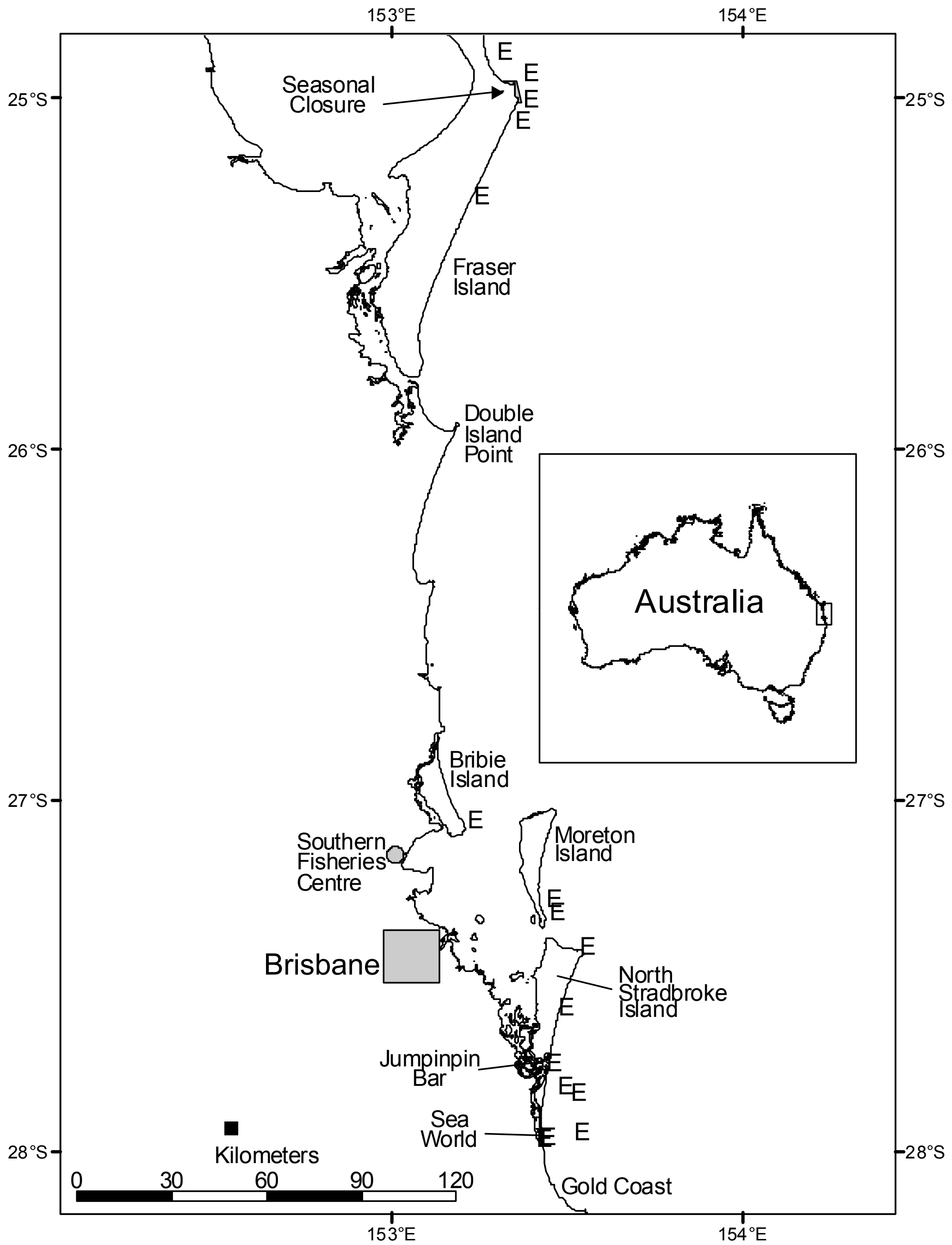

Figure 6.1 Location of sampling and experimental facility sites in southeast Queensland. Sample sites are denoted by a cross (+). GIS data sourced from Auslig.

tourist facility was closed to the public. Recapture data would be analysed for tag-shedding and tag-related mortality rates. Because of low return rates from the wild population, we also established a captive population at the Southern Fisheries Centre. The aims of this exercise were to determine the reason for tag losses, and also to enable a quantitative comparison of the relative effectiveness of two fluorescent marking compounds – oxytetracycline and calcein. A summary of all tagging operations is shown in Table 6.1.

Table 6.1 Summary of all tagging operations conducted during the Tailor Age Validation project.

Description	Year	Month	No. tagged	Release location	No. recaptured	No. kept
Wild population	2000	Sept.	2275	Fraser Is.	25	11
	2001	Feb – Sept	560	SE Qld	5	3
Semi-captive popn.	Nov 1999 – May 2001		887	Sea World	122	118
Captive population	2001	June – July	128	SFC	125	125

On completion of the validation exercise we conducted a workshop with research personnel from Western Australia to review the results and develop a common protocol for future reading of the otoliths of this species.

All recaptured *P. saltatrix* were examined for evidence of growth and presence of OTC uptake in their otoliths. OTC-labelled otoliths were examined as whole and sectioned samples by light microscopy for evidence of growth and annulus formation outside the fluorescing mark. Some sections were polished and etched prior to SEM examination (at the University of Queensland's Centre for Microscopy and Microanalysis) for evidence of daily growth rings. Where daily rings were discernable, the counts were to be validated by reference to sequential OTC marks of known periodicity.

The second objective was addressed by surveying offshore charterboat operators, line fishers, and commercial netters working waters south of the GBR. Initially we collected anecdotal information on the characteristics of *P. saltatrix* inhabiting inshore and offshore waters, i.e. the beach gutter and areas beyond the surf zone accessed by shore-based anglers. We sought the perceptions of fishers about the size-structure of fish in these areas, in order to determine whether there was any evidence of size segregation between the nearshore and offshore components of the population. This information was used to develop hypotheses on spatial variability in the age-structure of *P. saltatrix* in east-coast waters, and whether this could seriously bias population age-structure estimates from routine recreational fishery catch sampling.

6.2 Identification of First Annulus

Between late 1999 and 2001 we obtained samples of juvenile *P. saltatrix* (<1 yr old) from commercial trawlers off Double Island Point (26° 27.07'S, 153° 12.34'E) and within Moreton Bay (27° 10'S, 153° 08'E) (Fig. 6.1). Trawler skippers kept these fish under a DPI permit arrangement. Samples in 2001were small but were collected almost bi-monthly throughout the year (Table 6.2), and pooled with samples from previous years prior to analysis.

The samples were sorted from the catch, frozen on board and shipped to the laboratory in plastic bags. In the laboratory, each fish was measured (FL), weighed (0.01g), sexed (if possible) and the otoliths removed. Each otolith pair was cleaned in 70% ethanol and placed in a paper envelope to dry. After a drying period of three to six weeks, the otoliths were weighed (0.001 g) and transferred to labelled 20 ml vials for storage.

Each otolith pair was examined under a low power microscope, to which was attached a CCD camera linked to a PC with image analysis software. Images were collected (e.g. Fig 6.2) using ImagePro© 4.5.1 and saved in chronological order of

Table 6.2 Date and sample size of trawl caught juvenile *P. saltatrix* used to establish details of inner portion of otolith.

Date	n
(1)15/11/1999	33
(2)10/02/2000	22
(3)5/04/2000	26
8/01/2001	7
(2)27/02/2001	2
(3)3/04/2001	7
28/05/2001	4
9/06/2001	5
1/08/2001	4
(1)7/11/2001	2

(1): Bracketed superscripted numbers relate to the samples that were combined during analysis.

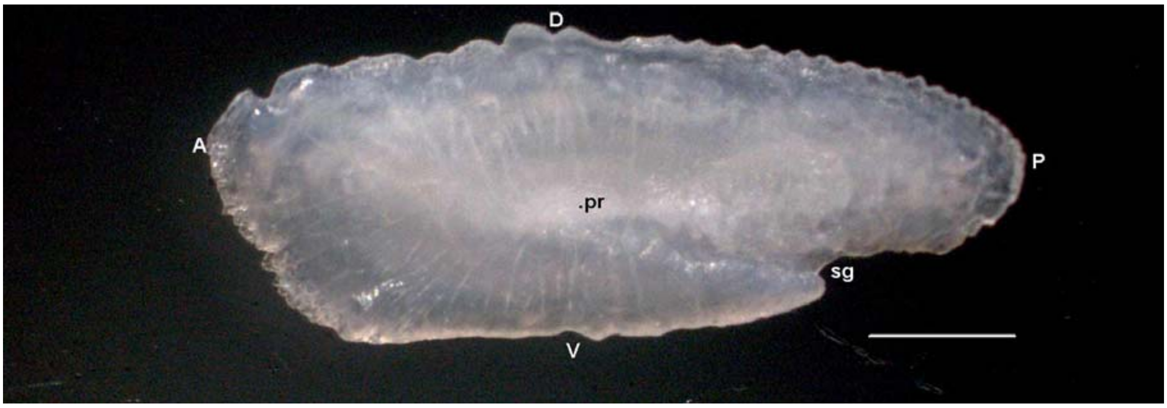

Figure 6.2 Whole otolith from juvenile *P. saltatrix* (20.7 cm FL) caught off southern Bribie Island Beach on 28/5/2001. A = anterior surface, D = dorsal surface, P = posterior surface, V = ventral surface, pr = primordium, sg = sulcal groove. Bar = 1.5 mm.

capture. These images provided a time-series of otolith images for a range of juvenile sizes. The time-series was used to compare the structure in the inner portion of the otoliths, and establish the position of the first annulus.

6.3 Mark and Release: Wild Population

In September 2000, project staff, along with 17 volunteer recreational anglers visited Fraser Island (25° 01’S, 153° 20’E) (Fig. 6.1) for 14 days. During this period 2275 *P. saltatrix* ranging in size from 24.6 to 56.2 cm FL were caught (Table 6.3) using standard tailor beach fishing gear of monofilament line, 3 x 4/0 gang hooks, 20 kg monofilament trace and blue pilchards (*Sardinops sagax*) as bait.

As many as 20 fishers (DPI staff and volunteer anglers) were involved in catching during a tagging session. Catch rates were variable, with more fish caught during the second week of tagging. Upon capture the *P. saltatrix* were carefully placed in one of two 50 l holding bins, half-filled with seawater at tagging stations (Fig. 6.3). These were set up with a team of 3 people per station. One person tagged, the second recorded, and the third was responsible for releasing the tagged fish into the ocean, observing their condition at release, and replenishing the water in the holding bins as needed.

Figure 6.3 Tagging station on south side of Waddy Point, Fraser Island, September 2000. Note the use of aluminium tagging platforms designed to support the measuring board as well as provide storage for tags, syringes etc.

Prior to release, all *P. saltatrix* were tagged using a standard procedure. The head was covered with a damp cloth, they were placed on a measuring board on a tagging stand (Fig. 6.4), measured (fork length) and tagged with a green T-bar anchor tag (Fig. 6.5). Each tag had an identifying number with reporting instructions ('Suntag Phone 1800 077 011; Record date, place, length. Keep frame'). The phone number is a free-call to the national tagging database operated by Infofish Services Inc., the principal of which (Mr Bill Sawynok) had previously agreed to handle all the tag reporting, database maintenance and recapture notification for the Project.

Captured *P. saltatrix* were also injected with a marking compound, either oxytetracycline (OTC) or calcein. OTC was purchased as Terramycin™, a broad-spectrum antibiotic. It was pre-packaged in the form of an injectable solution at a concentration of 100 $mg.ml^{-1}$ of oxytetracycline hydrochloride. Calcein was purchased in powdered form as Fluorexon™. This was added to a bacteriostatic, 0.9% solution of sodium chloride (obtained from a veterinary supplier) at a rate of 40 $mg.ml^{-1}$. To increase the powder's solubility in water, sodium bicarbonate was added to the solution until a neutral pH (7) reached.

Figure 6.4 Measuring wild caught *P. saltatrix* at the tagging station. A damp cloth placed over the eyes has the effect of calming the fish.

Figure 6.5 Inserting a T-bar tag into the shoulder region of a small wild caught *P. saltatrix*.

The resultant solution was filtered and stored in brown glass bottles wrapped in aluminium foil to prevent light from denaturing the solution. Initial trials indicated that because of its low viscosity the calcein solution was inclined to leak from the injection site after administration. On the advice of staff at the Department of Pharmacology, University of Queensland, we increased the solution's viscosity with Hypromellose™ (hydroxy-propyl-methyl-cellulose). This was added at a rate of 100 $mg.ml^{-1}$, stirred and left to stand for 24 hours to be absorbed into the solution. The resulting solution was then filtered to remove any small particulate matter. The marking compound was injected via syringe into the dorsal musculature of the fish, on the left side immediately below the dorsal fin, while it was on the measuring board (Fig. 6.6).

OTC was injected at a rate of 50 mg.kg^{-1} of body weight, at a concentration of 100 mg.ml^{-1}. Calcein was injected at a rate of 20 mg.kg^{-1}of body weight, and a concentration of 40 mg.ml^{-1}. A length-weight relationship formula obtained during the Integrated Stock Assessment and Monitoring Project (FRDC 94/161) (Hoyle *et al*. 2000), enabled dosages to be tabulated for a range of possible fork lengths. The two marking compounds were prepared at different concentrations so that the final delivery rate (volume injected) was the same for each, requiring a single dose-rate table for each tagging station.

Figure 6.6 Injection dose of OTC into the dorsal musculature of *P. saltatrix*, just anterior to the site of T-bar tag.

On release, *P. saltatrix* were observed where possible for up to one minute to determine their condition, and a 0-3 rating was recorded for each fish as follows: 0 (moribund) - the fish did not recover from the tagging process; 1 (poor condition) - the fish failed to swim away rapidly and either remained stationary for some time or swam away slowly; 2 (good condition) - the fish swam away strongly and rapidly; or 3 (excellent condition) – the fish swam away too quickly to be observed closely.

Nearly 83% of the released fish displayed an excellent response on being released (Table 6.4). Only 3 fish (0.1%) were found to have suffered mortality during the tagging process, although a further 7 fish were later retrieved dead from a nearby gutter after one morning of tagging. Another 21 fish were released at night and their release condition was not able to be observed, although only three of these fish appeared to be suffering some physical distress prior to release. When the capture rates were low only one tagging station would operate. However when capture rates increased two tagging stations would operate with up to 5 people staffing each one to maintain an adequate supply of fresh seawater in each 50 l holding bin. Tagging operations continued as long as the fish were being

Table 6.3 Numbers of *P. saltatrix* tagged each day at Fraser Island during the 2000 season.

Date	# tagged
9/09/2000	159
10/09/2000	222
11/09/2000	233
12/09/2000	92
13/09/2000	76
14/09/2000	38
15/09/2000	123
16/09/2000	167
17/09/2000	245
18/09/2000	215
19/09/2000	506
20/09/2000	102
21/09/2000	97
Total	2275

caught. If no fish were caught within a half-hour period, then the fishing session was terminated.

Because of the very small numbers of fish recaptured and reported from the 2000 tagging operation we decided not to do a repeat in 2001 at Fraser Is., considering the cost and organisational time required. Instead we chose to focus our tagging effort on the more southern parts of the State, specifically the beaches of Moreton Is (27° 10'S, 153° 25'E), North Stradbroke Is (27° 30'S, 153° 30'E) and Bribie Is (27°S, 153° 07'E) (Fig 6.1). An additional 560 wild fish between 17.6 and 48.2 cm (FL) were caught with the help of about 35 recreational fishers (Table 6.5). These were tagged, injected with OTC and released back to the wild. Again, the release condition was exceptional, with 92% returning to the water in excellent condition (Table 6.6).

Table 6.4 Release condition of *P. saltatrix* tagged and released at Fraser Island, September 2000.

Release Condition	# released
0	3
1	76
2	294
3	1881
Night (no observ)	21
Total	2275

Table 6.5 Southern Queensland wild *P. saltatrix* population tagging exercise catch rate during 2001 season.

Date	# tagged
28-Feb-01	1
08-May-01	1
09-May-01	1
10-May-01	1
12-May-01	27
23-May-01	10
24-May-01	22
25-May-01	14
27-May-01	18
05-Aug-01	2
06-Aug-01	10
27-Aug-01	17
28-Aug-01	63
29-Aug-01	68
31-Aug-01	1
01-Sep-01	4
03-Sep-01	102
04-Sep-01	143
05-Sep-01	34
07-Sep-01	21
Total	560

Table 6.6 Release condition of tailor tagged and released in southern Queensland during 2001

Release Condition	# released
0	0
1	5
2	37
3	518
Total	560

The program was widely publicised on popular fishing television programs, in recreational and commercial fishing magazines, through letter and pamphlet mail outs to clubs, and via a wide reaching pamphlet and poster distribution to tackle shops and tourist stops throughout coastal southern Queensland. Rewards were offered as an added inducement. These included printed t-shirts and reels of fishing line donated by Platypus™ Fishing Lines. Anglers who caught tagged *P. saltatrix* from the wild were encouraged to phone the InfoFish freecall number and lodge their personal contact, capture and tag details. InfoFish then notified Departmental project staff of these details and the angler was contacted and arrangements made to collect the *P. saltatrix* and supply an appropriate reward.

6.4 Mark and Release: Semi-captive (Sea World) Population

Sea World management and staff supported this project by allowing us to establish a semi-captive population in the Sea World Ski Lake for the duration of the Project. The lake is a 0.36 ha "L"-shaped shallow body of water (mean depth 2 m) situated on the Southport Spit (27°55' S, 153°25.1' E) which is used daily for water ski displays. Water is exchanged via tidal flow over a tidal barrage, and also via an 8" pump that moves water out of the Ski Lake. The lake is populated by a diverse ichthyofauna that has entered via the daily tidal flow and become established. Large predators are prevented from entering the lake from the adjacent Southport Broadwater by a steel grille, although resident fish of various species were noted to have reached considerable size in this environment.

P. saltatrix destined for the Sea World Ski Lake (Table 6.7) were captured from two areas: estuarine waters inside the Jumpinpin Bar (27° 44.5' S, 153° 25.3' E) and waters offshore from the Gold Coast from depths of 10 m to 60 m between 27° 52.5' S and 28° 04.3' S and 153° 26.1' E and 153° 37.3' E (Fig. 6.1).

Initially, the 20 m research vessel *Sea World I* was used as a capture platform. However, on two occasions the 14 m DPI research vessel *Warrego* was used, and in 2001 a smaller (5 m) DPI vessel was the primary capture platform. *Sea World I* carried a 3,000 l flow-through tank on the aft deck. *Warrego* carried 2 x 2000 l flow-through tanks and the 5 m vessel carried a single 1000 l tank on deck. Water flow was maintained at a minimum 75 $l.minute^{-1}$.

Valuable assistance was provided by recreational anglers from the North Brisbane Sports Fishing Club, the Bribie Island Sports Fishing Club and the Gold Coast Sports Fishing Club. Recreational volunteers and DPI Fisheries staff used rod and line to capture *P. saltatrix*. Fish were released into a flow-through tank on the back deck. In the deeper waters fishers used the traditional four x 4/0 hooks (Mustad 4202D) ganged with blue pilchard bait. For waters shallower than 20 m, either traditional gear or light tackle (two Mustad 4200D #2 hooks and white bait, *Hyperolophus vittatus*) was deployed. Initially monofilament lines were utilised, but lines were changed to braid after reports of higher catch rates from anglers using braided lines. This was thought to be due to the reduced stretch and finer line diameter of braided line, giving greater line sensitivity to the angler. Later sampling using braided lines resulted in improved catch rates, especially when fishing deeper waters (>20 m).

To monitor the potential impact of placing a large population of predators into the confined space of the Sea World Ski Lake, 91 *P. saltatrix*, averaging 28.7 ± 0.6 cm FL were caught, tagged, injected and stocked in November/December 1999. Forty-four were injected with calcein and 47 with OTC to compare the effectiveness of the two substances as otolith markers. After tagging, the fish were placed in 50 l transfer bins of clean seawater, and later released into the Sea World Ski Lake. During the initial releases, fish were liberated in small batches of one or two at a time. Large resident schools of bream (*Acanthopagrus* *australis*) were seen harassing the recovering *P. saltatrix*, often biting at the T-bar tag. To reduce the risk of tag loss through the predatory behaviour of other fish, subsequent releases were in batches of ten to twelve fish. All *P. saltatrix* were observed twice daily by Sea World staff for interactions with the existing fish populations.

After a period of three months, when no adverse interactions were observed, Sea World Research staff approved additional stocking with the previously-agreed number of fish. Between January 2000 and May 2001 an additional 796 *P. saltatrix* were caught off the southern Queensland beaches, tagged, injected with either OTC (n = 736) or calcein (n = 60), and released into the Sea World Ski Lake. Catch rates were quite variable, although there was a general increase over the later six months probably as a result of increasing experience on the part of the anglers (Table 6.7). Thirty of these fish were double-tagged with T-bar tags to assess the tag loss rate. The average size of all fish stocked was 26.9 ± 3.3 cm FL, although the size ranged from 16.6 to 46.6 cm FL. Release condition was generally very good, with more than 93% being returned to the water with a condition of 2 or 3 (Table 6.8).

Table 6.7 Numbers of wild *P. saltatrix* captured, tagged and released into the Sea World Ski Lake from each operation in 1999, 2000 and 2001.

Date (1999)	n	Date (2000)	n	Date (2001)	n
08-Nov-99	21	18-Jan-00	8	31-Jan-01	1
16-Nov-99	9	20-Jan-00	29	13-Feb-01	5
03-Dec-99	33	08-Feb-00	8	14-Feb-01	21
09-Dec-99	10	09-Feb-00	10	15-Feb-01	35
22-Dec-99	18	10-Feb-00	9	27-Feb-01	3
		18-Feb-00	8	28-Feb-01	9
		12-Apr-00	10	01-Mar-01	21
		16-Apr-00	3	21-Mar-01	7
		18-Apr-00	2	22-Mar-01	22
		19-Apr-00	3	23-Mar-01	77
		05-May-00	2	24-Mar-01	30
		16-May-00	25	27-Apr-01	13
		23-May-00	20	02-May-01	45
		25-May-00	11	03-May-01	78
		07-Jun-00	14	04-May-01	71
		08-Jun-00	15	11-May-01	97
		09-Jun-00	12	17-May-01	1
		16-Jun-00	4		
		27-Jun-00	8		
		28-Jun-00	1		
		25-Jul-00	31		
		06-Dec-00	8		
		13-Dec-00	2		
		18-Dec-00	17		
TOTALS	91		260		536

Table 6.8 Release condition of *P. saltatrix* tagged and released into the Sea World Ski Lake between November 1999 and May 2001.

Release Condition	# released
0	33
1	25
2	266
3	563
Total	887

The semi-captive population was sampled periodically over the next 6 months for the OTC-calcein comparison, then after a period of 12 months to obtain otoliths for analysis (Table 6.9). Resampling *P. saltatrix* from the Sea World Ski Lake population required a range of methods. Recreational anglers from the North Brisbane, Bribie Island and Gold Coast Sports Fishing clubs volunteered their time to fish the lake in the evenings after the Sea World complex was closed to the public. Anglers used various baits and lures in attempts to catch *P. saltatrix*, with mixed success. Project staff also set multi-panel mesh nets of 2 ¼", 2 ¾", 3" and 4" stretched mesh to recapture *P. saltatrix* from deeper parts of the Ski Lake (Fig. 6.7). On four occasions, professional fisherman assisted the Project, using commercial gear (400 m headline length; 2 $^{3}/_{8}$" mesh) to help capture *P. saltatrix*. All capture methods were used at dawn before the facility opened and at night after it had closed. The evening sessions tended to be more productive than those in the morning.

Figure 6.7 Setting multi-panel mesh nets across the Sea World Ski Lake to recapture *P. saltatrix* from deeper areas.

Recapture rates of tagged fish during preliminary trials were low. Despite changes to the initial release strategy, many of the recaptured *P. saltatrix* lacked the external tag, but bore a tagging scar on the left hand dorsal surface (Fig. 6.8), at the location where the tag should have been. This suggested that the changes to the initial release strategy had not been entirely effective in preventing fish (possibly including conspecifics) from biting off or pulling out the tags.

To maximise the likelihood of being able to identify recaptured fish as having initially been tagged, the process was extended to include the use of VIE (visual implant elastomer) marks injected into one of the fins. VIE tags were sourced from Northwest Marine Technology in the USA. The 'tags' were formed by mixing a pigmented fluorescent liquid with a curing agent.

Table 6.9 Sampling dates, gear used, and numbers of *P. saltatrix* recaptured from the Sea World Ski Lake population.

Date	Capture Method	Time	n
02/02/2000	Line	PM	1
08/02/2000	Line	AM	1
09/02/2000	Line	PM	2
12/04/2000	Line	AM	1
16/05/2000	Line	PM	3
31/05/2000	Line	PM	3
28/06/2000	Research Net & Line	PM	16
06/12/2000	Research Net & Line	PM	10
13/12/2000	Research Net & Line	PM	10
18/05/2001	Research Net & Line	AM	1
17/07/2001	Research Net & Line	PM	11
30/10/2001	Comm. Net & Line	PM	20
31/10/2001	Research Net & Line	PM	6
01/11/2001	Research Net & Line	PM	8
06/11/2001	Comm. Net & Line	PM	3
07/11/2001	Research Net & Line	PM	2
20/11/2001	Research Net & Line	PM	2
12/12/2001	Comm. Net & Line	PM	10
12/02/2002	Comm. Net & Line	PM	11

Figure 6.8 Tagging scar on dorsal surface (dark area on dorsal surface below and slightly forward of dorsal fin) of *P. saltatrix* recaptured from the Sea World Ski Lake. Note that abdominal lesions occurred during capture by gill netting.

