QO99011

# Integrated Fish Stock Assessment and Monitoring Program


S. Hoyle, I. Brown, C. Dichmont, M. Sellin, M. Cosgrove and M. McLennan

FISHERIES RESEARCH & DEVELOPMENT CORPORATION

QUEENSLAND GOVERNMENT

DPI QUEENSLAND DEPARTMENT OF PRIMARY INDUSTRIES

Project Report QO99011

# Integrated Fish Stock Assessment and Monitoring Program

S Hoyle, I Brown, C Dichmont, M Sellin,

M Cosgrove and M McLennan

QUEENSLAND GOVERNMENT

DPI QUEENSLAND DEPARTMENT OF PRIMARY INDUSTRIES

**Project No. 94/161**

**June 2000**

FISHERIES RESEARCH & DEVELOPMENT CORPORATION

Q099011
ISSN 0727-6281
Agdex 476/10



Southern Fisheries Centre
Department of Primary Industries
PO Box 76
Deception Bay Qld 4508

# Contents

## List of Figures

## List of Tables

# 1 NON-TECHNICAL SUMMARY

| | |
|---|---|
| 94/161 | Integrated Fish Stock Assessment and Monitoring Program |

**PRINCIPAL INVESTIGATOR:** Simon Hoyle

**ADDRESS:** Department of Primary Industries
Southern Fisheries Centre
PO Box 76, Deception Bay, Qld. 4508
Telephone 07 3817 9500 Fax 07 3817 9555
email: hoyles@dpi.qld.gov.au

## OBJECTIVES:

To develop and implement a program for monitoring and assessing the status of marine fish stocks in southern Queensland.

## NON-TECHNICAL SUMMARY:

Motivation for this project arose from the perceived needs to establish fisheries stock assessment in Queensland, to identify methods of stock assessment that were appropriate to small-scale multi-species fisheries, and to develop the techniques to be used in these assessments.

The success or otherwise of this work may be judged by (i) the utility and timeliness of the information it provides to the Queensland Fisheries Management Authority (QFMA), (ii) critical reviews of the project's outputs by the QFMA and the Queensland Commercial Fishermen's Organisation (QCFO), and (iii) by a commitment on the part of the Queensland Government to adopt the work process as a core program, with the provision of appropriate resources.

### Communication and review of results

The Stock Assessment Review Workshop (Dichmont et al. 1999) was used as the major forum for reviewing the outcomes from this Project, and of other local projects with a stock assessment focus. The Workshop included research staff from around Australia who had appropriate experience with the species under review, as well as stock assessment experts, statisticians, representatives of the QFMA, QCFO, and relevant Management Advisory Committees, and fishermen with direct involvement in the various fisheries. The workshop provided a forum for critical evaluation of the Project, and presented a number of conclusions which have already been acted upon. Through this forum, the results of the present study were communicated to industry and management.

The primary objective of this research work, the development of a long-term monitoring program for fishery stocks in southern Queensland, has now been achieved. The development

of the new Department of Primary Industries, Queensland (DPI) Monitoring Program (which covers the whole of the State) was supported by the present project work; that of a related project in north Queensland (Tropical Resource Assessment Program); and the employment of an experienced stock assessment scientist based at the Southern Fisheries Centre.

The findings were also used in the stock prioritisation process, which not only ranked the 'importance' of the stocks, but also identified methodology to determine what level of monitoring and assessment would actually be feasible.

**Approach**

The objectives of the project included developing and implementing an assessment process for key inshore finfish fisheries in southern Queensland. The five species yellowfin bream (*Acanthopagrus australis*), sand whiting (*Sillago ciliata*), golden-lined whiting (*Sillago analis*), dusky flathead (*Platycephalus fuscus*), and tailor (*Pomatomus saltatrix*) were selected as the main subjects for the study. They were seen as the most significant species in the combined commercial and recreational fishery.

In identifying appropriate methods of stock assessment, various modelling approaches were assessed, beginning with virtual population analysis (VPA) based modelling. Sampling designed to support this technique was undertaken. We investigated the structure of the fisheries, the potential for age sampling, ageing and sampling methodologies, and the biology of the species involved. Stock assessment and management are interrelated, so we considered also the implications of various ways of assessing and managing the fisheries.

**The fishery**

The estuarine and near-shore finfish fishery is a multi-species, multiple gear fishery shared between a commercial fleet landing an average annual catch of about 900 tonnes, and a large population of recreational anglers taking a somewhat larger, and growing, catch (Higgs 1999). A suite of species, including yellowfin bream, summer whiting (two species), trumpeter whiting, tailor, sea mullet and flathead, are the mainstay of this fishery. The inshore/estuarine and near-shore fishery can be divided into an ocean beach fishery and an inshore/estuarine fishery.

**Ageing**

We spent considerable time and effort developing ageing techniques for the five species.

Otoliths were found to provide a useful means of ageing yellowfin bream, sand whiting, golden-lined whiting, dusky flathead, and tailor. For production ageing, cost savings can be achieved by reading tailor, flathead, and possibly bream otoliths whole (rather than sectioned). However because of their thickness, the otoliths of both whiting species must be sectioned before reading.

Marginal increment analysis provided a basic validation of the ageing procedures used for sand whiting, dusky flathead, and tailor. Bream marginal increment analysis was equivocal, but our readings are consistent with those obtained from a tetracycline-mark validation study on bream in New South Wales.

## Catch curves and growth models

Bearing in mind these limitations for ageing, we developed catch curves and growth models. The catch curves were affected by capture method and fishing sector. There was very considerable variation in growth of individuals within species, and between local areas.

We estimated total mortality for bream, flathead, sand whiting, and tailor from catch curves. Mortality rates for bream, sand whiting, and flathead were found to vary by location, possibly as a result of differing levels of fishing pressure. Mortality rates for these species were higher in Moreton Bay than in Hervey Bay. Bream total mortality rates were moderate and suggested little cause for concern. Sand whiting mortality rates were higher, but error in ageing reduced confidence in these estimates. Flathead mortality was also moderately high, with higher rates for males than females in Moreton Bay, associated with a slower male growth rate.

Tailor mortality rates suggested cause for concern, but this conclusion is clouded by doubt about the assumptions used in estimating these rates. Data on other tailor stocks, and anecdotal evidence, suggest that samples from the recreational and commercial tailor fisheries may not represent the age and size structure of whole population. This hypothesis is currently being investigated by an FRDC-funded project motivated by the ISAMP results.

Growth curves were estimated for bream, sand whiting, dusky flathead, and tailor. All species showed a wide range of length at age. Growth rates showed significant differences between the sexes for dusky flathead and sand whiting. Dusky flathead males grew more slowly than females but asymptotic lengths were not significantly different. Sand whiting females grew slightly faster than males but with slightly smaller asymptotic length. Female tailor were slightly longer at a given age than males, which may be due to differences in either size of availability to the fishery or growth rate. As with sand whiting this difference was not large enough to affect management.

## Yield per recruit modelling and optimum size limits

Yield per recruit monitoring can be used to estimate potential long-term yield at alternative legal sizes. Increased legal sizes have many consequences. Positives may include increased yield, greater spawning biomass, and greater perceived quality of the fishing experience with larger average fish sizes. Negatives may include increased discard of undersized fish, ramifications for fishing equipment, and reduced yield in the short term until fish grow through to the new size.

The dusky flathead fishery may obtain considerably more yield in the long term from an increase in legal size. There would also be large increases in spawning biomass and the average size of flathead captured. A value of 550 mm total length is most likely to give optimal yield (in weight) with an estimated increase at equilibrium of 86 ± 37%. However, a legal length of 450 mm would increase yield by almost as much, and sooner.

Yield per recruit modelling suggested that yield (in weight) from the sand whiting fishery may increase with a greater minimum legal size. A value of 27 cm total length is suggested. This would also increase the spawning biomass and the average size of fish captured. However, there is considerable uncertainty about this estimate.

Yield per recruit modelling of yellowfin bream and tailor indicated that current minimum legal sizes for these species are not inappropriate from a yield perspective. Increasing minimum legal sizes would be likely to reduce yield (in weight) from the bream fishery, and have little effect on the yield of tailor.

### Sampling unit

All estuarine species showed significant variation between catches in size structure, implying that catch should be regarded as an important sampling unit, and that many catches should be sampled in order to represent the population's size and age. Mesh nets were more size selective than tunnel nets, requiring more catches for a consistent and statistically valid index of size or age structure.

Tailor also showed considerable size variation between schools of fish, as defined by groups of catches taken from a particular area and time. Size variation between schools implies that, to obtain age and size indices of recreational catch, sampling should target as many different schools as possible. Different schools can be targeted by sampling a number of times at intervals of several weeks, and covering as much ocean beach as possible each time.

### Tailor

No evidence was found for a reduction in the average size of tailor caught by recreational club anglers between 1973 and 1991, associated with increased fishing pressure. There was considerable variation between years. This was probably due to annual variation in tailor recruitment, which results in strong and weak age classes passing through the fishery. A very slight increase in average size may have been due to changes in the technology available to anglers, and an increased level of expertise in targeting large fish.

Tailor egg distribution was relatively even, suggesting that spawning is distributed 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. Larvae were on average distributed slightly closer to the shore than eggs. Some spawning occurred throughout the year, rising in June to reach a peak in September and declining again by November.

The size and age structure of tailor catches on ocean beaches may not be representative of the population as a whole. If this is the case, it matches the situation for tailor populations in Brazil, north Africa, Western Australia, and possibly the United States. There is some evidence of larger length offshore from New South Wales recreational catch data.

If beach-caught tailor are not representative, then our estimates of total mortality have been biased upwards, and the situation may not be as serious as it appears. However, in this case we could not estimate total mortality, with data on neither the age distribution of offshore tailor nor the proportion of fish offshore relative to the onshore stock. Obtaining these data is not possible with current technology and available funds. We therefore could not estimate total mortality, which is one of the main purposes of age-based monitoring. However, such monitoring could be used to estimate an annual recruitment index, by noting the relative proportions of tailor in each age class.

### Stock assessment and monitoring options

We reviewed data needs associated with the two main forms of population assessment model: surplus production–biomass dynamic and age structured (VPA) models.

Biomass dynamic models require an annual index of abundance, and good annual estimates of total catch over the medium to long-term. While the latter may be obtainable in commercial fisheries, it is difficult if not impossible to gather them in recreational fisheries at this time. Also, the existing CFISH system has limitations. The consequence is that biomass dynamic modelling is not a feasible option for these fisheries.

The alternative suite of age structured models also requires data on total catch, and a matrix of age structures over time. In addition to the problems described above, representative samples of overall age structure cannot be obtained in practice for either the recreational or the commercial catch.

All models need catch and effort time series. We reviewed what was available, and found severe restrictions in terms of accuracy and comprehensiveness for stock assessment purposes.

We found that it was not possible to sample, in a representative way, the size and age distribution of the total commercial catch of yellowfin bream, dusky flathead, golden-lined whiting, sand whiting, or tailor. This was because of the small scale and extremely subdivided nature of the fisheries, the variability of size composition in time and space, and our inability to sample a large proportion of the catch.

VPA-type modelling methods require representative samples from all sections of the fishery—recreational as well as commercial. They also require annual estimates of total catch. These methods are therefore not practical for the ISAMP fisheries. Thus future monitoring will rely on, a) estimates of total catch and CPUE from the commercial and/or recreational fisheries, and, b) indices of age and size structure from a subsection of the fishery (preferably recreational), to identify year class strength and changes in age or size structure.

Since the fisheries considered here have larger recreational than commercial catches, the recreational catch is particularly important. If the QFMA's recreational fishing surveys program (RFISH) can provide reliable estimates of total annual recreational catch by stock and species, biomass dynamic modelling may be used eventually to estimate stock size. This requires annual catch estimates, and estimates by location of catch instead of angler postcode. At least five years of data are required to begin modelling.

Estimates of total catch and CPUE require accurate confidence intervals if they are to be useful for stock assessment and as stock status indicators. This is particularly true if recreational catch rate and total catch are to be used as reference points for fishery management. Confidence intervals on total catch and CPUE from the RFISH program should be estimated using the bootstrap-t method, since our analyses show that these estimates are considerably more reliable than other methods.

Age and size structure indices will be obtained more reliably, with greater geographical precision and with greater statistical validity, from the recreational than the commercial fishery for all species investigated. It is not practical to obtain reliable long-term age and size-structure indices from the commercial fishery. Fishery-independent sampling would also achieve useful results but at a greater cost than recreational catch sampling.

Long-term monitoring of stocks of the species examined in this study will continue to rely (at least partially) on commercial catch and effort statistics. Our investigations have revealed inadequacies in the existing commercial logbook system which, unless remedied, will severely compromise the value of these statistics as reliable indicators of stock abundance. Some of the main areas of concern are:

- inadequate precision in the specification of 'fishing method' codes;
- lack of validation and appropriate range-checking at data entry;
- lack of follow-up to correct reporting errors such as fishing methods that are inappropriate for the reported species or location, and incorrect units of measurement, e.g. for net lengths and mesh sizes;
- inadequate or inappropriate effort statistics, particularly in fisheries such as the ocean beach haul-net fishery where searching-time is a very important component of actual fishing effort;
- lack of provision for recording species targeted in a particular fishing operation;
- lack of a time-series of wharf-price or market-value information for any of the species examined.

**Recommended monitoring**

The main existing monitoring tool is the CFISH database, which applies only to the commercial portion of the fishery. These data will be applied most usefully to monitoring catch per unit effort. CPUE estimates can be useful in some cases as indices of abundance, although not where catch is allocated to more than one species (e.g. whiting spp.), or effort cannot can be estimated accurately (e.g. tailor). Total catch estimates are also useful, though in this fishery the commercial catch is the minor part of the total catch.

The developing program to monitor the recreational fishery may also be useful for monitoring total catch and CPUE. The existing program would be more useful for stock assessment with annual surveys, appropriate confidence intervals, and more attention to where fish are caught rather than where anglers live.

Any monitoring of size and age structures should focus on clearly-defined areas of particular importance to anglers, and operate using creel surveys, preferably on-water. Particular attention should be paid to defining the objectives of any such monitoring program. With clear objectives and pilot studies, statistical power analysis can be used to allocate appropriate levels of resources.

## 2 BACKGROUND

The Queensland commercial fishing industry has a gross value of production around $270 million per year. It is responsible for employing nearly 6500 master and assistant fishers, with over 2300 commercial fishing operations licensed in the State. In addition to being a very important local and regional economic activity, commercial fishing in Queensland is a significant earner of export dollars, with some 70% of total production being exported, mainly to Taiwan, Japan and other South-East Asian countries. There is also a very significant recreational fishery with an estimated 600 000 participants State-wide. The value of this component of the industry is very difficult to estimate, but is without doubt of great significance to the State's economy and social welfare. The bulk of recreational fishing occurs in southern Queensland, and both allocation and exploitation issues are becoming increasingly critical as the region's population increases.

A significant amount of biological research has been conducted on most of the species tabulated above during the last decade or so, and much of this work has focussed on populations in southern Queensland. Kerby and Brown (1994) provide a comprehensive review of historical and current studies on estuarine target species (bream, whiting and flathead). Critical age, growth and reproductive characteristics of the prime reef fish species have been estimated, e.g. Spanish mackerel (McPherson 1981); coral trout and redthroat emperor (Brown 1994); snapper (Sumpton & Ferrell 1999); jobfish and pearl perch (Sumpton 1999). Similar information exists for school mackerel (Cameron 1998). However, for a number of other important 'bread-and-butter' species the critical population dynamics parameters are poorly estimated at best or completely unknown.

## 3 NEED

The adoption of ecologically sustainable development principles has begun to focus the attention of management agencies on very specific questions about the status of fish stocks for which they have management responsibility. Similar questions are being raised as a result of greater understanding within industry and the general community about the relationships between stock dynamics and fisheries management. This is particularly evident among the membership of the Queensland Commercial Fishermen's Organisation's various fishery-based committees, and in increasingly vocal and well-organised recreational fisheries lobby groups.

The Queensland Government's Fisheries Policy Discussion Paper (Anon. 1993b) identifies sustainable use of fish stocks as the first of a number of issues facing fisheries management in this State. It confirms the Queensland Government's endorsement of ESD principles at the Council of Australian Governments meeting (7 December 1992).

To achieve the stated policy on sustainable use, a strategy is proposed in the Discussion Paper of 'developing and implementing specific Fisheries Management Plans .... for each of the State's major fisheries'. In addressing the issue of information and research the Government proposes to 'maintain and improve fisheries data collection ....', and to '...continue its commitment to research necessary to ensure that fisheries management decisions are based on the best available information.'

Consultations between research and management agencies (particularly in the context of the Management Advisory Committees) have identified a lack of the sort of information required to develop effective management plans for Queensland's major fisheries.

The State's commercial fisheries catch and effort database does not yet span a sufficiently long time period to be of much value in assessments involving biomass dynamic modelling. Stock assessment procedures therefore need to incorporate catch-at-age and size-at-age techniques so that changes in population structure can be tracked from year to year.

A formalised monitoring program is essential if the management requirements and ESD needs of the Queensland Fisheries Management Authority, as detailed in the Queensland Government's Fisheries Policy Legislation Discussion Paper (August 1993), are to be met. Such a program would ensure that appropriate data on the State's major fish stocks are collected and subjected to continuous monitoring and periodic intensive assessment.

## 4 OBJECTIVES

To develop and implement a program for monitoring and assessing the status of fish stocks in southern Queensland.

## 5 INTRODUCTION

Indigenous communities along the coast of Queensland have been involved for centuries in small-scale fisheries for inshore species such as sea mullet. Little information exists on the magnitude or composition of catches by Aborigines in the southern part of the State. However, catches were probably small in comparison with the present-day commercial and recreational finfish landings.

The estuarine and near-shore finfish fishery is the longest-established fishery in Queensland, dating back to the mid 1800s. It is a multi-species, multiple gear fishery shared between a commercial fleet of some 300 small vessels, landing an average annual catch of about 900 tonnes, and a large population of recreational anglers taking a somewhat larger catch (Higgs 1999).

A suite of species, including yellowfin bream, summer whiting (two species), trumpeter whiting, tailor, sea mullet and flathead, is the mainstay of this fishery. These species are typically sub-tropical and generally do not extend the length of the Queensland coastline. This is evidenced by the fact that, over the period 1988 to 1994, 88% (by weight) of the State-wide commercial catch of these species was derived from latitudes south of 22° 30'S (a line between Cape Clinton and the southern tip of the Swain Reefs).

The inshore/estuarine and near-shore fishery can be divided into an ocean beach fishery and an inshore/estuarine gill and tunnel net fishery. In the commercial ocean beach fishery, mullet and tailor are taken exclusively by haul or seine net. Occasionally haul nets are used in the estuarine fishery where the structure of the shoreline permits (e.g. around the Redcliffe Peninsula), but gill (mesh) and tunnel nets are the usual methods used in the protected estuarine and inshore waters.

### 5.1 Historical features of fishery

Commercial fishing in Queensland began in the early 1800s with settlement at the Redcliffe Peninsula, and until the turn of the century was largely confined to the Bay foreshores and the Brisbane River. Whiting, bream, and flathead have been the basis of the inshore commercial fishery since the early 19th century (Kailola *et al.* 1993).

From the early 1900s there are reports of significant catches of fish; up to 900 tonnes per year (Williams 1993). However, regular catch data by species or species-group did not become available until 1945, when the Queensland Fish Board began to record landings at its regional depots along the coast.

Recreational activity has almost certainly been a feature of the exploitation of the State's inshore finfish resources, since the development of the fishing industry. Some angling clubs have records of yellowfin bream and whiting catches from Moreton Bay dating back to the early 1920s. With the growth of population centres along the eastern seaboard, particularly in the south, recreational fishing pressure has been increasing steadily. Both recreational and commercial activities have been made more efficient by the evolution and ready availability of outboard motors, light-weight trailable runabouts, off-road four-wheel-drive vehicles, and affordable electronic fish-finding and navigational instrumentation.

## 5.2 Target and bycatch species

In the commercial 'mixed' fishery (all types of fishing operation including crabbing but excluding trawling), the species targeted depend to some extent upon the type of fishing gear employed. The main non-crustacean species taken in the mixed fishery include:

- yellowfin bream (*Acanthopagrus australis*)
- sand or summer whiting (*Sillago ciliata*)
- golden-lined or summer whiting (*Sillago analis*)
- trumpeter or winter whiting (*Sillago maculata*)
- dusky flathead (*Platycephalus fuscus*)
- mullet (*Mugil cephalus, M. georgii, Myxus elongatus,* and *Liza argentea*)
- tailor (*Pomatomus saltatrix*), and
- small mackerel species (*Scomberomorus queenslandicus*, *S. munroi* and *S. semifasciatus*).

The catches of the major fish groupings taken in the estuarine fishery are given in Figure 5.1. The commercial fishery takes school mackerel (*Scomberomorus queenslandicus*) in winter with inshore set nets, grey mackerel (*S. semifasciatus*) sporadically throughout the year with set nets, and spotted mackerel (*S. munroi*) in summer (further offshore in protected coastal embayments) with ring-nets (mesh nets set in the style of purse-seines). At times when the fish are not schooled-up, bottom-set nets are also used in deeper water to catch school and particularly spotted mackerel. School and spotted mackerel are also caught in substantial numbers by recreational anglers mainly in summer months, while grey mackerel are the focus of a much smaller specialist lure/fly fishery throughout the year.

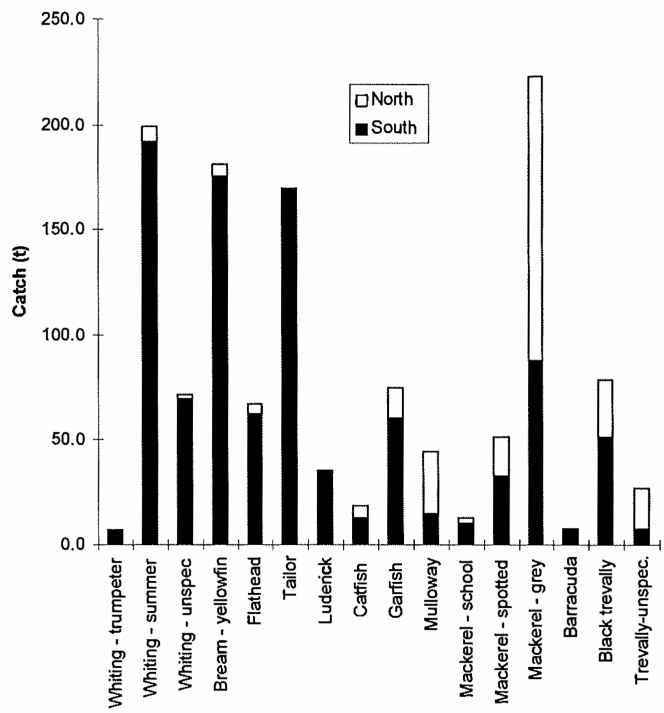



Figure 5.1 Mean annual catch (1988–1994) of the main components of the southern estuarine fishery derived from the Queensland coast north and south of Cape Clinton (22°30'S).

A number of other species, considered as by-catch because of sporadic occurrence or relatively limited quantity rather than necessarily lower economic value, are also taken. They include the luderick (*Girella tricuspidata*), garfish (*Hemiramphus, Hyporhamphus* and *Arrhamphus* spp.), striped sea pike (*Sphyraena obtusata*), black trevally (*Siganus spinus*), tarwhine (*Rhabdosargus sarba*), mulloway (*Argyrosomus hololepidotus*), catfish (*Neoarius australis*), bar-tailed flathead

(*Platycephalus endrachtensis* and *Platycephalus indicus*), fringe-eye flathead (*Cymbacephalus nematophthalmus*), and barracuda (*Agriosphyraena barracuda*). Butterfish (*Scatophagus multifasciata*), rock cods (*Epinephelus* species), tarpon (*Megalops cyprinoides*), and various sharks are also captured to a lesser extent.