When combined, the mixture remains in liquid form for at least 24 hours if kept chilled (<3°C), after which it begins to set. The liquid elastomer was injected into the fin of the fish (Fig. 6.9) with a 27-gauge 1 ml insulin syringe needle and set to an inert and non-toxic rubbery consistency after 1 to 2 hours at room temperature. The tag was highly visible under UV light (Fig. 6.10). The addition of a second VIE tag enabled the identification of release date for batches of fish that might have subsequently lost their external T-bar tag. Injecting a different colour elastomer into a different fin ray enabled replicate batches to be differentiated, as long as each batch contained a similar VIE colour and location during each tagging session (Table 6.10). However, individual fish were not identifiable with this method.

Figure 6.9 Injecting yellow VIE tag into dorsal fin of *P. saltatrix*.

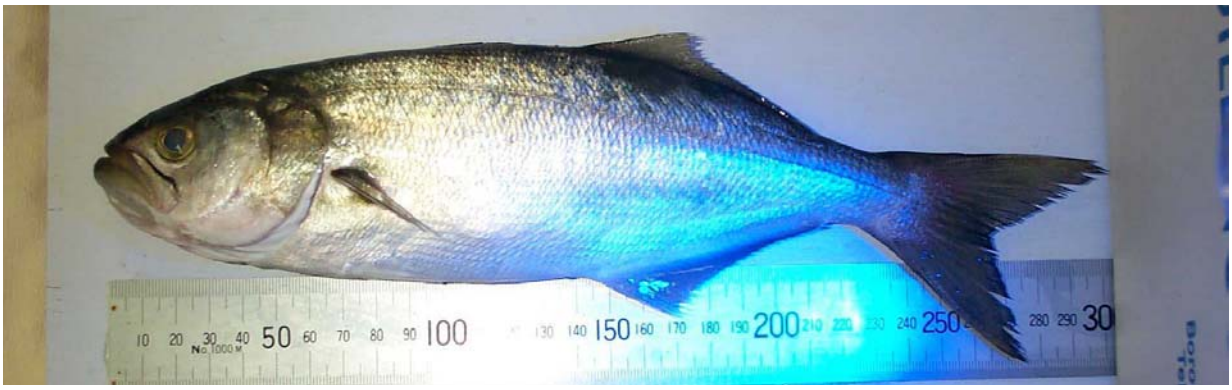

Figure 6.10 VIE tag visible in the anal fin of a *P. saltatrix* when exposed to UV light.

Table 6.10 Application dates and locations of VIE tags used to identify batches of *P. saltatrix* stocked into the Sea World Ski Ski Lake. D2 = 2nd dosal fin, A = anal fin, P = pectoral fin.

Dates	VIE ID#	Location of injection site	n
18/12/2000	1	2 orange into rays 1 and 2of D2	17
31/1/2001	2	2 orange into rays 4 and 5 of D2	1
13-15/02/2001	3	2 red into rays 1 and 2 of D2	61
27/02 to 1/03/2001	4	3 yellow into rays 2, 3 an 4 of D2	34
22-24/03/2001	5	1 red midway along D2	136
27/04/2001	6	1 yellow A	13
2-4/05/2001	7	2 yellow A	194
11/05/2001	8	1 red A	70
11/05/2001	9	1 red left P	27
Total			553

The addition of a VIE tag (multi-tagging) increased the time required to handle each fish. To minimise any additional stress that this procedure might have on the fish, they were anaesthetised by placing them carefully in a seawater-clove oil bath (0.05 ml clove oil per litre of water), for 2 minutes prior to tagging. After tagging, the anaesthetised fish were released into a tank of fresh aerated seawater. The fish typically revived within 2-5 minutes, resuming normal swimming behaviour. They were then released into the Sea World Ski Lake in the usual manner.

6.5 Tag Loss Experiment

A laboratory-based tank experiment was developed to examine the incidence of tag loss, our specific interest being in whether tag loss was caused by other *P. saltatrix* in close proximity biting and/or pulling the tags, or as a result of rejection of the tag for physiological reasons. Another concern was that while Western Australian Department of Fisheries staff had expressed a preference for using calcein over OTC as a marking compound, our early trials (see section 6.4 above) indicated that OTC produced a more consistent mark. The tag-loss experiment was also designed to investigate (a) the effectiveness of each marking compound (OTC and calcein), both in terms of uptake of the compound and its effect on the survival of the fish, and (b) which of two injecting locations (intramuscular and intraperitoneal) was the more effective. All fish were used to assess T-bar tag loss, and there were also four replicates of four treatments (2 compounds x 2 injection sites), with eight fish in each treatment.

In May 2001, 144 *P. saltatrix* were captured from the beach at the southern end of Bribie Island (27º 5.5’ S, 153º 12.1’ E) for the tank experiment at the Southern Fisheries Centre. DPI staff used small spinning lures with flattened hook barbs to capture fish that were then released directly into aerated seawater in 1,000 l polyethylene holding bins (Nylex Rotomould Cool Bins™) mounted on a 4WD vehicle. When each bin contained about twenty *P. saltatrix*, or the first fish caught had been in the bin for half an hour, fishing ceased and the captured fish were then transported back to base. This process was repeated over several consecutive mornings, until adequate numbers of fish were caught for the experiment. Back at base, the fish were released into four 5,000 l tanks (32 fish per tank) of aerated seawater with an exchange rate of at least 20 $l.minute^{-1}$. The four tanks were located in a covered shed with one open side. The captive fish were treated with a prophylactic fungicide (100 ppm formalin) for half an hour and then allowed to acclimate for about 2 weeks. Successful acclimation was gauged by the commencement of feeding behaviour. After three days of starvation, fish were fed daily on whole white pilchards, and to a lesser extent chopped blue pilchards.

On 11 July 2001 the captive *P. saltatrix* were scoop-netted from the tanks at the Southern Fisheries Centre, and placed in a 1,000 l holding bin with flow-through seawater. Individual fish were removed randomly from the holding tank, placed into a small bin and anaesthetized with a small quantity of clove oil (0.05 ml clove oil per litre of seawater). These individual fish were then measured, T-bar and VIE tagged and then injected with a marking compound according to the experimental design shown in Table 6.10. Intra-muscular injections were effected in the dorsal musculature just anterior of the dorsal fin. Intra-peritoneal injections were achieved by inserting the needle into the body cavity mid-way along its length and about 1 cm above the ventral wall. After injection, the fish were released back into the 5,000 l tanks and observed for signs of recovery. All four 5,000 l tanks contained replicates. The anaesthetized fish revived within a period of two to five minutes, and resumed what appeared to be normal swimming behaviour in the tanks. VIE tags, using a combination of different colour and injection site patterns (Table 6.11), were included to enable identification of individual fish in the event of loss of the numbered anchor tag.

Table 6.11 Tag loss experiment division of *P. saltatrix* into separate treatments. L-P = left pectoral fin; R-P = right pectoral fin; D = 1st dorsal fin; A = anal fin; IM = intra muscular; IP = intra-peritoneal.

Fish #	VIE colour & location	Marking Substance & injection site
1	Red: L-P x1	IM Calcein
2	Red: L-P x 2	IM Calcein
3	Red: R-P x 1	IM Calcein
4	Red: R-P x 2	IM Calcein
5	Red: D1 x 1	IM Calcein
6	Red: D1 x 2	IM Calcein
7	Red: A x 1	IM Calcein
8	Red: A x 2	IM Calcein
9	Yellow: L-P x1	IP Calcein
10	Yellow: L-P x 2	IP Calcein
11	Yellow: R-P x 1	IP Calcein
12	Yellow: R-P x 2	IP Calcein
13	Yellow: D x 1	IP Calcein
14	Yellow: D x 2	IP Calcein
15	Yellow: A x 1	IP Calcein
16	Yellow: A x 2	IP Calcein
17	Orange: L-P x1	IM OTC
18	Orange: L-P x 2	IM OTC
19	Orange: R-P x 1	IM OTC
20	Orange: R-P x 2	IM OTC
21	Orange: D x 1	IM OTC
22	Orange: D x 2	IM OTC
23	Orange: A x 1	IM OTC
24	Orange: A x 2	IM OTC
25	Green: L-P x 1	IP OTC
26	Green: L-P x 2	IP OTC
27	Green: R-P x 1	IP OTC
28	Green: R-P x 2	IP OTC
29	Green: D x 1	IP OTC
30	Green: D x 2	IP OTC
31	Green: A x 1	IP OTC
32	Green: A x 2	IP OTC

On 10 December 2001 all four tanks at the Southern Fisheries Centre were drained, leaving between 15 and 20 cm of water. All fish were scoop-netted out of each tank into a 50 l bin half filled with the standard anaesthetic solution (1 ml clove oil/ 20 l seawater) until anaesthetised. They were then measured and the presence/absence of a T-bar tag recorded, along with the tag number and VIE location. Each fish was then placed into an ice slurry until the onset of rigor, and then removed to the laboratory for processing.

6.6 Otolith Processing

The tag number, catch date, catch location, fisher, fork length, and total length were recorded for each fish. After removal from the fish or frame, the sagittal otolith pairs were rinsed clean, dried, and then stored dry in labelled plastic vials. After a drying period of three to six weeks, the otoliths from each sample were weighed to the nearest 0.001 mg using a Sartorius™ 1700 balance.

6.6.1 Ultra-thin sectioning for high power light microscopy

If a sample was to be examined for daily ring analysis, then the two whole otoliths were examined under low-power (x 40) light microscopy. An image of each whole otolith was captured via a digital camera mounted on the microscope, processed into a computer image via a frame grabber, and saved to a .jpg file for further analysis. The right otolith (or the left if the right one was broken) was mounted on a heated glass slide using Crystal Bond™ thermal adhesive. The otolith was positioned longitudinally so that the primordium aligned with the end of the slide. The anterior part of the otolith extending past the end of the slide was then ground down by hand using wet and dry sandpaper (400, 800, 1000, 1500, 2000 grit). The ground end was then polished with diamond paste (8000 and 14000 grit). The slide was then re-heated, the otolith removed and repositioned with the freshly polished surface face down on the slide. The posterior part of the otolith was then ground down to the primordium and polished using the same technique.

The ground otolith sections were then viewed under x 400 magnification on a compound microscope, and the daily rings identified and counted where possible. Images of each section were captured via a digital camera mounted on the microscope, processed into a computer image via a frame grabber and saved to a .jpg file for further analysis.

6.6.2 Processing for Scanning Electron Microscopy

A sub-sample of otoliths from tagged and injected fish were examined using Scanning Electron Microscopy (SEM). Ten otolith stub residuals remaining from the sectioning process (see section 6.6.3 below) were ground on a sheet of 10 mm thick glass with progressively finer grades (280, 400, 800, 1500 grit) of wet and dry emery paper using water as a lubricant. Finer grades of paper were used each time until the previous scratch marks were removed. The stubs were then polished using fine grades of diamond paste in the same manner

Table 6.12 Otolith etching times (5% EDTA solution) for SEM examination, and estimated age from whole otoliths.

Otolith ID	Etching time (min.)	Est. age
TAV028	1	1+
TAV029	2	0+
TAV030	3	0+
TAV031	1	0+
TAV032	1.5	1+
TAV046	2	0+
TAV056	2.5	2+
TAV057	3	3+
TAV058	3.5	2+
TAV059	4	1+

(8000, 14000, 50000) before being given a final polish using a polishing fluid. Unless etched, all otoliths were then washed in distilled water, dried, mounted on SEM stubs with Crystal Bond™ and platinum sputter coated.

Several of the otolith sections were exposed to a variety of etching processes in 5% EDTA (ethylene diamine tetra-acetate) solution. To test the process, three otoliths were exposed to 1, 2 and 3 minutes of etching prior to washing and mounting for sputter coating. Later, another seven otoliths were prepared and etched at half-minute intervals from 1 minute to 4 minutes to test for the best etching exposure (Table 6.12).

SEM otolith stubs were initially viewed on a JEOL 6400™ Field Emission Scanning Electron Microscope. Final images were taken on the Philips XL30™ Scanning Electron Microscope at the Centre for Microscopy and Microanalysis, University of Queensland. Images were saved to CD as .tiff files for further examination.

6.6.3 Processing for visible and ultraviolet light microscopy

Otoliths were sectioned for light and UV microscopy. If intact, the left otolith was chosen for sectioning. If the left had been broken or was for some other reason incomplete, the right otolith was used instead. The otolith was embedded in a polyester resin block using latex moulds. A Buehler Isomet™ low speed saw fitted with a diamond wafering blade was used to cut transverse sections through the core of each otolith. Sections were generally cut to a thickness of 300 µm. Each section was examined under a stereomicroscope immediately after cutting. If it was of unsatisfactory quality or location, cutting was repeated until the best possible section was obtained. The left-over stubs from the sectioning process were later used for scanning electron microscopy (see section 6.6.2 above). After rinsing in ethanol and drying (to remove cutting fluid and particulate matter) the section was mounted on a labelled 1.0 mm glass slide under a cover slip (0.3 mm) using polyester resin as the mounting medium.

For whole otolith readings, the left or right otolith, or both when available, were immersed in vegetable oil in a clear glass petri dish on a black background. Magnification varied depending on the size of the otoliths, but was usually set at x 40. Reflected incident light was provided with a optical fibre light source.

Slide-mounted otolith sections were viewed under low power (x 40) on a Nikon Microphot FXA™ UV microscope with either transmitted or reflected light. Transmitted light was provided by the microscope’s built-in light source, while incident light was provided by a fibre optic light source. The terminology used for otolith readings followed that of Kalish *et al.* (1995).

Ultra-violet microscopy was used to determine the presence of a fluorescing check in the otolith section. After viewing an otolith cross-section preparation on the Nikon Microphot FXA™ UV microscope with transmitted light, the light was turned off, and the ultraviolet lamp was opened to the otolith slide, via a range of excitation filters. These included ultraviolet, blue-violet and blue. The blue violet filter, having an excitation wavelength range between 400 and 440 nm, was the most useful for displaying both OTC and calcein mark within the otolith microstructure. Calcein produced a pale yellow fluorescence (Fig.

6.11) while OTC produced a more orange fluorescence (Fig. 6.12). An image of the otolith cross section, with fluorescent mark, was captured via a top mounted digital colour camera and transferred to a desktop PC for analysis with the software package ImagePro™ Version 4.5.

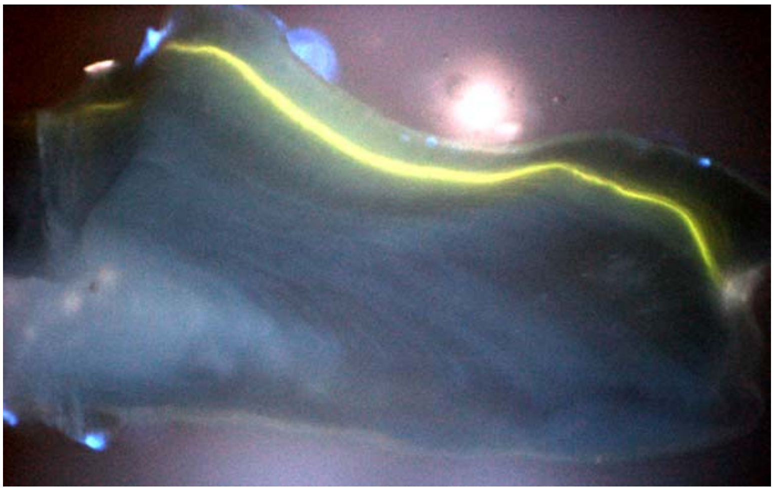

Figure 6.11 UV micro-photograph (x 100) of *P. saltatrix* otolith transverse section showing yellow calcein fluorescing band.

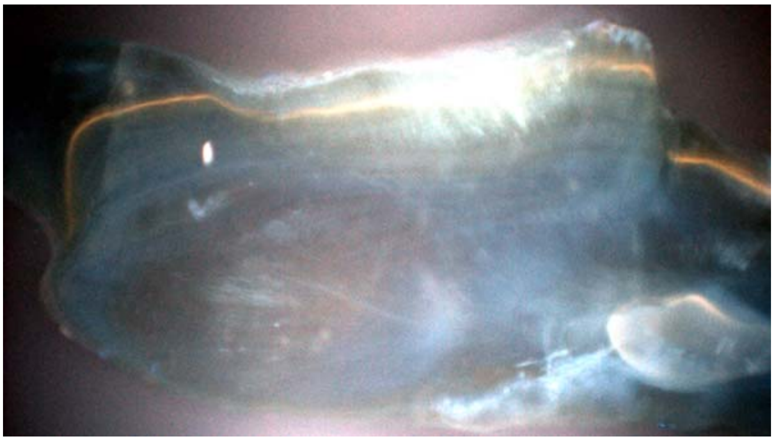

Figure 6.12 UV micro-photograph (x 40) of *P. saltatrix* otolith transverse section showing orange OTC fluorescing band.

6.7 Image Processing and Measurement

All image processing procedures used standard techniques associated with Leica MZ6™ or Wild MZ3™ binocular and Nikon Microphot FXA™ UV microscopes, with a Pulnix TMC6™ colour digital camera attachment. For each procedure, the sectioned or whole otolith sample was mounted on the microscope stage and an image of the otolith was collected by the digital colour camera. The image was processed into a computer image via a frame grabber and saved to a .jpg file for further analysis. All images were saved and archived as jpeg files. Saved images were later viewed with the image analysis software package, ImagePro™ 4.5.1 and individual structures were marked on the screen (Fig.

6.13). The software package automatically counted and measured these rings and exported the data to an Excel spreadsheet for further analysis.

Figure 6.13 Image of *P. saltatrix* cross-section from ImagePro© 4.5.1 software package, showing axis used for measurements. F = false check, A = annual growth check, U = UV mark, E = edge of otolith.

6.8 Direct evidence of periodicity of annulus formation

All otoliths with known dates for at tagging were analysed for distances from the the UV mark to the edge (observed) against time at liberty. Those estimated to be of age one or more at time of tagging also had a prior growth check to UV distance measurement, and some had a UV mark to post -ring distance measurement. All had a distance measurement from the UV mark, or 'post' growth check to the edge. These distance measurements were plotted for individual otoliths to evaluate trends in growth check periodicity against known dates of marking (UV) and recapture.

6.9 Indirect evidence of periodicity of annulus formation

6.9.1 Analysis of time of growth ring formation

For all wild and Sea World Ski Lake samples with known mark and recapture dates, the otolith had distances and dates for the UV mark (at tagging), and the edge (at sacrifice). Those aged one year old or more also had a prior-annual-ring distance, and some had a post-ring distance. From all, the otolith growth rate ($\mu m.day^{-1}$) was calculated, and these data were subjected to general linear model analysis to determine the overall trends of age and season. To investigate growth beyond the linear dimension, a second seasonal growth model was also fitted (Somers 1988). Length at recapture was taken as the dependent (Y) variable, rather than the more usual 'growth amount' because the latter incorporates length at release, which also appears in the equation being fitted and can cause statistical correlation problems. The equation was thus -

$$L_t = L_{t-\delta} + (L_\infty - L_{t-\delta}) \times \{ 1 - \exp [-K \delta + S (t - \delta) - S (t)] \} \qquad \textit{Eqn. 6.1}$$

where L_t is length at recapture,
t is day of recapture,
δ is time at liberty (days),
$L_{t-\delta}$ is length at release,
L_∞ is the asymptotic length,
K is the average exponential growth rate,
$S (i) = C K \sin [2 \pi (i - t_s)] / 2 \pi$,
C measures the magnitude of the seasonal oscillation, and
t_s is time shift for the annual cycle.

The parameters in italics were estimated via a nonlinear regression using Genstat (2000).

When a growth band fell outside the range of known dates, extrapolation (using the average growth rate of each otolith, to remove overall size differences) was used to estimate the date it was laid down. However, initial attempts at this gave very variable results, spread across the whole year, and with 24% of these estimated time-gaps being greater than the boundary value of one year.

Greater confidence was placed in interpolative methods in situations where prior and post rings (presumably one year apart) spanned the UV ring (of known date), or when the UV ring and the edge (both with known dates) spanned a post ring.

For both types of data, two forms of estimation (of the date that the growth ring was laid down) were available – the first was direct linear interpolation, where the respective length differences were calculated into ratios which were then applied to the time-scale. The second method used numerical integration of the fitted age-dependent growth curve to estimate the time intervals associated with the different length ratios. The solver function in Excel was used to optimise the fit, separately for each individual. By accounting for the observed seasonal growth patterns, this second method was expected to produce more accurate estimates.

These estimated dates are a type of circular statistics, with day one (1st January) following directly on from day 365 (31st December). The average date can be estimated by transforming each datum point onto a circle (Mardia 1972). This is achieved by the following equation:

$$y = \cos(2 \pi \text{ day} / 365) \qquad \textit{Eqn. 6.2}$$

Here y represents a transformation of the day and *cos* is measured in radians. The mean of y is then back-transformed to give the average day (of the year) by:

$$\text{day} = 365\ cos^{-1}(y) / 2\pi \qquad \textit{Eqn 6.3}$$

These data were analysed for any differences in dates against the factors of sex, presence/absence of T-bar tag (tag loss), type of data (interpolation based on the 'prior – UV-post' ring sequence, vs the 'UV-post-edge' ring sequence), and method of estimation (linear or nonlinear).

6.9.2 Statistical validation of annual periodicity of growth checks

While more than half the recaptured fish had been at liberty for less than a complete year, the data obtained were still of value. To fully utilise these data we used a modified version of Govender's (1999) model, which allows age estimates derived from scales or otoliths to be validated using corresponding mark-recapture data. The model is based on the premise that if a growth equation derived from size-at-age data reasonably predicts the growth increment during the time-at-liberty of tagged individuals, then the estimated growth parameters and the assumed time period for deposition of the seasonal bands are appropriate. The model consists of two components. The first estimates growth parameters from size-at-age data based on different deposition periods of hard structure bands. The second then predicts the growth increment during the time-at-liberty of recaptured tagged individuals, using the growth parameters derived from the first model component. If the growth increments are reasonably predicted, then the assumption of periodicity in hard structure deposition is assumed to be valid.

Govender's model used Schnute's (1981) parameterisation of the von Bertalanffy growth function. We modified this growth model to incorporate length-of-otoliths vs age (rather than length of fish) and fitted the otolith measurement data set, assuming rings were laid down either a) annually, b) bi-annually, or c) biennially. The numbers of observations was used as a weighting factor in these regressions. The 'false-check' (f) band was not used, as its position on the growth curve did not match the predicted value when omitted. As we were only interested in predicting the growth of first-band and older fish, it was deemed more important to get a good fit in this region. For the three base assumptions, the modified Schnute relationship was used to predict otolith growth for the period from marking to sacrifice.

6.9.3 Comparison of otolith morphology by age group

Lastly, we examined 125 otoliths from tagged and recaptured *P. saltatrix*. These were aged according to our ageing protocol (see section 7.9 below, and Appendix 4). The individual otoliths were measured along the longitudinal and transverse axes and these measurements were plotted as individual age groups to determine the degree of overlap, indicative of an accurate age interpretation.

6.10 Independent Age-Assessment (Central Ageing Facility)

In August 2001 a sample of 200 whole tailor otoliths was sent to the Central Ageing Facility, MAFRI, for independent interpretation. These otoliths had been collected during a previous FRDC project (FRDC 94/161) and had been randomly selected from a pool of more than 1000 for an age interpretation accuracy trial during that project. They had previously been examined by two experienced readers and the age interpretations compared for between- and within-reader bias.

As 21 preparations were damaged in transit, 179 were examined according to standard CAF procedures. All sections were viewed under low-power light microscopy and aged twice by CAF laboratory manager Simon Robertson. The resulting age estimates were compared for differences using an index of average percent error or IAPE (see Sect. 6.12). In addition, thirteen specimens were ground to ultra-thin sections and viewed under high-power microscopy for daily ring count analysis. Images of each whole and sectioned otolith were stored as .jpg files on a CD. A report on this assessment appears in Appendix 3.

6.11 Development of Ageing Protocol

The data obtained from viewing juvenile otoliths, whole and sectioned adult otoliths and the CAF independent assessment were reviewed. We sought to identify common features present in all otoliths. These were determined separately for whole and sectioned otoliths. Once identified, these features formed the basis for the development of a set of procedures that would aid an inexperienced tailor otolith-reader to identify common features and annual growth structures. The protocol was reviewed and refined at a four-day *P. saltatrix* Ageing Workshop held in the North Beach Fisheries Laboratory of the Western Australian Department of Fisheries in December 2001. Project staff Adam Butcher and Mark McLennan (DPI, Queensland) arranged this workshop, which was also attended by Suzanne Ayvasian and Jason How (WA Fisheries; Long-term stock recruitment project [FRDC 99/153]) and Richard Steckis (WA Fisheries; researching *P. saltatrix* biology as part of a PhD study). The workshop outcome was a draft *P. saltatrix* ageing protocol that was further refined by scientists from Queensland, Western Australia and CAF to the point where it could be used by routine ageing groups in both States to improve the accuracy and precision of their estimates of tailor age.

6.12 Analysis of ageing protocol precision

Percent agreement has been used widely to quantify the precision of *P. saltatrix* age estimates (Van der Elst 1976, Richards 1976, Bade 1977, Krug and Haimovici 1989, Barger 1990, Hoyle *et al*. 2000, Wischniowski and Bobko 2000, Salerno *et al*. 2001, Sipe and Chittenden 2001, Lucena and O'Brien 2001). However this statistic may not adequately describe ageing precision when fishery-dependent age samples are restricted to a range smaller than that of the population (Campana 2000), and the alternative index of average percentage error (IAPE) is recommended by the Central Ageing Facility (S. Robertson pers. comm.) to quantify precision between readers. IAPE is defined as:

$$IAPE = \frac{100}{N}\sum_{j=1}^{N}\left[\frac{1}{R}\sum_{i=1}^{R}\frac{|X_{ij}-X_j|}{X_j}\right] \qquad \textit{Eqn. 6.4}$$

where N is the number of fish aged, R is the number of times fish are aged, X_{ij} is the ith determination for the jth fish, and X_j is the average estimated age of the jth fish.

We used this method to evaluate the precision of the draft ageing protocol. To achieve this, two experienced readers examined both whole and sectioned otolith samples, using standard 'blind' techniques (Hoyle *et al.* 2000). These were the same otoliths used in the ISAMP (FRDC 94/161) *P. saltatrix* age precision trial, and examined by CAF staff. Each otolith was read twice by two readers independently on two separate occasions without referring to any other data, such as month of collection or length of fish. Age and readability indices were assigned to each sample. Age was estimated by counting annuli or opaque zones. Readability indices were assigned in an attempt to quantify the degree of confidence each reader placed in his or her age estimate. These were as follows:

1 - Unreadable
2 - Multiple interpretations possible
3 - Readable, but not confident
4 - Readable, but not totally confident
5 - Readable, totally confident

The overall sample IAPE was calculated as the unweighted sample mean. To generate confidence intervals around these estimates of precision from the sectioned and whole otolith reading trials, a bootstrap technique was employed on the individual error estimates, following the methods described in Efron and Tibshirani (1993). One thousand samples of error estimates (each the same size as the original) were randomly calculated, with replacement, from the repeated readings, and a new IAPE calculated for each. The mean of these replicates was the mean IAPE and the standard deviation is the standard error of the mean. The bootstrap procedure had to be adjusted to correct for the bias present in the original estimate. This was achieved by adding the difference between the original statistic and the bootstrap mean, to the original estimate. The bias-corrected bootstrap mean is calculated as:

Bias-corrected IAPE = Original IAPE + (Original IAPE - mean bootstrap IAPE)

The 95% confidence interval was calculated as:

95% C.I. = Bias-corrected IAPE ± (1.96 x Standard error of bootstrap IAPE) *Eqn. 6.5*

To test for bias between readers (as a result of differences in the interpretation of internal structure), and between ageing methods (due to differences in the way that they affect the visibility or clarity of internal structure) we used Bowker's (1948) chi-square test of symmetry, as applied to age determination comparisons by Hoenig *et al*. (1995). Bowker's method tests the null hypothesis that an *m* x *m* contingency table that classifies a sample (eg. of ages) into two categories (eg. two readers or methods) is symmetrical about the diagonal. The test statistic, distributed as chi-square, is large if the differences between the two categories are systematic (ie. the distribution is asymmetrical), and small if the differences are random (symmetrical distribution) (Hoenig *et al*. 1995).

6.13 Influence of ageing protocol on mortality estimates

Previously the ISAMP project (FRDC 94/166) estimated total mortality using catch curves, containing data from all *P. saltatrix* collected during 3 years of that project, from both the recreational and commercial sector. All valid age estimates for each *P. saltatrix* were included in the catch curve, weighted so that each fish made the same contribution to the result.

We reviewed a random sub-sample of 390 ISAMP tailor otoliths and estimated their age, based on the ageing protocol. The resulting sub-sample age-at-length structure was used to construct a catch curve containing the entire 6010 ISAMP tailor samples, collected from recreational and commercial sources during the 3 years of that project. The natural logarithm of the frequency at age was taken, and the slope of the age log-frequency curve was used as the estimate of total mortality rate. The two estimates of mortality were compared by calculating the implied survival from each estimate.

6.14 Inshore-offshore size composition differences

The question of representative *P. saltatrix* catches was examined by four separate methods.
a) Initially, mobile tailor schools were actively targeted and sampled to ascertain their size-composition. Schools were targeted in six zones (Table 6.13): (1) inshore in the surf zone, (2) in bays and estuaries, (3) waters adjacent to rocky headlands, (4) in inshore waters beyond the surf zone (<5 fm), (5) mid shelf

Table 6.13 Sampling locations and depths for *P. saltatrix* size composition analysis.

Location	Depth (fm)	# sampling days
Beach	1	15
Estuary	1-2	37
Headland	3	13
Outside breakers	5	8
Shallow inshore Reef	11	7
Mid-shelf Reef	22-24	17

waters (~11 fm), and (6) off-shore reefs (>20 fm). These locations ranged from Fraser Island in the north to the Gold Coast region in the south.

Tailor were located in the various depths by echo-sounder and observation of bird activity, "chopping" the surface of the water or black patches in the water. Located schools were sampled with various hook and line techniques, depending on the depth of water. If a school was located inshore near the surface, spinning lures with barbless treble-hooks were cast through the school to attract and hook individual fish. If schools were in shallow depths, but behind the breakers (<5 fm), they were sampled using light tackle consisting of two Mustad 4200D #2 hooks and white bait, *Hyperolophus vittatus*, attached to 10 kg monofilament lines. In greater depths (10-25 fathoms), standard bottom fishing gear with 2 sets of 4/0 triple-gang hooks baited with blue pilchard, was used. Sinker weights were adjusted depending on the amount of current or tide. Measurement records (FL) were taken for all *P. saltatrix* captured, along with location and depth. The catch length-frequency from paired depths was compared using standard Pearson Chi-square techniques to determine whether there was any significant variation between the two depths.

b) A second method of examining temporal activity of *P. saltatrix* was to survey fishers most active in offshore waters to ascertain their perceptions of *P. saltatrix* activity. Charter vessel operators (CVO's) were deemed the most active group in southern Queensland waters and a list of these were retrieved from the Telstra Yellow Pages© online directory. This source was chosen over the Queensland Fishery Service licensed charter boat operators data on the assumption that Yellow Pages© listed operators would be more likely to be more active in southern Queensland waters, and thus experienced with contemporary and historical tailor behaviour, than unlisted operators that were licensed but not currently active.

The listed operators were asked a series of questions about their perceptions of tailor activity. The operators' region of activity ranged from Fraser Island to the Qld/NSW border, and was divided into 3 major areas: Sandy Cape to Cape Moreton (North), Cape Moreton to Jumpinpin Bar (Central) and Jumpinpin Bar to the Tweed River (South). Their responses were tabulated as nominal scale data in an Excel™ spreadsheet and examined to determine statistical significance of spatial influence on operators replies. This was achieved via a Pearson Chi-square goodness of fit test, the null hypothesis (H_0) being that there was no variation in nominal answers across the three regions of operator activity.

c) A third method of investigating temporal activity of tailor was to interview serious recreational tailor anglers to gather their perceptions about the species' activity. These fishers were selected from the winners of fishing competitions, by their reputation amongst the angling fraternity, and by word of mouth. They were surveyed in a similar way to the CVOs.

d) Commercial beach haul fishers with K1 to K8 endorsements were interviewed to gather their perceptions about tailor stock structure and activity. Their individual selection was based on word of mouth recommendation and their willingness to participate. They were asked a similar range of questions as were the recreational tailor fishers. The resulting answers were examined collectively, without any regional classification, because many of the interviewed K-endorsed licence-holders are entitled to fish in a number of different regions or management zones.

7 RESULTS

7.1 Tag Recaptures – Wild Population

Twenty-five (1.1%) of the 2275 *P. saltatrix* tagged during 2000 were reported as having been recaptured. Two of these, which had been at liberty for only 3 and 4 days respectively, were re-released by the angler who caught them after the tag numbers and lengths had been noted.

Eleven of the tailor released from the beach at Fraser Is. were recaptured and returned to Project staff for analysis (Table 7.1). These fish had been at large from 4 to 39 days (mean: 15 ± 6 days) with most fish being recaptured within the first month (Fig. 7.1). Estimated daily growth was highly variable, averaging 0.6 ± 0.3 $mm.day^{-1}$ between release and recapture. OTC marks were apparent on the otoliths of only two fish, which had been at large for 24 and 39 days, but the time-at-large was too brief to show any marked change in the otolith structure outside the very faint mark (Fig 7.2). Another five tagged fish were reported as having being kept, but Project staff were unable to recover any additional data. Most of the reported recaptures occurred while the fish were still in waters adjacent to Fraser Island, less than 25 km from the site of release. However, one fish which had been released at Waddy Point on the eastern side of Fraser Island was recaptured in Hervey Bay on the western side of the island, some 120 km from the site of release.

Table 7.1 Details of *P. saltatrix* recaptured from tagging operations in 2000 (Fraser Is.) and 2001 (Gold Coast).

Tag Date	Release Condition	Release Location	Recapture Date	Recapture Location	# Days Liberty	Growth
10/09/2000	3	Waddy Pt	16/09/2000	Orchid Bch	6	0.5
17/09/2000	3	Indian Hd	22/09/2000	Dundaburra	5	0.5
11/09/2000	3	Waddy Pt	23/09/2000	Fraser I.	12	0.8
19/09/2000	3	Indian Hd	23/09/2000	Fraser I.	4	0.8
10/09/2000	3	Waddy Pt	26/09/2000	Nth Ngala Rocks	16	0.8
12/09/2000	3	Sth Ngala Rocks	28/09/2000	Fraser I.	16	0.7
10/09/2000	3	Waddy Pt	29/09/2000	Happy Valley	19	1.3
20/09/2000	2	Happy Valley	29/09/2000	Happy Valley	9	0.5
10/09/2000	3	Waddy Pt	04/10/2000	Sth Ngala Rocks	24	0.5
20/09/2000	3	Happy Valley	05/10/2000	Happy Valley	15	0
09/02/2000	3	Waddy Pt	18/10/2000	Sth Ngala Rocks	39	0.6
04/09/2001	3	Gold Coast	23/12/2001	Jumpinpin Bar	110	0.5
03/09/2001	3	Gold Coast	26/12/2001	Gold Coast	114	3.2
07/09/2001	3	Gold Coast	08/03/2002	Gold Coast	182	-0.4

Of the 732 tailor tagged during the 2001 season in southern Queensland, five recaptures (0.7%) were reported by anglers, but the frames of only three were kept and handed in to Project staff (Table 7.1). These three fish had all been released in excellent condition after tagging, and had been at liberty for 110, 114 and 182 days respectively. Again, growth was highly variable, averaging 0.1 ± 0.2 $mm.day^{-1}$ between tagging and recapture. The otoliths of all three showed a distinct growth check outside the OTC mark (e.g. Fig 7.3). None of these fish was recaptured more than 15 km from its site of release, although another *P. saltatrix* (not kept) was reported to have been recaptured some 245 km from its site of release after 18 days at liberty.

Six DPI staff were involved in tagging *P. saltatrix* in 2000. All had a similar level of tagging experience, and more than 80% of the fish released by each tagger was judged to have been in excellent condition (Fig 7.4). The small recapture data set (even when the results of the two years' tagging operations were pooled) provided insufficient statistical power to allow any meaningful analysis of the relationship between tagger skill and the recapture (survival) rate of the tagged fish.

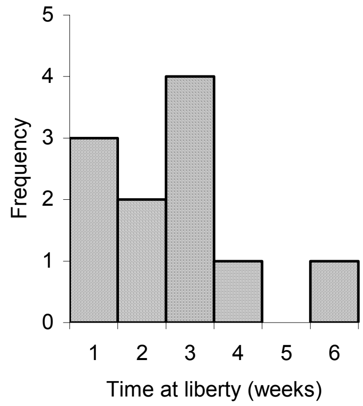

Figure 7.1 Pattern of recaptures of *P. saltatrix* tagged in 2000 on Fraser Island.

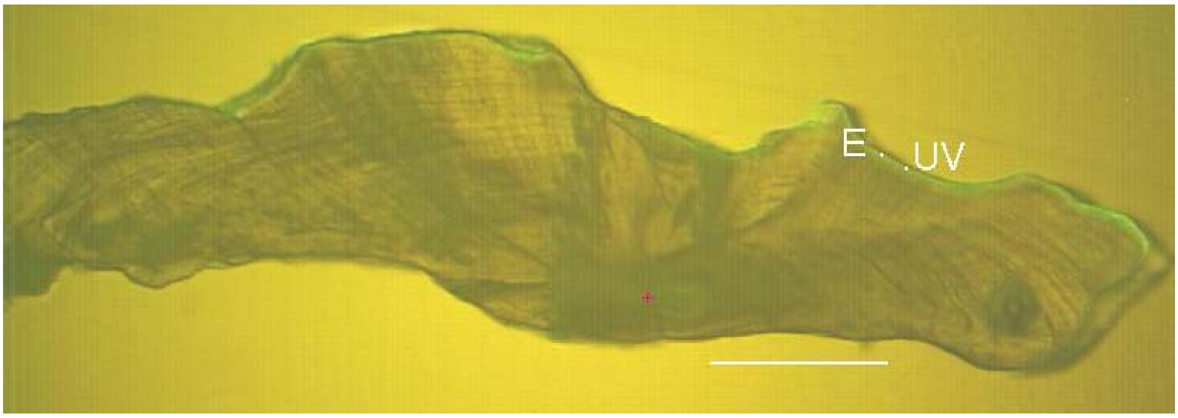

Figure 7.2 Colour-enhanced transmitted and ultraviolet light photomicrograph of proximal portion of *P. saltatrix* otolith section, showing primordium (+), ultraviolet fluorescence (UV) and edge (E). Fish was tagged 18/04/2000 and recaptured 28 days later. Scale bar = 0.5 mm.

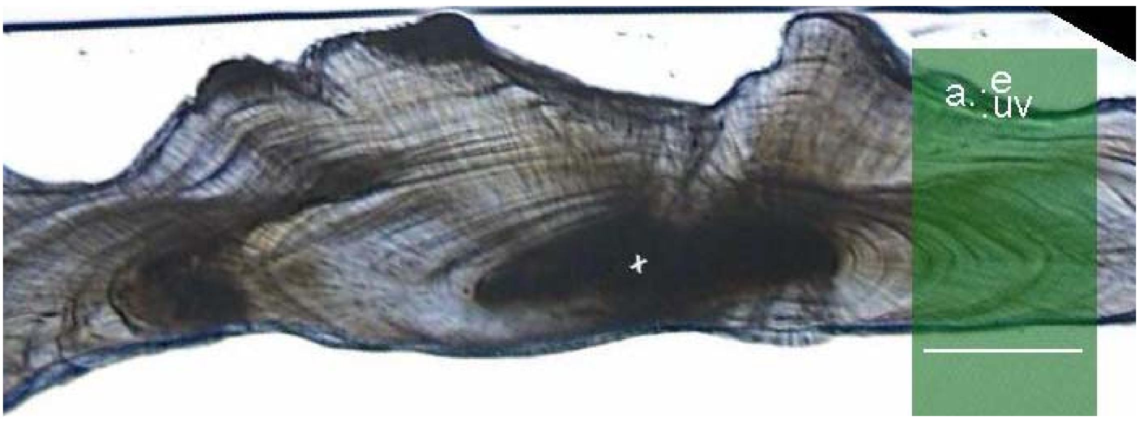

Figure 7.3 Transmitted light image of otolith section with portion of matching ultraviolet image super-imposed showing, post-tagging growth check (a), ultraviolet fluorescence (uv) and edge (e). Fish was tagged 07/09/2001 and recaptured 182 days later. Scale bar = 0.5 mm.

Figure 7.4 Relative similarity in release condition of *P.saltatrix* tagged by six different tagging staff during the tailor tagging program at Fraser Island, September 2000.

The INFOFISH Inc. database contained 97 records relating to tailor tagged between 4 March 2000 and 3 February 2003. Fifty of the records related to fish tagged during this Project. The remaining 47 were for tailor tagged by local anglers affiliated with Australian National Sportfishers' Association (ANSA). We received notification of 53 recaptures in total, three of which came about from direct contact by the angler. Generally, the use of INFOFISH Inc. as a point of first contact worked well, although the recapture rate was too low to really test this procedure. The low recapture rate of tagged tailor from the wild population justified our decision to maintain a semi-captive population at the Sea World site.

Overall, the INFOFISH Inc. database contains records for 1674 tailor tagged between September 1986 and February 2003 that were not related to the current project. Of these, 73 (4.4%) were recaptured. Between July 2001 and February 2003, a volunteer fisher associated with this project tagged and OTC-labeled another 291 tailor, nine of which (3.1%) were subsequently recaptured. There was no significant difference in recapture rates between these two tagging data sets (P=0.32, df=1).

To further investigate possible tag loss in the wild population, we examined otolith pairs from 1200 tailor sampled during the Long-Term Monitoring survey of the ocean beach fishery in 2001. We reasoned that if a significant number of fish that had been OTC-injected and tagged in 2000 lost their tags, but were recaptured by anglers the following year, they might be able to be detected from the LTMP samples through having a fluorescent mark in the otoliths. Initial scanning of the otoliths by UV microscopy revealed 53 that may have shown a mark, but closer examination failed to substantiate this. None of the 1200 otolith pairs displayed any UV fluorescence that could be attributed to the tagging operation.

7.2 Tag Recaptures – Semi-Captive (Sea World) Population

Between February 2000 and January 2002, 122 fish (14%) were recaptured from the Sea World Ski Lake. Volunteer recreational fishers and DPI staff line-fished on each occasion. However, from June 2000 onwards, nets were also set in the Sea World Ski Lake in areas beyond the reach of the shore-based line fishers. Capture rates from both nets and line were higher at night than in the mornings and nets were more productive than lines. Four of the recaptured fish were retagged (double T-bar) and re-released back into the Ski Lake to augment the tag loss assessment. This meant that the nett recapture rate (fish retained) was 13%. Of the 118 fish retained, only 34 (29%) still had their T-bar tag in place, although a further 39 (33%) had VIE tags only, and another 33 (28%) had a scar in the tagging location. The remaining 12 (10%) displayed fluorescence on their otoliths, but were unable to be identified individually.

The fact that 33% of all recaptured tailor were still identifiable to a known stocking date because of the presence of a VIE tag, despite losing their T-bar tag, has justified the use of the dual marking system. Six of the original 30 double T-bar tagged tailor were recaptured. One had lost one of the two T-bar tags when recaptured. Four of these fish had only been free for 20 days. However, one had been free for about six months, as had the fish that lost one of its T-bar tags. Of the 52 tailor recaptured with no T-bar tag, VIE tag, or tagging scar, 48 had a definite fluorescing mark on their otolith, 2 had a very weak (possible) mark and 2 showed no mark at all. Two of the multi-tagged fish (T-bar and VIE) had lost their VIE tags. However, they had both retained their T-bar tag and displayed damage and scarring to the dorsal fin, in the area where the VIE had been implanted.

Of the original 887 *P. saltatrix* tagged and released into the Sea World Ski Lake, 783 (88%) were marked with OTC and 104 (12%) were marked with calcein. However, of the 122 tailor recaptured from the Sea World Ski Lake, 83 (68%) displayed the orange–white colour characteristic of OTC fluorescence on their otolith, while 39 (32%) displayed a characteristic yellow calcein fluorescence on their otolith. This was significantly different from the numbers tagged ($p<0.01$). There was no significant difference in mean daily growth between fish marked with OTC (0.08 $mm.day^{-1}$) and those marked with calcein (0.12 $mm.day^{-1}$) ($p>0.05$). The average growth rate of all recaptured Sea World fish with a tag of any kind was 0.09 ± 0.03 $mm.day^{-1}$. This compares closely with the growth rate estimated for *P. saltatrix* from the Fraser Island population of 0.06 - 0.10 $mm.day^{-1}$.

7.3 Tag Loss Experiment and OTC/Calcein Comparisons

The captive population of *P. saltatrix* was maintained in four tanks at the Southern Fisheries Centre for a period of 152 days. During this time five fish perished, between days 59 and 130 (mean 113 ± 24 d), as a result of leaping out of the tanks. Tags and otoliths were obtained from each of these fish. Another three fish disappeared, either to cannibalism or to predation by a grey heron which was seen in the vicinity of the tanks. After the bird appeared the tanks were covered with shade cloth to prevent further depredation.

Another fish lost its T-bar tag five days before the termination of the experiment. The tag was recovered from the tank, and the fish was seen swimming normally with no sign of distress, but with a fresh wound site on its shoulder where the tag had been inserted. This fish was recaptured when the experiment was terminated and matched with the recovered tag by its VIE tag. The remaining 124 *P. saltatrix* were anaesthetised,

Table 7.2 Biological and experimental data relating to the eight *P. saltatrix* that perished prior to the termination of the tag-loss experiment.

Tag No.	Tank	Recapture Date	Marking compound	Injection site	Tagger	Growth (mm)	Time at large (d)	Growth ($mm.d^{-1}$)
N05108	B	20-Sep-01	Calcein	IP	1	0.2	71	0.03
N05124	B	21-Nov-01	OTC	IP	1	5.9	133	0.44
N05125	B	21-Nov-01	OTC	IP	1	5.9	133	0.44
N05134	C	12-Oct-01	Calcein	IM	1	2.9	93	0.31
N05144	C	19-Nov-01	Calcein	IP	1	3.5	131	0.27
N05089	A	unknown	OTC	IM	1	—	—	—
N05123	B	unknown	OTC	IP	1	—	—	—
N05129	B	unknown	OTC	IP	1	—	—	—

measured and identified, then sacrificed by ice slurry brine immersion at the termination of the experiment. Their otoliths were removed and relevant biological data recorded.

Tag loss during the course of the tank experiment was negligible (<1%), a clear demonstration that physiological exclusion is a minor cause of tag loss in captive *P. saltatrix*. It also indicates that, even in close proximity there is no tendency for the tags to be bitten off or pulled out by other tailor. When administered intra-muscularly, both OTC and calcein were taken up by all of the otoliths, appearing in all section preparations under UV illumination (Table 7.3). However when the marking compound was administered as an intra-peritoneal injection, OTC was slightly more effective than calcein (86% vs. 72%). Overall, the intra-muscular injection (100%) was a more effective method of delivering the marking compound than the intra-peritoneal injection (79%). Although not quantified, the OTC marks tended to be more consistent and continuous around the otolith than the calcein marks.

Table 7.3 Effectiveness of calcein and OTC at producing an ultraviolet fluorescing ring on the otolith cross-section of *P. saltatrix*. Calcein and OTC were administered as intra-muscular (IM) or intra-peritoneal (IP) injections.

Injection Site	No. injected with OTC	No. with fluorescent mark	No. injected with calcein	No. with fluorescent mark
IM	32	32	31	31
IP	29	25	32	23

The mean growth of fish from all tanks during the course of the experiment was 45 mm, giving a mean daily growth rate of 0.3 $mm.day^{-1}$, which was much higher than either the wild (0.03 to 0.08 $mm.day^{-1}$) or semi-captive (0.06 to 0.10 $mm.day^{-1}$) growth rates. This was not surprising, given that the captive tailor were fed to satiation.

Growth was not affected by either marking compound ($F = 0.01$, $P = 0.934$, d.f. = 1; 117), nor site of injection ($F = 0.001$, $P = 0.967$, d.f. = 1; 117), but was significantly affected by the influence of individual tanks ($F = 4.8$, $P<0.001$, d.f. = 3; 120). We have attributed the influence of tank on growth to the location of each tank in relation to the degree of exposure to sunlight via the open southern side of the covered tank shed (Fig. 7.5), but it is not obvious as to why this should influence feeding behaviour and growth of an inshore pelagic species such as *P. saltatrix* to such an extent.

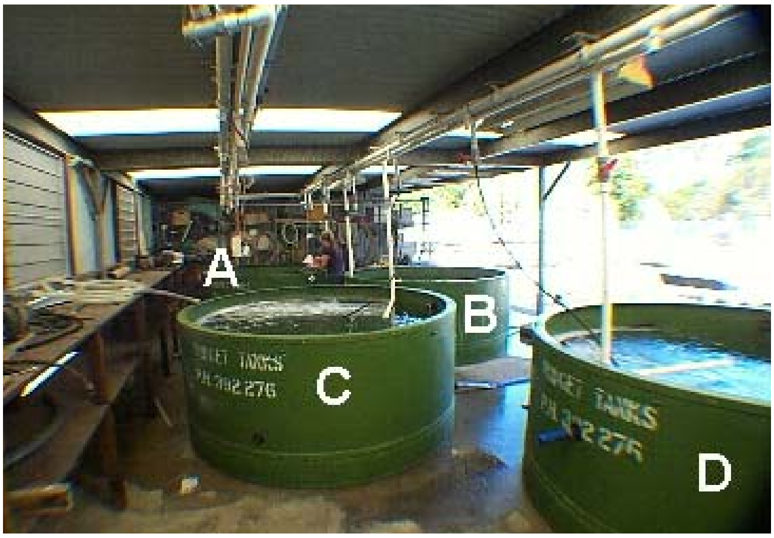

Figure 7.5 Position of the four tanks used for the *P. saltatrix* tag-loss experiment in covered wet area. Sunlight exposure on open southern side.