The recreational estuarine fishery also targets yellowfin bream, sand, golden-lined, and trumpeter whiting, and dusky flathead. Other species caught include tailor, luderick, tarwhine, and dart (Pollock & Williams 1983).

Commercial quantities of whiting (mainly the trumpeter or winter whiting *S. maculata*) are caught as bycatch in the prawn trawl fishery in Moreton Bay and other estuarine areas. Small quantities of flathead are taken as well, but these are mostly species other than *P. fuscus* that are not generally caught in the net fishery. No appreciable by-catch of yellowfin bream is taken by the trawl fishery. There is another fishery, separately managed, which targets the prolific school whiting (*S. robusta*) offshore in depths of 25–32 m between Sandy Cape and Bribie Island. *S. robusta* does not occur in the estuaries, and is therefore not part of the estuarine/inshore fishery.

We chose to concentrate on the five species that were most significant in the commercial and recreational fisheries: yellowfin bream, sand and golden-lined whiting, dusky flathead, and tailor.

## 5.3 Fishing gear

The commercial estuarine/inshore mixed fishery catch is taken mainly by mesh and tunnel net. Significant quantities of trumpeter whiting are taken as by-catch by the Moreton Bay prawn trawl fleet. Some haul or seine netting also takes place around the foreshores of the Bay for mullet, whiting, and, with nets of smaller mesh size in seagrass areas, garfish.

Gill or mesh netting involves the deployment of a light monofilament net in an area where fish are likely to be moving and may swim into the net. Fish become caught in the meshes by protruding fin spines or gill covers, or simply by trying to force their way through the mesh. Sometimes the net is shot around a visible school of fish, and a disturbance made in the water in an attempt to frighten the fish into the net. This technique is used in the fishery for spotted mackerel, where the net is set and retrieved in the fashion of an open purse-seine.

Dusky flathead, for example, are usually captured in mesh nets by entanglement. The existence of vomerine teeth, preopercular spines, assorted head ornamentation, and a large flat head in relation to the main body trunk appears to predispose flathead to capture in nets of various mesh sizes. Flathead are consequently captured in nets of a mesh size which would usually not retain a more fusiform shaped fish with an identical girth measurement. Most flathead larger than 50 cm are captured by the entanglement of several separate meshes over each pair of preopercular spines.

Estuarine species are often specifically targeted during a net shot by inshore mesh net fishers. Fishers are able to target particular species by considering factors such as mesh selectivity, bottom substrate, state of tide, and season. Consequently, the catch on any given day by a particular fisher will tend to be dominated by one species.

Tunnel netting is a 'draining off' operation involving the use of a fixed net staked out in the intertidal zone, usually on mud-flats in front of mangrove forests or near the mouth of a river or creek. The wings of the net are fixed in such a way as to shepherd fish towards a long sock or blind tunnel submerged in a shallow gutter on the ebbing tide. As the tide falls, the wings are normally dismantled so that ultimately only the tunnel remains, at least partly submerged in sufficient depth of water to allow the catch to swim freely until they are sorted. At certain times of the year concentrations of jellyfish (blubber) can build up against the net and force it beneath the surface, and drifting filamentous algae (blanket weed) covering the mesh can reduce the net's efficiency.

Tunnel nets are not as selective as mesh nets and tend to capture a broader range of species. Though also captured occasionally in mesh nets, silver biddies (*Gerridae*), yellowtail pike (*Sphyraena obtusata*), jew or mulloway (*Argyrosomus hololepidotus*), black trevally (*Siganidae*) and pike eels (*Muraenesox cinereus*) are more commonly captured in tunnel nets with all of the previously mentioned species.

Seine or haul netting is normally conducted from the foreshore or beach, generally with the aid of a small vessel to lay the net out in an arc, surrounding an area of water suspected of containing fish. The net is then hauled in to the shore (sometimes with the aid of a vehicle equipped with a winch) where it is 'dried out' in very shallow water enabling the catch to be sorted manually.

As significant quantities of trumpeter whiting (*S. maculata*) are taken as a by-catch in the prawn trawl fishery, it is necessary, for completeness, to include otter trawls in the description of catching apparatus. Most trawl-caught trumpeter whiting are taken in the Moreton Bay area, where trawling is restricted to vessels less than 14 m towing (usually) twin trawls with a combined headrope length not exceeding 8 fathoms (14.6 m). Trawls are generally of the Sandekan or Florida Flyer design, with minimum stretched mesh of 1.5" (38 mm).

The recreational catch from the estuarine/inshore finfish fishery is taken almost exclusively by baited rod-and-line and handline (Kailola *et al.* 1993), with a maximum of 6 hooks per line. This type of gear is used from small boats, the foreshore, river mouths, and man-made structures such as rock walls, wharves, and jetties. Recreational anglers are not permitted to use nets apart from bait nets (maximum length and width 16 m and 3 m respectively) and cast nets (maximum diameter 6 m). The maximum mesh size permitted for both types of net is 28 mm to ensure that the catch comprises fish of a size suitable only as bait.

### 5.4 Spatial distribution of fishing grounds

A number of rivers and creeks provide estuarine habitat along the length of the Queensland coastline. In addition to the rivers themselves, estuarine mangrove and seagrass habitats occur in areas such as Moreton, Shoalwater, and Hervey Bays, which are protected from oceanic influence to a greater or lesser degree. These large embayments are highly productive areas, and the shelter they provide permits a variety of fishers to take advantage of this. For example, although Moreton Bay represents only 3% of the Queensland coastline, it produces 10% of the total volume of commercial seafood landings and accounts for one third of the recreational fishing effort in the state (Quinn 1992).

Moreton Bay is a large wedge-shaped body of water protected by Moreton and North Stradbroke Islands in the east. It opens to the ocean at various points in the north, centrally, and in the south, and is fed by a number of rivers. It also contains a wide variety of marine habitats. The waters vary from turbid muddy estuarine on the western side of the bay to clear near-oceanic waters in the east. Substrates vary from clean sand in the east, far north, and south to fine muds in the west. Vegetation includes large seagrass meadows in Deception Bay, near Fisherman's Island and inside the southern portion of Moreton Island; and mangrove forests in Pumicestone Passage, North Pine River System, Boondall Wetlands, and in the south between Victoria Point and the Coomera River (Quinn 1992).

Hervey Bay is a large embayment open to the north, covering an area of 3940 $km^2$. It is bounded to the east by Fraser Is., and connected via the Great Sandy Strait to a secondary estuarine system (Tin Can Bay) at the southern end of the Island. The Hervey Bay–Tin Can Bay complex comprises a variety of marine and estuarine habitats, including important areas of seagrass, mangrove, saltmarsh, and algal beds. There are also a small number of rocky and coral reefs as well as artificial reefs in the region. The foreshores of Hervey Bay are drained by numerous small tidal creeks and several rivers (Hyland 1993).

Moreton Bay and Tin Can Bay are the major commercial fishing areas for summer whiting in Queensland. The most popular angling locations for summer whiting in south-east Queensland are the surf bar spawning areas, such as those at Inskip Point, Bribie Island, Moreton Island, Jumpinpin, and Southport (Dredge 1976; Morton 1982).

In Queensland the yellowfin bream fishery extends from Bundaberg to the New South Wales border (about 28°S), with almost half the commercial catch taken from Moreton Bay (Kailola *et al.* 1993). Dusky flathead are captured from the New South Wales border north to Princess Charlotte Bay (about 13°S). The majority of the catch is taken in the Hervey Bay–Sandy Straits Region and Moreton Bay. In Queensland, tailor are found in greatest quantity in the waters south of the Breaksea Spit, at the northern tip of Fraser Island. However, they occur along all of the ocean beaches south to northern New South Wales, particularly during the spring spawning run. Throughout the year mullet of various sizes are found (and fished) in the southern estuaries. Mature roed-up adults are not restricted to the ocean beach run, but also contribute to the estuarine catch.

## 5.5 Resource allocation

Bream, whiting, flathead, and tailor are the most popular angling species in the estuaries and inshore waters of southern Queensland. Yellowfin bream is the main species taken by recreational fishers in the estuarine areas of Moreton Bay, Caloundra, Jumpinpin, and Southport (Anon. 1992). Also, these species are all very important components of the commercial fish catch. Estimates of the recreational harvest of finfish species from Queensland waters have been obtained by a recent recreational diary-based survey (Higgs 1999). These indicate that in the southern part of the State, anglers currently take an annual catch of approximately 6.6 million bream, 1.4 million flathead, 1.3 million snapper, 1.5 million tailor, 10.2 million whiting (of several species), and 0.2 million school and spotted mackerel.

Several attempts have been made in the past to estimate the size and species composition of the recreational catch. However, it was not until the recent telephone and diary-based survey

(Higgs 1999) that a properly-resourced program arrived at an indicative estimated total recreational catch by species or species-group across the whole State. Pollock (1980) conducted a series of angler interviews at Jumpinpin and Caloundra in 1979, and estimated the recreational catch of yellowfin bream in those areas to be 160 tonnes. He concluded that on a regional basis it probably exceeded the reported commercial net catch of 275 tonnes (data from Queensland Fish Board Reports, averaged over the period 1977–1980). Assuming that the typical recreationally-caught bream weighed 250 g, the catch estimates of Higgs (1999) for southern Queensland would amount to more than 1600 tonnes. The recreational catch of tailor in the southern region was also believed to be at least as large as the commercial catch (Pollock 1980), catches from Fraser Island alone in 1979 amounting to 180 tonnes. The estimates of Higgs (1999) suggest that the equivalent weight of the current annual recreational tailor catch would be around 490 tonnes. Pollock (1980) estimated that the recreational summer whiting catch was less than that of the commercial sector in southern Queensland. On the basis of Higgs' (1999) numerical estimates, the total inshore whiting catch (including trumpeter whiting and two species of summer whiting) would amount to about 500 t, assuming an average weight of 50 g. This is about twice the size of the commercial catch.

Pollock (1980) considered that during the previous decade the catch from the commercial net fishery had increased only slightly, in contrast to a much greater rise in angling activity. Small-scale recreational creel surveys in Moreton Bay in 1993 indicate that the total recreational catch of dusky flathead is at least equivalent to, and probably exceeds, the total commercial catch (Darren Cameron, unpublished data).

There is a perception among anglers that decreases in their catch rates result from commercial fishing activities. Moore (1986) found that 67% of Hervey Bay anglers believed that catch rates had declined. In 57% of these cases the decline was attributed to too many trawlers and anglers, in 20% to commercial netters, and in 19% to trawlers. Articles in recreational fishing publications in southern Queensland often attribute the perceived decline in recreational flathead catches to commercial netting activity. There are few hard data that can be used to support or refute these claims.

There is no formal mechanism, other than the general and indirect mechanism associated with fisheries Management Plans, for apportioning the available catch of inshore/estuarine fish between commercial and recreational sectors.

## 5.6 Markets and commercial value

The commercial section of the estuarine fishery supplies most of its product to the local south-east Queensland market, though some is sent to Sydney, depending on price differentials. Yellowfin bream are sold almost exclusively on domestic fresh fish markets, usually in whole chilled form (Kailola *et al.* 1993). Large bream (>25 cm) from Moreton Bay are often sent interstate and sold at the Sydney Fish Market. On the basis of an average wholesale price (to the fisher) of $3.50 per kg, the commercial bream fishery is currently worth around $0.5 million. Price is size-dependent, ranging from $3.00–3.50/kg for average sized fish to $4.50–5.00/kg for large fish (1996 prices).

Whiting are marketed locally as chilled or fresh whole fish or fillets. Summer whiting species command high prices ($6.00–6.50/kg for mediums and $7.50–8.00/kg for large fish) compared to trumpeter whiting ($2.00/kg) because of their larger size and superior flesh quality. The combined value of the summer and trumpeter whiting catch (i.e. not including trawl-caught stout whiting) is probably in excess of $1.3 million before any value-adding.

The estuarine fishery supplies local southern Queensland markets with fresh flathead throughout the year. A significant amount of dusky flathead sourced from throughout Queensland is auctioned whole, fresh iced, by Raptis and Sons at Colmslie, Brisbane. Prices obtained by fishers vary between about $2.50 and $7.50 per kg depending on demand and availability. Based on these prices and the quantity of flathead caught, the gross value of flathead to fishers (not including any value-added benefits from processing and additional employment) is estimated to be between $170 000 and $500 000.

The commercial catch of tailor and dart, principally for a relatively small fresh-chilled market, is currently valued at around $300,000. No reliable figures are available for the amenity value of the recreational tailor and dart beach angling fishery, but the associated flow-on to infrastructure industries (purchase and maintenance of beach vehicles, fishing gear, fuel etc.) would certainly be substantial.

## 5.7 Management

### 5.7.1 General management objectives

The goal of the Queensland Fisheries Management Authority is to ensure that Queensland's fisheries resources are used in accordance with the principles of ecologically sustainable development. This use must also achieve the optimum community, economic, and social benefits obtainable from the resource, and ensure fair access. This goal reflects the objectives of the *Fisheries Act 1994* (Qld).

### 5.7.2 Strategies

Queensland's fishery resources are managed largely through input controls. There is an overall State-wide ceiling on the number of licences permitted, gear restrictions, spatial restrictions, and temporal closures. There is increasing consideration of output controls for the recreational fishery, through bag limits. The spanner crab fishery has recently become Queensland's first major output-controlled (TAC) fishery, but this form of management is unlikely to flow on to other fisheries in the foreseeable future.

### 5.7.3 Regulations

The main controls applied to Queensland's commercial fishery consist of limited licence schemes, gear restrictions, area closures that may be total or gear-specific, and seasonal closures (Quinn 1992). The commercial fishing industry is closed in the sense of 'limited entry', and most of the individual fisheries (trawl, net, line, crab etc.) are subject to transferable endorsements.

Commercial net fishers are subject to gear restrictions in terms of type of net, net length, mesh size, and drop. There are also weekend closures on all rivers and creeks south of Baffle Creek, and in Moreton Bay.

Size limits apply in both commercial and recreational sectors. Minimum legal sizes of the species most frequently encountered in the inshore fishery are as follows: yellow-fin bream 23 cm, summer whiting 23 cm, tarwhine 23 cm, flathead 30 cm, luderick 23 cm, and 'lesser' mackerels 50 cm. There are no bag limits on recreational fishers at present for bream, whiting, or flathead, though they are currently being considered. Input controls on recreational fishing restrict gear to a prescribed number of fishing lines and hooks.

The fish species under consideration in this Project fall within the sphere of the Subtropical Finfish Management Advisory Committee. A discussion paper including management options for the ocean beach fishery was released by QFMA in August 1996, and the Draft Fishery Management Plan is due for release in early 2000.

Zoning has already been introduced into the ocean beach fishery, prior to finalisation of the Management Plan. This will possibly have the effect of encouraging fishers to form groups within their allocated zones, further decreasing social conflicts in the fishery. This grouping of fishers with ocean beach licences has been evident in some of the zones prior to zoning being implemented.

On Fraser Island there is also a closure to all forms of fishing during the month of September in the area between 400 m south of Indian Head and 400 m north of Waddy Point, and 400 m seaward of the shore between these two points. This closure is designed to afford some protection to large numbers of tailor that aggregate in that area to spawn each year. Only five commercial fishers are permitted to fish on the ocean beaches of Fraser Island between 1 September and 31 March.

### 5.7.4 **Performance indicators and reference points**

To date only a*d hoc* analyses of commercial catch-per-unit-effort have been used in an attempt to draw conclusions about trends in most of Queensland's fish stocks (see Williams 1997). Such analyses have been hampered by lack of resolution in the data, poorly-defined measures of fishing effort, and an inherent but completely untested assumption that catch rates provide an unbiased index of stock size.

With the development of Fisheries Management Plans, formal performance indicators and reference points are starting to be developed for the State's fin-fisheries. These will provide formal mechanisms for assessing trends in stocks, and (more importantly) specifying courses of management action if and when the reference points are reached.

## 5.8 Available fisheries statistics.

Commercial statistics relating to the estuarine and near-shore fisheries are available for most of the period from 1944 to the present, but the reliability of the figures is highly variable. During the post-war period until 1981 the Queensland Fish Board was the primary marketing agency for seafood products in this State. Records of daily landings (by species) were maintained by the Board, but no records of fishing effort were collected. Illegal marketing (outside the QFB system) is known to have occurred, but it is impossible to gauge the extent of this with any confidence. The landings figures are therefore considered to underestimate the actual landings by an unknown and probably variable factor. During the period 1944–1969 fish landings were recorded in pounds (lb) whole weight. From 1970 onward separate records were kept for whole fish (presumably gilled and gutted) and fillets. Between 1970 and 1973 all records were expressed as pounds; thereafter (from 1974 onward) they were recorded as kilograms. For the purpose of our analysis, all figures have been converted to whole weight (kg) equivalent on the basis that 1 lb = 2.2 kg, and whole (gilled and gutted) weight = 2 x fillet weight.

In 1988 the DPI introduced a fishery-wide compulsory commercial logbook program (CFISH), which required licence-holders to submit monthly catch returns detailing basic daily catch, effort and location information. Unfortunately, for a period of about seven years between the privatisation of the QFB and the establishment of CFISH, no fishery statistics were collected routinely (i.e. apart from short-term voluntary research logs) in Queensland. Subsequently, the logbook system was taken over by the new Queensland Fisheries Management Authority (QFMA) and became known as the Queensland Fisheries Information System (CFISH). The INGRES database, running under a UNIX operating system, is based on the Australian Fishing Zone Information System (AFZIS), which was developed jointly by CSIRO and AFS (now AFMA). Access to the system for researchers outside the QFMA is obtained via Telnet. Data are available as 'dumps without aggregation', or as an 'aggregated retrieval', where catches are aggregated by time, position, or boat. During the course of the ISAMP project a number of changes were made to the QFISH system, many of them at our suggestion. The main ones were the establishment of a web page to provide information for users, and the addition of the 'dumps without aggregation' option. This option enables serious users to retrieve data at the level of the individual record. The QFISH system has a second component, RFISH, which deals with recreational fishing data. Further information on this database is available on the world-wide web at http://www.squirrel.com.au/qfma/cfish/background.html.

## 5.9 Available information on age and growth.

Ageing data are required for a range of fish stock assessment methods. Assessment procedures such as cohort or virtual population analysis (VPA) require a time-series of regular catch-at-age information. Dynamic stock production models and most advanced models require some information about the growth rate of the stock being assessed, which in turn is dependent upon the availability of reliable length-at-age data. Even in the absence of adequate population or fishery models, age-composition information from periodic catch samples can be a very valuable aid to the most basic assessment procedures, such as the periodic analysis of catch-rate trends.

Within the last decade there has been an increasing acceptance by fishery management authorities of the need for ecologically sustainable management, or ESD as it is more usually known. This brings with it the need not only to ensure that provision is made for assessing the status of natural resources, but also to ensure that the data required for these assessments is gathered with appropriate regularity and in the required form. This is particularly so in Queensland, where a large number of relatively small finfish stocks are exploited over wide geographical areas by a large mobile recreational fishery, in addition to a multi-species and multi-gear commercial fishery. As a consequence, there has been little attempt prior to the initiation of this FRDC-supported project to come to grips with the question of how best to monitor and assess the status of our fish stocks, particularly in inshore waters of the southern part of the State.

Queensland's Fishery Management Advisory Committees are all focussing on the need for adequate monitoring procedures. However, Government resources limit the extent, detail, and diversity of monitoring programs. This means that, if full monitoring is to become a reality, there will have to be a significant element of cost-recovery. As a result, any long-term monitoring and assessment proposal will be very closely scrutinised with respect to its cost-effectiveness.

Most of the species selected for examination in this project have been the subject of previous research investigations. However by far the majority of these projects focussed on aspects of the biology and life history of the species, at the expense of less tractable questions relating to the dynamics of their populations. Nevertheless, some data of relevance to this study have been collected, particularly that relating to growth rates, which (except for tag-recapture or length-frequency techniques) require estimation of individual ages.

### 5.9.1 **Bream**

Growth rates of yellowfin bream have been estimated in several studies, which show some

Table 5.1 Growth parameter estimates for yellowfin bream (*A. australis*) from previous studies.

| Source | Sex | $L_\infty$ | K | $t_0$ | Method | Location |
|---|---|---|---|---|---|---|
| Munro 1944 | M+F | - | (linear) | - | Scales | Queensland |
| Dredge 1976* | M+F | -26.4 (FL) | 0.28 | -0.18 | Otoliths, l/f | Queensland |
| Henry 1983** | | 63.6 | 0.11 | -1.07 | ? | Tuggerah Lake (NSW) |
| Pollock 1992 | M+F | 29.5 | 0.51 | -0.32 | Mark-recapture | Queensland |

*estimated by fitting VBF to mean lengths-at-age for years 1–4 inclusive.
**estimated by fitting VBF to mean lengths-at-age for years 1–3 inclusive.

interesting inconsistencies (Table 5.1). The earlier studies of Munro (1944) and Dredge (1976) suggest that bream grow relatively slowly, taking four years or so to attain a length of 20 cm. In contrast, Pollock (1982b) and Henry (1983) estimated that the species grows much more quickly, reaching 20 cm FL in about 2 years.

Although these studies examined bream populations from widely separated areas, regional environmental differences cannot entirely explain the differences in growth, as the south Queensland population was examined both by Dredge (1976) and Pollock (1982) with differing results. It is probable that the differences result from the age estimation techniques used. Munro's (1944) estimates based on scale-checks and length-frequency analysis were corroborated by those of Dredge (1976) who did not, however, consider scales to be appropriate structures in this species because the outer checks were poorly defined. Dredge found a linear relationship between otolith length and fish length, which allowed length-at-age to be estimated by back-calculation from otolith growth-check radii. Dredge concluded (from marginal increment analysis on whole otoliths) that the first three of four hyaline bands were true annuli and were laid down in the winter months, but he experienced difficulties with otoliths showing more than four checks, as the fifth and subsequent bands were thickened or doubled (split) and could not be separated reliably for ocular micrometer measurement. Moreover Dredge (1976) found length-frequency analyses to be of little value in estimating bream age.

Pollock (1982), on the other hand, suggested that the checks on the scales and (whole) otoliths of yellowfin bream are not all annual in origin, and can therefore not be used with confidence for ageing this species. He therefore estimated the age and growth of bream populations in Moreton Bay from a tag-recapture study and length-frequency analysis, which yielded consistent results, but indicated a much faster rate of growth than had been assumed previously.

### 5.9.2 **Whiting**

Estimates of length-at-age for summer whiting (*Sillago ciliata*) area available from studies of populations in NSW (Cleland 1947) and southern Queensland (Dredge 1976) (Table 5.2). Neither study presented estimates of the VBG parameters, so they were estimated from the tabulated mean lengths-at-age for years 1–3. In both studies scales were used to determine age. The mean lengths-at- age (at least for years 1–3) were in close agreement, although the variability in length within age-classes reported by Dredge 1976) was quite high. Unfortunately in Cleland's study the two species of summer whiting (*S. ciliata* and *S. analis*) were not distinguished, so the accuracy of these particular data is questionable.

Dredge (1976) experienced difficulty in determining the nature and position of scale checks, and therefore used otoliths to estimate the ages of *S. ciliata* in Moreton Bay. However some difficulty was encountered in interpreting banding patterns in the whole otoliths. The author concluded that there are two distinct phases in the growth of sand whiting, and interpreted bands in fish smaller than 20 cm separately from larger individuals.