The addition of individual shade-cloth coverings on each tank during the experiment did not appear to alter the effect of each tank on average growth. It appears that the effect of the tank on growth was mediated through food consumption rates (Fig. 7.6), as the highest growth rates and food consumption rates were recorded from fish in tank C, followed by tank A, then tank D. These differences have not been tested for statistical significance.

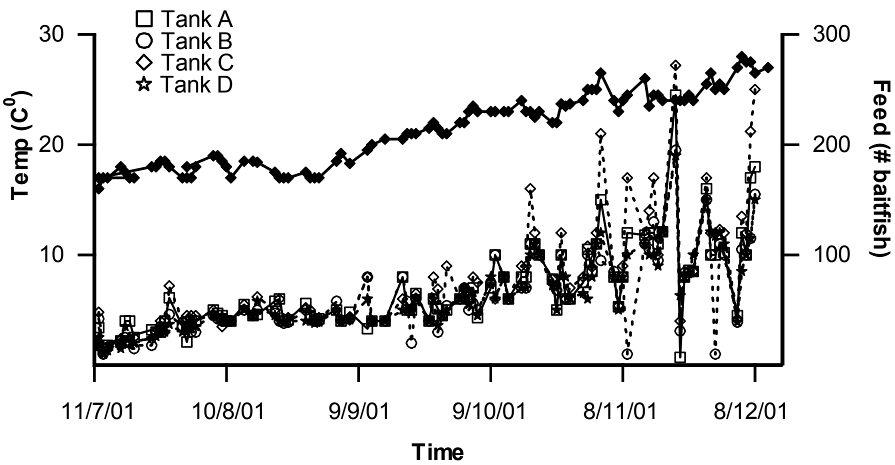

Figure 7.6 Daily temperature and average food consumption in all tanks used during the tag loss experiment.

7.4 Otolith Morphology and Internal Structure

Krug and Haimovici (1989) described whole *P. saltatrix* otoliths from Brazilian stocks as being 'elongated, laterally compressed with serrated edges'. This description applies equally well to those from Australian east coast stocks (Fig. 7.7). We observed elongation of the whole otolith along the anterior-posterior axis during the first year of growth, after which the otolith displayed growth principally on the lateral margins.

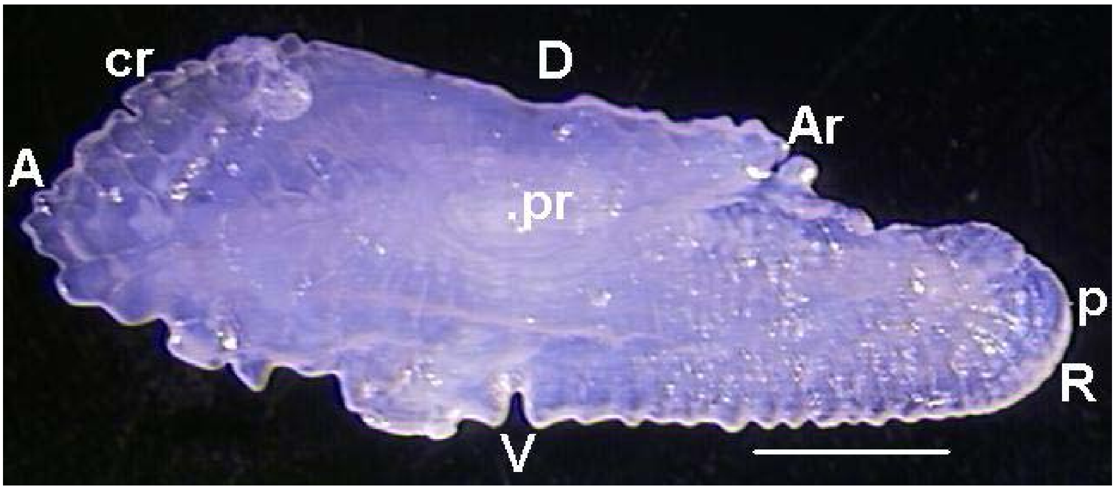

Figure 7.7 Whole otolith of *P. saltatrix* showing anterior (A), posterior (p), dorsal (D) and ventral (V) margins, primordium (pr), rostrum (R), antirostrum (Ar), and crenulated margin (cr). Scale bar = 0.5 mm.

In transverse section (Fig. 7.8), the otolith comprises alternating opaque and translucent zones in concentric patterns around an opaque primordium. The *sulcus acusticus* forms a distinct valley on the proximal surface and an antirostrum is present on the anterior dorsal surface. The presence of annular bands is usually discernable by an interruption along the margins of the sulcus. When interpreting the otolith cross-section, it is important to take into account the effect of the method of illumination on the otolith microstructure. If transmitted light is used to view a transverse section (e.g. Fig 7.8) then the otolith can be described as having an opaque primordium (nucleus) that is dark, surrounded by concentric translucent (light) and opaque (dark) bands. The annulus is an opaque (dark) band.

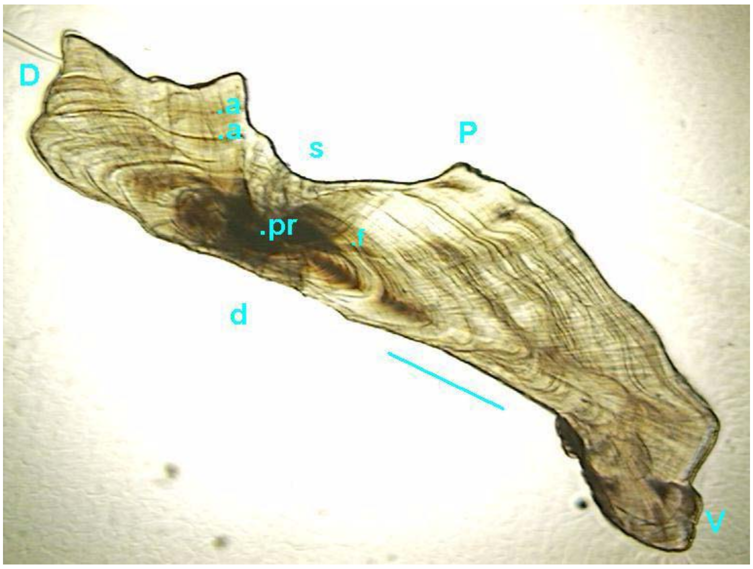

Figure 7.8 Transmitted light image (x40) of *P. saltatrix* otolith cross-section showing; proximal (P), distal (d), dorsal (D) and ventral (V) margins, primordium (pr), dark annuli (a), and sulcus (s). Scale bar = 0.5 mm.

If reflected light is used to view the transverse section (e.g. Fig 7.9), then the otolith description is different. Under these conditions the opaque primordium (nucleus), which appears light, is surrounded by concentric dark (translucent) and light (opaque) bands. The annuli appear as light-coloured opaque bands.

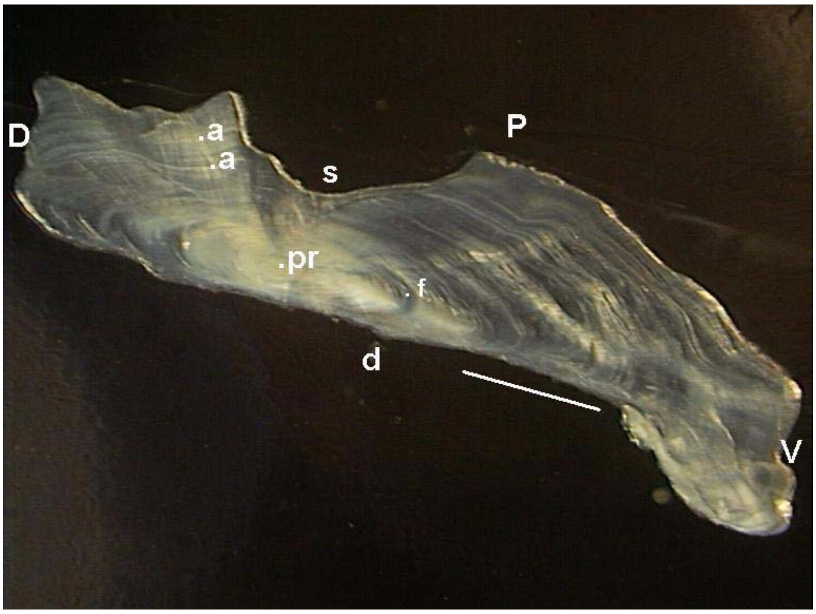

Figure 7.9 Reflected light image (x40) of the same otolith as in Fig. 7.8, showing proximal (P), distal (d), dorsal (D) and ventral (V) margins, primordium (pr), light annuli (a), and sulcus (s). Scale bar = 0.5 mm.

7.5 Daily Growth Increment Analysis

7.5.1 Scanning electron microscopy

A total of 11 otolith stubs were processed for SEM investigations. Some ring formation was evident on most otoliths, but no OTC mark or evidence of a major ring formation could be detected under normal SEM illumination. All showed OTC fluorescence under UV illumination. SEM of unetched otoliths, showed some crystal formation, or a uniform surface, but no continuous rings that could be interpreted either as daily or annual growth checks (Fig. 7.10). These otoliths were also exposed to cathodoluminescence to determine whether the OTC marks would fluoresce, but there was no visible evidence of the fluorescent mark.

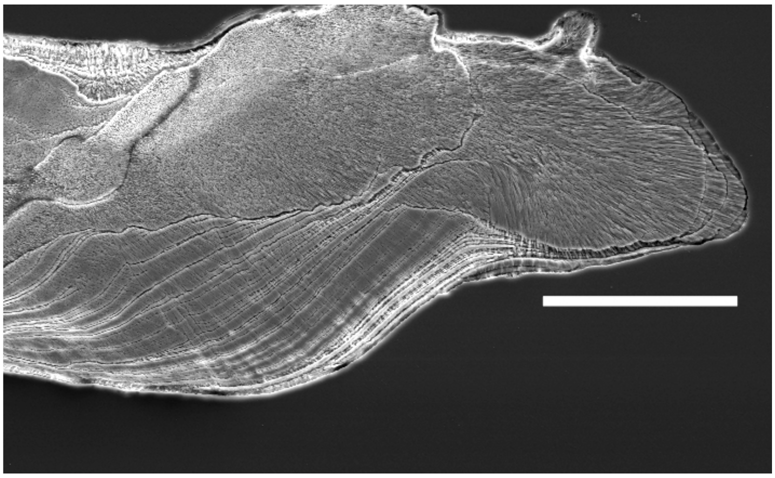

Figure 7.10 SEM photomicrograph of *P. saltatrix* otolith cross-section near dorsal surface showing some crystal structure but no internal structure that could be interpreted as representing annuli. Scale bar = 200 µm.

Etched otoliths showed varying amounts of ring formation, depending on the degree of etching. Preliminary investigations using 0.1M HCl produced little or no surface relief that could be interpreted as a consistent pattern of growth increments. Further trials using 5% EDTA solution produced somewhat more surface relief. Areas adjacent to the sulcus that typically show useful age-determination features under light microscopy showed a uniform crystalline formations under SEM and little evidence of growth-related structures (Fig. 7.11). Both otoliths used in preliminary EDTA investigations appeared as though they may have been too heavily etched in these areas. Nevertheless, the lateral extremities of the otolith stubs showed what may be an annual ring (Fig. 7.12), and there was some evidence of what may be daily rings, but only in isolated areas towards the tips of the otolith 'section' (Fig. 7.13).

Figure 7.11 SEM photomicrograph of *P. saltatrix* otolith cross-section near the primordium and sulcus. No distinct rings are visible. Scale bar = 100 µm.

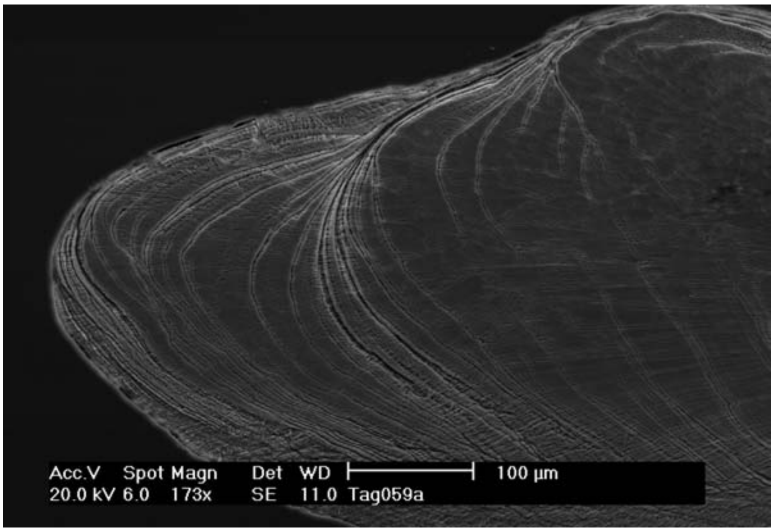

Figure 7.12 SEM photomicrograph of *P. saltatrix* otolith cross-section near the dorsal margin showing ring formation and what may be an annulus. Scale bar = 100 µm.

When etching times were increased (from 1 to 4 minutes) we found an increase in the amount of relief and apparent structure visible. However increased etching also had the disadvantage of causing the most ablation and thus loss of visible information. The extremities of otoliths which had been subject to longer etching times had areas that showed potentially useful structures, but also areas that had apparently been etched

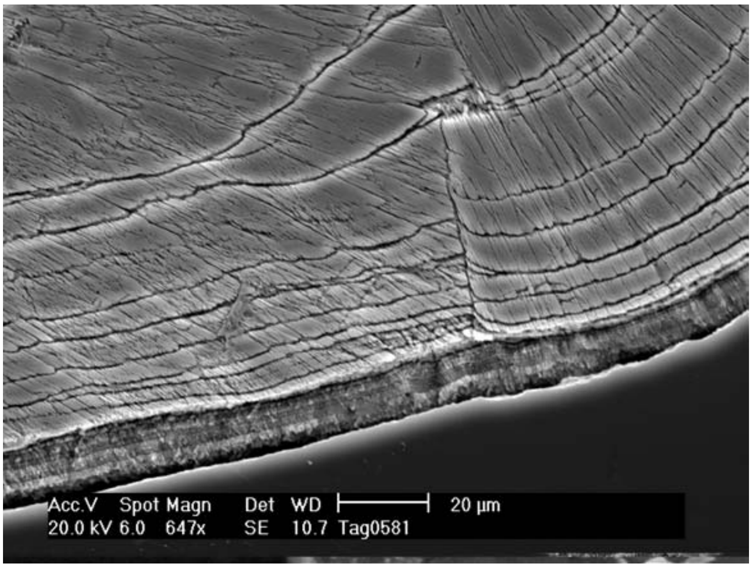

Figure 7.13 SEM photomicrograph of *P. saltatrix* otolith cross-section near the dorsal margin showing ring formation and what may be daily rings near the margin. Scale bar = 20 µm.

into the underlying crystal structure without any evidence of ring formation (Fig. 7.14). Even after 4 minutes of etching, there were still smooth areas (no vertical relief) on which the etching had evidently not impacted. The reason for this is not clear. A decrease in etching exposure translated into more smooth surface area between rings. On all of these otoliths, the area beside the sulcus shows minimal (if any) ring formation, regardless of etching exposure time. We are forced to conclude that with any SEM technique trialled it is not possible to consistently detect structures which could be interpreted as daily growth checks or fluorescent bands across the otolith section.

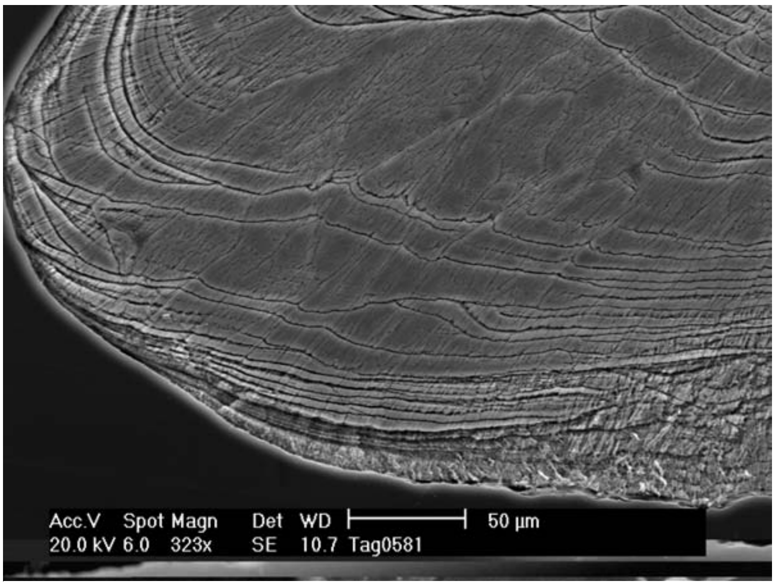

Figure 7.14 SEM photomicrograph of *P. saltatrix* otolith cross-section near the dorsal margin showing effect of longer etching times: apparent ring formation (centre left) and areas etched to the underlying crystal structure without any evidence of ring formation (bottom right). Scale bar = 50 µm.

7.5.2 High-power light microscopy

Initial observations on thin-ground preparations under high power light microscopy revealed structures that we believed could conceivably be daily growth rings in the inner parts of the otoliths. To obtain advice and clarification about this we arranged for staff at the Central Ageing Facility (Queenscliff, Victoria) to examine seven ground and polished sections and provide us with an interpretation. While CAF had no prior experience reading *P. saltatrix* otoliths, we considered that their general expertise with a broad range of species would allow as good an opinion as could be obtained anywhere. The CAF investigations concluded that there are rings of probable daily periodicity observable in the inner regions of the otolith.

The estimated time (number of days) from the biological centre to the edge of the dark primordium ranged from 27 to 48 days (n = 11). The number of days to the beginning of the first zone ranged from 45 to 63 days (n = 7). The zones past the growth check were diffuse and increments could not be resolved. This pattern of not being able to resolve daily increments past the first growth check is common with most species. Based on the limited number of daily grinds, these data suggest that the dark primordium is a function of the larval/juvenile phase and the translucent zone before the first growth check (identified as f in Figure 7.19) represents a change in habitat. The first annual zone represents the first exposure of the individual to environmental conditions that cause the opaque zone to be deposited on the otolith. If a completed growth period is defined as one completed opaque and one completed translucent zone, then the position of the first zone when examining whole and sectioned otoliths represents about two months after spawning (0.2 - 0.3 years). The second zone represents one full year of growth.

Otoliths from 37 *P. saltatrix* were examined for daily rings (Table 7.4). Counts from the nucleus to the edge of the primordium (zone *a*) were possible in 18 of these very thin sections (Fig. 7.15). These averaged 17 rings ± 4 (95% C.I.). Outside this region lies a more translucent zone containing more incremental rings. In 16 otolith sections, it was possible to discern a distinct growth check outside the opaque primordium. These otoliths had an average of 40 rings ± 18 (95% C.I.) between the primordium and the growth check (zone *b*). Thus there is an average of around 57 incremental rings between the nucleus and the first major growth check identified as *f* in Figure 7.9. It was not possible to count many rings beyond this inner growth check as the patterning of rings became diffuse and resolution was poor (Figure 7.15).

Counts of microincrements between the UV mark and the edge produced results that were not consistent with an interpretation of daily frequency. One fish that was recaptured from the semi-captive population had been at large for 189 days (approx. 6 months), but showed only 12 of these microincrements (ranging from 11 to 15 from 3 counts) between the UV mark and the edge of the otolith (Fig. 7.16). This suggests that the annuli are of approximately fortnightly periodicity. Similar results were observed from the otoliths of six other tagged and injected fish.

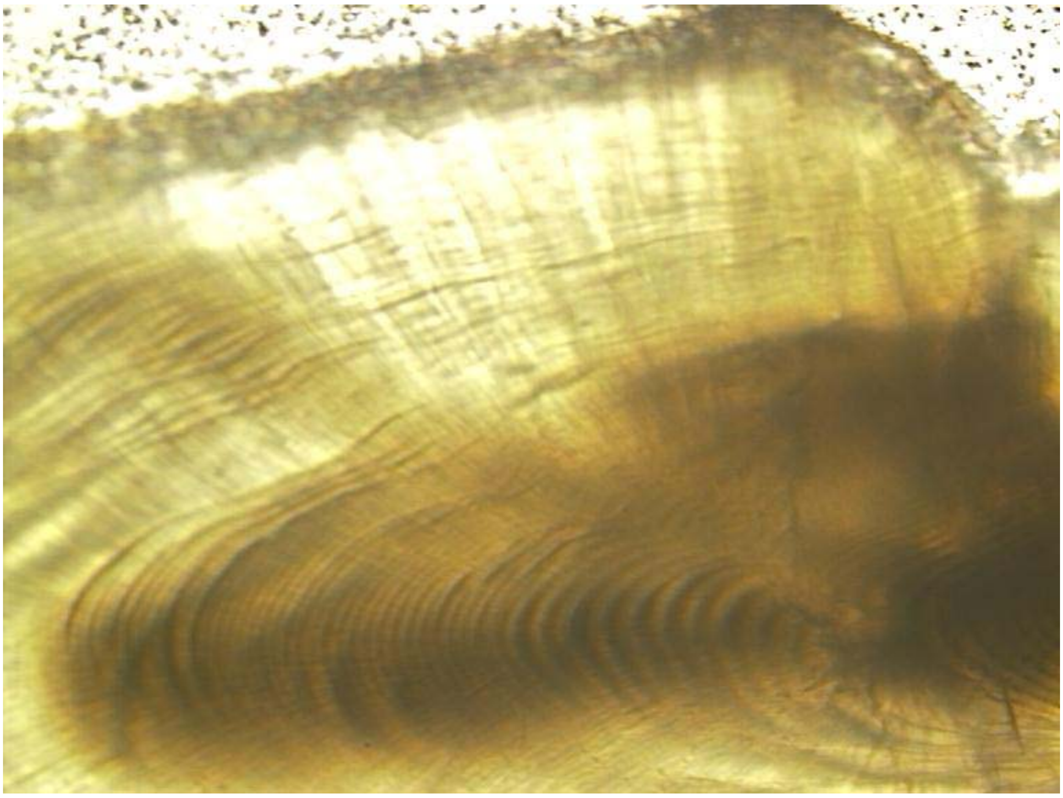

Figure 7.15 High-power image (x 200) of a sectioned *P. saltatrix* otolith, ground ultra-thin for daily ring counts, showing difference in ring clarity between the densely opaque inner region (zone *a* [Table 7.4]), and the less opaque outer zone.

Table 7.4 Inner ring estimates from *P. saltatrix* otoliths. Zone *a* = increments from nucleus to the edge of the densely opaque primordium. Zone *b* = increments between densely opaque primordium and presumed first growth check *(f*).

	No. rings in zone a	Width of zone a (μm)	No. rings in zone b	Width of zone b (μm)
Mean	17	459.8	40	304.8
95% c.i.	± 4	± 24.8	± 18	± 12.2

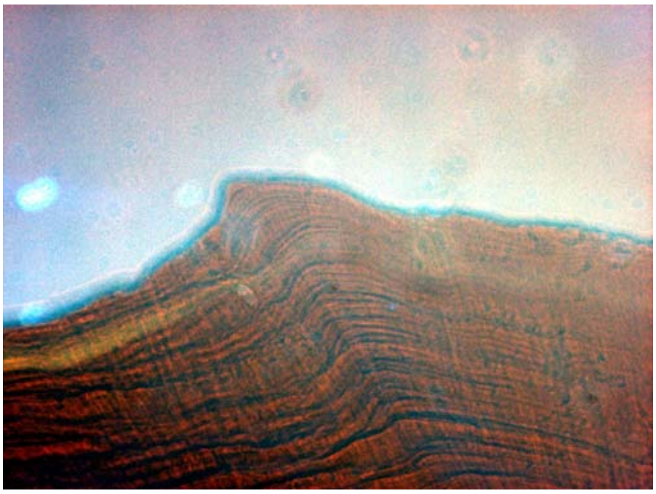

Figure 7.16 High power (x 200) micrograph of *P. saltatrix* otolith section showing approximately 12 “daily” rings between UV mark (orange) and edge.

7.6 Identification of First Annulus

Definition of the first annual band or growth check is important, to ensure that there is a reliable base from which to count subsequent annual increments. The internal structure of *P. saltatrix* otoliths is complex and its interpretation is quite difficult (see previous sections in this report). We considered that the best way to approach this issue was through an examination of a time-series of otoliths from fish which we were confident were less than one year old. Because of the relatively small size (and thinness) of the otoliths we assumed that sequential changes in the internal structure surrounding the nucleus would be easier to track than they would be in otoliths from older fish.

To provide the material for this investigation, 156 juvenile *P. saltatrix* were collected from trawler operators, principally from within Moreton Bay, between November 1999 and November 2001. These fish ranged size from 5.0 to 24.7 cm FL (mean: 14.6 ± 0.6 cm FL). Several of the samples were combined across years to build up the numbers and size-range of fish in each bi-monthly sample (Table 7.5). No samples were available for the months of March, July, September, October, or December.

Table 7.5 Sample size and range of opportunistically-caught juvenile *P. saltatrix*. All sizes are in cm.

Month	n	Av. FL	95% C.I.	Min FL	Max FL
January	7	9.5	2.0	4.2	13.5
February	24	15.6	1.1	5.0	19.2
April	33	13.4	0.8	10.4	18.0
May	48	21.3	0.4	17.9	25.5
June	5	20.7	3.2	17.5	24.9
August	4	22.8	3.0	19.4	24.7
November	35	13.7	0.4	9.1	14.2

7.6.1 Whole otoliths

Based on reproductive investigations reported by Hoyle *et al.* (2000), November 1 has been suggested as the nominal birth date for east-coast *P. saltatrix*. By examining a time series of images of whole otoliths from juvenile (<1 yr old) fish through the calendar year, we were consistently able to identify three regions on the otolith that occur before the first annual growth check is laid down (Fig. 7.17).

Surrounding the opaque primordium is a densely opaque inner region which is referred to as zone *a*. Outside this central zone there is a less opaque portion, zone *b,* which in turn is surrounded by a translucent zone - zone *c*. The width of zone *c* is equal to or greater than that of the first annual growth increment. Most otoliths from larger *P. saltatrix* (>22 cm FL) display one or several inner false bands, especially near the junction of zones *a* and *b* (Fig 7.18). This corresponds to the "f" check visible on otolith sections (Fig. 7.8), and probably represents settlement checks associated with changes in the habitat or feeding regime of the juvenile fish.

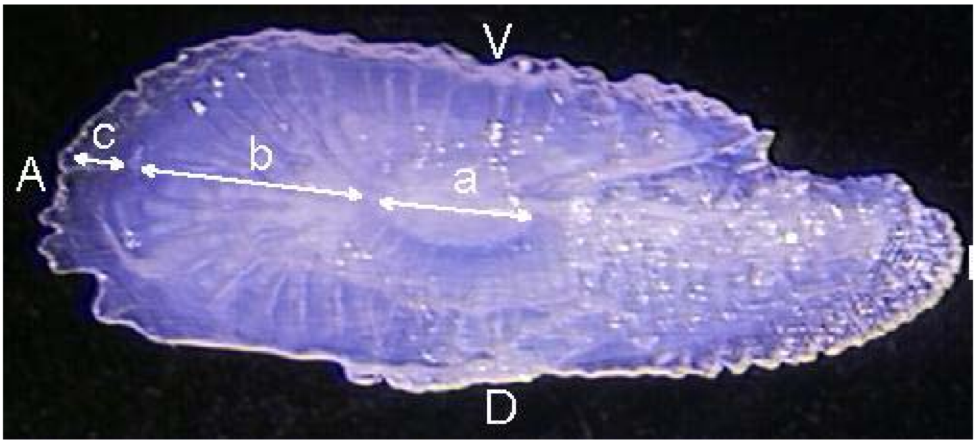

Figure 7.17 Whole otolith (x 40) of juvenile *P. saltatrix* (23.4 cm FL) showing zones a, b and c.

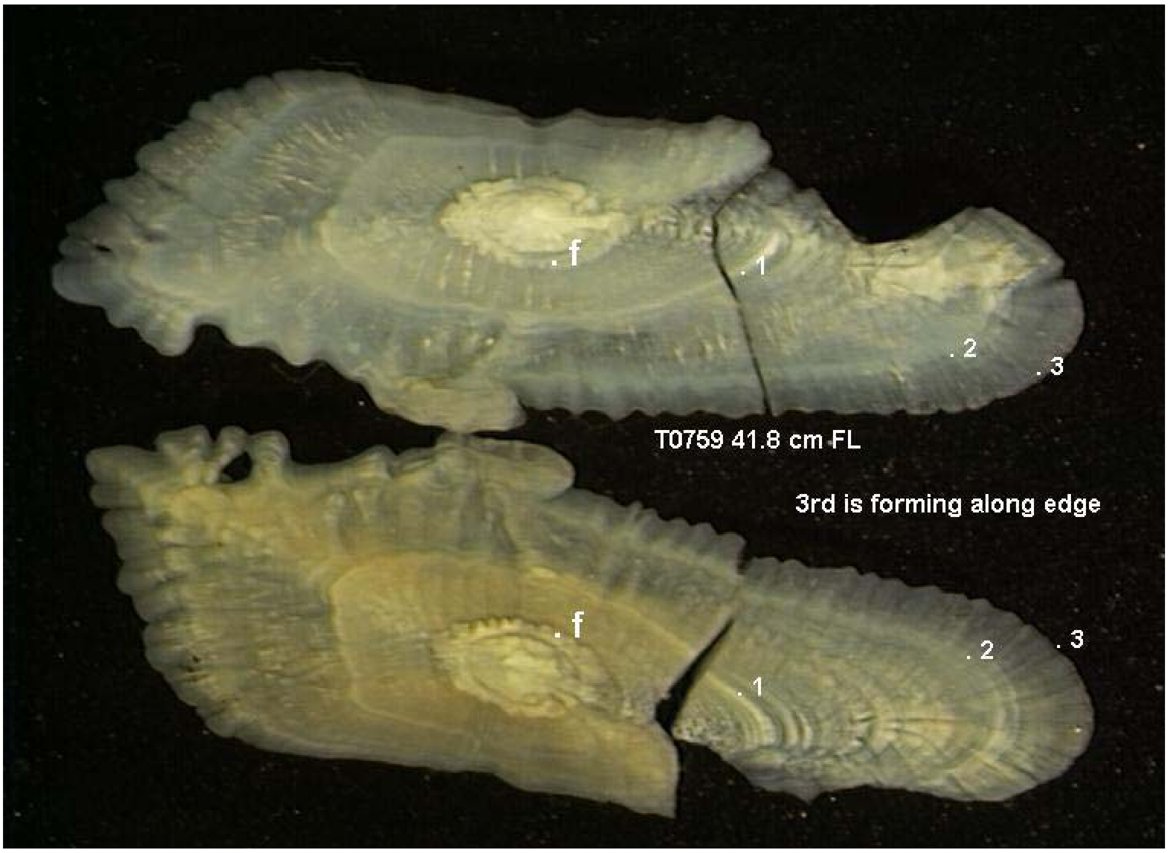

Figure 7.18 Whole otoliths of *P. saltatrix* collected from the ISAMP project showing distinct inner "f" check outside zone *a*, extended zone *b* surrounding the "*f*" check, but little evidence of zone *c*. The lower otolith was burned on a hot plate at 50°C for 5 minutes to enhance the visual resolution of the growth checks. Annual growth checks are marked as 1, 2 and possibly a third is forming on the edge.

7.6.2 Sectioned otoliths

The otoliths from 16 young-of-year *P. saltatrix* were sectioned and examined under transmitted or reflected light. Internal structures were comparable to those in whole otoliths. A densely opaque inner primordium was evident, identified as zone *a*. This was surrounded by less opaque zone *b* and then a broader translucent zone *c* containing numerous fine ring structures. Several otoliths also displayed a distinct inner growth check, identified as a false annulus (*f*) within zone *b* (Fig. 7.19).

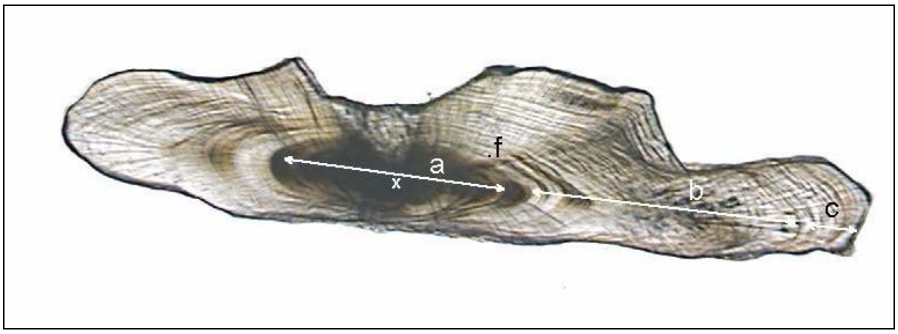

Figure 7.19 Otolith transverse section (x 40) of young-of-year *P. saltatrix* showing the *a*, *b* and *c* zones and the "*f*" check. x = primordium

7.7 Direct validation of Annual Growth Increment

Previous research (Hoyle *et al*. 2000) had established a birth date for *P. saltatrix* around November 1, based on time of maximum spawning activity. Observations made during this project indicate that the annulus appears to form on otoliths by late September. Subsequently, for all ageing estimates, we assumed that while the Hoyle *et al*. (2000) estimate for a birth date was accurate, the time of complete annulus formation, such that there is evidence on the otolith margin of a complete translucent and opaque growth cycle visible, with the next cycle commencing, was the (more or less) arbitrary date of September 30. Evidence for this assumption is also supported by the findings of Haimovici and Krug (1989), and Govender (1999), that *P. saltatrix* from other southern hemisphere waters lay down an annulus by mid- to late spring.

A total of 275 *P. saltatrix* otoliths were examined for growth after OTC injection. Of these 208 had a known or approximate tag and release date, and thus their time of freedom could be calculated with some degree of accuracy and compared against their otolith growth. The average time at liberty was 155 ± 11days (range: 4 - 785 days). However, only 38 were at liberty for greater than 180 days. Measurements from 76 fish were analysed to establish the average distance from the nucleus to the various structures present in otolith sections. The distance to the false "f" or settlement check represented the greatest increment (307 μm), with a lesser increment to the first annulus (Table 7.6). Thereafter the increments were relatively uniform, at about 90 μm (Table 7.6, Fig. 7.20).

Table 7.6 Average distance (μm) from nucleus to major structures, and between major structures, in *P. saltatrix* otolith cross-sections. Measurements were made at a magnification of x 40.

Structure	Distance from nucleus(μm)	Mean distance from previous structure (μm)	Sample size (n)
f check	307.3 ± 9.0	-	110
1st annulus	475.7 ± 14.7	168.3	109
2nd annulus	582.5 ± 14.6	106.8	75
3rd annulus	680.1 ± 24.8	97.6	37
4th annulus	763.7 ± 32.4	83.6	17
5th annulus	851.9 ± 57.5	88.2	5

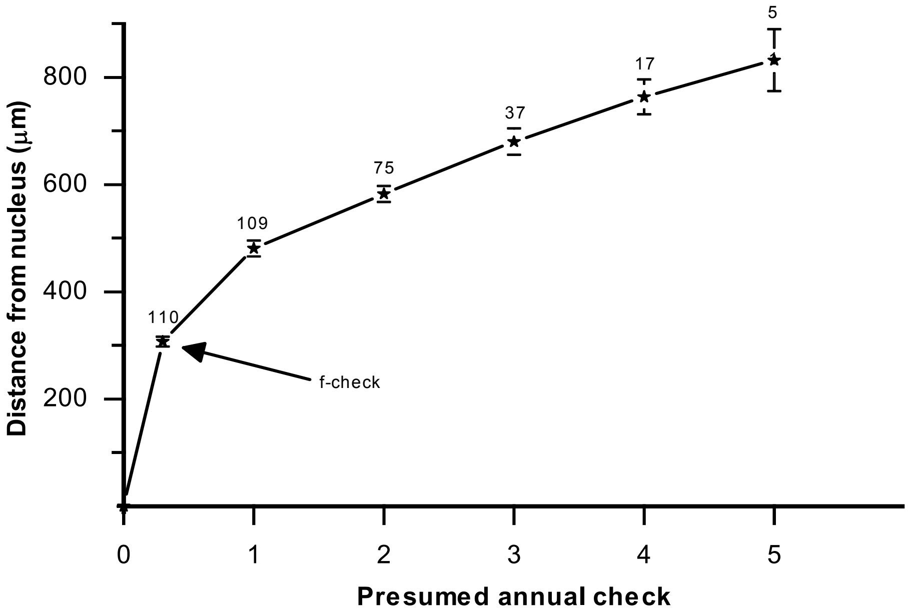

Figure 7.20 Radial distances (μm) from *P. saltatrix* otolith nucleus to the supposed annual growth checks. Vertical bars are the 95% confidence intervals, and sample sizes are shown above each data point.

We examined these otoliths for evidence of the periodicity of annulus formation. Otoliths were divided into age groups and the area between the ultraviolet fluorescing ring and the edge was examined for evidence of annuli. Empirical evidence of the annual periodicity of the growth check is presented in Fig. 7.21 for age classes 1 to 5.

Assuming that the time at liberty is about 1 year, then we should expect to see not more than one annual growth check between the fluorescent mark and the otolith margin. Depending upon the date of deposition of the growth check, if the time at liberty is more than one year but less than two we should expect to see at least one but not more than two checks outside the fluorescent mark.

The otoliths depicted schematically in Fig. 7.21 include the entire range of age-classes from young-of-the-year to 5+, and the results are consistent with the hypothesis that the annuli are of annual periodicity. In each of the two fish (i/d 225 and 135) whose times at liberty were less than 365 days there was a single annular check between the UV mark and the otolith edge. In the fish that had been at large for the least amount of time (i/d 225), the check was very close to the UV mark, suggesting that the check may have formed a short time after the fish was released in early July.

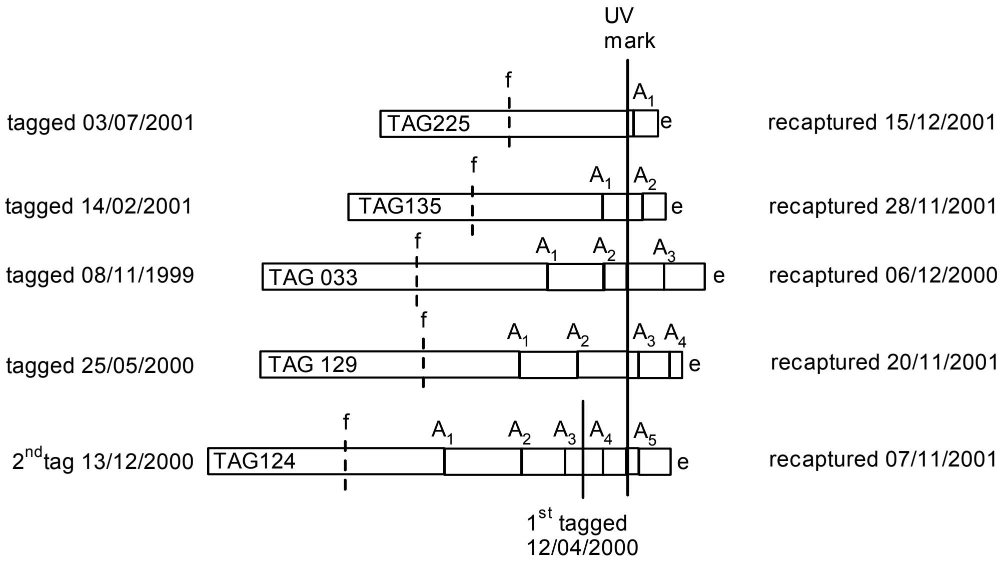

Figure 7.21 Measurements of the relative positions of presumed annual growth checks and fluorescent marks on five typical sectioned *P. saltatrix* otoliths.

Two of the fish (i/d 033 and 129) had been at liberty for somewhat more than a year, but less than two. In one case (033) there was a single check between the UV mark and the margin, and in the other there were two, the outermost being very close to the margin. This indicates that its period of liberty (18 months) spanned two 'non-growing' periods.

The oldest fish (i/d 124) was of particular interest in that it had been tagged twice, the first recapture occurred in summer, after 8 months of liberty and a UV mark was visible between the 3rd and 4th growth checks. This fish was re-injected and released back into the Ski Lake for a further 11 months. A second UV mark was clearly visible between the 4th and 5th growth check indicative of a total time of liberty (19 months) spaning two 'non-growing" periods. The second (outer) UV mark was much brighter than the first (inner) UV mark suggesting either that the efficacy of the first injection was not as great as the second injection, or perhaps that the fluorescing quality of the UV mark had degraded over time.

Most of the fish that were recaptured with a T-bar tag still in place (83%) had been at liberty for less than 200 days. However, the distance between the presumed annual and UV growth checks and the edge, when compared to the known dates of tag and recapture, inferred a cyclical periodicity of growth check deposition (Fig. 7.22). In comparison, 22% of all fish recaptured without a T-bar tag, but with a VIE tag were at liberty for less than 200 days. Again, examination of the distances between the presumed growth check, the UV mark and the edge also infers a cyclical periodicity in annulus formation (Figure 7.23).

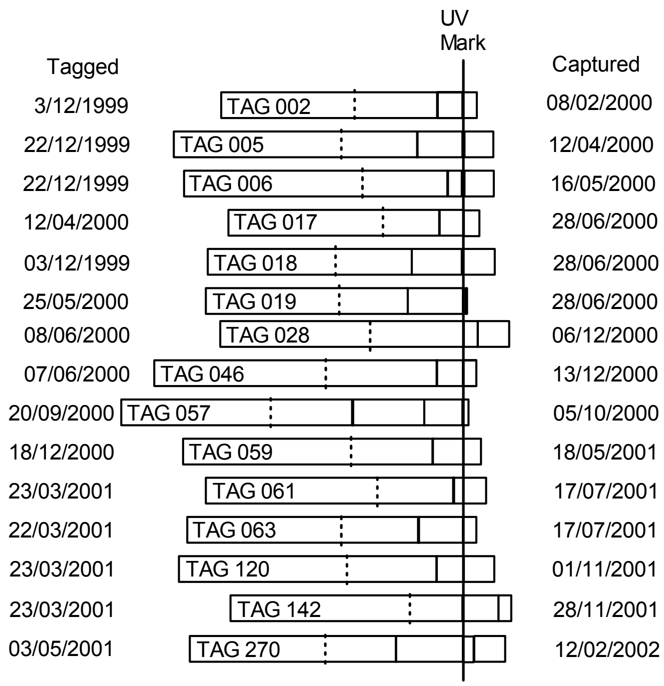

Figure 7.22 Measurements of the relative positions of presumed annual growth checks and fluorescent marks on sectioned *P. saltatrix* otoliths from fish with their T-bar tag intact at time of capture. Dotted line represents the ‘f’ check.

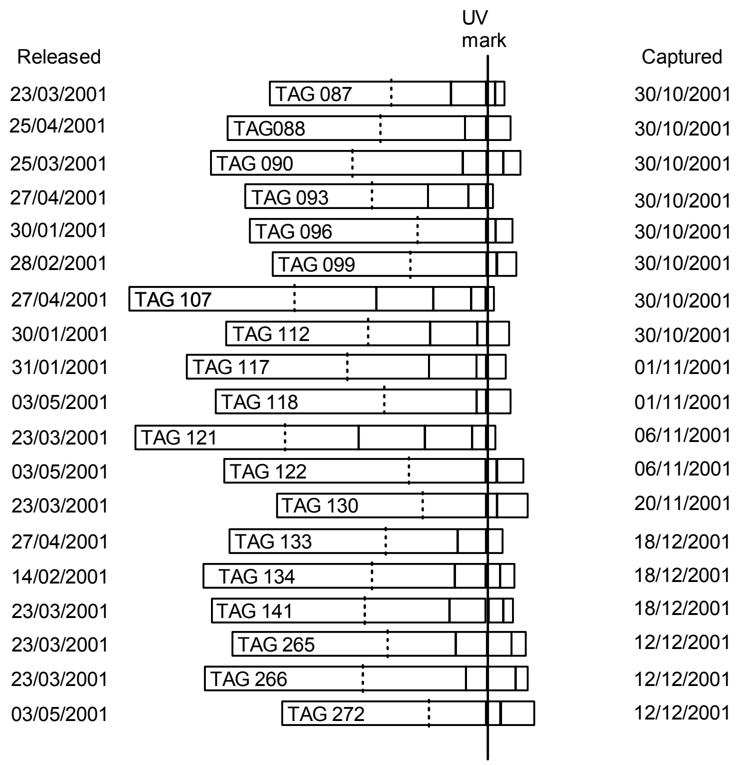

Figure 7.23 Measurements of the relative positions of presumed annual growth checks and fluorescent marks on sectioned *P. saltatrix* otoliths from fish without their T-bar tag at time of capture, but with a VIE tag. Dotted line represents the ‘f’ check.

7.8 Indirect validation

7.8.1 Analysis of time of growth check formation

In the 'first-look' general linear model analysis of Sea World fish, the largish times at liberty meant seasons had to be pooled. A significant model ($P<0.05$) was found, with results, as listed in Tables 7.7 and 7.8, confirming our expectations.

Table 7.7 Effect of fish age on adjusted otolith growth rates (µm/day).

Age	1	2	3	4
Growth rate	0.294	0.276	0.258	0.239

Table 7.8 Effect of seasons on adjusted mean otolith growth rates (µm/day).

Season	Summer/Autumn	Winter/Spring	Sum/Aut/Win	All-year
Growth rate	0.359	0.188	0.261	0.286

Given the two-fold difference in growth across 'gross' seasons, it was no surprise that the seasonal exponential growth model of Somers (1988) fitted well (adjusted $R^2 = 0.89$). It predicted maximum growth in late February and minimum in late August (Fig 7.24). The seasonal integrals corresponded well with the general linear model r esults – overall, the average summer-autumn growth was 2.08 times that of winter-spring (vs 1.91 in the GLM), and autumn-winter-spring growth was 1.38 (1.39 in the GLM) times that of winter-spring. This compared favourably with the average daily temperature recorded in the Sea World Ski Lake between 1 January, 2000 and 31 December 2001 (Figure 7.25).

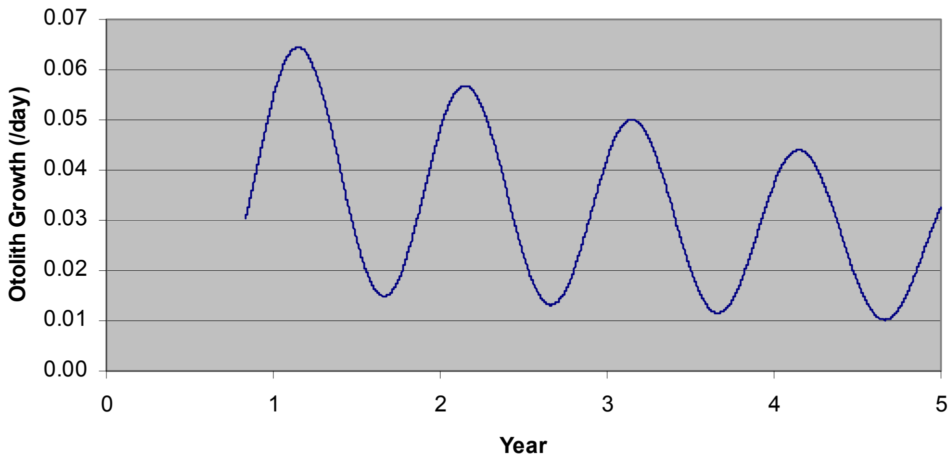

Figure 7.24 Age-dependent seasonal growth model of Somers (1988) applied to *P. saltatrix* otoliths. Year axis marks are at 1 January.

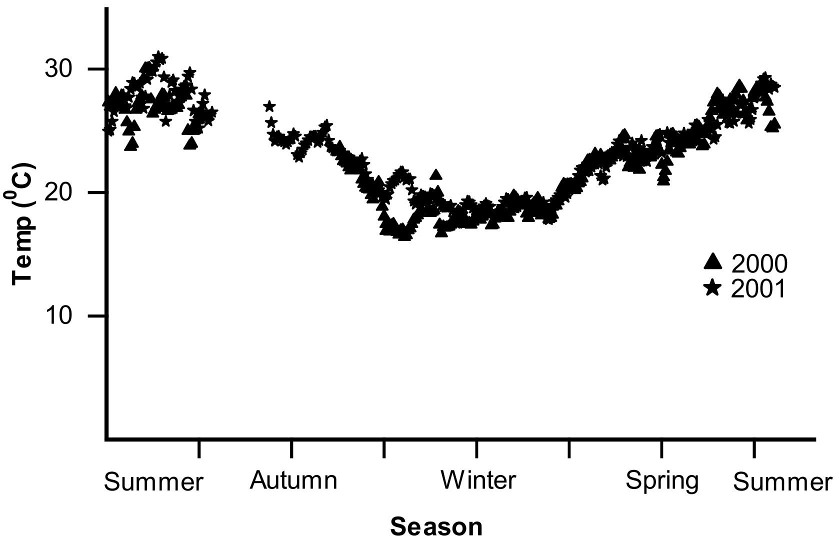

Figure 7.25. Mean daily seawater temperature in the Sea World Ski Lake between 1 January 2000 and 31 December, 2001. Temperature was measured 0.5 m off the bottom on a pylon located 20 m from the inlet using a small submersible temperature logger.

Circular statistical analyses of the differences in ring dates estimates indicated that none of the factors other than method of estimation (linear or nonlinear) was significant, as shown in Table 7.9.

Table 7.9 Effect of estimation method on the distribution of *P. saltatrix* growth check dates.