The only growth data available for the golden-lined whiting *S. analis* are from a study by Gunn (1978) of populations in the Townsville region (Table 5.3). Lengths-at-age were derived from length frequency modes, and no comparative information based on direct ageing of hard structures is available. The VBF parameter estimates in the table below, derived from fitting the model to the first four average modal lengths, only describe growth for these first four age

Table 5.2 Growth parameter estimates for sand whiting (S. *ciliata*) from previous studies.

| Source | Sex | $L_\infty$ | K | $t_0$ | Method | Location |
|---|---|---|---|---|---|---|
| Cleland 1944* | M+F | 40.9 | 0.39 | -0.27 | Scales | NSW |
| Dredge 1976 | M+F | 66.5 | 0.11 | -1.51 | Otoliths | Queensland |

* probably includes *S. analis*.

classes. Extrapolation beyond this is not reliable, which is illustrated by the discrepancy between the asymptotic length estimate (65.2 cm) and the maximum recorded length (45 cm TL) reported by McKay (1992).

Table 5.3 Growth parameter estimates for golden-lined whiting (S. *analis*) from previous studies.

| Source | Sex | $L_\infty$ | K | $t_0$ | Method | Location |
|---|---|---|---|---|---|---|
| Gunn 1978 | M+F | 65.2 | 0.11 | -0.51 | L/f analysis | Nth Queensland |

5.9.3 **Flathead**

Dredge (1976) estimated the growth of dusky flathead (*Platycephalus fuscus*) in southern Queensland estuarine waters using whole otolith interpretation and length-frequency analysis (Table 5.4). Scales were not used because of the lack of clarity of the internal structure. The mean lengths for the first four years (1+ to 4+) were estimated to be 23, 33, 44, and 52 cm TL respectively. Fitting the VBG model to these averages produces parameter estimates as shown in the table below. More recently, Cameron (pers. comm.) also investigated the growth of dusky flathead (using whole otoliths) from southern Queensland. These estimates vary somewhat from those of Dredge (1976), perhaps because of a difference in interpretation of the first annulus, which is often difficult to detect. The large asymptotic lengths are consistent with the maximum size of 130 cm reported by Roughley (1951) and Kailola *et al.* (1993), and the maximum length recorded during Cameron's work (90 cm TL).

Table 5.4 Growth parameter estimates for dusky flathead (*Platycephalus fuscus*) from previous studies.

| Source | Sex | $L_\infty$ | K | $t_0$ | Method | Location |
|---|---|---|---|---|---|---|
| Dredge 1976 | M+F | 92.4 | 0.18 | -0.54 | Otoliths | Sth Queensland |
| Cameron (unpublished) | M+F | 84.4 | 0.21 | -0.94 | Otoliths | Sth Queensland |

5.9.4 **Tailor**

Unlike the preceding species, which are more or less endemic to the eastern seaboard of Australia, the tailor (*Pomatomus saltatrix*) has a world-wide distribution. Parameters of the von Bertalanffy growth function have been estimated from tailor stocks in the Pacific Ocean (Bade 1977), Indian Ocean (van der Elst 1976, Govender 1996) and Atlantic Ocean (Krug and Haimovici 1989, Chiarella and Conover 1990, Terciero and Ross 1993, and Barger 1990) (Table 5.5).

There is considerable variation in these growth estimates, with k-values ranging from 0.096 (Barger 1990) to 0.461 (Krug and Haimovici 1989). There is also a clear inverse correlation between k and $L_\infty$. Govender (1996) suggests that this variation may be attributable to actual

Table 5.5 Growth parameter estimates for tailor (*Pomatomus saltatrix*) from previous studies.

| Source | Sex | $L_\infty$ | K | $t_0$ | Method | Analysis | Location |
|---|---|---|---|---|---|---|---|
| Bade 1977 | | 72.6 | 0.327 | -0.296 | Scales | Walford | Qld Australia |
| Bade 1977 | | 72.7 | 0.163 | -0.409 | Scales | Walford | Qld Australia |
| van der Elst 1976* | | 67 (FL) | 0.18 | -1.23 | Scales | Walford | Sth Africa |
| Krug and Haimovici 1989 | M | 58.9 (TL) | 0.461 | -0.209 | Scale back-calc. | Walford | Brazil |
| Krug and Haimovici 1989 | F | 68.0 (TL) | 0.368 | -0.321 | Scale back-calc. | Walford | Brazil |
| Krug and Haimovici 1989 | M+F | 66.2 (TL) | 0.387 | -0.321 | Scale back-calc. | Walford | Brazil |
| NOAA 1989 | | 94.6 | 0.242 | -0.128 | | | US Nth Atlantic |
| Chiarella & Conover 1990 | | 90.0 (FL) | 0.22 | -0.71 | | Non-linear | New York Bight |
| Barger 1990 | | 101.9 (FL) | 0.096 | -2.493 | | Non-linear | US Sth Atlantic |
| Barger 1990 | | 94.4 (FL) | 0.180 | -1.033 | | Non-linear | Gulf of Mexico |
| Govender 1996 | | 55.2 | 0.43 | -0.97 | Otoliths | Non-linear | Sth Africa |

* Corrected estimates provided by Govender 1996 ** in Terciero and Ross 1993

differences in growth rate in widely diverse marine environments (temperate to subtropical), with subtropical stocks (eg. Brazil, Australia, KwaZulu Natal) generally having higher k and correspondingly lower $L_\infty$ than those in temperate areas such as the North Atlantic. However the trends are not entirely consistent, and it is possible that the differences may also be due (at least in part) to differences in age-determination methods (scales, otoliths) and to differences between readers in interpreting zonation patterns. A further possible explanation is that in heavily fished populations few large old fish are available, so $L_\infty$ is underestimated.

The only available published data on tailor growth rates in Queensland are equivocal. Bade (1977) estimated two alternative sets of growth parameters for the von Bertalanffy growth curve because of uncertainty about the number of growth increments laid down on the scales each year. The strong probability that the widely disparate and uncertain growth parameter estimates from these studies is due in part to differences in age determination necessitates a study of ageing methods with respect to stocks of bream, whiting, flathead and tailor in southern Queensland waters.

Because of the general acceptance that otoliths are more likely than scales to provide accurate age estimates, we chose to concentrate on otolith reading for the various species in this study. Otolith sections are generally considered more reliable than whole otoliths, in which marginal thickening can result in loss of resolution between bands in older otoliths. However, in recommending a particular strategy for long-term monitoring of finfish stocks in southern Queensland, we wished to take account of the added cost of sectioning and mounting otoliths, as well as the relative precision and bias of the two methods.

## 5.10 Population modelling

The objective of the modelling process was to develop appropriate methods for stock assessment of the five main species (yellowfin bream, dusky flathead, and whiting, golden-lined whiting, and tailor), taking into consideration the cost of data acquisition and the precision of the results. This objective was to be reached via (i) commercial catch per effort data from the QFISH logbook system (see section on commercial fishery statistics), (ii) cohort or virtual population analysis (VPA) of stocks for which age- or size-structured data have been obtained and for which the total catch can be estimated with some degree of precision, and (iii) analysis of year-to-year changes in age- or size-structure of catches and mortality rates. Yield per recruit and surplus production models were also considered.

However, it soon became clear that some of the methods required knowledge of the annual total catch, which was not available with any degree of reliability. These methods were VPA or cohort analysis, and surplus production modelling. Recreational catches form a large component of the total catch of each of the investigated species, but it was not until the completion of the Project that some preliminary estimates of State-wide recreational catches became available. These current estimates (Higgs 1999) give catch by the residential area of the angler rather than the location of the fishery, do not separate the species for bream and whiting, and do not estimate tailor catch for New South Wales. Confidence limits on catch estimates are given based on normal assumptions, which are known to be inaccurate (see section 6.3.7 for a review of this issue and a solution). Finally, these estimates are biennial rather than annual, so are difficult to use effectively in stock assessment models.

Total catch-based methods have potential if the above obstacles can be overcome. Given additional resources and a change in methodology, catch by fishing location could be estimated, and if location and time of year information were available the total catch of bream and perhaps whiting may be determined. Recreational catch estimates from New South Wales would allow estimates of total catch for tailor. Additional funding may allow annual estimation of recreational catch. These catch estimates require accurate confidence intervals to be useful for stock assessment. We therefore addressed the problem of estimating appropriate confidence intervals on recreational catch from diary data. We compared methods for estimating confidence intervals on recreational catch from diary data, using data from the FRDC-funded project on small mackerel species, FRDC 92/144.

Biomass dynamic modelling is a method with some potential, because the required time series of catch rate is already available, and total catch is the only other variable needed. Cohort analysis also requires age samples representative of the catch, which are very expensive to obtain. Biomass dynamic models may in any case produce more accurate estimates of management parameters than age-structured approaches, even when important parameters unused by the simpler model are known (Ludwig and Walters 1985).

However, biomass dynamic models require contrast in the catch rate data to provide good estimates of parameters and hence to be useful for prediction (Hilborn 1979). There is little variation in the catch rates estimated between 1988 and 1997 for the ISAMP species. This shortcoming similarly affects cohort analysis methods. The potential of the total-catch based methods is at best a number of years from being realised, since analyses with fewer than 10 years of data are unlikely to provide useful information. At this stage only yield per recruit modelling could be applied to the ISAMP species.

Yield per recruit models are generally used to address the issue of growth overfishing, which reduces the potential return from a fishery. Yield per recruit models use estimates of growth rate, age-specific selectivity, natural mortality rate (M), and fishing mortality rate (F) to model the progress of cohorts of fish through time. To address growth overfishing, the modeller compares the potential of various management options to optimise the yield from each recruit to the fishery—hence the term 'yield per recruit'. In fisheries where F can be manipulated, they have been used to estimate the F that will give the maximum sustainable yield ($F_{MSY}$). However, given the large recreational component of our fisheries there is little potential to manipulate F. We therefore focused our attention on estimating the minimum legal size that would maximise yield from the fishery.

Estimates of a number of population parameters are required for yield per recruit modelling. These include growth rate, total mortality, natural mortality, and the uncertainty in these parameters. In order to determine appropriate spatial scales for application of conclusions, we also investigated changes through time and between areas in population age and length-structure.

Uncertainty was a major issue for the population modelling since data were sparse, age estimates contained considerable error, natural mortality was very poorly known, and there was variation between samples in age and size structure. Uncertainty in inputs must be reflected in management recommendations. We therefore attempted to incorporate as much of the uncertainty as possible in the output, by developing stochastic yield per recruit models.

# 6 METHODS

## 6.1 Commercial fishery statistics

Commercial catch and effort statistics, along with location and associated data, are collected routinely by the Queensland Fisheries Management Authority (QFMA) as part of the State-wide CFISH system, which includes Trawl and Mixed Fishery databases. Since 1988, the commercial sector has been required to provide daily fishery statistics by way of fishery-specific logbooks. The data are transferred to the CFISH Database by QFMA staff, and then become available (at various levels of detail) to authorised users. Although there are many reservations among users regarding its accuracy and applicability to stock assessment, this database represents the most extensive and longest-running source of information about changes in most of Queensland's fisheries.

In this project, daily commercial catch, effort and location information (together with other relevant details) were retrieved from the Mixed Fishery database using one of several variants of a basic SQL dump script which select records for a particular species code, geographic range and time period. The retrieved files were then downloaded to a PC and imported into a Microsoft Access™ database for subsequent processing.

### 6.1.1 Standardisation of CPUE

#### *6.1.1.1 Data extraction*

To ensure the inclusion of the most up-to-date information, individual daily catch records were retrieved from CFISH in August 1998. Data fields required for standardising CPUE were vessel sequence number, catch, operation latitude and longitude, operation date, net length, and mesh size. The 'fishing-day' was the effort unit used in this analysis, and CPUEs are therefore expressed as catch per day (kg.day$^{-1}$).

The following linear additive model (Rawlings 1988) was used to describe the relationship between the dependent variable (CPUE) to subsets of *p* independent variables (listed above):

$$Y_i = \beta_0 + \beta_1 X_{i1} + \beta_2 X_{i2} + \cdots + \beta_p X_{ip} + \varepsilon_i$$

In this model the $\beta_i$ are parameter estimates of various factors tested, and $\varepsilon_i$ is the error term.

Some data filtering was required. Records were discarded prior to running the GLM if:

- latitude was less than 18° (the record was outside the geographical range), or
- fishing method was not equal to 4 (the record does not relate to a net fishery), or
- net length information was unavailable (meaning that net type could not be deduced), or
- net length was greater than 800 m and operation location was other than Moreton Bay or Hervey Bay (see below for explanation), or
- *ln*(CPUE) was in the upper 95 percentile for the particular year (to remove outliers—often erroneous records).

In effort standardisation procedures, vessel characteristics such as length, tonnage, horsepower and crew number are used frequently as indicators of fishing power (e.g. Robins *et al.* 1998). However, the artisanal 'low technology' nature of the south Queensland net fishery, the general absence of reliable data on vessel characteristics, and the fact that the database representation of 'vessels' is of little relevance to many beach-based haul net operations, precluded the use of such factors. Instead, the supposedly unique QFMA 'vessel sequence number' was used as a category that encapsulated a range of variables which would contribute to differences in fishing power between fishing units.

#### *6.1.1.2 Categorising the data for the GLM*

Linear modelling analysis was carried out only for essentially estuarine netting operations that resulted in catches of bream, whiting and flathead (i.e. not ocean beach haul-net sets for tailor). In the CFISH logbook system there is some provision for identifying gear type, but the reliability and consistency of reporting is clearly very variable, and it is rarely possible to distinguish between even the major net types (e.g. mesh and haul) from this data field. Moreover, general-purpose nets can be used in a variety of 'modes'—e.g. as haul nets and fixed 'trap' nets—depending on prevailing conditions and target species' behaviour. We therefore had to deduce the type of net from its reported length and the operation location. Although there is certainly some error using this method, there did not appear to be a more reliable alternative. The following criteria were used to discriminate between tunnel netting and gill or general-purpose netting, on the basis that gill nets are normally less than 800 m in length, and that the longer tunnel nets are only permitted (by legislation) in Hervey Bay and Moreton Bays:

- If the net was 800 m or less in length it was assumed to be a gill or general purpose net
- If the net was more than 800 m in length, and the operation location was within the bounds of Moreton Bay or Hervey Bay, it was assumed to be a tunnel net.

As mentioned above, any record of a net longer than 800 m in areas outside the two Bays was assumed to be invalid, and had already been filtered out of the data set.

Factors tested against the *ln*(CPUE [in kg.day$^{-1}$]) were:

- year (Y) between 1988 and 1997;
- area (A): Hervey Bay, Moreton Bay, and other regions south of 24.5° latitude;
- season as a factor nested in year (Y(S));
- vessel sequence number (VSN) as a surrogate for vessel and skipper effects.

Two 'seasons' were examined for yellowfin bream: May–August and September–April. For flathead four seasons were used: December–February (summer), March–May (autumn), June–August (winter) and September–October (spring).

As the CPUE data were log-normally distributed and General Linear Models assume a normal distribution, the data were transformed by taking the natural log of CPUE. Prior to analysis the distributions of *ln*(CPUE) were tested for normality, and in most cases further filtering was required to pass normality tests. Outliers at the lower extreme of the *ln*(CPUE) distribution were not of concern, as data was aggregated by day, and no extremes in effort per record were possible. To remove the larger *ln*(CPUE) outliers, the upper 95 percentile of the data from each year was removed.

All explanatory variables were categorical, and the lack of zero catches in the data avoided problems with a straightforward log transformation. To identify which of the explanatory variables were significant, a 'forward selection' technique was used. This involved adding one variable at a time to the model until the increase in the explanatory power of the model (as determined by adjusted $r^2$) fell below 5% of that of the previous less complex model. The alternative 'backward selection' technique was not applied, because of the extremely heavy requirement for computing resources when starting with the most complex model and successively removing variables. The number of degrees of freedom (a surrogate for computer processor time) was also a practical consideration in the selection of the final model.

The first model fitted contained Year because of our interest in the trend of CPUE over time. The GLM procedure of the SAS/STAT statistical package (Ver. 6.12) was used for all analyses. This uses least squares to fit the general linear models. Adjusted $r^2$, AIC and root mean square error (RMSE) were used to monitor explanatory power. Adjusted $r^2$ is calculated using the formula:

$$Adjusted\ r^2 = 1 - \left(1 - r^2\right)\left(\frac{n-1}{n-p}\right)$$

and AIC using:

$$AIC = n \ln\left(\frac{errorSS}{n}\right) + 2(p+1)$$

where $n$ is the number of records and $p$ the degrees of freedom of the model. Finally, residual plots were checked for normality. All standardised CPUEs were compared with the unstandardised CPUEs to determine what (if any) effect the standardisation process had on our ability to interpret changes in catch rate in the three species of interest.

### 6.1.2 Catch sampling

The overall goal of this project was to 'develop and implement a program for monitoring and assessing the status of fish stocks in southern Queensland'. Catch sampling comprised one of four separate elements in this program, which required the collection of size structured catch data and biological material from which age-structured catch data could be derived.

The intention was that the monitoring and assessment program would be based on age-structured catch data. However age-structured modelling is not always the best way to monitor populations. In subtropical fisheries ageing can be difficult, since fish are able to feed and/or reproduce all year round and there may not be the same annual cycle of growth checks on otoliths as in the temperate waters where ageing was developed. In addition, small-scale multiple boat multi-species fisheries may not allow representative catch sampling at reasonable cost, and VPA-type modelling may therefore not be appropriate. The catch sampling therefore needed to answer these questions as well as provide inputs for models.

Stock assessment requires specific goals, since the methods of data collection depend on the modelling methods to be used. An initial goal was to develop VPA-type methods, and sampling was targeted in this direction. However, the project also needed to determine whether VPA modelling was possible, and if not, what other stock assessment methods might be more appropriate. Appropriate modelling methods depend on the management methods and nature of the fishery, the sources and amount of variability in the data, the biology and population structure of the organism, and the resources available. There were therefore a number of stages to go through before appropriate stock assessment methods could be identified.

The first aim of the sampling program was to determine a cost-effective method of obtaining age and size samples from the commercial and/or recreational fisheries for the five main species (yellowfin bream, golden-lined whiting, sand whiting, dusky flathead, and tailor). We did not have the resources to obtain representative samples from both the commercial and recreational sector, so we concentrated on the commercial fisheries for all species except tailor. When the opportunity arose we obtained samples of the other species from recreational fishers.

A second aim was to identify appropriate areas to consider as units for stock assessment purposes. Considerations here were migration between areas, the spatial precision of available catch data, and variation between areas in fishing pressure. Variation between areas in size and age structure, and also growth rate, provided information for defining such areas.

A third aim was to characterise the variability in the size and age structure data. The sources of this variability, along with the analysis methods and the precision required in the results, determine the sampling effort and methods. Variability in size and age structure can occur between locations, years, months, fishing methods, fishers, and individual catches. The sources of variability can also be different for each of the five main species.

For example, if there is little variation in average length between catches, a few catches will characterise the length distribution of the overall catch. If there is significant variation, however, many catches are required. Similarly, significant variation in length between years may indicate that strong year classes are moving through the fishery. Strong year classes imply that sampling during a number of years is required to develop a catch curve. Variation may also stem from localised overfishing, fishers targeting different areas due to prevailing weather conditions, or the changing demands of the market. The small size of the fisheries, and the relatively low number of catches that we could sample with the available resources, limited our ability to accurately characterise the sources of variation.

A fourth aim was to obtain monthly samples of all species for marginal increment analysis, to validate the annual nature of rings for ageing. Age sampling relies on growth rings being laid down annually, and ageing validation provides a foundation for this assumption.

A fifth aim was to obtain fishery independent samples of fish smaller than the minimum legal size, which were not available from the fishery. These fish were required for ageing in order to develop growth curves, which were not reliably available for most of the species examined.

#### *6.1.2.1 Commercial fishery*

Length and otolith samples from the commercial fishery were obtained from commercial processors. Point of capture sampling by project staff was not practical because of the diversity of landing sites, the diversity of species in each small catch, and the large number of individual catches taken. Length measurement by fishers themselves was also impractical due to concerns about data quality and reluctance by fishers to participate.

All major processors in Brisbane and surrounding areas were contacted and arrangements made to collect samples of bream, whiting, flathead, and tailor. Owing to a general change in marketing strategy for reef fish from fillets to whole chilled and in some cases live (e.g. coral trout), it became impossible to collect sufficient numbers of reef fish frames.

During the fishing season processors were contacted weekly, or more frequently if necessary, to obtain available frames. Where frames could not be obtained fish were measured at the processors' premises.

For each species the goal of sampling was to obtain at least 20 catches from each area of interest each year. A catch was defined as all the fish obtained from a single fisherman on one day. From each catch a sample of approximately 30 fish per species was taken at random. Each fish was measured (fork length for bream, whiting spp. and tailor; total length for dusky flathead) to the nearest 1 mm. Where frames were available, sex was recorded if the gonad could be identified as ovary or testis. Both of the sagittal otoliths were removed, cleaned, dried, and stored in plastic containers.

#### 6.1.2.2 *Recreational fishery*

The recreational fishery for tailor was specifically targeted, since it comprised the majority of the fishery, and the commercial fishery was small and unlikely to provide sufficient representative samples.

Each year during the tailor season between August and October fish were sampled from the catches of anglers on Fraser Island. During 1995 two field trips were undertaken, while in 1996 and 1997 this number was increased to four and seven respectively.

During each field trip a catch was defined as all the fish caught in a particular location during a morning or evening. We approached anglers as they were cleaning their catches on the beach, and asked them to donate the frames. Sex was recorded for all fish where the gonad had not been removed and was identifiable as an ovary or testis. Where anglers had a preference for removing either ovary or testis (for human consumption), sex was not recorded for any tailor obtained from that angler's catch. Fish were measured to the nearest 1 mm. Both of the sagittal otoliths were cleaned, dried, and stored in plastic containers.

#### 6.1.2.3 *Fishery-independent sampling*

Fish were obtained in two different ways. First, we used fish collected by other projects based at the Southern Fisheries Centre. These fish came from research projects operating in the Maroochy River estuary and in Moreton Bay. Species collected were bream, whiting (*S. analis* and *S. ciliata*), and flathead, both from the Maroochy River and Moreton Bay. Maroochy River fish were collected using mesh nets and beam trawls, while Moreton Bay fish were collected largely using mesh nets with some fence netting and beam trawling.

Second, juvenile tailor were collected as part of the present project. They were caught from a 4 m boat using hook and line at Jumpinpin, an area of tidal channels near a surf bar at the southern end of Moreton Bay.

## 6.2 Ageing

### 6.2.1 Fish and otolith collection

Catches of yellowfin bream, dusky flathead, sand whiting, golden-lined whiting, and tailor were sampled in south-east Queensland during 1996. Fish frames were collected from seafood processors, fish markets, as well as directly from commercial and recreational fishers. The samples were blast-frozen and stored at -24°C until processed. The sample number, catch date, catch location, fisher, fork length and sex were recorded for each fish.

### 6.2.2 Otolith preparation

After removal from the fish or frame, the sagittal otolith pairs were rinsed clean, dried and then stored dry in labelled airtight plastic vials. Both otoliths from each sample were weighed to the nearest milligram using a Sartorius® 1700 balance. As a result of the ageing experiment (described below), it was decided that 'production' ageing would involve the use of whole otoliths in the case of bream, flathead and tailor, and sectioned otoliths in the case of sand whiting and gold-lined whiting.