Method of estimation	Average day of year	Corresponding date	S.D.
Linear	104	14 April	87
Non Linear	88	29 March	81

For both of these data sets, the Rayleigh test for uniformity (Mardia 1972) proved significant (P<0.01), with test values of 0.27 and 0.37 for linear and nonlinear respectively. This indicates that these dates are not distributed randomly throughout the year. As circular histograms can be difficult to interpret, Mardia (1972) recommends cutting the circle at the side opposite to the median or mean, and representing the data on the more usual linear scale (Fig 7.26)

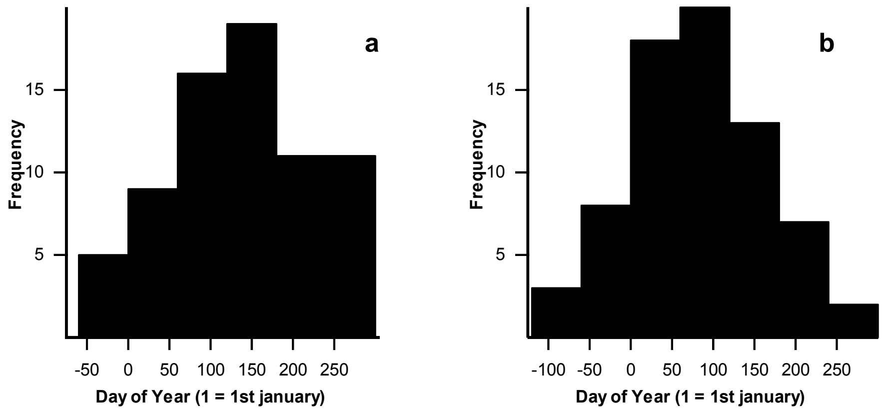

Figure 7.26 Date of growth check formation on otoliths of *P. saltatrix* recaptured from the Sea World Ski Lake, when estimated by linear (a) and non-linear (b) models. *n* = 71.

The 'post' measures (UV mark – post ring – edge) were available for 57 of a possible 128 individuals recaptured from the tag loss experiment. As all but three of these were at large for 152 days, it was not possible to fit a growth equation (which is required to estimate the nonlinear adjustment). Also, we did not wish to make the assumption that tank fish grew at the same rates (overall, as well as seasonal patterns) as the Sea World fish, so nonlinear adjustment was not used. The average date of annulus formation for this group was September 10, with a nearly normal distribution (Fig. 7.27).

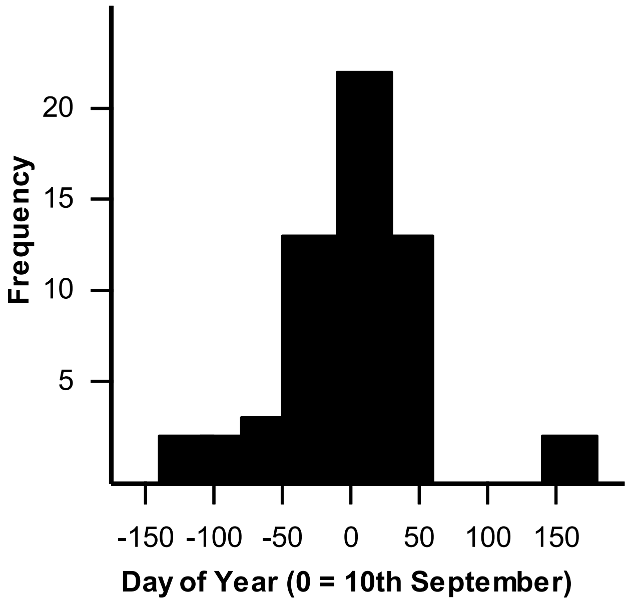

Figure 7.27 Date of growth check formation on otoliths of *P. saltatrix* recaptured from the tag loss experiment when estimated by linear model. *n* = 57.

7.8.2 Statistical validation of frequency of growth check

A total of 109 otoliths were measured for bands ranging from 1 to 5 (109, 75, 37, 17 and 5 observations, respectively). Otolith radius data were used instead of fish length (as in Govender 1999) along with their corresponding mark/recapture dates, and were fitted to the modified Schnute model (Fig. 7.28).

A degree of growth bias was noted in these original fits, which appeared to be due to a short period of non-growth following the original capture. This was added to the growth equation, with an estimate of 10 days 'sook' (no growth) being fitted. A plot of predicted vs observed otolith growth (Fig 7.29) clearly supports the interpretation that one growth check is formed each year.

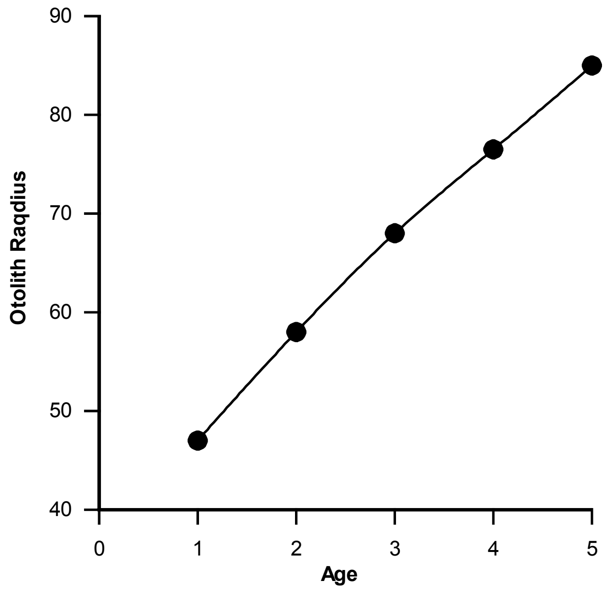

Figure 7.28 Modified Schnute growth model of *P. saltatrix* otolith radius at age. Data points are the mean observed distances between nucleus and each successive assumed age check and include tag data (as shown in Fig 7.20) in addition to material from a selection of large fish from the ISAMP study. $R^2 = 0.99$.

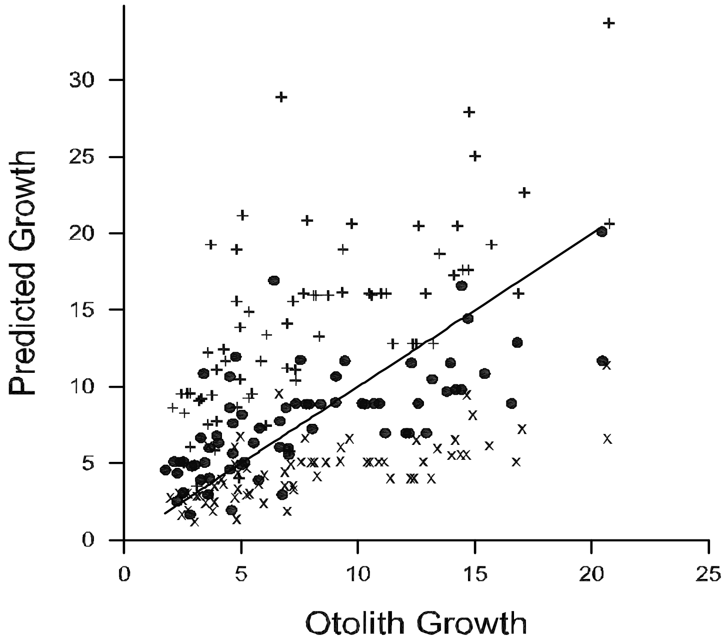

Figure 7.29 Relationship between predicted and observed otolith growth given the three scenarios that growth checks are laid down annually (●), bi-annually (+), or biennially (x).

7.8.3 Comparison of otolith morphology by age group

A plot of otolith morphometry based on separate age classes (Fig. 7.30) supported our interpretation about the periodicity of the *P. saltatrix* otolith growth structures. Most of the 128 otoliths (97%) could be differentiated by their axis measurements, although there was a degree of overlap particularly among the younger age groups. This was not unexpected, given the rapid growth displayed by young *P. saltatrix*. Four otoliths (notable outliers) were found to be incomplete; they had been damaged during removal and were excluded from further analysis.

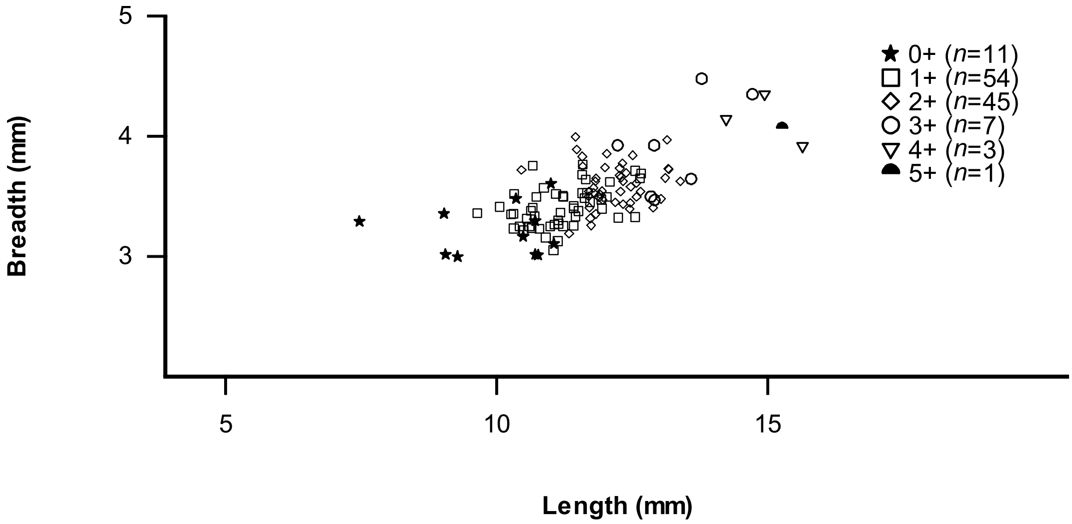

Figure 7.30 Plot of *P. saltatrix* otolith length against width, by individual age group. Sample size (*n*) is given in brackets.

7.9 Independent Interpretation – Central Ageing Facility

Staff at the Central Ageing Facility compared the accuracy of age estimates from whole and sectioned otoliths. They were unable to derive consistent estimates from whole otoliths due to the translucent nature of the zones and the highly variable number of 'false' zones. Sectioned otoliths were read four times. During the first reading, 160 samples were assigned an age. The second reading produced 179 estimates due to the reader being more confident in the otolith structure. An IAPE was calculated from the 160 paired first and second readings. A second IAPE was calculated from estimates obtained from the second and third readings.

The observed IAPE for the first and second readings (n = 160) was 5.89%. The maximum difference between the first and second reading was two years. The mode of the differences was zero, accounting for 107 samples (66.9%). The distribution of the age differences between the first and second reading showed a slight tendency to overestimate the age-class on the second reading. Using the third estimates from samples where the age differed by one or more years, a 'best' age estimate was established. The best estimate was compared to the second age estimate. The IAPE for this comparison was 3.16% (n = 179). The mode of the differences was zero, accounting for 149 samples (82.8%). Again, a slight tendency to overestimate the age of the samples was evidenced a second time.

7.10 Development of Ageing Protocol

We examined both whole and sectioned otoliths and based on the above evidence supporting a single annulus formation per annum and definition of the first annulus location. We developed a basic ageing protocol for the routine ageing of *P. saltatrix* using either whole or sectioned otoliths (Appendix 4). The underlying objectives of the ageing protocol were to identify consistent structures on the inner portion of the otolith that would indicate the position of the first annulus, and to provide a consistent set of rules by which routine and repeatable ageing could be undertaken with an acceptable level of accuracy and repeatability. These were achieved by identifying three zones on the inner portion of the otolith, inside the first annulus (Fig. 7.17). Although some otoliths had several spurious annuli, including a false or settlement check, inside the first annual growth check (annulus), identifying the three zones provided a consistent method for determining the position of the first annulus. Following identification of the first annulus, additional annuli were located, if present, following a set of guidelines. These principles worked equally well with either sectioned or whole otoliths, but if a fish was larger than 45 cm (FL), we recommend the concurrent use of both techniques to determine an accurate age estimate. The protocol was reviewed and revised at the *P. saltatrix* ageing workshop held at the Western Australian Fisheries Department Marine Laboratory in December 2001.

During day 1, the workshop attendees presented the problems with ageing *P. saltatrix* from an individual state perspective, and reviewed the international literature on *P. saltatrix* age validation methods. Days two and three were spent in the laboratory, examining *P. saltatrix* otoliths from both states and refining the preliminary draft ageing protocol. Day four was spent reviewing and clarifying the protocol decision rules. It was acknowledged that the draft protocol still require further revision before acceptance by routine tailor ageing scientists from both states. This was achieved: the protocol has been accepted by Queensland, Western Australian and CAF scientists, and is now available to researchers generally.

7.11 Precision of Age Estimates (from Ageing Protocol)

Two experienced *P. saltatrix* otolith readers examined a sample of 172 otoliths twice, once using interpretive experience and a second time using the ageing protocol. There was 72% agreement between the two readers at the first reading. This improved to 93% after using the protocol. Likewise, the bias corrected IAPE declined from 13.9 ± 3.9 to 3.7 ± 2.4 after using the protocol (Table 7.10). This compares favourably with the IAPE derived from the independent CAF readings (5.89). Both reader's assessments for the sectioned otoliths were consistent between readings (Fig 7.31). In 11 of the 12 otoliths where the readings differed the difference was 1 year; in the other instance it was 2 years. In most cases the disparity between age estimates was due to uncertainty about the completeness or otherwise of the outer annulus.

The trial was repeated using whole otoliths. Initially both readers examined 173 otoliths and estimated their age using interpretive experience. The level of agreement was 72%. The trial was repeated following the procedures outlined in the protocol. After the second reading, the level of agreement increased to 91% and the IAPE reduced significantly from 13.9 ± 4.0 (95% c.i.) to 5.3 ± 2.0. A difference greater than 1 was observed in six cases. In each of these, the second year discrepancy related to whether the reader interpreted the edge of the otolith as displaying a complete annulus, or if the annulus was still forming.

Table 7.10 Level of precision from multiple ageing of *P .saltatrix* otoliths.

	% Agreement	Bias Corrected APE	95% CI	n
Initial Whole Otolith	72	13.9	4.0	172
Initial Sectioned Otolith	72	13.9	3.9	173
Protocol Whole Otolith	91	5.3	2.0	172
Protocol Sectioned Otolith	93	3.7	2.4	173

Interpretations before and after using the protocol did vary, improving after using the protocol. Bowker's (1948) chi-square test of symmetry found significant differences between the two readers before using the protocol ($p_{section} = 0.02$, $p_{whole} = 0.02$). These differences declined after using the protocol ($p_{section} = 0.04$, $p_{whole} = 0.25$). Reading whole otoliths gave less inter-reader variability than sections. Readability indices varied between readers with reader B consistently assigning a lower readability value than reader A for both techniques (Fig. 7.31).

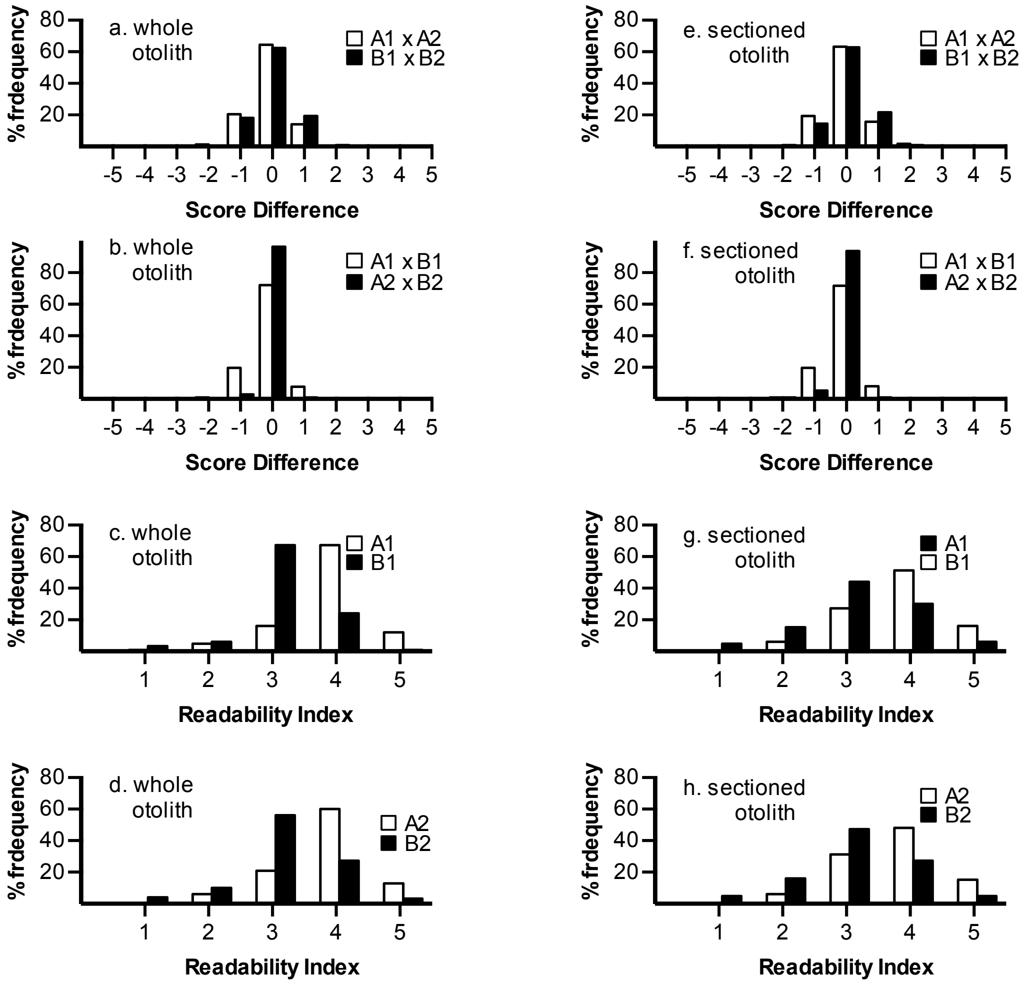

Figure 7.31 Comparison of age estimates between two readings by each of two readers prior to using the protocol on whole (a) and sectioned (e) otoliths, and between readers (2 readings each) using the protocol on whole (b) and sectioned (f) otoliths. The lower panels compare the attributed readability indices between two readers prior to using the protocol on whole and sectioned otoliths (c and g respectively) and after using the protocol (d and h respectively).

7.12 Revision of Total Instantaneous Mortality Rate Estimates

A random subsample of 390 ISAMP *P. saltatrix* otoliths were examined and their age estimated, based on the ageing protocol. Reader agreement was 91% and IAPE was 5.5 ± 1.9 (95% C.I.). The resulting 355 age estimates on which both readers agreed were used to calculate a proportional age distribution. This was applied to all of the original ISAMP *P. saltatrix* length-frequency data to establish a revised age frequency table (Table 7.11). The 0+ age group was not included as this age-class is not fully recruited into the fishery. This was plotted on an age-frequency graph (Fig. 7.32) and the slope was calculated and compared to that published by Hoyle *et al.* (2000). Recalculation of Z resulted in an estimate (1.95 ± 0.77 [95% c.i.]) corresponding to an annual survival rate of about 14%. This result is within the confidence intervals published by Hoyle *et al.* (2000), and a t-test found no statistical difference between the two estimates ($p>0.05$).

Table 7.11 Age frequency distribution and total mortality (Z) estimate of *P. saltatrix* based on the TAV review of the original ISAMP samples, along with the confidence intervals.

Age class	0+	1+	2+	3+	4+	5+	6+	n	Z	CI (95%)
TAV age-distribution	5	210	118	13	5	3	1	355		
Revised ISAMP age-distribution	47	2771	1715	185	5	3	1	4727		
Original ISAMP Ln age-distribution	3.84	7.93	7.45	5.22	1.61	1.10	0		2.03	0.61
Ln TAV	4.28	7.49	4.89	4.39	2.01	0.92	0		1.95	0.77

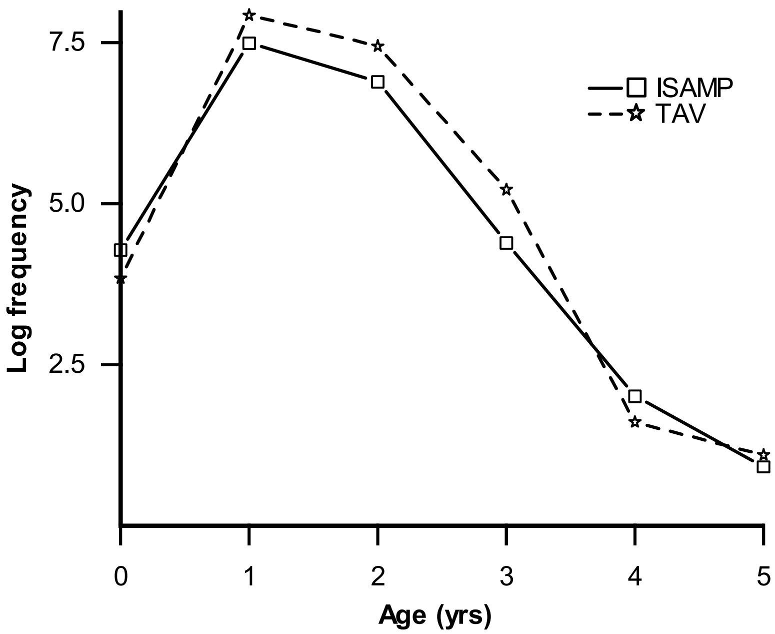

Figure 7.32 Catch curve for *P. saltatrix* from combined commercial and recreational catch for 1995 to 1998 (Hoyle *et al*, 2000) calculated by ISAMP data and by TAV review of this data.

7.13 Inshore-Offshore Size Composition Differences

7.13.1 Fishery-independent sampling

A total of 3794 tailor were collected by DPI staff during 97 fishery independent sampling trips between November 1999 and July 2002. The average length of all tailor caught was 31.7 cm (FL). These fish were sorted into 19 two-centimetre size-classes over 6 depth categories (Table 7.12). The depths of 2 and 3 fathoms were combined because these sample sites were both from estuary/bay sites. The depths of 22 and 24 fathoms were combined as these were both from reefs more than 5 nautical miles offshore. Bays and estuaries, inshore, midshelf and offshore sites were sampled all year round. The beach and headland sites were sampled only during the peak tailor season.

The size-distribution of tailor sampled from the beach (range: 22.8-55 cm FL) was most similar to that from the headland (range: 24.6-56.2 cm). These two depth categories both had the largest size-range and produced the largest fish. Bay/estuary (range: 17.6-38.5 cm) and Inshore depth size-distributions (range: 16.6-36.7 cm) were similar and produced the smallest fish. The mid-shelf sites (range: 19.5-32.7 cm) were similar to these, but slightly truncated in the smallest and largest size-classes. The size distribution from offshore sites (range: 20.3-43.5 cm) was different from all others, having a greater number of large fish than either of the bay/estuary or inshore sites, but fewer than at the beach and headlands sites. Overall there was a general trend towards increasing size as depth increased, but only up to medium sizes: the largest fish were found at the beach and headland sites. These trends in size-frequency distribution (Table 7.12) were reflected in a visual comparison of the mean sizes of fish sampled from the various habitats (Fig. 7.33).

Table 7.12 Size-class and depth categories of *P. saltatrix* sampled for size-spatial abundance relationship. Number in brackets represents number of sampling episodes in each depth category.

Size-Class (cm)	Beach 1 fm (15)	Headland 2 fm (13)	Bay/estuary 2 & 3 fm (37)	Inshore 5 fm (8)	Mid-shelf 11 fm (7)	Offshore 22 & 24 fm (17)
Average	35.1	35.9	24.1	25.8	24.9	29.4
18	0	0	4	2	0	0
20	0	0	60	2	1	0
22	0	0	83	14	21	4
24	1	0	67	66	182	12
26	1	6	55	62	225	31
28	9	11	57	55	116	55
30	70	19	37	40	16	58
32	165	83	29	14	1	40
34	218	230	3	6	2	40
36	236	347	0	1	0	21
38	185	256	0	1	0	3
40	96	143	1	0	0	1
42	55	56	0	0	0	1
44	17	32	0	0	0	1
46	10	16	0	0	0	0
48	3	17	0	0	0	0
50	5	5	0	0	0	0
52	3	1	0	0	0	0
54	3	4	0	0	0	0
Total	1077	1226	396	263	564	267

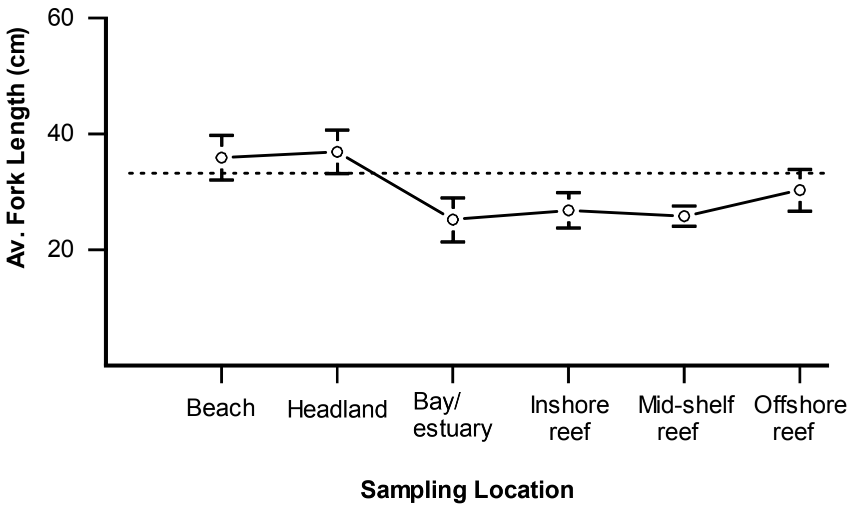

Figure 7.33 Mean fork-length (± 1 s.d.) of tailor captured from six depth-stratified sampling locations (refer to Table 7.12) during fishery-independent sampling between November 1999 and July 2002. The horizontal dotted line indicates the overall mean size.

7.13.2 Survey of charter vessel operators

A total of 45 charter vessel operators (CVOs) were interviewed in early 2002. Their experience in the fishery ranged from 1 to 65 years (mean = 16 ± 4 [c.i.]). We analysed their responses based on the area of their operation to determine if this influenced their perceptions. These CVOs were classified on their area of operation as being from (a) North (Fraser Island to Cape Moreton), (b) Central (Cape Moreton to Jumpinpin Bar), or (c) South (Jumpinpin Bar to the Tweed River). Area was a significant factor in determining which parts of the fishery CVOs perceived as catching the most tailor (χ^2 = 13.17, P = 0.010 with 4 d.f.), with southern operators perceiving that more tailor were caught from boats than from the beach (by either hook and line or net). Area of operation was also a significant factor in determining where CVOs perceived medium and small tailor were caught, with most of the southern operators considering that fish of this size are more common on inshore reefs out to 24 fathom depth. Otherwise, CVOs shared a common perception, irrespective of their area of operation with respect to range of experience, knowledge of large tailor habitat, and size categories.

Most operators considered tailor between 51 and 70 cm TL 'large', those between 40 and 50 cm 'medium', and those less than 35 cm (TL) 'small'. More than 90% of CVOs thought that large tailor were most likely to be caught off the beach in depths less than two fathoms. Nearly 80% believed that medium and small tailor were more common on the inshore reefs (less than 5 fathoms) than anywhere else. More than 50% were of the opinion that trawling for stout whiting (*Sillago robusta*) was having a greater impact on mortality of small to medium-sized *P. saltatrix* than most people acknowledged. Nearly 75% of the CVOs believed that otter trawling had affected the bottom structure, levelling out a lot of inshore rubble reefs on which tailor had previously aggregated. More than 60% wanted to see further research carried out to establish what oceanographic/behavioural factors influence the species' migration patterns.

7.13.3 Survey of Recreational Fishers

Twenty-two dedicated recreational tailor anglers were interviewed; their experience targeting tailor recreationally averaged 29 ± 5 years. As with the CVOs, their responses were analysed in accordance with their area of operation to test whether this influenced their perception. Classification of area of operation was similar to that used for the CVOs. Area of operation was not a significant factor, although southern fishers felt that more fish were taken by hook and line than did the central or northern based fishers (χ^2 = 9.03, P = 0.060 with 4 d.f.). The recreational anglers classed large tailor as at least 3 kg (>67 cm TL), medium-sized fish between 35 and 65 cm and small fish less than 35 cm TL. Nearly 75% of the surveyed anglers considered that large tailor could only be caught in inshore gutters or ‘back banks’. Most (>86%) felt that large tailor generally occur in very small aggregations (<6 individuals) outside the back break and make periodic foraging raids into the inshore gutter. It was during these raids that they were most likely to be caught. However, some anglers (23%) also acknowledged that large tailor were highly mobile and could occasionally be caught out wider on the inshore reefs. About 90% of those surveyed thought that small and medium sized tailor were most accessible from the inshore gutters, and 10% thought that small and medium sized tailor were also accessible from headlands and inshore reefs. All the anglers surveyed used specialised fishing rigs and bait to target large tailor, although they believed large fish could occasionally be caught on standard beach fishing rigs and bait.

7.13.4 Survey of Commercial Fishers

We interviewed 10 commercial ocean beach haul licensees (with K1 to K8 endorsements). These fishers had an average of 30 ± 5 years of fishing experience, spotting and netting for tailor. We did not analyse the responses of these fishers against their area of operation because of the small sample size. Most commercial fishers classed large tailor as being longer than 60 cm TL, medium fish between 40 and 60 cm, and small fish less than 40 cm TL. These net fishers only catch tailor from the inshore gutter, although they do spot schools swimming seaward of the back break (see Fig 7.34).

Most of the fish caught in nets are in an advanced reproductive state, with ovaries and testes near running ripe. The commercial tailor season starts in late July along the Tweed coast up to mid-August on Fraser Island. The general rule of thumb is for a run of small tailor, followed by medium-sized fish 2 to 3 weeks later. By the second month of the season, a third run of small to medium tailor is encountered. However, late in the season schools of large fish may be encountered. The ability of commercial fishers to access these schools is strongly influenced by the prevailing weather, as strong south-easterly winds seem to be required to initiate the northward spawning migration, but westerly weather is then needed to calm the seas encouraging the fish to ‘lay over’ in inshore gutters and channels and allow the fishers adequate time to shoot their nets. Over half of the commercial fishers expressed a belief that while the number of schools had declined only marginally, schools tend to have decreased somewhat in size. More than 75% of commercial fishers believe that the pattern of migration of tailor has changed over the years as a result of increased ambient light levels from urban strip development on the Gold Coast particularly, and the large increase in vehicular traffic at night along the popular ocean beaches in general. The increase in ambient light is believed to have resulted in the northward-migrating tailor schools remaining further offshore than previously, thus reducing their accessibility to fishers and anglers. None of the commercial fishers offered an opinion as to where large tailor might be located when not on their spawning run, but several had observed tailor moving offshore after reaching Sandy Cape. Several commercial fishers noted that large tailor were often found in association with large schools of mullet, and can be taken as bycatch in mullet nets.

Figure 7.34 Small school of tailor crossing a shallow sandbar at Indian Head, Fraser Island. The school (dark shadow in foreground) has come from deep water around the headland (lower right), and the fish are beginning to aggregate on the inshore side of the bar (upper right).

8 DISCUSSION

8.1 Collection and Tagging

Collection and tagging of tailor was an evolving process. Our wild tagging process followed the procedures established by several previous tailor-tagging programs (Bade 1977; Halliday 1988; Morton and Halliday 1993). However, there was some concern as to the level of post-tagging mortality, particularly after the finding of seven dead tagged fish in the shallows adjacent to the release area on Fraser Is. To reduce handling stress as much as possible we did not hold fish captive for more than three minutes, and over 80% of our wild tagged fish that were returned to the water displayed excellent release response behaviour.

The survival of tagged fish in the semi-captive (Sea World) and captive (Southern Fisheries Centre) populations was maximised by (i) not releasing damaged fish and (ii) anaesthetising the fish prior to tagging (Munday and Wilson 1997; Walsh and Pease 2002; Woody *et al*. 2002). This enabled fish to be handled with a minimum of stress, which was important when visual elastomer marks were injected into the fin rays after insertion of a standard t-bar tag and administration of an otolith marking substance. The use of VIE marks proved to be a successful way of ensuring that fish could be identified (at least to release batch level) if the conventional tags were lost.

8.2 Tagged Fish Recaptures

The recapture rates recorded from wild populations in this program were unexpectedly poor (0.01% in 2000 and 0.68% in 2001). These figures are well below those reported for other tailor tagging programs (Table 8.1) and it is appropriate to examine some of the reasons as to why this might have occurred. There are several factors that can influence the recapture rate of tagged fish and affect the number of fish recaptured (Infofish Inc. 2003). These include:

- Intensity of fishing effort in the vicinity of release sites, and movement of fish to areas of different or no fishing effort.
- Mortality resulting from handling, tagging or release procedures
- Variation in natural mortality after release
- Shedding or removal of tags
- Non-reporting of the capture of tagged fish
- Ineffective detection of tags
- Incorrect reporting of tag details

8.2.1 Spatial variation in fishing effort intensity.

The prime reason for choosing the Fraser Island tailor fishery closure area for tagging fish was that this was likely to yield the best catches and enable us to tag the greatest number of fish. Previous tagging programs from this area had experienced a high proportion of recaptures within one month of release (Bade 1977, Halliday 1990). We chose to tag during the closure period (September) so that tagged fish would not immediately be vulnerable to capture, as the information gained from such short-term recaptures would be of very limited value to an age-validation study. On the assumption that the fish would disperse into the wider stock within days or weeks and undertake another northward spawning run in 2001, it was argued that there was a reasonable probability that a proportion of the fish might be recaptured in the same general region as they were released. There was no *a priori* reason to believe that the level of fishing intensity would undergo a significant reduction from one year to the next, although Higgs and McInnes (2003) have since reported a slight reduction in the overall rate of participation in recreational fisheries in Queensland, and there is some anecdotal evidence of some movement of fishing activity from beach to rocky shores and headlands in recent years (B Sawynok, pers. comm.). However National Parks and Wildlife Service annual data indicate a steady increase in camping visitor numbers to Fraser Island between 1996/97 (~23 000) and 2001/02 (~25 000), most of whom would probably have been engaged in angling.

When comparing tag recapture rates it is important to consider the time at which the fish were at large. While some of the studies listed in Table 8.1 showed significant periods of time at liberty, only Van der Elst (South Africa, 1990) and Young *et al*. (Western Australia, 1999) reported the recapture of any tailor more than a year after release.

Table 8.1: Comparison of recapture rates in various tailor tagging programs.

Author	Date of trial	No. tagged	Number recap.	% recaptured	Ave days at liberty	Range of days at liberty
Bade (1977)	Jun-Oct 1976	170	13	7.6	15	2 - 39
Halliday (1988)	Feb-Sept 1987	3071	308	10	62[j]	0 - 210[j]
					52[a]	8 - 256[a]
Halliday (1990)	Sept-1988	1381	295	21.4	27	0 - 158
Halliday (1990)	Aug-Oct 1989	3254	256	7.9	25	0 - 207
Halliday (unpub. data)	Aug-Oct 1990	2066	69	3.3	24	11 - 44
Van der Elst (1990)	1984-1993	2737	108	4	54	0-374
Young et al. (1999)	1994/95	1075	37	3.4	122	16-725
Young et al. (1999)	1995/96	4032	141	3.5	62	0-580

[j] juveniles; [a] adults

Generally the bulk of recaptures in these studies were made within a relatively short time of release, which is reflected to some extent in the average days at liberty figures in Table 8.1. We believe that our comparatively low recapture rates were due to (i) our scheduling of the tagging operation so as to purposely avoid exposing the fish to peak-season fishing pressure, and (ii) a high natural mortality rate in this species. When included with fishing mortality, the latter would have contributed to a high total mortality rate, our estimate of which was not greatly reduced because our study had validated the previous age estimation process. The net result of these two factors was probably that most of the tagged fish avoided early post-release recapture, but were subsequently subject to very high natural mortality which significantly reduced the likelihood of their recapture. Other potential contributing factors are discussed below, but without more specific knowledge of the species' behaviour (in terms of the proportion of the stock that migrates each year, the perceived negative impact of migrating fish to vehicle lights on the ocean beaches, and a reliable estimate of natural mortality which could help in the estimation of total stock size) we think this is the most plausible explanation.

8.2.2 Mortality due to handling, tagging etc.

The vast majority (97%) of tailor tagged during the 2000 and 2001 operations on Fraser Is and south Queensland coastal sites respectively were recorded as being in excellent condition on release. All personnel involved in the tag-release process were highly skilled and experienced, and best-handling practices were observed at all times. Apart from one instance where a group of seven fish that had been tagged some hours previously were found dead in a gutter near the beach, only three of the 3007 tailor tagged and released into the wild were reported to have failed to survive capture and tagging. A larger proportion (7%) of the tailor released into the Sea World facility were in poor condition at release. Most of these occurred during the earlier part of the tagging program, probably as a result of the extra handling required to transport them from off-shore and coastal capture locations back to the Sea World Ski Lagoon. Later releases were modified to ensure that fish were in better condition prior to tagging and releasing, which resulted in 93% of the released fish being in excellent condition. The captive population of 128 fish held in tanks at SFC suffered only minor mortality (3.9%) over a period of five months, and this was due to factors unrelated to tagging and handling. From these results we consider it unlikely that tagging mortality *per se* could have accounted for the low recapture rates from the wild population.

8.2.3 Variation in natural mortality after release

It is possible that the process of tagging tailor could alter their vulnerability to factors causing natural mortality. If a fish were disoriented on release, or unable to swim away as quickly as usual, it may be at greater danger from predators. It is probable that some of the fish captured close to the beach at night in one tagging session on Fraser Is were attacked by sharks, a number of which were observed to chase the hooked tailor in to very shallow water. However, on release, the majority of tailor swam away strongly and very rapidly, disappearing into the surf almost instantly. Such a response would be expected in a schooling species such as tailor when released individually. Future tagging programs could attempt to release tailor in small batches, but the main concern with our exercise was to minimise the amount of time the fish were out of the water.

8.2.4 Shedding or removal of tags

If a tagged fish loses its tag – for whatever reason – it becomes impossible for an angler to recognise the fact that it had been marked. Low recapture rates can clearly result if a substantial number of fish lose their tags, either because they were of an inappropriate type, insufficiently well embedded in the fish, or were physically pulled out or sheared off. Van der Elst (1990) reported that tag loss was significant for tailor kept in tanks over a period of one year in South Africa. Early in the Sea World experiment we noticed tagged tailor being 'mobbed' by certain resident fish species (notably large yellow-fin bream

[*Acanthopagrus australis*]) which picked at the tags. Subsequently during recapture sessions we observed some tailor with no tag but with scarring in the exact location where a tag would have been implanted. It seemed likely that the resident fish were either biting the tags off or pulling them out of the tailor, so we established a procedure for double-marking all t-bar tagged fish, using colour and location-coded visual implant elastomers. While the VIE marks could not be used to identify individuals, they proved particularly useful in identifying the release batch of a number of fish that lost their tags in the Sea World environment. Estimates of tag loss may have been possible had we double-tagged a large proportion of the fish, but this was not done, although the VIE tags provided a proxy for double tagging. Double tagging may have added value to the tagging experiments, but our prime objective was to establish otolith development patterns, not tag loss rates, and implanting a second anchor-tag would magnify any potential adverse effect on the fishes' subsequent survival.

To investigate the tag-loss issue further, we established the captive population of fish in four tanks at SFC. After being anaesthetised these fish were all tagged conventionally and with a VIE mark, as well as being injected with a fluorescing compound. Of the 125 fish that survived to the termination of the experiment, only one lost its t-bar tag, and then only five days before the experiment concluded. We were unable to determine why this tag was shed, but it had evidently not been bitten off by another tailor. These tank experiments provided clear evidence that the Sea World tag losses were unlikely to have been due to the activity of conspecifics (other tailor). This suggests that, in the natural state where tailor are schooling primarily with conspecifics or with basically herbivorous sea mullet (*Mugil cephalus*), the removal of tags by other fish is not likely to have been a major contributor to the low rate of tag recaptures.

Finally, we carried out an additional check on the possibility that a significant number of the tailor tagged in 2000 may have shed their tags. We reasoned that tagged fish might return on a spawning run to Fraser Is the following year and be sampled from the recreational angling fishery as part of the annual monitoring survey undertaken by Queensland Fisheries Service. Even if they had lost their tags, these fish should be identifiable by a fluorescent otolith band as having been tagged previously (although the specific tagging operation would not be able to be determined). Accordingly, we examined (by fluorescence microscopy) the 1200 tailor otolith pairs sampled by QFS during the 2001 season. None of the otoliths showed any convincing evidence of having been labelled with tetracycline, so we concluded that none of the sampled fish had been part of a previous tag release.

8.2.5 Non-reporting of the capture of tagged fish

Throughout the Project we were acutely sensitive to the need to continually publicise to anglers the need for tailor tags (and associated data and material) to be returned to project staff. While it is obvious that our publicity programme was not able to reach every member of the south-east Queensland angling community, we maintained a constant and (we believe) successful advertising presence in south Queensland and northern New South Wales via bait and tackle shops; general stores on the islands; fishing magazines; bulletin-boards at wharves, boat-ramps and piers; vehicle ferries, fishing clubs, mailouts, and the internet. A recreational angler mentioned to project staff that 'it was difficult to go anywhere on Fraser Island without seeing one of the tagging campaign posters in a public area'.

A trend towards catch-and-release amongst the angling fraternity in Queensland had some impact on the Project's ability to retain the necessary otolith material, as we have become aware that several anglers re-released fish because they were carrying tags. An unfortunate example of this was recently reported to us via the InfoFish database system, where one of the tailor, tagged at Fraser Is on 15 September 2000, was recaptured in Coochin Ck (close to Moreton Bay) on 6 July 2003 and released. The fish had been at large for 1024 days, and would have been an exceptionally valuable piece of validation evidence had the fish been retained.

8.2.6 Ineffective detection of tags

The T-bar tag chosen is a widely used and versatile tag for marking small and medium sized fish. To the experienced tagger it is highly visible protruding from the dorsal muscle, even when encrusted with algal growth. However, there is still a degree of ineffective detection within the recreational fishing sector (B Sawynok, pers. comm.). This is especially so amongst the casual and interstate recreational fishers who are unfamiliar with the Suntag/Austag program. However detection rates have probably improved over the past decade because of the wide publicity the program attracts amongst recreational anglers.
A T-bar tagged tailor would be less visible amongst a commercial haul. Fortunately, most tailor beached by Queensland commercial netters are processed in southeast Queensland. For this reason, all of the major buyers were targeted with a publicity campaign to raise their awareness of the tagging program. Several of our tagged fish were returned from processors, vindicating this strategy. While it may have been a contributing factor, ineffective tag detection was probably only a minor cause of low recapture rates.

8.2.7 Incorrect reporting of tag details

Discussions with the manager of Infofish Services (responsible for maintaining the tagging database), has reinforced our impressions that incorrect reporting of tag details is negligible in Queensland. A fisher can make contact with Infofish Services via a toll-free number, e-mail, or the postal service. All of these methods mean that the fisher is traceable. Infofish Services operating procedures include verbal communication with any fisher that contacts them to report a tagged fish recapture. During this interview, the database is "live" so that tag numbers can be directly checked against the fishers' information. This ensures that both tag number and fish identification is accurate, and that all the relevant recapture information is acquired. For this reason, incorrect reporting is considered to have negligible impact on the rate of tag returns in Queensland.

8.3 Otolith Interpretation

Otoliths from east coast Queensland tailor are similar in morphology to those from Western Australia (S. Ayvasian, pers. comm.) and east coast USA (Conover, pers. comm.; Barger, 1990; Sipe and Chittenden 2001; Wischniowski and Bobko 2000). The rapid growth of *P. saltatrix* during the first 12 months reported by Juanés and Hare (1996) can be discerned from the otolith as large increments along the vertical and longitudinal axes. After the first year the otolith growth slows down, but is still most visible along the longitudinal axis. As has been noted elsewhere (Barger 1990; Wischniowski and Bobko 2000; Sipe and Chittenden 2001) there is also some thickening of the otolith as the fish increases in size. This as an important influence on the recommended method for preparing and reading the otolith (see Appendix 4).

Sectioned otoliths display an inner dense opaque region around the nucleus which we refer to as 'zone a' that expands out to first major growth check (the *f*-check), which may represent a change from yolk-feeding to planktivory (Barger 1990; Govender 1999; Morales-Nin 2001; Sipe and Chittenden 2001). Outside this is a second opaque zone (zone b), often comprising several false checks which have been observed in other studies (Barger 1990; Morales-Nin 2001; Robertson 2001; Sipe and Chittenden 2001). Beyond this second zone is a narrow translucent zone (c) that is either slightly wider than or of equal width to the first true annual growth check (A_1). In common with Wischniowski and Bobko (2000), we found that the first annual growth check was often associated with a prominent protrusion on the ventral surface. We also noted a change in the direction of growth along the dorsal surface, and an opaque band was usually visible on the proximal margin of the sulcal groove. Most reports link annulus formation with a period of slow growth during times of minimum water temperature (van der Elst 1976; Govender 1999; Swan and Gordon 2001; Newman and Dunk 2002), but several authors have noted that multiple annuli are sometimes visible, and question their annual periodicity (Vidalis and Tsimendis 1996; Wischniowski and Bobko 2000; Sipe and Chittenden 2001). An early theory was that the annuli were associated with bioenergentic stress, such as spawning behaviour (Bade 1977; Kimura 1984) and thus more than one may be present on the otoliths and scales of multiple spawners. However, Wischniowski and Bobko (2000) reported that multiple annulus formation occurred typically in older *P. saltatrix,* and during times of reduced growth.

There are several reported methods for interpreting multiple annuli. Wischniowski and Bobko (2000) considered the 'double annuli' to be one annulus when both marks joined to form a central origin, either at the sulcal groove or the outer peripheral edge of the otolith. Wright *et al.* (2002) noted that true annuli appeared as gradually declining increment widths whereas false rings were characterised by an abrupt check in otolith formation.

We examined the inner regions of the otolith section to look for corroborative evidence of micro-increments. Our findings were similar to those of Robertson (2001) that the number of micro-increments from the nucleus to the settlement (*f*) check was about 55. While much of the literature interprets these inner micro-increments as daily growth rings (Tabeta *et al*. 1987; Umezawa *et al*. 1989; D'Amours *et al*. 1990; Antunes and Tesch 1997; Ishikawa *et al*. 2001), evidence from older *P. saltatrix* injected with OTC has shown some conflicting results. If the inner micro-increments are assumed to be daily growth checks, there may be a change in the way rings are laid down beyond the inner *f*-check (Waldron and Kerstan 2001 [*Trachurus trachurus*], and Al-Husaini and Dashti 2001 [*Pomadasys kaakan]).* We were unable to resolve the number of rings beyond the settlement check (in contrast to these studies), but Robertson (2001) noted that in many species it is not possible to resolve such micro-increments.

Results of the SEM investigations were little more revealing than those of the daily ring analysis. While SEM was useful for examining inner micro-increments, inconsistencies across the outer regions of the otolith section confounded any reasonable interpretation of the number of micro-increments beyond the 'f' check. Despite using various etching solutions and concentrations according to the techniques recommended by Morales-Nin (1992) and Ashford *et al*. (1993), we were only able to resolve checks in small, discrete outer portions of the otoliths. Waldron and Kerstan (2001) noted that etching inconsistencies can occur and rejected 66% of otoliths in their study because of over, under or inconsistent etching across the surface of the otolith section. Most of the papers reporting on SEM techniques deal with interpretations of inner daily rings (Aps *et al*. 1988 *not sighted*; Pertierra and Morales-Nin 1989; Li *et al.* 1993; Li 1996); very few record the counting of daily rings for the first year and beyond (Suyama *et al*. 1996).

Determining the position of the first annulus has been a problem with both Queensland and Western Australian *P. saltatrix* ageing programs. The occurrence of spurious inner rings caused inconsistencies in interpretation of otolith age amongst multiple readers (Hoyle *et al*. 2000). Campana (2000) recognised the importance of monitoring a time-series of presumed YOY in conjunction with inspection of marginal increment to confirm the formation of the presumed first annulus, although marginal increment in YOY fish can sometimes be difficult to distinguish from false checks (Barger 1990; Wischniowski and Bobko 2000; Sipe and Chittenden 2001). By following a time-series of juvenile otoliths over a 12-month period, we were able to identify consistent internal structures and establish a protocol for determining the position of the first annulus. Cappo *et al.* (2000) observed that a bias in the interpretation of the position of the first annulus by an inexperienced reader caused significantly higher estimates of age, but not the number of annuli outside the fluorescing (OTC) mark.

The reliable identification of first increment has substantially increased the precision of our individual age determinations. To support our interpretations, we also measured the diameter of the YOY otoliths and achieved relatively distinct age groupings. Our research concurs with the findings of both van der Elst (1976) and Robertson (2000) that the first annulus does not always represent a full 12-month growth period.

Examination of otoliths marked with OTC leads to the conclusion that annulus formation outside the first annulus is an annual event, at least in *P. saltatrix* up to 6 years age. However, a significant proportion of our samples were at large for less than one year. Modelling the observed otolith growth patterns supports the interpretation of seasonal growth changes, with summer growth up to twice that in winter. We incorporated seasonal growth into Govender's (1999) model of proportional distances between expected and observed annuli to model the periodicity of annulus formation. These results indicate that growth checks in tailor older than one year are laid down annually. Newman and Dunk (2002) also reported a large proportion of recaptures with a time at liberty less than a year, but nonetheless used the data to infer annual periodicity of ring formation. This was in line with evidence from recaptured fish that displayed a complete annual growth cycle on the otolith. Cappo *et al*. (2000) reported low recapture rates, and developed a model to incorporate proportional information from samples that had not completed an entire year's growth. However, as we had demonstrated seasonality in the growth of *P. saltatix* otoliths this constant growth-rate model was inappropriate for our data. While our validation only covers a proportion of the known age range of *P. saltatrix*, it does include the range of ages represented in samples collected by the Queensland Fishery Service's Long Term Monitoring Program. It therefore provides sufficient validation for routine age-determination of tailor stocks in Queensland.

The development and use of an ageing protocol considerably increased the precision of our age estimates. One important aspect of the ageing protocol is the review of between-reader error. APEs up to 5% are considered acceptable for routine ageing (Campana 2000): as tailor otoliths are quite variable, such reviews are important to ensure that the error levels are appropriate for routine ageing and stock assessment.

Robertson (2000) and Sipe and Chittenden (2001) considered that sectioned tailor otoliths yielded more consistent results than did whole otoliths. However, the level of agreement we found between whole and sectioned otoliths, together with the absence of any evidence of systematic error in our interpretations, gives confidence to our methodology. This is important because, as Newman and Dunk (2001) point out, underestimating the age of younger fish can lead to over-estimation of natural mortality. The use of inflated natural mortality estimates to recommend stock exploitation levels increases the chance of over-exploitation. Sipe and Chittenden (2001) noted that sectioned otoliths took 1.5 times as long to read as whole otoliths. They also recorded a 95% agreement between whole and sectioned otolith from fish younger than 4 years, but less than 30% agreement for older otoliths. Given the similar values and confidence intervals we derived from whole and sectioned otoliths, coupled with the extra processing necessary for obtaining section estimates, we recommend that whole otoliths be used for ageing *P. saltatrix* up to 45 to 50 cm (FL). Above that size sections should be used for greatest accuracy. This means that about 98% of the QFS LTMP program's annual collection of 1000+ tailor otoliths can be aged without the need for sectioning. This has obvious advantages in reducing the time and cost associated with preparation and processing.