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. Each otolith was embedded in a polyester resin block using latex moulds fabricated at SFC. A Buehler Isomet® low speed saw fitted with a diamond wafering blade was used to cut transverse sections through the core of the otolith. Sections ranging in thickness from about 200 to 450 µm were compared initially to determine the optimum thickness with regard to ease of handling and readability. We found that sections of about 300 µm were generally appropriate.

Immediately after cutting, each section was examined under a stereomicroscope. If it was of unsatisfactory quality, cutting was repeated until the best possible section was obtained. After rinsing and drying (to remove cutting fluid and particulate matter) the section was mounted on a labelled glass slide under a coverslip, using polyester resin as the mounting medium.

### 6.2.3 Otolith reading

For whole readings both the left and the right otolith were immersed in vegetable oil in a black container. The concave sides of the otoliths were examined under a Wild® stereomicroscope at 10x magnification and a fibre optic light source, using reflected light.

The slide was then placed on a droplet of water on a black background, and examined with incident illumination from a fibre optic light source under a Wild® stereomicroscope at 40x magnification.

The terminology for otolith readings followed that of Wilson *et al.* (1987). There were two experienced readers selected for this experiment. Each reader examined the whole and sectioned otoliths independently on two separate occasions without referring to any other data, such as month of collection or length of fish. An age and a readability index 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. interpretable, but not confident
3. multiple interpretations possible
4. readable, but not totally confident
5. readable, totally confident.

### 6.2.4 Ageing experiment

An experiment was carried out to determine the most appropriate age-determination method for each of the five species (*Acanthopagrus australis* (yellowfin bream), *Sillago analis* (golden-lined whiting), *S. ciliata* (sand whiting), *Platycephalus fuscus* (dusky flathead) and *Pomatomus saltatrix* (tailor)). Two hundred otolith pairs from each species were selected randomly. Whole and sectioned otoliths were read twice each by two readers, using protocols described in Sections 6.2.2. and 6.2.3.

At each reading a readability index (RI) was recorded. The objective of the experiment was to quantify the degree of concordance within and between readers in their assessment of the relative readability of whole vs. sectioned otoliths, and between their estimates of age using the two preparation methods. Clearly greater confidence would be placed in the age estimates of one or other of the methods if the readers' results were in close agreement (both in terms of precision and bias) than if there were a high degree of within and/or between-reader error or relative bias.

This is an important factor in a long-term ageing program, as it will help determine which method is most appropriate, taking into account likely differences in processing costs as well as the precision and accuracy of the particular method. It may also indicate which species' otoliths require more time (e.g. multiple readings) to achieve a particular level of precision, and which require more intensive training of novice readers.

### 6.2.5 Validation

Although not a primary objective of this project, age validation was of considerable importance (Beamish and McFarlane 1983). We addressed that issue using marginal increment analysis.

The number of translucent zones on each otolith was recorded by each reader separately, and ages were assigned based on these counts. An arbitrary birth date was designated as coinciding with the midpoint of the main spawning period, based on trends shown by gonadal and oocyte development. Otoliths were examined for marginal increment measurement under the same conditions as for age estimation (see 6.2.3). The marginal increment (the distance between the outer edge of the outermost translucent zone and the otolith margin) was measured on one of the otoliths of each fish and expressed as either

a) a proportion of the distance between the focus and the outer edge of the translucent zone when only one translucent zone was present, or

b) as a proportion of the distance between the outer edges of the two outermost translucent zones when two or more translucent zones were present.

Measurements were made with the aid of a computer-based pattern recognition system (OPRS™), by capturing an image of the otolith at an appropriate magnification and then carrying out a series of manual cursor-movement measurements along a previously-defined axis. Within species, measurements were always made along the same axis. The measurement data were then recorded directly on computer file using an appropriate formatting template.

### 6.2.6 Statistical procedures

Opinions differ as to the best methods for estimating reader error (precision) and bias. It is generally accepted that a CV variant such as Beamish and Fournier's (1981) Index of Average Percentage Error (IAPE) or Chang's (1982) index of precision (D) is preferable to the (simpler) % agreement as a measure of precision. This is to overcome the problem of interpretational inconsistency between species with different longevity (i.e. different numbers of age-classes). Hoenig *et al.* (1995), while admitting the influence of sample age-composition on the interpretation of percentage agreement [Per cent agreement (PA) = $(n_{agree}/n) \times 100$], nonetheless believe that initial examination of this statistic (eg. between readers or between ageing methods) is intuitively valid and important for decision-making.

In our ageing comparisons we used several indices of precision, including percent agreement, IAPE and Chang's D. 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 $m \times m$ contingency table that classifies a sample (e.g. of ages) into two categories (e.g. 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 (i.e. the distribution is asymmetrical), and small if the differences are random (symmetrical distribution) (Hoenig *et al.* 1995).

General linear models were used to determine factors associated with changes in marginal increment sizes. Models were fitted using PROC GLM in SAS (SAS Institute 1996), using type-3 sums of squares to allow for lack of replication across all groups. Factors investigated were sex, number of translucent zones, location of capture, year of capture, and month of capture. Forward stepwise regression was used to determine significant factors. Significant effects were examined further via their least-squares means, and comparisons between least-squares means were carried out using Tukey's adjustment for multiple comparisons.

Mean marginal increments were plotted to ascertain if they follow a consistent annual trend and thus permit the translucent zones to be considered annuli. Dusky flathead otoliths were plotted separately for 1–4 and ≥5 translucent zones.

## 6.3 Estimation of population parameters (modelling)

### 6.3.1 Growth parameters

In order to avoid biases due to size selectivity in the catch, commercially and recreationally caught fish from age classes that were not fully recruited were omitted from the data used to fit the growth curve. Catch curves were used to determine the age of full recruitment. Fish caught in fishery independent sampling were used to estimate size at age for age classes not fully recruited.

Von Bertalanffy growth curves were fitted to the individual lengths of males and females at all estimated ages at capture by optimising a least-squares model implemented in Microsoft Excel 97 using Solver. The von Bertalanffy equation is

$$L_i = L_\infty[1-\exp(-k(t_i - t_0))] + \varepsilon_i,$$

where $L_i$ and $t_i$ are the length and age of the ith fish in the population, and $\varepsilon_i$ is a random error term. To allow for variation in the number of times fish were aged, the fitting routine was adjusted to give each individual fish equal weight in the model. This was achieved by dividing the squared error for each reading by the total number of readings for the otolith. Data were checked for homogeneity of variance and randomness of residuals using PCYield (Punt 1992).

Growth curves derived for males and females were compared using likelihood ratio tests (Kimura 1980). Where differences were not significant, data were pooled. Fish of unknown sex that were below the size at which sex can be generally determined were included for both sexes when estimating the final growth curve. However, they were not included when comparing male and female growth rates. Data were also pooled for bream, where sex changes occur with growth, and sexes were not compared.

Where appropriate similar comparisons were made between growth curves from different regions. In these comparisons care was taken to compare only datasets with similar selectivity. Where size selectivity differs between data sets, growth curves may differ even if the underlying growth rate is the same.

Estimates of parameter variance were obtained using a non-parametric bootstrap routine, PCYield, or a weighted non-linear regression in SAS (PROC NLIN, SAS Institute 1996). The non-parametric bootstrap routine differed from the Solver routine described above in randomly choosing a single ageing estimate for each fish. It is described in more detail in the yield per recruit methods section.

### 6.3.2 Total mortality

Total mortality for each region was estimated using catch curves, using data from all years combined. All valid age estimates for each fish were included in the catch curve, weighted so that each fish made the same contribution to the result. The natural logarithm of the frequency at age was taken, and the slope of the age log-frequency curve was used as the total mortality rate.

Total mortality was also estimated for bream, flathead, and tailor within the stochastic yield per recruit model. We did not carry out this procedure for whiting species because of the poor quality of the ageing data. This procedure used effectively the same procedure as a catch curve but incorporated sampling variation and ageing error into the estimate. For bream and flathead we estimated catch curves only for Moreton Bay using this method, while for tailor the data were pooled for all tailor captured in Queensland.

### 6.3.3 Natural mortality

Natural mortality was estimated using Pauly's (1980) method for estimating mortality from growth rate and mean water temperature. Estimates were made using the stochastic yield per recruit model, which calculated an estimate for each bootstrapped estimate of growth rate. Thus results are given with mean and standard deviation. However, this error does not include the much greater model-based error in Pauly's method itself.

### 6.3.4 Population length and age structure

#### *6.3.4.1 Estuarine species*

Data from catch sampling were pooled and general linear models were used to determine which parameters contributed to variation of length in the catch. Year and fishing method were examined, along with the nested variable catch.

#### *6.3.4.2 Tailor*

- *Length distribution of commercial catch*

The observed length distribution in our samples from the commercial catch was corrected for month and latitude of capture, based on logbook commercial catch in each month and area. This was only possible for 1997 since in 1995 and 1996 mostly recreational catches were obtained.

- *Length distribution of recreational catch*

The length distribution of recreational catch was not corrected for latitude or season since neither total recreational catch nor its proportional breakdown by either of these strata was known. Data used came from sampling trips to Fraser Island between 1995 and 1997.

- *Length and age structure with depth and distance from the coast*

Data for this analysis were provided by Dr A. Steffe (NSW Fisheries Research Institute) from two sources: (i) roving surveys of early morning shore-based recreational catch and effort in coastal areas from Coffs Harbour to Tweed Heads between March 1994 and February 1995 (Steffe 1996); and (ii) surveys of trailer-boat-based anglers at boat ramps between spring 1993 and winter 1995.

For the shore-based data, we investigated variation in length between quarters (3 month periods) and fishing platforms (rock headland/platform, ocean beach, and breakwall). Fishing site was also included in the analysis, nested within platform. Data were analysed using general linear modelling with a type 3 sums of squares in SAS (SAS Institute 1996).

A similar analysis was carried out on the boat-based data. A general linear model was used to compare lengths between quarters and sites.

Finally, average tailor length was compared between boat-based and shore-based anglers.

- *Length variation between catches*

Tailor lengths were compared between catches using a general linear model. Data were derived from two sources: a) recreational catches on Fraser Island sampled during August and October of 1995, and b) commercial catch data. For the recreational data, a 'catch' was defined as all samples taken from a particular fishing platform during a morning or an evening.

Fork length of fish taken in the recreational fishery was modelled as a function of date, location, and their interaction term, and catch nested within the interaction term. This compared catch composition between combinations of date and location, and between the morning and afternoon of the same date in the same place.

- *Change through time – average length from recreational catch records*

Data on the lengths of fish in club catches were provided by Mr A. Thwaites (QFMA). These data were recorded as part of club competitions, and include codes for the club, location, date, number of tailor in the catch, and weight of the tailor.

We calculated the average weight of each catch by dividing total weight by number of fish. Sample size was 582, between 1973 and 1991. We used the general linear modelling procedure (PROC GLM) in SAS to determine significant factors contributing to variation in average tailor weight and to observe trends in tailor weight through time, corrected for other factors, with type 3 sums of squares to compensate for non-orthogonal data.

Anecdotal evidence was also sought to provide alternative explanations for trends in length through time.

- *Trends in recreational fishing effort – Department of Environment Fraser Island access data*

No data are collected on recreational tailor fishing effort. In order to estimate very approximate trends in recreational tailor fishing effort, we examined records of visits to Fraser Island during the tailor season. Details of the permits issued to all visitors to Fraser Island were provided by the Department of the Environment (now the Environmental Protection Agency). Fraser Island is one of the major sites for recreational ocean beach fishing for tailor. Permits have been issued since about 1984 but details are only available since 1991.

Tailor fishers no longer comprise the majority of visitors to Fraser Island, because of the growth in eco-tourism to the island. The main tailor season extends from July to October, and the major holiday season is during December and January. The 'off-season' occupies February to June and November. We chose to use the number of passengers in vehicles as the best available index. We assumed that the difference in passenger numbers between the off season and the tailor season was, to some extent, correlated with recreational fishing effort directed towards tailor.

### 6.3.5 Age length keys

Age length keys are used to determine the distribution of ages within a particular length class. They portray age at length, in contrast to growth curves, which portray length at age. The distribution of age at length varies between years as cohorts of varying strength pass through the fishery.

Age-length keys were constructed for each year and location for which sufficient data were available. Where necessary, separate age-length keys were estimated for males and females.

All age estimates for each fish were included in the age length key, in order to allow for ageing error. Although some fish were aged more often than others, this was allowed for by weighting individual age estimates accordingly. Distribution of age at length is expressed in percentages.

Where appropriate age length keys were pooled across locations and sexes in order to increase sample sizes. We compared age length keys using $\chi^2$ contingency table analyses of length at age expressed in individual equivalents.

### 6.3.6 Yield per recruit

We developed separate yield per recruit models for all five ISAMP species. Deterministic yield per recruit modelling was applied initially. For those species for which it was considered appropriate a stochastic yield per recruit model was also developed.

Yield per Recruit (YPR) models are popular because they only require estimates of growth parameters, natural mortality rates and age specific selectivity to predict the yield per recruit and spawner biomass per recruit at different levels of fishing mortality (Butterworth 1989). They have been used widely in small-scale, multi-sector reef fisheries where data are relatively scarce (see for example Mason and Manooch 1985; Hughes 1986 and Bannerot et al. 1987) and where more detailed forms of stock assessment (e.g Virtual Population Analysis) are not considered to be cost effective. However, despite their simplicity and wide spread use YPR methods still have a number of restrictive assumptions including constant recruitment and equilibrium conditions, and there is often considerable uncertainty about the precision of parameters used in the analyses. Where such parameter uncertainty exists, model outputs that fail to recognise it may lead to faulty decisions. It is important that managers are aware of all possible outcomes from decisions so they can manage risk (Francis and Shotton 1997).

There have been numerous approaches to incorporating parameter uncertainty into per recruit models. Early attempts used combinations of parameter values to obtain 'best case', 'worst case' and 'most likely' assessments of fishery status. Later, Monte-Carlo based methods were used to investigate the effect of parameter uncertainty on Beverton and Holt's three-parameter relative yield equation (Restrepo and Fox 1988).

Model error (Francis & Shotton 1997) can sometimes have a significant effect on yield per recruit management recommendations. In general, the simpler the population model used, the more overconfident will the results be with respect to harvesting policy (Kokko et al. 1997). Parma and Deriso (1990) found that YPR estimates were sensitive to phenotypic variability in growth and that standard YPR analyses may result in biased estimates of mean spawning biomass per recruit and over-estimation of optimal fishing levels. However, Goodyear (1996) incorporated variation in size and age in a YPR model of the red grouper (*Epinephelus morio*) fishery and found that including variable growth in yield calculations did not alter the optimum minimum size limit. As well as variability in growth there may be uncertainty in the age estimates used to derive growth parameters. This uncertainty is even more pronounced for tropical and sub-tropical species, which also tend to exhibit greater variation in their pattern of growth. Coggins and Quinn (in press) noted that bias and imprecision due to ageing error had dramatic effects on estimates of sustained yield from a population of Gulkana River arctic grayling (*Thymallus articus*) in a catch at age model.

Here we present yield per recruit models that not only incorporate uncertainty in growth and natural mortality, but also incorporate uncertainties in other parameter estimates, such as age structure and length-weight relationship. This model incorporates the more important sources of parameter estimation error, and so produces results with appropriate confidence intervals.

Stochastic models were developed for flathead, tailor, and bream. The models were iterative, and each iteration was intended to represent a possible current state of the fishery. Running a model a number of times built up a picture of the range of possible states.

#### *6.3.6.1 Model structure*

The yield-per-recruit model is an equilibrium simulation that assumes a constant fishing mortality harvest policy, and stable recruitment, natural mortality, and growth rates through time.

An Excel workbook was developed to model an age-structured population, and evaluate the effects of parameter uncertainty and sampling processes.

The formulae for catch at age and abundance at age are as follows:

$$N_{a+1} = N_a e^{-Z_a} \qquad (1)$$

$$N_{A+} = N_{(A+)-1} e^{-Z_{(A+)-1}} + N_{A+} e^{-Z_{A+}} \qquad (2)$$

$$C_a = \mu_a N_a \qquad (3)$$

$$\mu_a = \frac{F_a}{Z_a}\left(1 - e^{-Z_a}\right) \qquad (4)$$

$$Z_a = F_a + M \quad (5)$$

$$F_a = s_a f \quad (6)$$

$$w_a = \alpha \cdot l_a^{\beta} \quad (7)$$

$$Y_a = w_a \cdot C_a \quad (8)$$

where $N_a$ is the equilibrium abundance of age a fish, $Z_a$ is the instantaneous mortality rate, $A+$ is an aggregate plus age group, $C_a$ is the equilibrium catch, $\mu_a$ is the equilibrium exploitation rate, $M$ is the instantaneous natural mortality rate, $F_a$ is the fishing mortality rate, $w_a$ is weight, $\alpha$ and $\beta$ are parameters of the length-weight relationship, $Y_a$ is yield, $s_a$ is the gear selectivity coefficient, and f is the full recruitment fishing mortality. The variability in the model's parameters represented the range of probable parameter values. These parameters were estimated directly from the data, as was the observation error.

#### *6.3.6.2 Ageing error*

Ageing of fish from otolith readings is often subjective and otoliths are frequently ascribed different ages on separate readings. It is possible to take the approach that only otoliths given the same age on all readings are included in an analysis. However, this not only omits potentially useful data, it can bias sampling by under-representing age classes for which otolith interpretation is difficult. It also implies that those otoliths remaining in the analysis have been aged correctly, although some may have been ascribed the same age by chance, despite reader error. We therefore chose to retain information about uncertainty in interpretation of age.

Each otolith was read once or twice by each of two readers, who on each occasion estimated the age of the otolith and its readability, on a scale from 1 (least readable) to 5 (most readable). The second reading of each otolith was carried out no earlier than four weeks after the first, and on both occasions the otoliths were in random sequence with only the sample number available to the reader. Ageing error was simulated at each iteration by randomly selecting one of the age estimates (and associated readability estimate) for each fish.

#### *6.3.6.3 Mean length at age*

Growth rate in the yield per recruit models was estimated using a method similar to that described in the growth rate methods section. An age was randomly selected for each fish from those allocated during the ageing process. All the fishery-caught fish that came from size-selected age classes (estimated previously using catch curves) were segregated, leaving fishery-independent and fully-recruited fishery-caught fish. A bootstrap sample was then taken, stratified by age.

A von Bertalanffy growth curve was fitted to the bootstrapped length at age data using least squares optimisation via Microsoft Excel's Solver add-in.

#### *6.3.6.4 Selectivity*

The selectivity of the modelled fisheries is controlled by minimum legal size. In the model, the proportion of fish larger than the modelled legal size in each age-class was estimated at each iteration from the mean length at age from the growth curve, and the standard deviation of mean length at age. For age classes where sample sizes were too small for accurate estimates of standard deviation, the average of the standard deviations of the younger age classes was assigned.

#### *6.3.6.5 Length weight relationship*

The length-weight relationship was calculated by regressing the natural log of weight against the natural log of length of a sample of weighed and measured fish, giving the parameters a and b where weight = a.Length$^b$. Sampling error in these parameters was simulated by selecting values of a and b from normal distributions with variances as estimated by the regression.

#### 6.3.6.6 *Natural mortality*

Natural mortality was defined by two methods. The first of these was Pauly's (1980) method, which estimates natural mortality from a combination of the population's growth parameters and mean ambient water temperature according to the formula $M = e^{-0.0066 - 0.28\ln(L\inf) + 0.65\ln(K) + 0.46\ln(T)}$, where T is the average water temperature. Second, a subjective 'prior' distribution was chosen, based on educated guesses about the true value. This method is commonly applied in stock assessment modelling to represent uncertainty (e.g. Restrepo *et al.* 1992, Poole *et al.* 1999).

In the deterministic yield per recruit model for whiting, Pauly's method gave a natural mortality estimate higher than our estimates of total mortality. An alternative value of natural mortality was therefore estimated using Hoenig's (1983) method. This is based on the age of the oldest fish caught. Since the oldest sand whiting caught was aged at 10 and 12 years, the average age of 11 was used. The same natural mortality rate was applied to both the Moreton Bay and Maroochy river models.

#### 6.3.6.7 *Fishing mortality*

The model estimated the current F for each iteration by fitting expected age frequency to that observed in the catch. The optimisation routine selected the value of F that minimised the following function: (observed age minus expected age)$^2$ / expected age. This gave Z, and since M had already been calculated, F = Z – M.

Uncertainty in the age frequency was estimated by using a two-stage bootstrap, to account for the variability of the age structure between and within catches. The models bootstrap a) catches and b) fish within catches. This bootstrap was separate from the one applied to the estimation of growth rate, which bootstrapped with age stratification to allow for variation in length at age. The two-stage type of bootstrap has previously been applied to a yield model by Pelletier and Gros (1991), who recommend that such bootstraps mimic the complexity of the original sampling design.

Total mortality was estimated by fitting the model to the observed age structure.

In the flathead model several additional changes were made. Growth rate differed substantially between males and females, so these two sections of the population were modelled separately. In addition, there was an indication of higher mortality among males than among females. We assumed that this was due to the selectivity declining with size and slower-growing males remaining in the high-mortality section of the population for longer. Current fishing mortality and the parameters of a selectivity curve were estimated from the data during each run of the program by fitting the model to observed catch age for each sex.

The flathead selectivity curve was represented by the minimum value at each age of two functions of the mean length at age. The first function, which represented the effect of legal size, was the cumulative normal distribution with a mean of the legal size and standard deviation of 2 cm. The second function was a curve that declined slowly with increasing length.

#### 6.3.6.8 *Optimising minimum legal size*

After estimating population parameters and hence a 'possible current state' of the fishery, we used Solver to estimate the minimum legal size that would maximise the yield per recruit from the fishery. All other parameters were held at the estimated current state. The array of minimum legal sizes estimated by the model were assumed to represent the distribution of uncertainty about the optimal minimum legal size.

### 6.3.7 Bootstrapping confidence intervals on recreational diary data

Data on recreational catch rates and total catch are being collected by the Queensland Fisheries Management Authority's RFISH program. This program uses angler diaries to estimate catch rates, and multiplies up by the number of individuals in the stratum to obtain total catch. As is explained below, normalised confidence intervals from such data can be very inaccurate. Such data are likely to be used in stock assessment for many of Queensland's fish stocks, since they provide a statewide picture of total catch by species or species group, and because the draft management plans prescribe changes in total recreational catch as potential trigger points for management action. Accurate estimates of uncertainty in the catch estimates are therefore essential. Furthermore, given changes in RFISH methodology to give annual data by region, total recreational catch estimates could in future be used in population models that require total catch, such as biomass dynamic models. In this case accurate confidence intervals will be required.

The following study develops appropriate methodology for estimating accurate confidence intervals from diary-based data. The data come from a diary-based study of recreational mackerel catches in Queensland.

Bootstrap methods are used increasingly in natural resource modelling applications. They are a fairly recently developed group of techniques (Efron 1979) that are still evolving. The basis of bootstrapping is the idea that the data represent the best available image of the population from which they were sampled. The data are therefore used to 'reconstruct' the population distribution. Bootstrap techniques are seen as having two main advantages over more traditional methods: a) they are more robust, in that they cope better with data that do not conform to standard Normal distribution assumptions, and b) they are often simpler to implement, replacing complex derivations with computer power.

Some doubt exists about the performance of bootstrapping in many situations. Manly (1997) states it can be risky to use bootstrapping since it does not always work as expected, and advises that its use should be simulated in each situation. This is particularly true when sample sizes are small. Like the traditional approach, the bootstrap's implementation depends on how the data were generated, but unlike the traditional approach, the appropriate implementation is not well known for many situations (Shao and Tu 1995). This is the motivation for our study.