In accordance with the recommendations of Campana (2000) and Buckmeier (2002), we have compiled a reference collection of otoliths of different degrees of readability. When used in conjunction with the ageing protocol, these examples will provide otolith readers with a guide for standardising the interpretation of future *P. saltatrix* otolith collections.

8.4 Adjustment of Mortality Rate Estimates

Our revision of the ISAMP age estimates has led to a marginally smaller total mortality (*Z*) estimate (1.95 ± 0.77), compared to the original ISAMP estimate (2.03 ± 0.24). This corresponds to an annual survival rate of about 14%, compared to the earlier estimate of 13%. Our slightly lower estimate of *Z* stems from a difference in interpreting the position of the first annulus, which led to a minor redistribution across the younger age groups (<6 yr).

9 BENEFITS

This research will benefit the recreational, commercial and Fisheries Management sectors in Queensland, New South Wales and Western Australia. For Queensland, the outcomes confirm the results of previous work, indicating that the tailor stock is characterised by a relatively low annual survival rate. This will lead to greater confidence in the results of the routine long-term monitoring of tailor stocks, and provide a significantly firmer basis for subsequent stock assessments. As a result, improved management arrangements should benefit the fishery, as well as the tourist and recreational industries that depend on the seasonal *P. saltatrix* fishery.

10 FURTHER DEVELOPMENTS

Age determination in some fish species is not straightforward. *P. saltatrix* is one in which ageing errors can exceed acceptable limits unless there is a clear understanding of the morphology of inner portion of otoliths. We recommend that any fish stock in Queensland that is managed on the results of age-based stock assessment should be subjected to a rigorous age-validation process.

In developing a successful ageing program, Campana (2000) recommended (*inter alia*) the establishment of a quality control process to help maintain ageing consistency in the longer term. To achieve maximum benefit from the reference material assembled during this Project, we intend to conduct in-house workshops with staff from the Queensland Fisheries Service's Long Term Monitoring Program (LTMP) responsible for routine ageing of tailor, to promote a more accurate and consistent interpretation of *P. saltatrix* otoliths. We also plan to help develop a quality assurance scheme involving periodic re-ageing using the reference collection and more recently obtained otoliths.

This and other recent projects have revealed that the reproductive aspect of the species' behaviour (on the Australian east coast, at least) is rather more complex than may previously had been believed. Evidence suggests that a significant 'background level' of spawning activity occurs throughout the year, and that perhaps only a proportion of the sexually mature stock undertakes the longshore migration. Knowledge of the fate of post-spawners is sparse, and the extent to which fish repeat the spawning run in successive years is highly uncertain. If these behaviours are variable and are influenced by environmental factors such as climatic or oceanographic conditions, they may have a significant impact on our ability to effectively track changes in population size and age-structure using traditional methods. Additional research is needed on (i) the species' behaviour, (ii) alternative stock assessment techniques such as the egg-production method, and (iii) the impact of environmental factors (e.g. global warming) on recruitment, if the managers are to be confident in their understanding of the complex dynamics of this important resource.

11 PLANNED OUTCOMES

The FRDC 99/123 project application identified four primary performance indicators for the Project. These are listed below, along with a summary of the Project's performance against them.

1. *We are able to demonstrate with statistical rigour either that the existing interpretation of internal banding structure in tailor otoliths is correct, or it is not. If not, an appropriate interpretation and reading protocol will have been defined and accepted by other States.*

We have demonstrated the cyclical nature of banding deposition in *P. saltatrix* otoliths. We have established that these bands are formed annually, and have developed a set of protocols to help ensure consistency in the interpretation of tailor otoliths. We have established the accuracy of these interpretations with an acceptable level of statistical rigour. Our results have been workshopped with colleagues in Western Australia and they are incorporating our ageing protocols into their routine *P. saltatrix* ageing program.

2. *It provides conclusive evidence, one way or the other, that the size- and age-structure of recreational tailor catches from the ocean beaches are representative of the entire southern Queensland tailor population.*

We have demonstrated that there is no known source of large fish in offshore Queensland waters. There is, however, a small but expanding fishery for larger *P. saltatrix* in a specialist night-time beach fishery. This fishery is relatively easy to sample, providing that close liaison is maintained with key recreational fishers.

3. *Far greater confidence can be placed in estimates of P. saltatrix mortality rates than is currently possible.*

Because we are now confident that the age interpretation for tailor used during the previous study (the Integrated Stock Assessment and Monitoring Programme) was essentially correct, and that there appears to be no large 'reservoir' of old fish in offshore waters, we can now place much greater confidence on catch-curve based estimates of the instantaneous rate of total mortality for this stock.

4. *The results of the research work are adopted by the relevant Management Advisory Committee and incorporated into the management arrangements for the Subtropical Finfish Fishery.*

Our validation of the age-determination process for tailor and the consequent verification of high total mortality rates in this species has signalled the need for caution in the management of this stock, and assisted the Subtropical Finfish Advisory Committee in its decision to recommend the introduction of a recreational bag-limit and a total allowable commercial catch in the fishery (Fishery Regulation Amendment No. 60; May2002).

12 CONCLUSIONS

1. The ageing process developed during the Integrated Stock Assessment and Monitoring Programme (FRDC) was essentially correct. Our tag recaptures provided evidence (from the relative locations of growth checks and fluorescing marks) that the checks are of annual periodicity, and therefore that the number of checks is numerically equal to the age of the fish.

2. There is some uncertainty as to whether the annuli are the result of a slowing in growth rate or to some physiological process related to spawning activity.

3. Our ageing protocols have resulted in an improvement in the ability of observers to interpret the inner structure of otoliths and thus in the consistency of age estimates.

4. Oxytetracycline and calcein are effective as fluorescent markers of *P. saltatrix* otoliths, whether administered as intramuscular or intraperitoneal injections. Both fluorochrome substances were more effective when administered as intramuscular injections than when administered as intraperitoneal injections. However we noted that OTC generally produced a more consistent and continuous mark than did calcein.

5. Tag losses in *P. saltatrix* released into the wild may be quite substantial, but tank experiments indicate that when the fish are kept well-fed and there are no other fish apart from conspecifics in the vicinity, tag losses are low. At least some of the tag loss from fish maintained in semi-captivity at the Sea World facility is attributed to the ‘predatory’ activity of other co-habiting species of fish (chiefly yellow-fin bream).

6. The low recapture rate of our wild-population tag releases probably reflects a combination of (i) limited fishing effort in the vicinity of release sites in the short term and (ii) high natural mortality rates.

7. There is no substantive evidence for the existence of a subpopulation of large, old *P. saltatrix* in offshore waters. Nevertheless, large *P. saltatrix* are targeted by specialised beach and headland based anglers who fish at times and in locations other than where typical beach anglers fish.

8. Revised estimates of instantaneous total mortality rates for *P. saltatrix* stocks in south-east Queensland are marginally lower than previously derived from the ISAMP study. This is a result of improvements in both the accuracy and precision of age estimates resulting from the use of the ageing protocol.

13 REFERENCES

Al-Husaini, M., S. Al-Ayoub, et al. 2001. Age validation of nagroor, *Pomadasys kaakan* (Cuvier, 1830) (Family: Haemulidae) in Kuwaiti waters. *Fisheries Research* 53(1): 71-81.

Anon. 2001. Fisheries Long-term Monitoring Program: Ocean Beach overview. Queensland Fisheries Service Information Brochure 4p.

Antunes, C. and Tesch, F.W. 1997. A critical consideration of the metamorphosis zone when identifying daily rings in otoliths of European eel, *Anguilla anguilla* (L.). *Ecology of Freshwater Fis*h 6(2): 102-107.

Aps, R.A., Paat, A.A. and Uder, Yu-OF. 1988. Age determination in the 0-group Baltic sprat according to daily increments in the otoliths. Fisheries Investigations of GDR and USSR in the Baltic. 1988, *Fischerei-Forschung*. 26(2): 82-86.

Ashford, J. R. Robinson K. and White M. G.1993. A method for preparing large numbers of otolith sections for viewing by scanning electron microscope**.** *ICES Journal of Marine Science* 50(2):227-229.

Bade, T.M. 1977. The biology of tailor (*Pomatomus saltatrix* Linn.) from the east coast of Australia. M.Sc. Thesis University of Queensland.

Barger, L.E. 1 990. Age and growth of bluefish *Pomatomus saltatrix* from the Northern Gulf of Mexico and U.S South Atlantic coast. *Fishery Bulletin* 88(4): 805-809.

Beamish, R. J. and D.A. Fournier 1981. A method for comparing the precision of a set of age determinations. *Canadian Journal of Fisheries and Aquatic Sciences* 38: 982-983.

Beverton, R. J. H. and S. J. Holt 1957. *On the Dynamics of Exploited Fish Populations*. London, UK Ministry of Agriculture and Fisheries.

Bowker, A.H. 1948. A test for symmetry in contingency tables. *Journal of the American Statistical Association* 43:572-4.

Brothers, E. B. 1990. Otolith marking. *American Fisheries Society Symposium* 7: 183-202.

Buckmeier, D.L. 2001. Assessment of reader accuracy and recommendations to reduce subjectivity in age estimation. *Fisheries* 27(11): 10-14.

Campana, S.E. 2001. Accuracy, precision and quality control in age determination, including a review of the use and abuse of age validation methods. *Journal of Fish Biology* 59: 197-242.

Cappo, M., Eden, P, Newman, S.J. and Robertson, S. 2000. A new approach to validation of periodicity and timing of opaque zone formation in the otoliths of eleven species of *Lutjanus* from the central Great Barrier Reef. *Fishery Bulletin* 98(3): 474-488.

Chang, W. Y. B. 1982. A statistical method for evaluating the reproducibility of age determination. *Canadian Journal of Fisheries and Aquatic Sciences* 39: 1208-1209.

Chiarella, L.A. and D.O. Conover 1990. Spawning season and first-year growth of adult bluefish from the New York Bight. *Transactions of the American Fisheries Society* 11(9): 455-462.

D'Amours, D., J. G., Landry, J.G. and Lambert, T. C. (1990). Growth of juvenile (O-group) Atlantic mackerel (*Scomber scombrus*) in the Gulf of St. Lawrence. *Canadian Journal of Fisheries and Aquatic Sciences* 47: 2212-2218.

Dichmont, C.M., Haddon, M., Yeomans, K. and Kelly, M. (eds) 1999. Proceedings of the south-east Queensland Stock Assessment Review Workshop. Southern Fisheries Centre, Deception Bay, Queensland. 16-28 August 1998. 179 p. FRDC 98/129.

Efron, B. and Tibshirani, R. J. 1993. *An Introduction to the Bootstrap*. Chapman and Hall, London. 435 p.

Francis, R. 1990. Back-calculation of fish length: A critical review. *Journal of Fish Biology* 36(6): 883-902.

Francis, R. I. C.C., Paul, L.J. and Mulligan, K.P. 1992. Ageing of adult snapper (*Pagrus auratus*) from otolith annual ring counts: validation by tagging and oxytetracycline injection. *Australian Journal of Marine and Freshwater Research* 43:1069-1089.

Gauldie, R.W. 1987. The fine structure of check rings in the otolith of the New Zealand orange roughy (*Hoplostethus atlanticus*). *New Zealand Journal of marine and Freshwater Research*. 21:267-274.

Genstat. 2000. *Genstat for Windows*. Release 4.2, Fifth Edition. VSN International Ltd., Oxford.

Govender, A. 1996. Mark-recapture models for determination of mortality, migration and growth in *Pomatomus saltatrix* (Teleostei). Unpubl. PhD thesis, Oceanographic Research Unit, Dept. Biology, University of Natal (Durban, Sth Africa). 148 p.

Govender, A. 1999. A statistical procedure for validating age estimates from otolith bands using mark-recapture data, with an illustration for *Pomatomus saltatrix*. *South African Journal of Marine Science.* 21: 1-8.

Halliday, I. 1988. Tailor tagging project: Summary of 1987 results. Department of Primary Industries Report. Brisbane, Queensland.

Halliday, I. A. 1990. Tailor tagging project. Summary of 1988 and 1989 results. Department of Primary Industries Report. Brisbane, Queensland.

Henderson-Arzapalo, A., Rago, P., Skjeveland, J., Mangold, M., Washington, P., Howe, J. and King, T. 1999. An evaluation of six internal anchor tags for tagging juvenile striped bass. *North American Journal of Fisheries Management*.19(2): 482-493.

Hernaman, V., Munday, P. L. and Schlappy, M. L. 2000. Validation of otolith growth-increment periodicity in tropical gobies. *Marine Biology* 137: 715-726.

Higgs, J.B. and McInnes, K.L. (eds) 2003. 2001 biennial recreational fishing survey of Queensland residents. DPI report ser. QI03028. 91 p.

Hoenig, J.M., Morgan, M.J. and Brown, C.A. 1995. Analysing differences between two age determination methods by tests of symmetry. *Canadian Journal of Fisheries and Aquatic Sciences*, 52: 364-368.

Hoyle, S., Brown, I., Dichmont, C., Sellin, M. Cosgrove, M. and McLennan, M. 2000. Integrated stock assessment and monitoring program. Queensland Department of Primary Industries and the Fisheries Research and Development Corporation final Project report (FRDC 94/161). 158 p.

Infofish. 2003. Factors influencing the recapture rate of tagged fish. Information leaflet, www.Info-fish.net

Ishikawa, S., K. Suzuki, K., Inagaki, T., Watanabe, S., Kimura, Y., Okamura, A., Otake, T., Mochioka, N., Suzuki, Y., Hasumoto, H., Oya, M., Miller, M. J., Lee, T. W., Fricke, H. and Tsukamoto, K 2001. Spawning time and place of the Japanese eel *Anguilla japonica* in the North Equatorial Current of the western North Pacific Ocean. *Fisheries Science* 67(6): 1097-1103.

Jones, R. 1958. Lee's phenomenon of "apparent change in growth rate", with particular reference to haddock and plaice. *Int. Comm. Northwest Atl. Fish.* Spec. Publ. 1: 229-242.

Juanes, F., J. A. Hare *et al*. 1996. Comparing early life history strategies of *Pomatomus saltatrix*: a global approach. *Marine and Freshwater Research* 47(2): 365-379.

Kalish, J.M., Beamish, R.J., Brothers, E.B., Casselman, J.M. Francis, R.I.C.C., Mosegaard, H., Panfili, J., Prince, E.D., Thresher, R.E. Wilson, C.A. and Wright, P.J. 1995. Glossary for otolith studies. In D.H. Secor, J.M. Dean and S.E. Campana (eds) *Recent Developments in Fish Otolith Research* - Outcomes from the first international symposium on Fish otoliths: research and application. Hilton Head, South Carolina, January 1993. 723-729

Kimura, S. 1984. Age and growth of three-line grunt *Parapristipoma trilineatum*, estimated by otolith reading. *Bulletin of the Japanese Society for Scientific Fisheries* 54: 1843-1848.

Krug, L.C. and Haimovici, M. 1989. Age and growth of *Pomatomus saltatrix* from southern Brazil. *Atlantica* 11(1):47-61.

Lee, R.M. 1912. An investigation into the methods of growth determination in fishes. *Cons. Explor. Mer*, Publ de Circonstance 63:35p.

Li, C. 1996. Observation on the check ring around the central nucleus of otolith of the early life history of *Anguilla japonica*. *Marine Sciences*/Haiyang Kexue Qingdao (1): 46-48.

Li, C., You, F., Feng, R. and Yang, C. 1993. Daily growth increments and effects of photoperiod on daily growth patterns in otoliths of *Sparus macrocephalus* (Basilewsky) larvae. *Oceanologia et limnologia sinica* 24(5): 511-515.

Mardia, K.V. (1972). *Statistics of Directional Data*. Academic Press, London.

McBride, R.S. and D.O. Conover 1991. Recruitment of young-of-the-year bluefish *Pomatomus saltatrix* to the New York Bight: Variation in abundance and growth of spring- and summer-spawned cohorts. *Marine Ecology Progress Series* 78(3): 205-216.

Morales-Nin, B. 1992. Determination of growth in bony fishes from otolith microstructure. FAO Fisheries Technical Paper 322: 51 p.

Morales-Nin, B. 2001. Mediterranean deep-water fish age determination and age validation: the state of the art. *Fisheries Research* 51(2-3): 377-383.

Morton, R.M., Halliday, I. and Cameron, D.A. 1993. Movement of tagged juvenile tailor (*Pomatomus saltatrix*) in Moreton Bay, Queensland. *Australian Journal of Marine and Freshwater Research* 44(6): 811-816.

Munch, S.B. and D.O. Conover 2000. Recruitment dynamics of bluefish (*Pomatomus saltatrix*) from Cape Hatteras to Cape Cod, 1973-1995. *ICES Journal of Marine Science* 57(2): 393-402.

Munday, P.L. and S.K. Wilson 1997. Comparative efficacy of clove oil and other chemicals in anaesthetization of *Pomacentrus amboinensis*, a coral reef fish. *Journal of Fish Biology* 51(5): 931-938.

Murawski, S.A., Rago, P.J. and E.A. Trippel 2001. Impacts of demographic variation in spawning characteristics on reference points for fishery management. *ICES Journal of Marine Science* 58(5): 1002-1014.

Newman, S. and I. J. Dunk 2002. Growth, age validation, mortality, and other population characteristics of the red emperor snapper, *Lutjanus sebae* (Cuvier, 1828), off the Kimberley Coast of North-Western Australia. *Estuarine Coastal and Shelf Science* 55(1): 67-80.

Pertierra, J-P. and Morales-Nin, B. 1989. Sardine growth in the Catalan Sea (NW Mediterranean) determined by means of otolith interpretation and length frequency data. *Scientia Marina* 53(4): 821-826.

Pollock, B.R. 1984. The tailor fishery at Fraser Island and its relation to the life-history of the fish. *Proceedings of the Royal Society of Queensland*. 95: 8-23.

Radtke, R.L., Fine, M.L. and Bell, J. 1985. Somatic and otolith growth in the oyster toadfish (*Opsanus tau* L.). *Journal of Experimental Marine Biology and Ecology*. 90:259-275.

Ricker, W.E. 1969. Effects of size-selective mortality and sampling bias on estimates of growth, mortality, production and yield. *J. Fish. Res. Board Can*. 26:479-541.

Ricker,W.E. 1975. Computation and interpretation of biological statistics of fish populations. *Bulletin of the Fisheries Research Board of Canada* 191:215-217 (382pp).

Robertson,S. 2001. Age estimation of tailor (*Pomatomus saltatrix*). Marine and Freshwater Resources Institute, Central Ageing Facility report to DPI Queensland, 21 p.

Schaefer, M. B. and C. J. Orange 1956. Studies of the sexual development and spawning of yellowfin tuna (*Neothunnus macropterus*) and skipjack (*Katsuwonus pelamis*) in three areas of the eastern Pacific Ocean, by examination of gonads. *Inter-American Tropical Tuna Commission* 1(6): 283-321.

Schnute, J., 1981. A versatile growth model with statistically stable parameters*. Canadian Journal of Fisheries and Aquatic Sciences*. 38: 1128-1140.

Somers, I. F. (1988). On a seasonally oscillating growth function. *Fishbyte*. April 1988, 8-11.

Steffe, A.S., J.J. Murphy, D.J. Chapman, B.E. Tarlinton, G. Gordon and A. Grinberg 1996. An assessment of the impact of offshore recreational fishing in New South Wales waters on the management of commercial fishing. Final Report on Project 94/053 to the Fisheries Research and Development Corporation.

Suyama, S., Sakurai,Y. and Shimazaki, K. 1996. Age and growth of Pacific saury *Cololabis saira* (Brevoort) in the western North Pacific Ocean estimated from daily otolith growth increments. *Fisheries Science*. 62(1): 1-7.

Swan, S.C. and Gordon, J.D.M. 2001. A review of age estimation in macrourid fishes with new data on age validation of juveniles. *Fisheries Research*. 51(2-3): 177-195.

Tabeta, O., K Tanaka, K., Yamada, J. and Tzeng, W.N. 1987. Aspects of the early life history of the Japanese eel *Anguilla japonica* determined from otolith microstructure. *Bulletin of the Japanese Society of Scientific Fisheries* 53(10): 1727-1734.

Trippel, E.A. 1998. Egg size and viability and seasonal offspring production of young Atlantic cod. *Transactions of the American Fisheries Society* 127(3): 339-359.

Trippel, E.A. 1999. Estimation of stock reproductive potential: history and challenges for Canadian Atlantic gadoid stock assessments. *Journal of Northwest Atlantic Fishery Science* 25: 61-81.

Umezawa, A., Tsukamoto, K., Tabeta, O. and Yamakawa, H. (1989). Daily growth increments in the larval otolith of the Japanese eel, *Anguilla japonica*. *Japanese Journal of Ichthyology* 35(4): 440-444.

Van der Elst, R.P. 1976. Game fish of the east coast of Southern Africa. 1. The biology of *Pomatomus saltatrix* (Linnaeus), in the coastal waters of Natal. Oceanographic Research Institute. Investigational Report No. 44: 59 pp.

Van der Elst, R.P. 1990. Marine fish tagging in South Africa. In *Proceedings of an Internatinal Symposium and Education workshop on Fish-Marking Techniques, Seattle*, 1988. Parker, N. C. *et.al*. (Eds). Bethesda; American Fisheries Society Symposium 7: 854-862.

Vidalisa, K. and N. Tsimenidis 1996. Age determination and growth of picarel (*Spicara smaris*) from the Cretan continental shelf (Greece). *Fisheries Research* 28(4): 395-421.

Villanuevaa, R. and Molí.B 1997. Validation of the otolith increment deposition ratio using alizarin marks in juveniles of the sparid fishes, *Diplodus vulgaris* and *D. puntazzo*. *Fisheries Research* 30(3): 257-260.

Waldron, M.E. and M. Kerstan 2001. Age validation in horse mackerel (*Trachurus trachurus*) otoliths. *ICES Journal of Marine Science* 58(4): 806-813.

Walsh, C. T. and B. C. Pease 2002. The use of clove oil as an anaesthetic for the longfinned eel, *Anguilla reinhardtii* (Steindachner). *Aquaculture Research* 33(8): 627-635.

Williams, L.E. 2002. Queensland's fisheries resources: current condition and recent trends 1988-2000. DPI Information Ser. QI02012 Dept Primary Industries, Queensland. 180 p.

Wischniowski, S. and Bobko, S. (2000). Age and growth laboratory manual: age determination procedures for bluefish, *Pomatomus saltatrix*. Centre for Quantitive Fisheries Ecology, Old Dominion University, 19 p.

Wright, P.J., Woodroffe, D.A., Cribb, F.M. and Gordon, J.M.D. 2002. Verification of first annulus formation in the illicia and otoliths of white anglerfish, *Lophius piscatorius* using otolith microstructure. *ICES Journal of Marine Science* 59(3): 587-593.

Woody, C.A., J. Nelson and Ramstad, K. 2002. Clove oil as an anaesthetic for adult sockeye salmon: field trials. *Journal of Fish Biology* 60(2): 340-347.

Young, G.C., Wise, B.S., Ayvazian, S.G. 1999. A tagging study on tailor (*Pomatomus saltatrix*) in Western Australian waters: their movement, exploitation, growth and mortality. *Marine and Freshwater Research* 50(7): 633-642.

Xiao, Y. (2000). Use of the original von Bertalanffy growth model to describe the growth of barramundi, *Lates calcarifer* (Bloch). *Fishery Bulletin*. 98(4): 835-841.

14 APPENDIX 1. INTELLECTUAL PROPERTY

Intellectual property arising from this project is confined to the development of a draft routine ageing protocol for *P. saltatrix*. The benefit of such a document is by its wide-spread dissemination and uptake amongst agencies undertaking routine ageing of *P. saltatrix* in Australia. Although it defines the current "best practice", it is by no means a definitive document, as ageing protocols will change with new technology developments. Currently, Fisheries Agencies in Queensland and Western Australia are the main users of such a document. This protocol has been reviewed by fisheries scientists from the Department of Fisheries, Western Australia at a workshop, convened in Perth, December 2001. It has also been reviewed by staff at the Central Ageing Facility, Marine and Freshwater Resources Institute, Queenscliff, Victoria. It will also be sent to fisheries agencies in New South Wales and further discussion may take place, at their discretion.

15 APPENDIX 2. STAFF ENGAGED ON PROJECT

Project staff engaged during the life of this project include:

Name	Commitment	Organisation	Position
Dr Ian W. Brown	20	DPI	Principal Investigator
Mr Adam Butcher	100	DPI	Project Leader
Mr Mark McLennan	100	DPI	Project Technician
Dr David Mayer	5	DPI	Project Biometrician
Mr Simon Robertson	2	MAFRI	Independent otolith age analysis/review.
Ms Denise Whyte	2	DPI	Casual Technician
Dr Sandra O'Sullivan	0.5	DPI	Casual Technician