We used simulation to examine the accuracy of six different methods for calculating bootstrap confidence intervals on estimates of recreational catch obtained from telephone and diary surveys. In the appendix we provide methodology and the SAS code for others to use in simulation of bootstrap methods with similar datasets.

We examined confidence intervals on two parameters: the mean catch per boat per quarter (catch rate) and the total catch per quarter of all boats. Although our analyses originate from recreational fisheries data, the conclusions are generally applicable to similarly distributed data from other sources.

Estimates of catch rate and total catch are required for managing both freshwater and marine fisheries, in both recreational and commercial sectors. Total catch estimates are used in stock assessment models, such as virtual population analysis and biomass dynamic models (Hilborn and Walters 1992). They are also useful for addressing allocation issues between sectors of a fishery, for example between commercial and recreational fishers eg. (Clarke and Buxton 1989, Changeux and Zylberblat 1993). Catch rate is often used in stock assessment models as an index of biomass (Hilborn and Walters 1992). It has also been used as a measure of the 'value' of a fishing site to recreational fishers (McGlennon and Branden 1994, Lucy and Barr 1994). In most of these analyses confidence intervals are very important, particularly with the growing emphasis on risk analysis in fisheries management (Cordue and Francis 1994, Rosenberg and Restrepo 1994, Francis and Shotton 1997).

Diary surveys are commonly used to estimate recreational catch rates. They are among the cheapest and most efficient ways of collecting catch information (Ebbers 1987), although biases are potentially high (Pollock *et al.* 1994). Estimates of catches from diary surveys are frequently given without confidence intervals, and where these intervals are given they are usually based on assumptions of Normality. However, catch distributions are generally highly positively skewed. It is a common feature of recreational catches that a few fishers catch most of the fish, and that many catch no fish at all (Jones et al. 1995). This distribution does not fit a standard such as the Poisson or the log-normal. Nor is there an obvious transformation available.

The sampling distribution of mean catch rate estimated from such a distribution becomes more Normal with increasing sample size. In other words, if the sample size is large enough, the standard error can be used to define the confidence interval around the estimated mean. However, in many surveys sample sizes are too small for Normality to be assumed. Jones et al. (1995) simulated the coverage of confidence intervals on estimates of catch rate under Normal assumptions, based on a sample where 27% of anglers caught nothing. They found that with sample sizes of 100 interviews, nominal 90% confidence intervals actually gave 88.6% coverage, with 9.0% error in the upper tail and 2.4% in the lower.

Furthermore, when mean catch rate is multiplied by effort to estimate total catch, error in estimates of both mean catch rate and effort must be combined to define confidence intervals. Multiplying two distributions can add positive skewness in the resulting distribution. Thus the sampling distribution of total catch can be even more positively skewed than that of mean catch rate.

In these situations the bootstrap provides an appropriate alternative to parametric methods (Efron & Tibshirani 1986). It avoids the need to decide which distribution the data are derived from, and simplifies the process of combining separate distributions. Examples of the use of bootstrapping to calculate confidence intervals on recreational catch estimates include Brown (1993), and West & Goode (1986).

A number of different methods are available for calculating bootstrap confidence intervals, but there is little guidance available on the best method to use in particular situations. The bootstrap-t and BCa methods are known to be among the most accurate, but fail in some situations. For example, Fletcher and Webster (1996) found that the bootstrap-t performed well in a stratified survey, and Smith (1997) found that the BCa method performed worse than the percentile method in a trawl survey application. Other methods (eg. the bootstrap percentile, BC, and hybrid bootstrap) are said to have the same accuracy as the Normal approximation given Normal data, but can lack consistency (Shao and Tu 1995). Probably the most commonly used method is the bootstrap percentile interval used by Brown (1993) and West & Goode (1986). It is popular because it is simple to use and intuitively easy to understand, but there is some doubt about its reliability.

Here we identify the best methods with which to calculate bootstrap confidence intervals for a typical sample of recreational fishing data. We compare the coverage and length of confidence intervals generated by the various methods, and compare these to intervals calculated under the traditional assumption of Normality. We also provide the SAS code for others to carry out simulations for their own data.

#### *6.3.7.1 Bootstrapping methods*

The six methods trialed in this study were:

- Bootstrap normal

This method is also known as the parametric bootstrap. It assumes that the means of the bootstrap samples are Normally distributed, and that the standard error of the raw mean is the standard deviation of the bootstrap means.

- Bootstrap percentile

This method uses the $\alpha/2$ and $1-\alpha/2$ percentiles of the distribution of the bootstrap parameter estimates as the $100(1-\alpha)\%$ confidence intervals (Efron 1981). It is amongst the most commonly used bootstrap methods, because of the ease with which it may be understood and implemented. It is also known as the 'percentile' (Efron and Tibshirani 1993), 'other percentile' (Hall 1992), and 'Efron's `backwards' percentile' (Hjorth 1994) method. However, the confidence set is often biased unless sample size is very large (Shao and Tu 1995).

- Bias-corrected (BC)

The bias-corrected or BC method corrects the percentile interval for bias, to some degree, by adjusting the percentile points to values other than $\alpha/2$ and $1-\alpha/2$ (Efron 1981). This method assumes that Normality and constant standard error can be achieved by some transformation of the data (Efron 1987). Where this assumption does not hold, the confidence set is not nominal.

- Bias-corrected accelerated (BCa)

In addition to the bias correction of the BC method, the BCa method corrects the percentile interval for skewness by introducing an acceleration constant $a$. It generally gives results that are more accurate than the BC method (Shao and Tu 1995). It is also known as the 'ABC' (Hall 1992) method. A disadvantage of the method is that the parameter $a$ can be difficult to calculate. It is estimated by jackknifing in this case.

- Hybrid

Other names for this method include the 'percentile' (Hall 1992), and the 'simple' (Hjorth 1994) method. Shao and Tu (1995) state that this method may not be as accurate as the bootstrap-t or BCa method but that it is often more convenient to use, and is more theoretically reasonable than the bootstrap percentile. They also state that it is used more frequently than any other bootstrap method, though we doubt that this is true for natural resource modelling situations. This method is said to be especially suited to complex problems where good variance estimators (see bootstrap-t), or methods to estimate the acceleration constant (see BCa), are not available (Shao and Tu 1995).

- Bootstrap-t

This method requires an estimate of the standard error of the statistic, and is not invariant under reparameterisation (Shao and Tu 1995). It is also known as the 'percentile-t' (Hall 1992), and the 'studentized' (Hjorth 1994) method.

#### *6.3.7.2 Data collection*

The data we use for the simulations come from a telephone and diary survey of recreational fishers undertaken in Queensland during 1994 and 1995 (Cameron and Begg 1998). Catch rate data were diary records of mackerel catches (*Scomberomus spp.*) from boats in Queensland. The diaries were completed by a random sample of boat owners. Catch rate represents the number of mackerel caught on a boat during a three-month period (quarter). The catch data derived from this survey were zero-inflated and highly skewed, with 89% of respondents reporting catches of zero fish and individual catches of up to 121 fish. The number of boats (effort) that caught mackerel was estimated with Normal confidence intervals from the telephone component of the survey. A range of values was estimated for different strata within the survey, so for the purposes of the simulation a value of 10 boats with relative standard error of 15% was used. The mean catch rate derived from all diarists was multiplied by the estimated total number of boats (effort) to give an estimate of the total catch for a quarterly period.

The catch rate distribution of the mackerel data may be more skewed than that of the ISAMP recreational fisheries. However, the form of the distribution is similar (see O'Neill 2000), and the conclusions are likely to be applicable.

#### *6.3.7.3 Simulation*

For the bootstrap simulation all catches were pooled to generate a source population of catches (Appendix Table 14.3.6). The probability distribution of number of fish caught on a boat during a quarter was calculated from the pooled data. This generated the probability of catching N fish in a quarter for all integer values of N between 0 and 121. In each simulation this probability distribution was used to generate 4000 datasets of catch rate data, with each dataset consisting of 100 catches. Each of these datasets of 100 catches represented a sample that might be obtained during a diary survey of a fishery.

The estimated number of boats, with standard error, was used to generate a matching set of 4000 estimates of boat number and standard error. The probability distribution of number of boats was assumed to be Normally distributed, and the Normal approximation was used to generate variates. Each of these variates represented an estimate of boat numbers that might be obtained from a telephone survey.

Manly (1997) and Efron and Tibshirani (1993) recommend at least 1000 and 2000 replicates for alpha levels of 0.1 and 0.05 respectively, when the distribution is close to Normal. Given the non-Normality of our data we chose to use 4000 replicates at our standard alpha level of 0.1. Each simulated dataset was bootstrapped 4000 times, using a modification of the JACKBOOT macro from the SAS Institute (SAS Institute 1996), to give estimates of catch rate and total catch with confidence intervals.

During each of the 4000 simulations one of the catch rate datasets was paired with one of the effort distributions. For each of these pairs the following procedure was carried out 4000 times.

1. A sample of m(n) items was drawn with replacement from the simulated catch rate dataset. The mean and standard error of this sample were calculated.

2. A random variate was drawn from the boat number distribution.

3. The variate and the mean catch rate were multiplied to provide a bootstrap estimate of total catch.

4. The variate and the standard error of mean catch rate were multiplied to provide an estimate of the standard error of the total catch estimate.

During each of the 4000 simulations, 4000 bootstrap estimates of total catch and standard error were used to calculate bootstrap confidence intervals using the six different bootstrap methods. Confidence intervals for mean catch rate were also calculated for each simulation.

In a series of trials we investigated the effect of changing aspects of the analysis, and the effect on our results of several data scenarios. These trials are detailed below. Each aspect of the analysis or data scenario was trialed at two or more levels, and one of these was designated the 'base' level. Only one aspect or scenario at a time was varied from its base level, since trialing all combinations would have required a prohibitive amount of time. We did not consider any interactions which may occur.

For each set of confidence intervals and for both estimated parameters we recorded the coverage and length of the intervals. We also recorded the proportion of upper confidence limits that were less than the value of the parameter (0.8017687 for catch rate and 8.01687 for total catch), and the proportion of lower confidence limits greater than the true value.

#### *6.3.7.4 Aspects of the analysis*

Several different alpha levels (0.05, 0.1, 0.2) were used to generate the confidence intervals, so as to observe the effectiveness of bootstrap methods at different levels of confidence. The base alpha level was 0.1.

Various resample sizes (10, 20, 30, 40, 50, 60, 70, 80, 90, 100, 200) were trialed. Shao and Tu (1995) advise that inconsistency of the bootstrap estimators can often be remedied by using a resample size m(n) that is smaller than the sample size n, where as n tends to infinity, m(n) also tends to infinity and m(n)/n tends to 0. The resample size used in the base simulation was m(n) =100.

#### *6.3.7.5 Data scenarios*

As sample size increases the sample mean becomes more Normally distributed. We therefore varied the sample size (50, 100, 200) and examined how much this affected the performance of the confidence intervals. The sample size used as the base was n = 100.

The effect of population distribution was investigated by varying the probability of zero catch in a season (0.5, observed). The observed proportion was used as the base level.

The influence of boat effort distribution on the total catch confidence limits was investigated by varying the relative standard error of the boat number estimate (5%, 15%, 25%). The base level was 15%.

When catch rate is distributed Normally rather than being severely skewed, bootstrap confidence intervals are generally more accurate. However, the multiplication of distributions involved in estimating total catch can introduce skewness. We therefore trialed the methods with Normally distributed catch rate, with the observed data as the base level for comparison (observed, Normal).

## 6.4 Evaluation of alternative assessment methods —egg production method

The egg production method can be used to estimate spawning biomass in species that spawn in a defined area over a relatively short period of time, and may therefore have potential for tailor. Samples of eggs are taken using plankton tows, and their density in the spawning area is scaled up by the size of the area to estimate the total number of eggs. This is then divided by an estimate of the number of eggs produced per female to give the number of spawning females. Incorporating an estimate of sex ratio gives total spawning biomass.

The method has potential for tailor if the most fish spawn in a relatively discrete area and over a short period of time. The primary aim of this part of the project was therefore to make an initial assessment of the temporal and spatial distribution of eggs and larvae in southeast Queensland. Information on egg distribution can also be used to infer the distribution of spawning adults. This information is not available from other sources, and may have implications for other aspects of the management of the fishery.

Plankton samples were collected as part of a Baitfish Stock Assessment Project (FRDC Projects 95/043 and 98/130). The surveys were primarily designed to optimise data collection from the pilchard fishery. Eleven cruises were completed between 28 August 1997 and 17 September 1998. Annual egg survey cruises covered a large area of the coastal waters of southern Queensland. Monthly cruises covered a small area that was identified as a significant spawning area for pilchards.

### 6.4.1 1997 annual egg survey cruise

A single cruise was completed between 28 August and 5 September 1997. Plankton tows were performed during the day (approx 7:00-18:00 EST) at 154 sites along 19 east-west transects between latitudes 24° 30' S and 28° S (Figure 6.1). Transects extended from depths of approximately 15 m to 180 m. Four transects were sampled inside Hervey Bay and Moreton Bay.

### 6.4.2 1998 annual egg survey cruise

Two short cruises of four and three days duration were completed between 18 August and 4 September. Plankton tows were performed during the day (between approximately 7:00 and 17:30) at 95 sites along 15 east-west transects between 24° 30' S and 28° S. Transects extended from depths of approximately 15 m to depths beyond which pilchard eggs were collected along the same transect in 1997 (Figure 6.2). Sites along two transects (26° 15' S and 26° 30' S) were sampled twice; once the day before starting to sample all transects to their north, and once the day before starting to sample all transects to their south. No sampling was carried out in Hervey Bay or Moreton Bay.

### 6.4.3 Monthly cruises

Plankton tows were performed at sites along two transects (26° 30' S, and 26° 30' S.; Figure 6.1) at approximately monthly intervals between the two annual egg surveys, and once after the 1998 annual egg survey.

### 6.4.4 Plankton Collection

Plankton samples were collected using paired conical plankton nets (internal diameter 0.285 m, 300 µm mesh) deployed to within 5 m of the substratum (in waters <70 m deep) or to a depth of 70 m (in waters >70 m deep). The net was retrieved vertically at a speed of approximately 1 m s-1. The distance travelled by the net was calculated using calibrated flowmeters. The sample from each net was stored in 5% buffered formaldehyde. Preliminary analyses showed little difference between nets, so samples from the two nets were pooled at each site. Surface water temperature (± 0.1 °C) was recorded at each site.

### 6.4.5 Identification

All teleost eggs and larvae were removed from plankton samples. Tailor eggs and larvae were identified using the criteria of Hardy (1978).

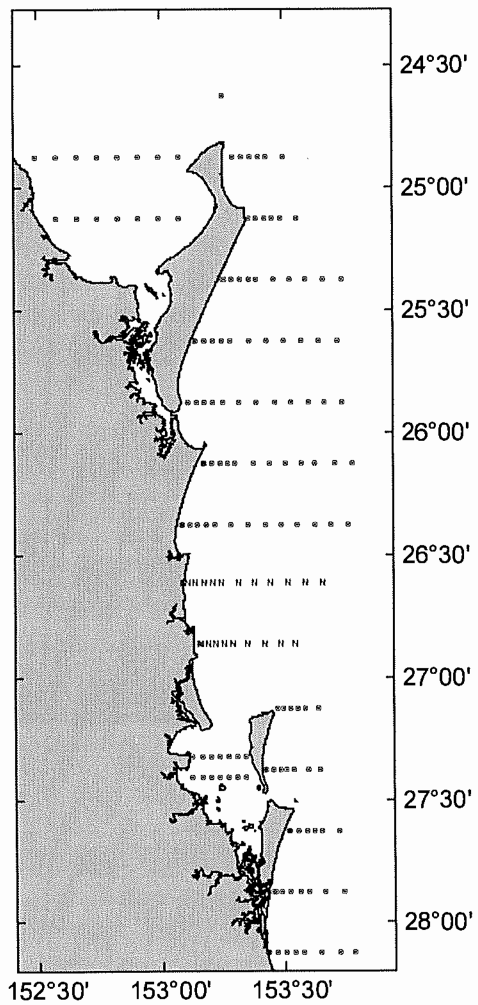



Figure 6.1 Sites for plankton tows during 1997 and 1998. ⊙ = 1997 annual egg survey sites; T = 1997 annual and monthly survey sites.

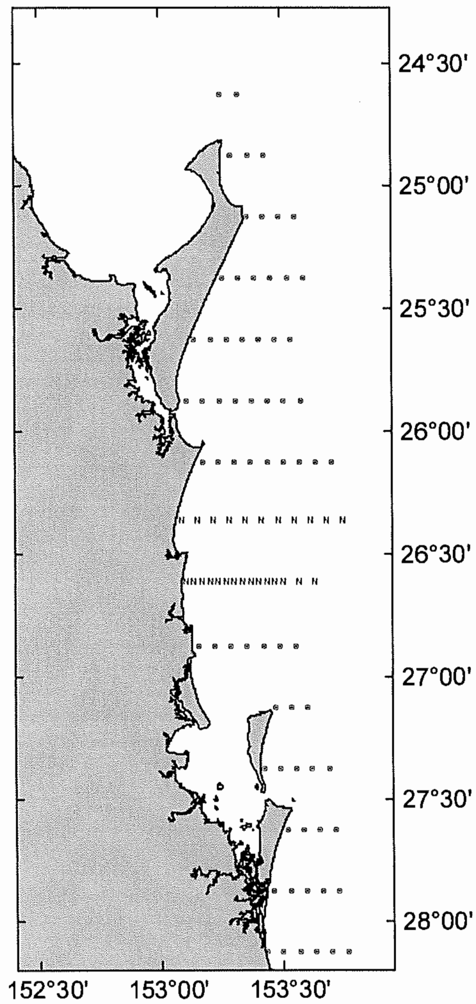



Figure 6.2 Sites for plankton tows during 1998 annual egg survey. ⊙ = sites sampled once; T = sites sampled twice.

### 6.4.6 Analysis

The distributions of eggs and larvae across both latitude and longitude were compared, using general linear models, with data normalised using a log(x+1) transformation. The analyses were carried out for four separate periods: August 97, September 97, August 98, September 98. Longitude was converted into distance from the coast and classified into 3 groups: 0 to 6 minutes, 6 to 15 minutes, > 15 minutes. Latitude was restricted to areas between 25 and 27.5 degrees. Due to the number of zero values in the data, a degree of non-normality remained after the log(x+1) transformation, but the general linear modelling technique is relatively robust to such a condition. The less sensitive and flexible Kruskal-Wallis non-parametric one-way analysis of variance was also carried out to cross-validate results.

# 7 RESULTS

## 7.1 Trends in Commercial Fishery Statistics

In this section we describe the status of the available commercial catch and effort data, and attempt to draw inferences about the status of the various stocks. We show that the fisheries are complex and employ a variety of fishing gears. They take a suite of species, some of which cannot be differentiated from others on the basis of the historical logbook data.

### 7.1.1 Catches, historical and current

Historical commercial catch data are available only through the records of landings at the Queensland Fish Board's regional depots and Fishermen's Cooperatives. These extend from the Second World War through to around 1980, when the Board was sold to private interests. During the period 1944-1969 fish landings were recorded in pounds (lb) whole weight. From 1970 onward separate records were kept for whole fish (presumably gilled and gutted) and fillets. Between 1970 and 1973 all records were expressed as pounds; thereafter (from 1974 onward) they were recorded as kilograms. For the purpose of our analysis, all figures have been converted to whole weight (kg) equivalent on the basis that 1 lb = 2.2 kg, and whole (gilled and gutted) weight = 2 x fillet wt.

It will be noticed that there is a gap between 1983, when the QFB was privatised, and 1988, when the QFMA and QDPI introduced the State-wide logbook program. The post-1988 data have been simply extracted from the CFISH database. It should be noted that the two datasets are not directly comparable.

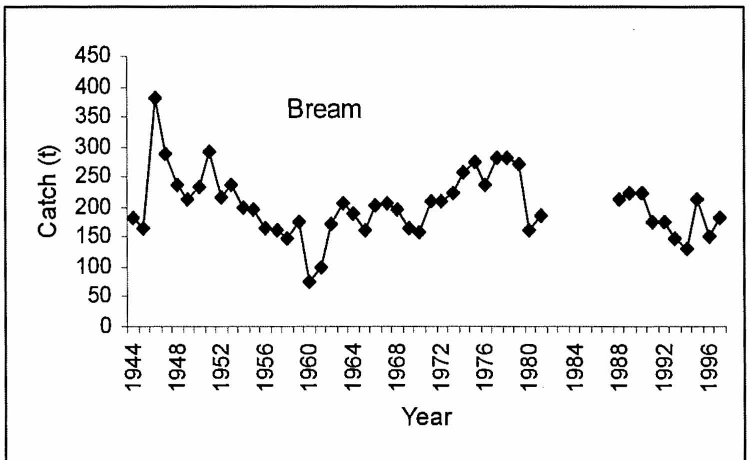



Figure 7.1 Annual reported landings (QFB; 1944–81) and catches (Q-Fish logs; 1988–97) of bream from Queensland waters.

The historical figures for bream (Figure 7.1), while not accounting for the entire commercial catch, are of interest in that they do not exhibit any consistent long-term trend. There appears to have been a post-war decline in landings over the 15 years to 1960, then a gradual increase to a second peak in the late 1970s. The long-term mean annual catch over that period was 220 tonnes, but individual yearly catches ranged from about 70 t in 1960 to 380 t in 1946. The reported annual catch of yellowfin bream during the period of the CFISH logbook program has also varied, from about 220 t in 1990 to 120 t in 1994. This variability is well within the "historical" range mentioned above.

The landings of whiting (Figure 7.2) declined after the war during the 20 years to about 1965, then increased gradually to a second peak in the mid to late 1970s. This pattern is curiously similar to that of the bream landings (Figure 7.1), suggesting either a long-term cycle in abundance in both species, perhaps due to the same environmental influences, or a consistent bias across species in the data reporting process. The long-term mean annual catch of whiting over that period was 270 tonnes, but individual yearly catches ranged from about 190 t in 1960 to 431 t in 1974. The reported mixed fishery annual catch of whiting during the period of the CFISH logbook program has also varied, from about

320 t in 1988 to 175 t in 1994. Allowing for the fact that the historical data presumably includes a prawn-trawl bycatch of *S. maculata*, this variability is probably within the "historical" range mentioned above.

Flathead data also do not exhibit any consistent long-term trend (Figure 7.3). Following a period of stable catches between 1946 and 1959 averaging 91 t, catches up to 1980 averaged 71 t apart from peaks in 1974 and 1975 of about 100 t. The long-term mean annual catch over that period was 77 t, but individual yearly catches ranged from about 53 t in 1970 to 106 t in 1958. The reported annual catch of flathead during the period of the Q-Fish logbook program has also varied, from about 83 t in 1989 to 45 t in 1994, with a declining trend (Figure 7.3). However subsequent catches have shown a slight up-turn since 1995.

The history of commercial tailor catches in Queensland appears to comprise two phases (Figure 7.4). The first phase, prior to 1975, is characterised by a mean annual catch of 290 t, while from 1976 onward annual catches have been consistently and substantially lower, at around 170 t. It is important to note that the sudden decrease did not occur in the period of change from one reporting system to the other, but while the Queensland Fish Board was in operation. The sudden fall-off in annual catches of tailor may have been related to market demand, which is known to have slumped in the mid-1970s when the QFB lost its regular contract with the Queensland Government for the supply of fish products to the State's public hospitals and institutions. After 1976, in fact, there would appear to have been a slight overall downward trend in the size of the annual commercial

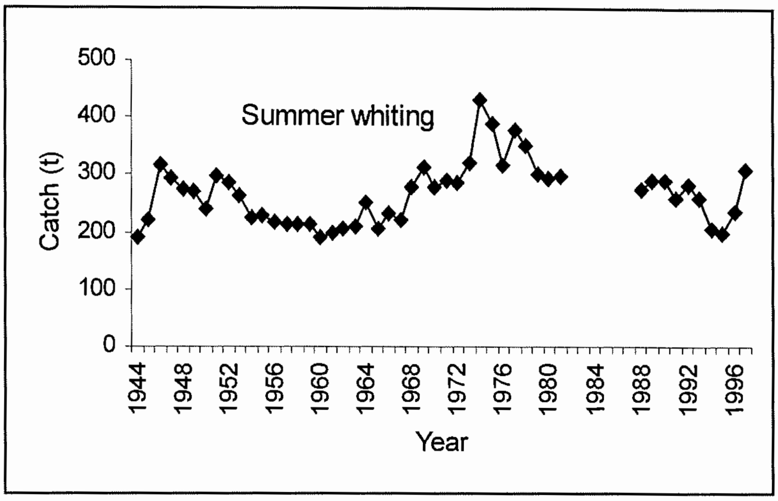



Figure 7.2 Annual reported landings (QFB; 1944–81) and catches (Q-Fish logs; 1988–97) of summer whiting from Queensland waters. Note that the QFB records may also include trumpeter whiting.

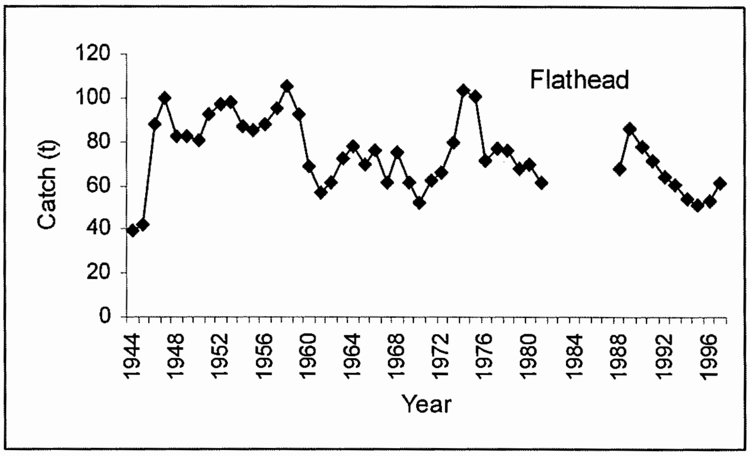



Figure 7.3 Annual reported commercial landings (QFB; 1944–81) and catches (Q-Fish logs; 1988–97) of flathead from Queensland waters.

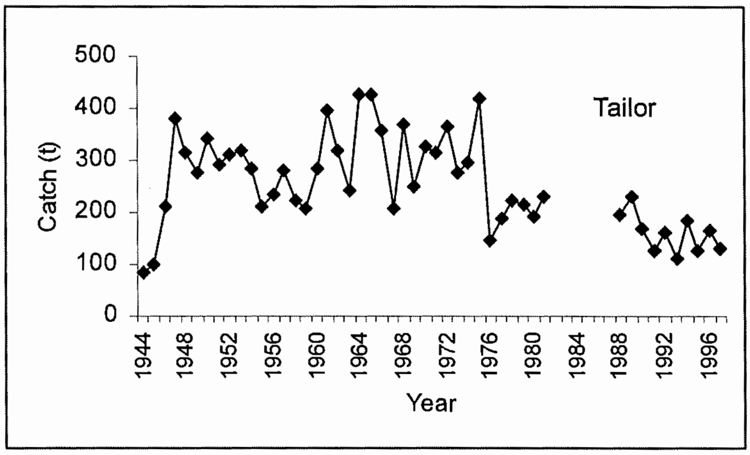



Figure 7.4 Annual reported landings (QFB; 1944–81) and catches (Q-Fish logs; 1988–97) of tailor from Queensland waters.

catch of tailor. To determine whether this reflects a similar trend in stock size would require a far more sensitive measure of population abundance than raw annual reported catches.

### 7.1.2 Catch, effort and CPUE

#### *7.1.2.1 Tailor*

As there is only a single code number for tailor in the CFISH database there is no confusion over the species composition of the catch and effort data extracted from this source. The ocean beach seine fishery takes the majority of the commercial catch on schools of tailor on the offshore beaches between April and August. The remainder of the commercial catch is taken by the set gill and tunnel nets in estuaries (Williams, 1997). The number of vessels participating in the commercial fishery have varied between about 110 and 165 (Figure 7.5). Tailor is also an extremely popular recreational species caught on the surf beaches from Fraser Island to the New South Wales border. The size of the recreational catch has been estimated from preliminary results of a recent recreational diary survey undertaken in 1998 at approx. 290 t (max 440 t) for that year (Dichmont *et al.*, 1999). A more recent analysis of the same data, including beach-fishing units, suggests a figure of around 490 t (Higgs, 1999).

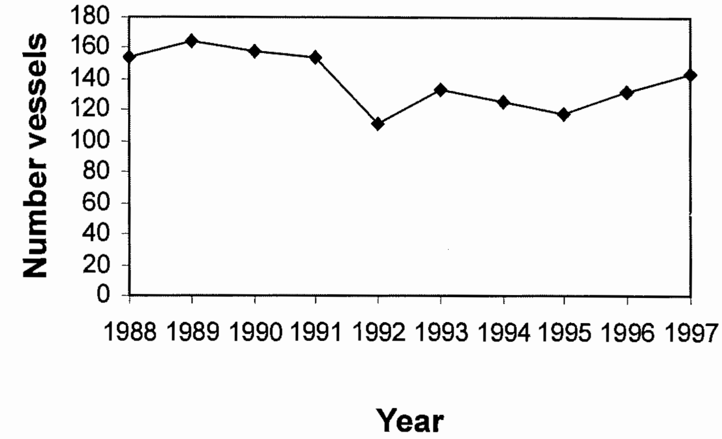



Figure 7.5 Number of "vessels" in a year that recorded a tailor catch in areas >18° latitude.

During the first few years of the compulsory logbook program little of the commercial catch recorded in the database was allocated to a specific fishing method (Table 7.1). However, over time the 'unallocated' catch declined, and that attributed to mesh netting increased proportionately. It is highly likely that most of the catch with no specific method was taken by net. Year to year variation in the total catch of tailor is believed to be more a function of market demand and price than stock availability (Dichmont *et al.*, 1999). The product is sold on local and interstate fresh fish markets.

A large proportion (>40%) of the net-fishing fleet reported catching tailor on fewer than 5 days each year (Figure 7.6), and only about 17% of the vessels reported catches of more than 1 t in a year. Total effort was high (>2000 fishing days) during the first few years of the logbook period, but then declined quite suddenly between 1990 and 1992 (Table 7.1). Very few large catches of tailor have been recorded in the database, relative to the many records which have shown zero or small catches (Figure 7.7). Large catches (primarily from the ocean beach fishery) tend not to include any bycatch of bream, whiting

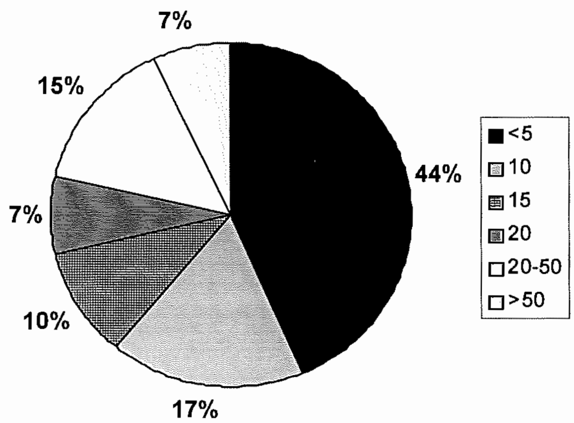



Figure 7.6 Number of vessels (%) that have recorded tailor catch in latitudes south of 18° at a certain level of effort (days) in an average year. Legend effort categories are in days. Note: the intervals in the last two categories are larger than the other categories.

or flathead. However, most of the tailor catch records (from the estuarine fishery) were in combination with a mix of bycatch. In about 85% of cases, this bycatch amounted to less than 100 kg (in total) daily. It is of some concern that zero catches are not recorded in the CFISH database even if the species was targeted. It is therefore impossible at present to determine whether the zero catches are due to (i) vessels that did not fish, (ii) vessels that fished but did not target or catch tailor, or (iii) vessels that fished and targeted tailor, but failed to catch any.

We believe that knowledge of the number of records where the vessel fished and caught other fish, but not tailor, is important. Unless the fisher was targeting other fish, much of non-targeted effort should theoretically be attributed to tailor, as zero catches are as important as non-zero catches in terms of analysing spatial and temporal effects. It is clear that in more than 80% of the zero tailor catch records where some bream, flathead or whiting was caught, only 100–200 kg of this byproduct was recorded (Figure 7.8).

In the Stock Assessment Review Workshop (Dichmont *et al.*, 1999), an attempt was made to separate the

Table 7.1 Annual catch (t) of tailor by method type and total effort recorded in CFISH for latitude >18°.

| Year | Fishing method specified | | | Total Effort (boat days) |
|---|---|---|---|---|
| | Nil | Mesh net | Other | |
| 1988 | 191 | 6 | 2 | 2031 |
| 1989 | 223 | 6 | 10 | 2177 |
| 1990 | 146 | 19 | 2 | 2251 |
| 1991 | 35 | 90 | 1 | 1829 |
| 1992 | 0 | 162 | 1 | 1118 |
| 1993 | 4 | 106 | 1 | 1267 |
| 1994 | 7 | 177 | 0 | 1268 |
| 1995 | 9 | 119 | 0 | 1232 |
| 1996 | 18 | 147 | 0 | 1243 |
| 1997 | 5 | 124 | 3 | 1670 |

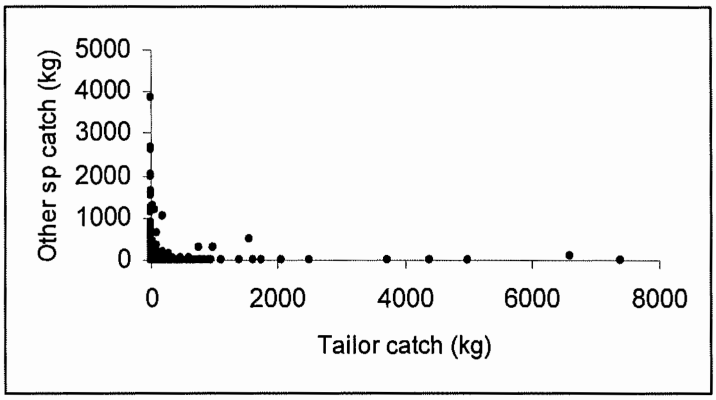



Figure 7.7 Relationship between daily catches of tailor and other species (whiting, flathead and bream) taken by randomly selected commercial net fishers in southern Queensland.

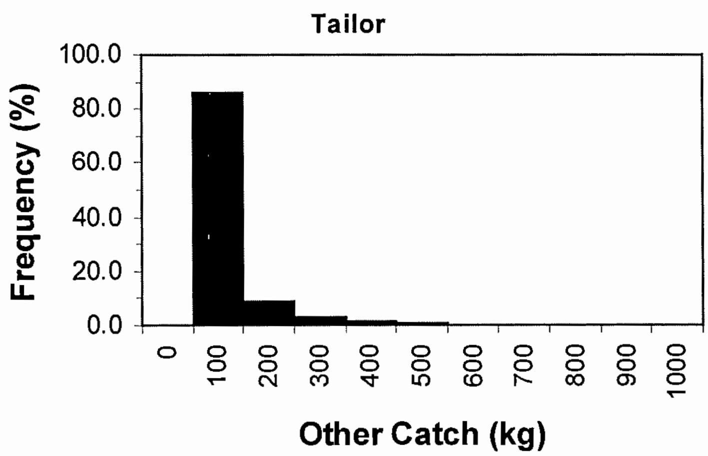



Figure 7.8 Number of catch records in which zero tailor catches are recorded versus the total catch of bream, whiting and flathead caught in the mesh net. Note: due to no zero logs being recorded, it is impossible to gain information where the vessel fished and did not catch anything.

net mesh method catch and effort into the different gear types used by the fishery. This is important, as the catchability of the various gear types can differ substantially. It was not possible to use mesh size to identify gear type, because there has evidently been considerable confusion about the measurement units, which differed by up to three orders of magnitude (Figure 7.9).

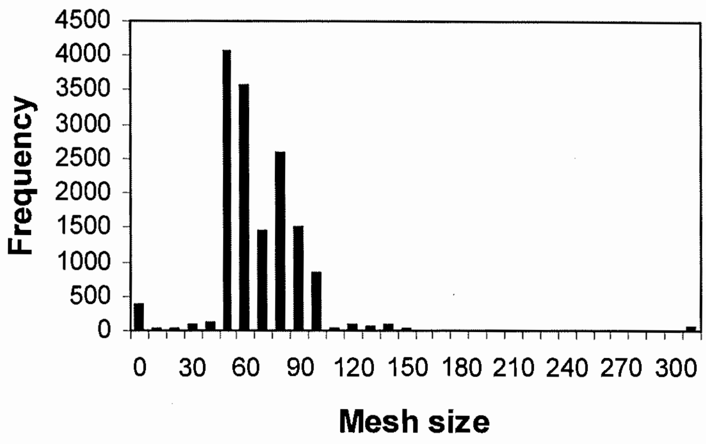



Figure 7.9 Frequencies of mesh sizes in the CFISH system from vessels that recorded tailor catch between 1988 and 1997 within southern Queensland. The last column is for mesh sizes >300. This graph excludes 1024 records with no mesh size recorded.

The frequency of net lengths recorded by vessels taking bream within south-east Queensland also display a large range (Figure 7.10). However, this is a reflection of the two main types of gear used within the fishery—gill nets usually being much shorter than tunnel nets. In the Stock Assessment Review Workshop the following simple algorithm was used to assign the tailor catch and effort data to one of two fishery categories;ocean beach and "incidental" (estuarine). Ocean beach catches of tailor were defined as those caught by a 'K'-endorsed fisher between April and August (the peak of the ocean beach fishery), while all remaining records were classed as 'incidental'. The Tailor Working Group did not subdivide the "incidental" fishery any further.

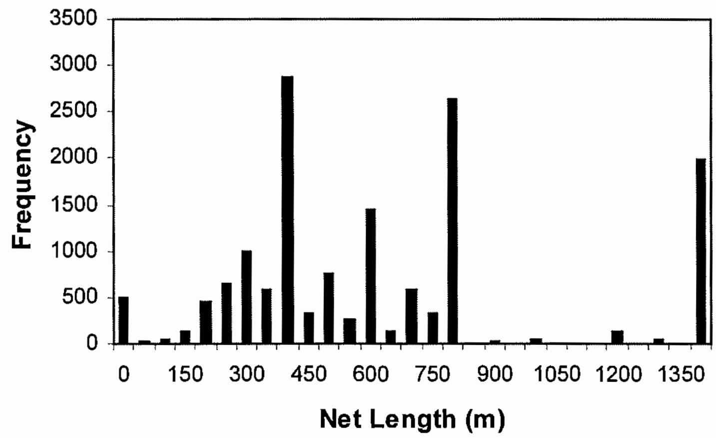



Figure 7.10 Frequency of net lengths recorded by vessels between 1988 and 1997 that have logged tailor catches in southern Queensland. The graph excludes 1123 records in the same period with no net length recorded.

A different algorithm (which could equally be applied to tailor) was developed by the Mullet Working Group in the Workshop to separate the CPUE into more categories. However this method would only apply to the estimation of catch rates, as it deletes records which must be included in calculations of total catch. The alternative algorithm is as follows:

i) Delete all records where no net length is recorded or where the net length is greater than 2000 m.

ii) If the net length ≤ 800 m and the fisher does not have a K endorsement, then the catch is attributed to a non-ocean beach fishing operation using *gill or mesh* nets.

ii) If the net length ≤ 800 m and the fisher has a K endorsement but the date is outside the declared ocean beach season, then the catch is attributed to an ocean beach fisher using *gill or mesh* nets, presumably in an estuarine situation.

iii) If the net length ≤ 800 m and the fisher has a K endorsement and the date is within the declared ocean beach season, then the catch is attributed to an ocean beach fisher using *haul* nets.

iv) If the catch location is within Moreton Bay or Great Sandy Straits/Hervey Bay (CFISH grids V34, W34 or W37) and the net is longer than 800 m then the catch is attributed to a *tunnel* net fishing operation.

#### *7.1.2.2 Whiting*

Of the eight whiting categories in the CFISH database, five may be relevant to southern Queensland catches (Table 7.2). Three categories ('whiting-unspecified', 'whiting-sand' and 'whiting-summer') are used to record catches of the two summer whiting species (*S. ciliata* and *S. analis*) on the Mixed Fishery logsheets. The trumpeter whiting *S. maculata* could be referred to as either 'whiting-unspecified' or 'whiting-trumpeter/diver' in the Mixed Fishery (where it probably represents only a small fraction of the whiting catch). In the Trawl Fishery database all species would be referred to as 'whiting-unspecified', but the category would refer principally to *S maculata* in the south of the State, and possibly *S. sihama* ('whiting-northern') further north.

Table 7.2 Total cumulative catch (t) over the entire logbook period of each of five codes covering the sillaginid whiting species. Stout whiting, which is mainly caught by trawlers, is not included in the table. Any catch recorded by trawl gear has been excluded.

| CFISH Category Name | CFISH Code | Total Catch (t) | % of total | First year recorded |
|---|---|---|---|---|
| Whiting-trumpeter/diver | 330004 | 58 | 2 | 1988 |
| Whiting-northern | 330006 | 0.7 | <0.1 | 1992 |
| Whiting-sand | 330008 | 15 | 0.5 | 1993 |
| Whiting-summer | 330800 | 1476 | 53 | 1988 |
| Whiting-unspecified | 330900 | 1233 | 44 | 1989 |

Most of the whiting catch is recorded in "whiting-summer" and "whiting-unspecified". There is no objective method of splitting the 'unspecified' catch, and therefore no way of identifying whiting catch and effort to species level. Due to the trawl caught component of trumpeter whiting, any data characteristics hereafter are for the categories "whiting-unspecified", "whiting-sand" and "whiting-summer" in locations south of 18° latitude. The stout whiting *Sillago robusta* is essentially an offshore trawl-caught species and does not fall within the scope of this project. The category 'whiting-western school' has no catch reported since 1988, is almost certainly a misidentification, and has no useful place in the CFISH system.

The number of vessels in a year reporting a catch of sand, summer or unspecified whiting has ranged from about 200 to 270 (Figure 7.11). There appears to have been a slight decline between 1991 and 1992, whereupon numbers remained fairly constant. By far the greatest proportion of the catch in all years has been associated with the net mesh fishing method category (Table 7.3). Less than 15% of the catch relates to records that do not contain reference to a fishing method, and there is no trend in this figure over time. If the trawl catch is included, then most of the trumpeter whiting catch is taken in Moreton Bay and Hervey Bay as a byproduct by prawn trawlers (Williams, 1997).

About a third of the fleet involved in catching whiting recorded whiting catches on fewer than five days each year (Figure 7.12), and fewer than 4% of the vessels caught more than 1 t of whiting in a year. Total effort declined over the early 1990s and recovered to pre-1990 levels in 1997 (Table 7.3).

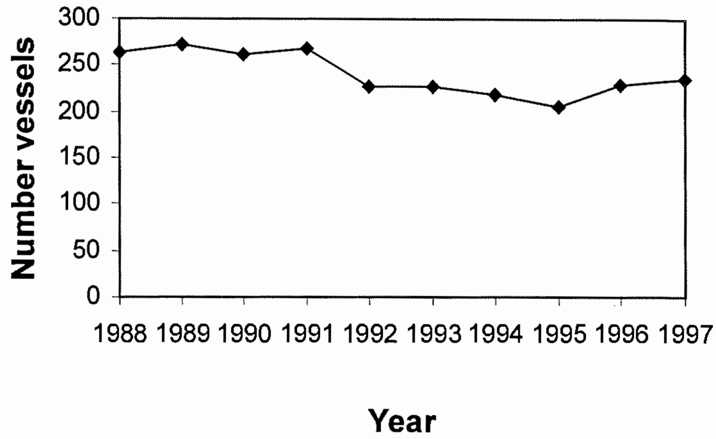



Figure 7.11 Number of vessels in a year that recorded whiting in the sand, summer and unspecified categories in locations south of 18° latitude.

In more than 85% of the records where whiting, bream, flathead and tailor catch are recorded, less than a total of 100 kg of product was caught (Figure 7.13). The few large whiting catches observed were generally not associated with any bream, tailor or flathead catch. On the other hand, small whiting catches could be associated with a range of bream, flathead and tailor bycatch levels.

The number of records where the vessel fished, caught bream, flathead and tailor, but not whiting, is shown in Figure 7.14. In more than 80% of the records, only 100–200 kg of bream, flathead and tailor bycatch was recorded (Figure 7.14). It should be noted that most effort values published would only be effort of a successful whiting trip and would not include any zero records where the fisher did use a net. As mentioned previously, the database does not enable a ready distinction between gill and tunnel net catches, whereas the 'effective effort' of the two net types could be very different. Like the situation for tailor, the frequency distribution of reported mesh-sizes (Figure 7.15) presents a confused picture, probably because of different measurement units being used. The frequency of net lengths recorded by bream vessels within southern Queensland also covers a large range, from about 150 to 1400 m (Figure 7.16). This reflects the two main types of gear used within the fishery—gill nets (up to 800 m) and tunnel nets (>1000 m).

Table 7.3 Annual catch (t) of whiting by method type and total effort (days) recorded in CFISH for latitude >18°.

| Year | Fishing method specified | | | Total Effort (boat days) |
|---|---|---|---|---|
| | Nil | Mesh net | Other | |
| 1988 | 38 | 279 | 10 | 6043 |
| 1989 | 18 | 282 | 10 | 6940 |
| 1990 | 12 | 288 | 10 | 7016 |
| 1991 | 6 | 262 | 14 | 6396 |
| 1992 | 2 | 290 | 0 | 4973 |
| 1993 | 13 | 256 | 0 | 5043 |
| 1994 | 10 | 204 | 0 | 4655 |
| 1995 | 11 | 196 | 0 | 4506 |
| 1996 | 21 | 229 | 0 | 4919 |
| 1997 | 44 | 268 | 6 | 6066 |

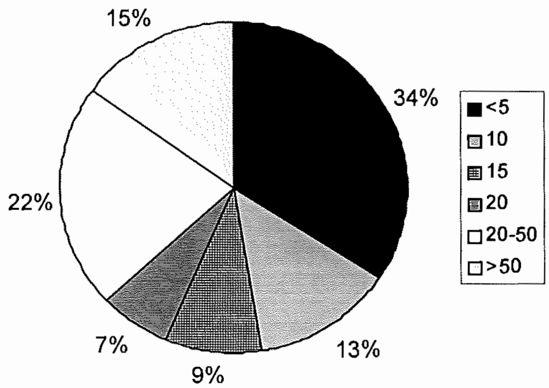
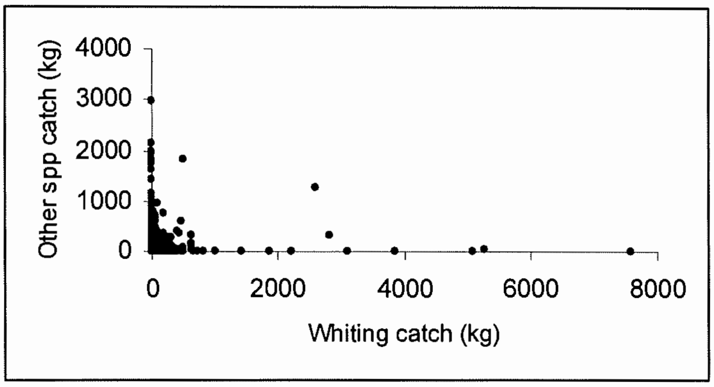



Figure 7.12 Number of vessels (%) that have recorded "whiting-unspecified", "whiting-sand" and "whiting-summer" catch in latitudes south of 18° at a certain level of effort (days) in an average year. Legend effort categories are in days. Note: the intervals in the last two categories are larger than the other categories.



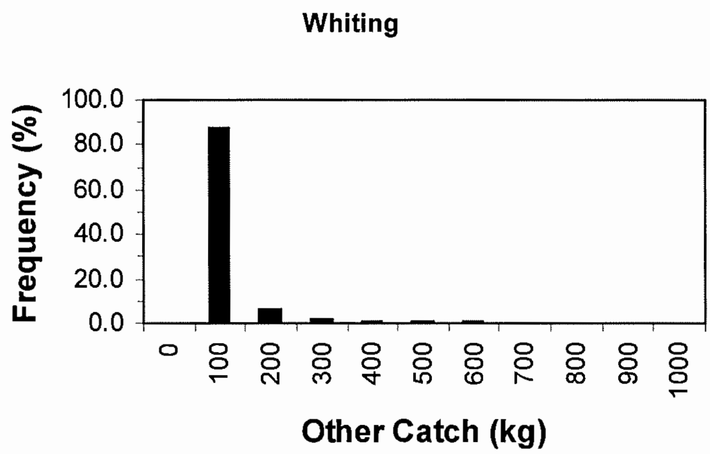




Figure 7.14 Number of "whiting-unspecified", "whiting-sand" and "whiting-summer" in latitudes south of 18° records in which zero tailor catches are recorded versus the total catch of bream, whiting and flathead caught in the mesh net. Note that no records reflect zero other catch as this would not be recorded in the logbook. Note: Since no zero logs were recorded, no information is available about times where the vessel fished and did not catch anything.

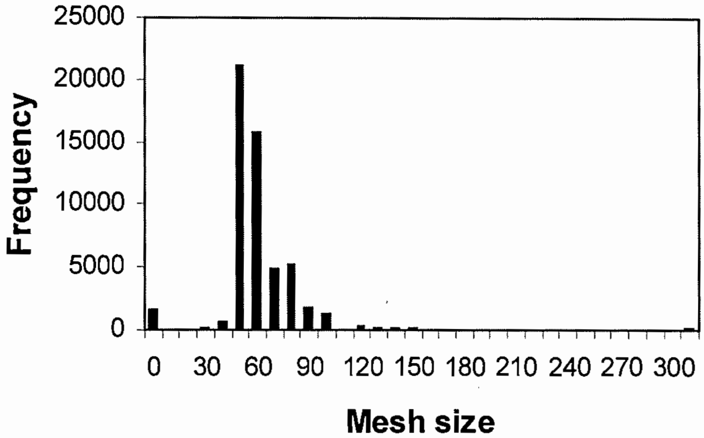



Figure 7.15 Frequencies of mesh sizes in the CFISH system from vessels that recorded sand, summer or unspecified whiting catch between 1988 and 1997 within southern Queensland. The last column is for mesh sizes >300. This excludes 2829 records with no mesh sizes recorded.

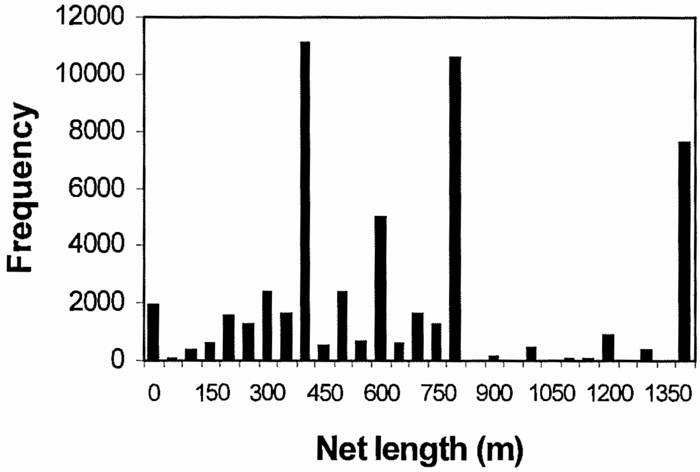



Figure 7.16 Frequency of net lengths recorded by vessels between 1988 and 1997 that logged sand, summer or unspecified whiting catches in southern Queensland. The graph excludes 3338 records in the same period with no net length recorded.

Table 7.4 Total cumulative catch (t) over the entire logbook period of each of the three codes covering bream and related species in southern Queensland.

| CFISH category name | CFISH code | Total catch (t) | % of 3 categories | First year reported |
|---|---|---|---|---|
| Bream –Yellowfin | 353004 | 8.7 | 0.46 | 1992 |
| Bream – Tarwhine | 353013 | 2.6 | 0.14 | 1995 |
| Bream – | 353900 | 1820 | 99.4 | 1988 |

### 7.1.2.3 *Bream*

Three 'species categories' in the CFISH database have possibly been used with reference to yellowfin bream (*Acanthopagrus australis*) catch and effort (Table 7.4). At the commencement of the logbook program in 1988 there was no other category available in the database for tarwhine (*Rhabdosargus sarba*), with the result that this species was bundled into the 'bream-unspecified' category between 1988 and 1991. Even though separate tarwhine and yellowfin bream codes were included in the database thereafter, there was no specific provision for tarwhine on the log-sheets, so most of the catch was still being included in 'bream-unspecified'. As there was no obvious way of separating the 'bream-unspecified' catches into species, all the catch and effort of the three categories were combined and assumed to represent the catch and effort of yellowfin bream in the following analyses. The recent Stock Assessment Review Workshop (Dichmont *et al.*, 1999) failed to produce a better solution to this problem of species definition. However it is likely that (compared to bream) the tarwhine landings are relatively small, and the 'unspecified' category probably refers primarily to yellowfin bream in locations south of 18° latitude.

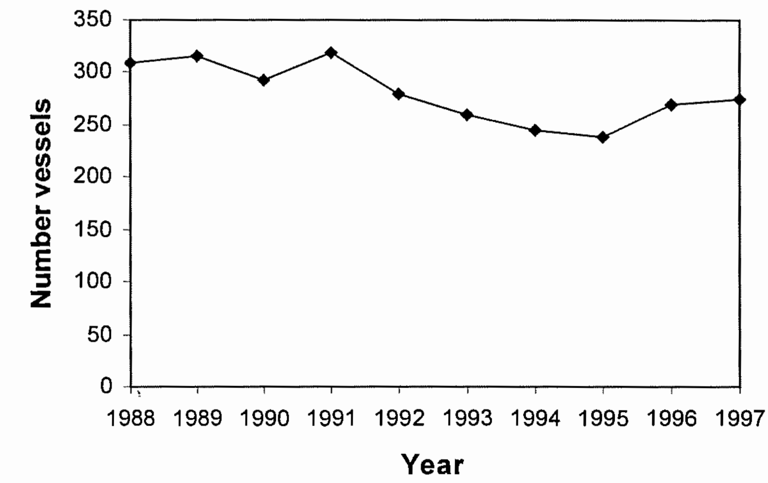



Figure 7.17 Number of vessels that have logged a bream catch using gill or tunnel nets in southern Queensland annually.

The number of vessels that logged yellowfin bream catches ranged from about 230 to 300 per year. A slight decline in numbers was observed after 1991, but this increased in 1996 and 1997 (Figure 7.17). A relatively small proportion (<10%) of the yearly catch had no allocated method (Table 7.5), and less than 10 t per year of the catch is attributed to fishing methods other than 'mesh nets' (which in the CFISH database has to date represented all kinds of netting). By far the largest component of the commercial catch is

Table 7.5 Annual catch (t) of bream by method type and total effort (days) recorded in CFISH for latitude >18°.

| Year | Fishing method | | | Total Effort |
|---|---|---|---|---|
| | Nil | Mesh | Other | (days) |
| 1988 | 4 | 204 | 6 | 6246 |
| 1989 | 20 | 192 | 10 | 6273 |
| 1990 | 3 | 213 | 6 | 6270 |
| 1991 | 1 | 169 | 4 | 5632 |
| 1992 | 4 | 170 | 2 | 4283 |
| 1993 | 5 | 139 | 1 | 3949 |
| 1994 | 10 | 120 | 1 | 3360 |
| 1995 | 24 | 188 | 2 | 3949 |
| 1996 | 13 | 135 | 2 | 3741 |
| 1997 | 12 | 162 | 6 | 4801 |

taken by seine, gill or tunnel net operations.

Of the vessels that caught bream, 40% recorded fewer than 5 days of effort in an average year (Figure 7.18). On the other hand, only 9% of the fleet have fished for more than 50 days in an average year. As a consequence, fewer than 5% of the vessels recorded an annual bream catch of 1 t or more.

There are few records of very large daily catches of bream. Modest catches of bream appear generally to be associated with only small quantities of other bycatch species such as flathead, tailor and whiting (Figure 7.19). In more than 80% of the records where whiting, bream, flathead and tailor are recorded, less than a total of 100 kg of product was caught. On the other hand, small bream catches frequently appear to be associated with a range of the other species. Thus, most bream catches are small and mixed with other species.

The frequency of records where the vessel fished and caught whiting, flathead or tailor, but not bream, is shown in Figure 7.20. In over 80% of the records reporting a bream catch, the total weight of other species was less than 200 kg.

Again, there is not a clear pattern in the frequency distribution of either mesh size (Figure 7.21) or net length (Figure 7.22) that might otherwise enable a distinction to be made between the different gear types used in the fishery. Confusion as to the units of measurement may well account for this lack of clarity, although there is a strong possibility that carelessness in reporting may have been a contributing factor.

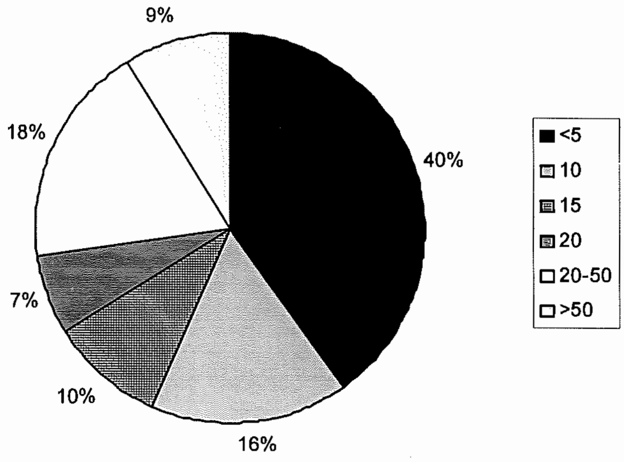



Figure 7.18 Number of vessels (%) that recorded a bream catch in latitudes south of 18° at a certain levels of effort (days) in an average year. Legend effort categories are in days. Note: the intervals in the last two categories are larger than the other categories.

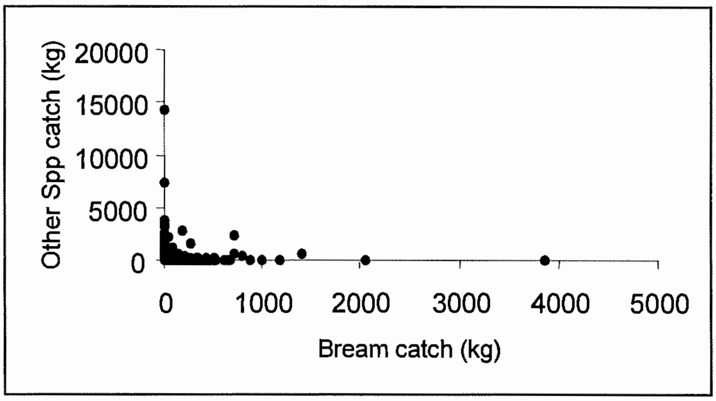



Figure 7.19 Relationship between daily catches of bream and other species (whiting, flathead and tailor) taken by randomly selected commercial net fishers in southern Queensland.

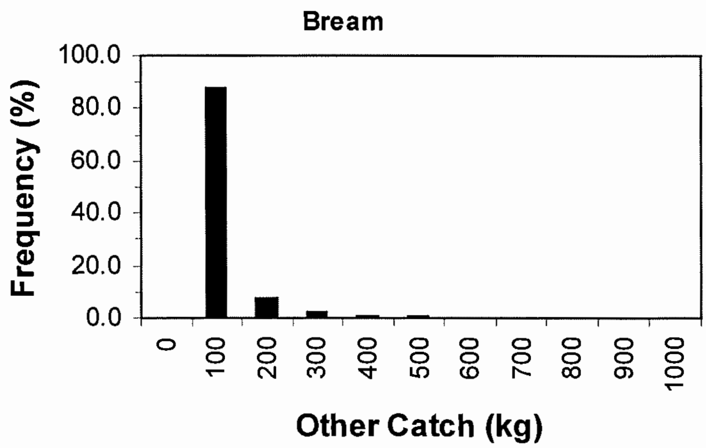



Figure 7.20 Frequency of the total flathead, whiting and tailor catches ("Other Catch" kg) for records with zero bream catch.

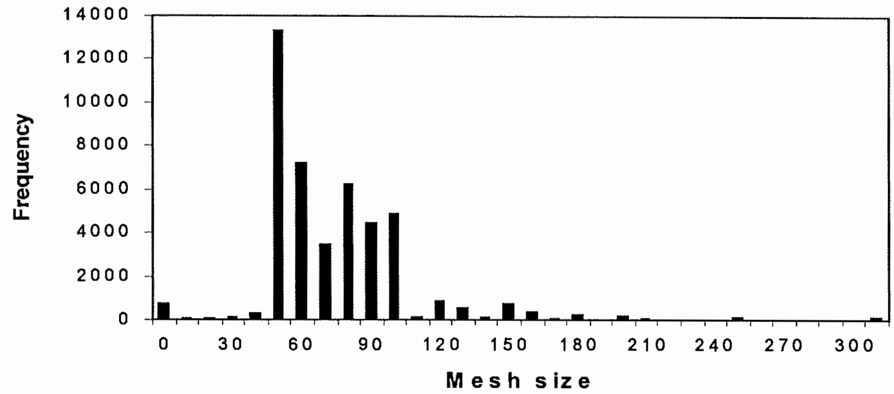



Figure 7.21 Frequencies of mesh sizes in the CFISH system from vessels that have recorded yellowfin bream catch between 1988 and 1997 within southern Queensland. The last column is for mesh sizes >300. This excludes 3520 records for the same period with no mesh sizes recorded.

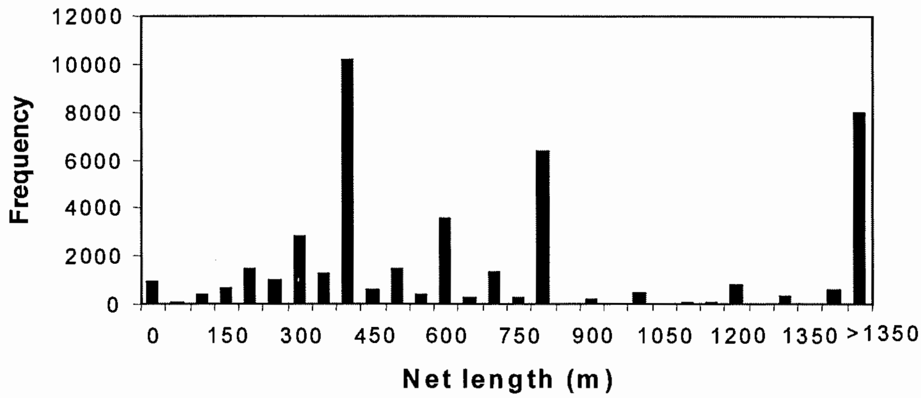



Figure 7.22 Frequency of net lengths recorded by vessels between 1988 and 1997 that have logged yellowfin bream catches in southern Queensland. The graph excludes 3988 records in the same period with no net length recorded.

### *7.1.2.4 Flathead*

Although there are six possible flathead 'species' codes in the CFISH database, only one, "flathead-unspecified" (CFISH code 296000) contains data (a total of 648 t from 1988 to 1997). There is general agreement amongst researchers and fishers that most of the catch recorded in this category is likely to be dusky flathead (*Platycephalus fuscus*) (Dichmont *et. al.*, 1999). As there is no way the catch data can be subdivided, it is assumed in the following analyses that the entire catch comprises dusky flathead.

The number of vessels that reported flathead catches has remained fairly constant over the logbook period, ranging from about 220 to 280 (Figure 7.23). Between 1988 and 1991, less than 50% of the flathead catch was allocated to a specific fishing method (Table 7.6). However this situation changed between 1991 and 1992, when more specific information was sought via the logbooks. Since then almost all of the catch has been associated with a fishing method, almost exclusively mesh netting. It is reasonable to assume that in earlier years the 'null' method would actually have been net mesh fishing as well.

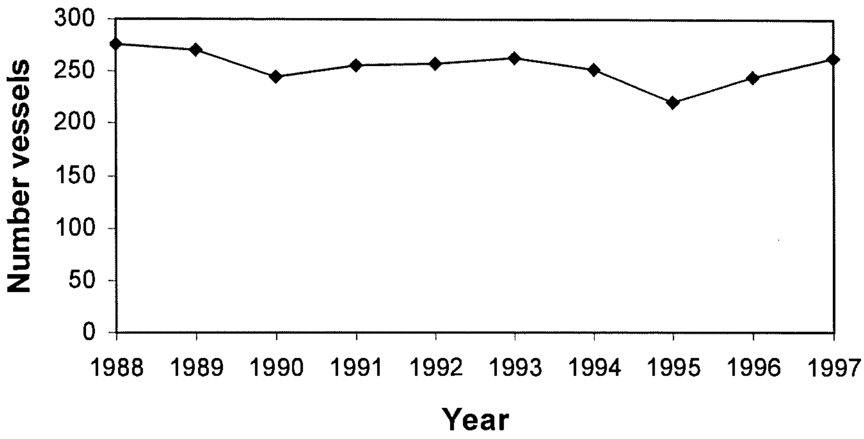



Figure 7.23 Number of vessels in a year along the Queensland coast that have recorded flathead catches.

Nearly half (45%) of the netting fleet recorded fewer than 5 days each year on which they caught flathead (Figure 7.24). A mere 10% of the vessels recorded flathead catches on more than 50 days each year.

As with the other net-caught species, there appears to be an inverse relationship between the size of the individual species catch and the summed catch of other ('bycatch') species. In more than 85% of the records where whiting, bream, flathead and tailor are recorded, less than a total of 100 kg of product was caught (Figure 7.25). However this may be an artefact of the large number of zero flathead catch records when varying quantities of other species were taken. Recent investigations by Halliday (pers. comm.) indicate that flathead are typically caught incidentally when whiting are being targeted, and they are rarely if ever targeted themselves. Daily catches of 20-30 kg would be considered 'good', and rarely would more than 50 kg be taken in a day's fishing. In more than 80% of the records identifying a flathead catch, the reported daily total catch of bream, whiting and tailor amounted to less than 100 kg (Figure 7.26).

Table 7.6 Annual catch (t) of dusky flathead by method type and total effort (days) recorded in CFish for latitude >18°.

| Year | Fishing method | | | Total Effort (days) |
|---|---|---|---|---|
| | Nil | Mesh | Other | |
| 1988 | 60 | 6 | 2 | 5336 |
| 1989 | 75 | 8 | 3 | 5681 |
| 1990 | 71 | 5 | 2 | 5285 |
| 1991 | 41 | 28 | 2 | 5326 |
| 1992 | 0 | 63 | 0 | 4177 |
| 1993 | 2 | 58 | 0 | 3814 |
| 1994 | 3 | 50 | 0 | 3506 |
| 1995 | 5 | 46 | 0 | 3535 |
| 1996 | 2 | 51 | 0 | 3578 |
| 1997 | 3 | 55 | 3 | 4442 |

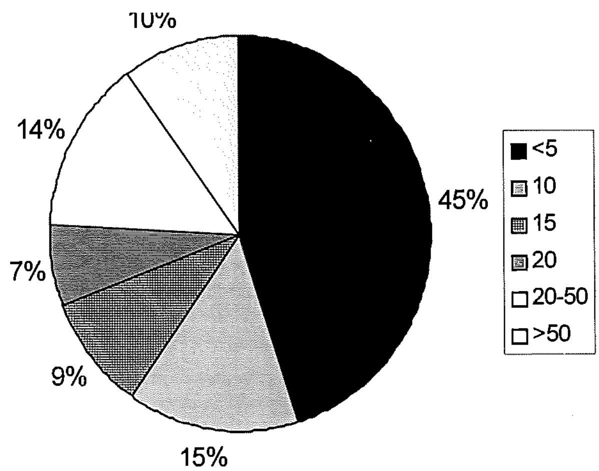



Figure 7.24 Percentage of vessels that reported a catch of flathead in latitudes south of 18° at various levels of effort (days) in an average year. Legend units are in days.

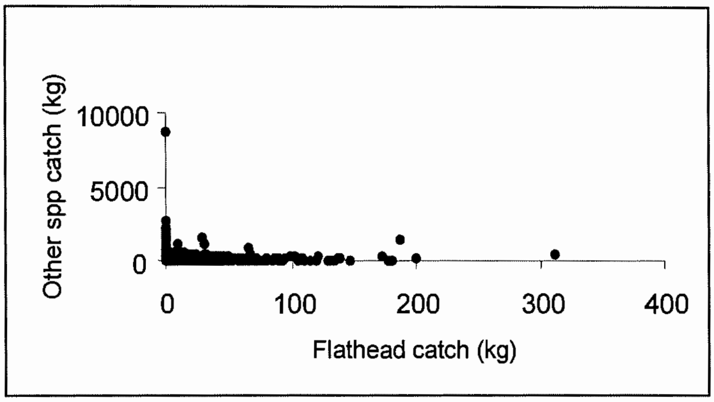



Figure 7.25 Relationship between daily catches of flathead and other species (whiting, bream and tailor) taken by randomly selected commercial net fishers in southern Queensland.

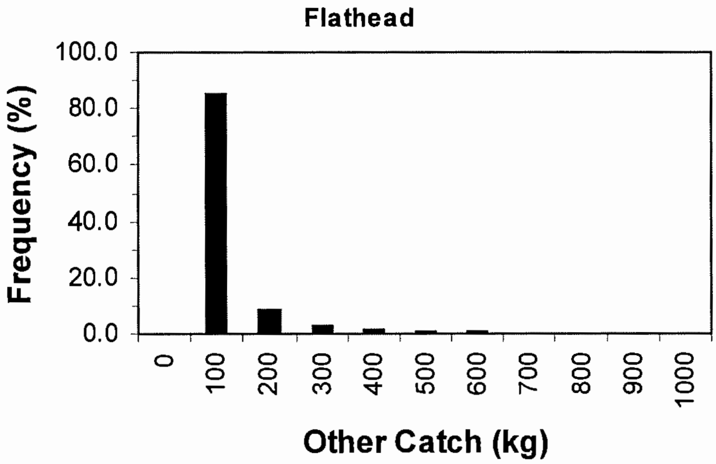



Figure 7.26 Frequency of zero flathead records with the total catch of bream, whiting and tailor for the mesh net fishery from 1988 to 1997.

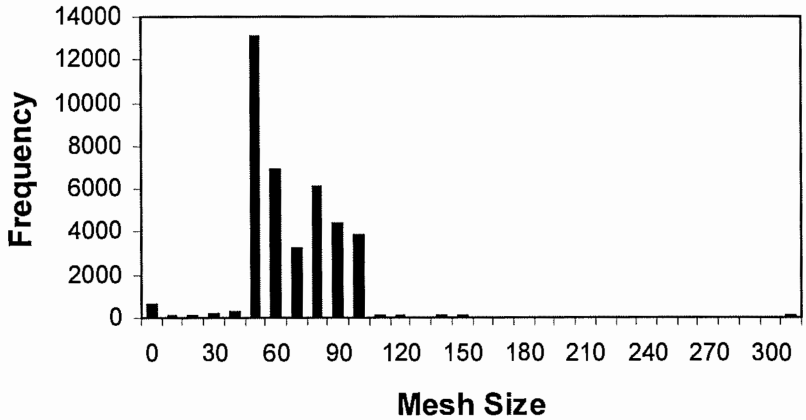



Figure 7.27 Frequency (numbers of records) of mesh size classes with flathead catch recorded in the CFISH database over the period 1988 to 1997. The last column is a greater than 300 category.

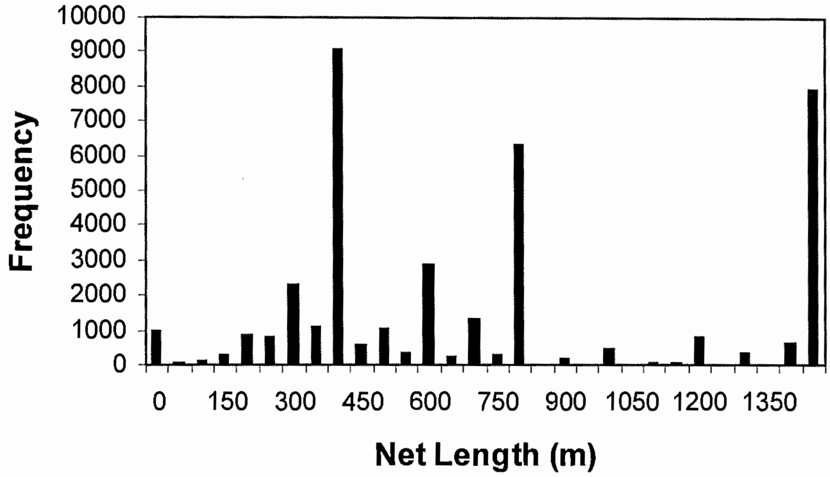



Figure 7.28 Frequency (number of records) of mesh net length categories from bream catch records in CFISH over the period 1988 to 1997. The last column is a 'greater than 1400 m' category.

### 7.1.3 **Standardised catch-per-unit-effort**

#### *7.1.3.1 Bream*

General linear modelling (GLM) was carried out to examine the parameters associated with variation in bream catch rates. Table 7.7 shows the adjusted $r^2$, AIC, degrees of freedom and sum of squares for some of the models. For the model with year and vessel sequence number as factors (Y V), the adjusted $r^2$ (0.354) is very much greater than that of the model with year (Y) as the only factor (0.013). On the other hand, for the model of year, vessel sequence number and their interaction (Y V Y*V), the adjusted $r^2$ increased by 28% on model Y V and explained 45% of the variance. In the forward selection process, using the rule that the adjusted $r^2$ had to increase by more than 5% from the previous set of simpler models, the best model was year, vessel sequence number and their interaction as factors (Y V Y*V). However there was a distinct cost in processing time between models. The smaller (Y V) model used less than an hour of computer processor time, in contrast to the larger (Y V Y*V) model which required more than 25 hours' run-time on a Pentium II to estimate the ANOVA table even without estimating parameters. Furthermore, any model tested with the interaction term (Y*V) had problems with missing values, and the least squares means were not always estimable or the matrix invertible. As a result, the model including year and vessel sequence number (Y V) is proposed, since degrees of freedom (and therefore computer time) and adjusted $r^2$ are optimised (Figure 7.29). This model explains almost 35% of the variance.

All models that explain more than 24% of the variance in catch rates include the factor vessel sequence number. Vessel sequence number is clearly a highly significant factor, even at the 99% level of confidence. The most complex model completed explains more than 50% of the variance in catch rates. The significance of both year and VSN in the model (Y, VSN) are shown in Table 7.8. The GLM model itself is highly significant at the 99% level, mainly due to the large number of observations.

Table 7.7 Degrees of freedom (d.f.), root mean square error (RMSE), model sum of squares (SS), correlation coefficient ($r^2$), adjusted $r^2$ and the AIC from various GLM models of bream commercial ln(CPUE). Y = year, S(Y) = season nested in year, A = area, V = vessel sequence number, N = net type and * denotes and interaction between factors. In all models the number of records used for the GLM was 41914.

| Factor | d.f. | RMSE | SS | $r^2$ | Adj $r^2$ | AIC |
|---|---|---|---|---|---|---|
| Y | 9 | 1.28 | 903 | 0.013 | 0.013 | -160847 |
| Y S(Y) | 19 | 1.28 | 1330 | 0.019 | 0.019 | -144577 |
| Y A | 11 | 1.23 | 5569 | 0.080 | 0.080 | -84574 |
| Y V | 784 | 1.04 | 24812 | 0.357 | 0.345 | -20407 |
| Y N | 10 | 1.22 | 7532 | 0.108 | 0.108 | -71923 |
| Y V Y*V | 2472 | 0.98 | 31829 | 0.458 | 0.424 | -6593 |
| Y V S(Y) | 794 | 1.04 | 25223 | 0.363 | 0.351 | -19698 |
| Y V A | 786 | 1.04 | 24822 | 0.357 | 0.345 | -20386 |
| Y V N | 785 | 1.04 | 25153 | 0.362 | 0.350 | -19834 |
| Y A N | 12 | 1.19 | 10329 | 0.149 | 0.148 | -58683 |
| Y A S(Y) | 21 | 1.23 | 6135 | 0.088 | 0.088 | -80499 |
| Y A Y*A | 29 | 1.23 | 6402 | 0.092 | 0.092 | -78698 |
| Y N S(Y) | 20 | 1.21 | 8060 | 0.117 | 0.116 | -69066 |
| Y N Y*N | 19 | 1.22 | 7598 | 0.109 | 0.109 | -71539 |
| Y V A V*A | 971 | 1.03 | 25644 | 0.369 | 0.354 | -18651 |
| Y V N V*N | 902 | 1.03 | 25988 | 0.374 | 0.360 | -18230 |
| Y V S(Y) V*S(Y) | 3841 | 0.94 | 35660 | 0.513 | 0.464 | 909 |
| Y A N A*N | 13 | 1.19 | 10559 | 0.152 | 0.152 | -57759 |
| Y A S(Y) A*S(Y) | 59 | 1.21 | 7182 | 0.103 | 0.102 | -73823 |
| Y N S(Y) N*S(Y) | 39 | 1.21 | 8264 | 0.119 | 0.118 | -67979 |
| Y V A N | 787 | 1.04 | 25177 | 0.363 | 0.350 | -19789 |
| Y V A S(Y) | 796 | 1.04 | 25231 | 0.363 | 0.351 | -19682 |
| Y A N S(Y) | 22 | 1.18 | 11006 | 0.159 | 0.158 | -56004 |
| Y V A N V*A*N | 1092 | 1.02 | 26795 | 0.386 | 0.369 | -16569 |
| Y V N S(Y) V*N*S(Y) | 4236 | 0.93 | 36807 | 0.530 | 0.477 | 3026 |
| Y A N Y*A*N | 49 | 1.18 | 11551 | 0.166 | 0.165 | -53922 |
| Y N A S(Y) A*N*S(Y) | 99 | 1.17 | 12623 | 0.182 | 0.180 | -50102 |
| Y V A N S | 788 | 1.03 | 25552 | 0.368 | 0.356 | -19167 |

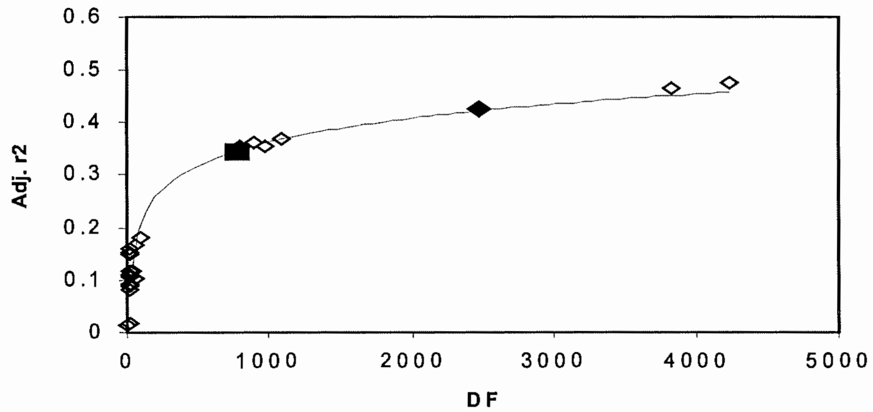



Figure 7.29 The adjusted $r^2$ (adj. r2) of generalised linear models of bream commercial catch rate data compared with model degrees of freedom (DF). DF can be seen as a surrogate for computer processing time as well. The dark diamond is the model with year, vessel sequence number and their interaction as factors. The dark square is the model with year and vessel sequence number as factors.

Table 7.8 ANOVA table of GLM with year and vessel sequence number (VSN) on yellowfin bream catch rate data.

| Factor | d.f. | Type III SS | Mean Square | F | P (>F) |
|---|---|---|---|---|---|
| Year | 9 | 239.1 | 26.57 | 24.48 | 0.0001 |
| VSN | 7 | 23909.7 | 30.85 | 28.42 | 0.0001 |

Annual changes in predicted CPUE from the GLM model (standardised by Y, VSN) are given in Figure 7.30, along with the unstandardised mean CPUEs from the same data set. The slope of a linear fit to the standardised data points is not significantly different from zero, whereas the unstandardised catch rate data display a significant positive trend, at least until 1995.

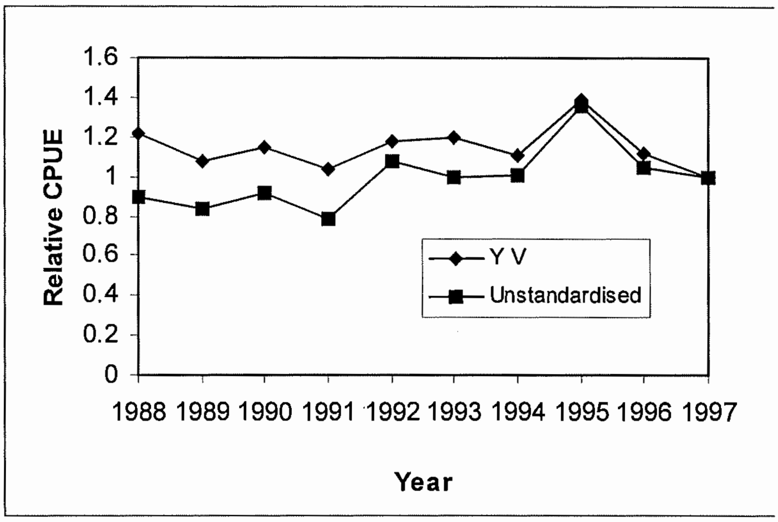



Figure 7.30 Results of GLM model with year and VSN as factors compared to unstandardised catch rate data for bream. For comparison, data are relative to 1997.

Most of the State's catch of bream is taken from the Moreton Bay area. Moreton Bay also yields a higher catch rate than elsewhere. Estimates of relative regional catch rate of bream from a GLM of *ln*(CPUE) with year and area as factors are 0.443, 0.875 and 0 for Hervey Bay, Moreton Bay and other regions respectively, both Hervey Bay and Moreton Bay being significantly different from 0 ($p<0.001$). In other words, compared to catch rates in "other areas", CPUEs in the Hervey Bay region were 44% higher, and those in Moreton Bay 87% higher.

Seasonal changes in catch rate were examined by a GLM of *ln*(CPUE) with year and two seasons nested in year as factors. The seasonal effect was highly significant ($p<0.0001$). In most years (1988, '91, '92, '94, '95 and '96) the estimated bream catch rate over the winter months (May-August incl.) was consistently higher than during the remainder of the year. These winter months coincide with a spawning migration of bream to the surf bars from the estuaries (Kerby and Brown, 1994).

### *7.1.3.2 Dusky flathead*

The results from a number of models tested to determine which factors explain the variability in ln(CPUE) are shown in Table 7.9. As with the yellowfin bream analyses, the model with year and vessel sequence number as factors (Y V) explained a very much larger amount of the variance than did the model with year (Y) as the only factor (adjusted $r^2$ values 0.411 and 0.019 respectively). By incorporating the year * vessel interaction effect (Y*V), the adjusted $r^2$ increased by 14% on the simpler model (Y V), and explained 45% of the variance. In the forward selection process using the 5% rule, the best model was year, vessel sequence number and their interaction as factors (Y V Y*V).

As with the bream analysis, the smaller (Y V) model used less than an hour's computer processor time, compared to the larger model (Y V Y*V) which required in excess of 20 hr run-time on a Pentium II

Table 7.9 Degrees of freedom (d.f.), root mean square error (RMSE), model sum of squares (SS), correlation coefficient ($r^2$), adjusted $r^2$ (Adj. $r^2$) and the AIC from various GLM models of bream commercial ln(CPUE). Y = year, S(Y) = season nested in year, A = area, V = vessel sequence number, N = net type and * denotes and interaction between factors. In all models the number of records used for the GLM was 24521.

| Factor | d.f. | RMSE | SS | $r^2$ | Adj. $r^2$ | AIC |
|---|---|---|---|---|---|---|
| Y | 9 | 1.07 | 562 | 0.020 | 0.019 | -92572 |
| Y S(Y) | 39 | 1.06 | 847 | 0.030 | 0.028 | -82461 |
| Y A | 11 | 1.06 | 1094 | 0.039 | 0.038 | -76237 |
| Y V | 688 | 0.83 | 12156 | 0.428 | 0.411 | -15830 |
| Y N | 10 | 1.07 | 580 | 0.020 | 0.020 | -91780 |
| Y V Y*V | 1796 | 0.78 | 14419 | 0.508 | 0.469 | -9428 |
| Y V S(Y) | 718 | 0.82 | 12296 | 0.433 | 0.416 | -15490 |
| Y V A | 690 | 0.82 | 12212 | 0.430 | 0.414 | -15714 |
| Y V N | 689 | 0.83 | 12160 | 0.428 | 0.412 | -15820 |
| Y A N | 12 | 1.05 | 1551 | 0.055 | 0.054 | -67669 |
| Y A S(Y) | 41 | 1.05 | 1364 | 0.048 | 0.047 | -70756 |
| Y N S(Y) | 40 | 1.06 | 870 | 0.031 | 0.029 | -81790 |
| Y V A V*A | 802 | 0.82 | 12455 | 0.439 | 0.420 | -15007 |
| Y V A Y*V | 1798 | 0.78 | 14447 | 0.509 | 0.470 | -9376 |
| Y V N V*N | 829 | 0.82 | 12513 | 0.441 | 0.421 | -14839 |
| Y V N Y*V | 1962 | 0.78 | 14674 | 0.517 | 0.475 | -8665 |
| Y V N Y*V Y*N | 2305 | 0.78 | 15016 | 0.529 | 0.480 | -7416 |
| Y V S(Y) V*S(Y) | 3778 | 0.75 | 16738 | 0.590 | 0.515 | -1806 |
| Y V S(Y) Y*V | 1826 | 0.78 | 14514 | 0.511 | 0.472 | -9207 |
| Y V S(Y) Y*V V*S(Y) | 3778 | 0.75 | 16738 | 0.590 | 0.515 | -1806 |
| Y A N A*N | 13 | 1.05 | 1555 | 0.055 | 0.054 | -67610 |
| Y A S(Y) A*S(Y) | 119 | 1.04 | 1800 | 0.063 | 0.059 | -63807 |
| Y N S(Y) N*S(Y) | 79 | 1.06 | 1056 | 0.037 | 0.034 | -76966 |
| Y V Y*V | 1796 | 0.78 | 14420 | 0.508 | 0.469 | -9426 |
| Y A Y*A | 29 | 1.05 | 1267 | 0.045 | 0.043 | -72590 |
| Y N Y*N | 19 | 1.06 | 651 | 0.023 | 0.022 | -88939 |
| Y V A N | 691 | 0.82 | 12212 | 0.430 | 0.413 | -15710 |
| Y V A S(Y) | 720 | 0.82 | 12346 | 0.435 | 0.417 | -15385 |
| Y A N S(Y) | 42 | 1.04 | 1841 | 0.065 | 0.063 | -63400 |
| Y V A N V*A*N | 894 | 0.82 | 12670 | 0.446 | 0.425 | -14403 |
| Y V N S(Y) V*N*S(Y) | 4220 | 0.74 | 17141 | 0.604 | 0.521 | -339 |
| Y V A Y*V*A | 1959 | 0.78 | 14627 | 0.515 | 0.473 | -8749 |
| Y A N Y*A*N | 49 | 1.04 | 1794 | 0.063 | 0.061 | -64016 |
| Y N A S(Y) A*N*S(Y) | 694 | 0.82 | 12269 | 0.432 | 0.415 | -15590 |

even without estimating parameters. Taking into account the problems associated with missing values, the occasional inability to invert the matrix or estimate the least squares means, and the computer resources required (Figure 7.31), the simpler model, which still explains 41% of the variance, is recommended.

All models that explained more than 40% of the variance included the factor vessel sequence number, and (as in the situation with the bream fishery) vessel sequence number was a highly significant factor. The most complex model explained over 50% of the variance, but this was little more than the simple (Y V) model explained. Table 7.10 shows an ANOVA tabulation of the results of running the model (Y V), demonstrating the high statistical significance of both year and VSN factors. The GLM model itself was highly significant at the 99% level, mainly due to the large number of observations.

Table 7.10 ANOVA table of GLM with year and vessel sequence number (VSN) on dusky flathead catch rate data.

| Factor | d.f. | Type III SS | Mean Square | F | P (>F) |
|---|---|---|---|---|---|
| Year | 9 | 72.0 | 8.00 | 11.74 | 0.0001 |
| VSN | 679 | 115972. | 17.08 | 25.07 | 0.0001 |

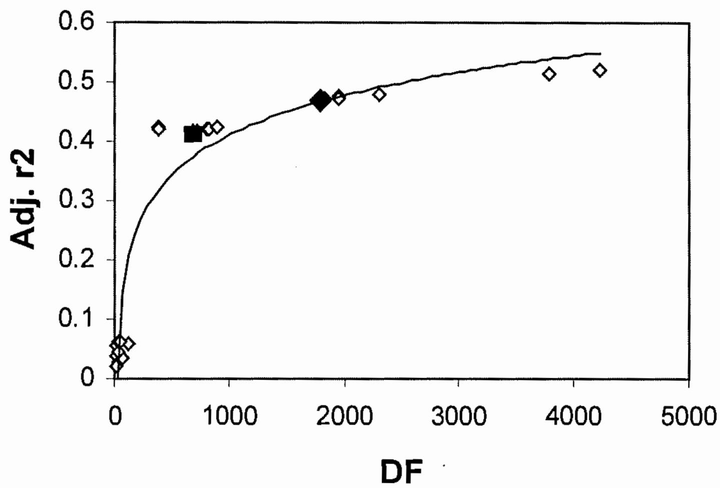



Figure 7.31. The adjusted $r^2$ (adj. r2) of generalised linear models of flathead commercial catch rate data as *ln*(CPUE) compared with model degrees of freedom (DF). DF can be seen as a surrogate for computer processing time as well. The dark diamond is the model with year, vessel sequence number and their interaction as factors. The dark square is the model with year and vessel sequence number as factors.

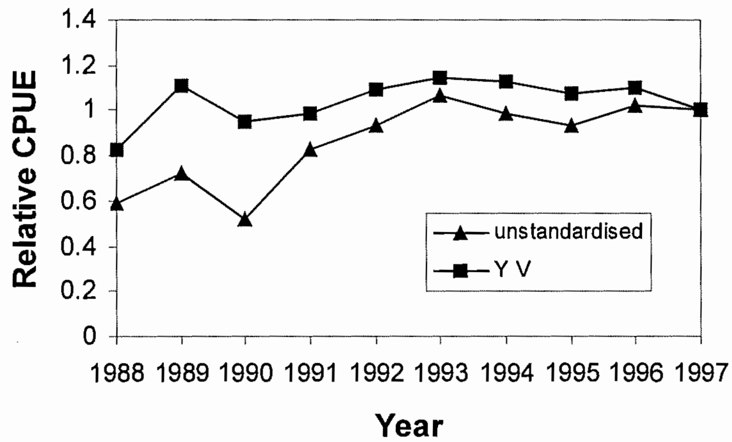



Figure 7.32 Results of GLM model giving relative CPUE with year (Y) and vessel sequence number (VSN) as factors compared to unstandardised relative flathead catch rate data. For comparison, data are relative to 1997.

Standardisation of annual CPUEs for dusky flathead indicates that early raw CPUEs were underestimated with respect to those later in the logbook period. This can be seen in Figure 7.32, which shows annual trends in both standardised (predicted from the GLM) and unstandardised (raw) catch rate data. The non-standardised data suggest that there has been an overall increase in catch rates, at least up until 1993, which might be attributed to increasing stock size. However the model predictions show a much less optimistic trend—essentially a line with a slope not significantly different from zero.

Most of the flathead catch comes from Moreton Bay, which also produces higher catch rates than elsewhere south of 18° latitude. Estimates of relative flathead catch rate from a GLM of *ln*(CPUE) with year and area as factors are 0, 0.126 and 0.355 for other areas, Hervey Bay and Moreton Bay respectively. This indicates that the catch rates of flathead in Hervey Bay and Moreton Bay are considerably higher than those in 'other areas' (by 13% and 35% respectively, though this 'rate' refers only to catches in which flathead are caught). Seasonal analysis of dusky flathead CPUE using GLM showed a highly significant effect, with the highest catch rates generally occurring during winter months.

## 7.2 Assessment of otolith-based age determination methods

### 7.2.1 Comparison of ring counts between methods and readers

#### *7.2.1.1 Bream*

Counts of growth checks in bream otoliths were highly consistent between first and second readings, both within and between readers. This applied both to sectioned and whole otoliths (average per cent error [APE] = 1.1% and 4.4% respectively), and for both readers (APE = 3.9% and 1.6%). In this section we assume the growth checks or rings to be of annual origin, and thus a direct indicator of age.

There was also a high level of agreement between whole and sectioned readings, regardless of reader or reading number (Figure 7.33). Averaged over two readings each by two readers, the percent agreement amounted to nearly 73%. However on both occasions each of the readers tended to count more checks in sectioned otoliths than in their whole counterparts, as evidenced by the slight left skewness of all graphs in Figure 7.33. Bowker's (1948) test revealed that this bias was statistically significant ($p<0.0001$). The tendency to estimate older ages in sectioned than whole otoliths increased with age (Appendix Table 13.4.1).

The lowest average monthly percent agreements between age estimates were recorded from otoliths collected in July and October-December. This approximates the periods (July and December) when the lowest average readability indices were recorded.

The relationship between otolith weight and estimated age in whole otoliths ($r = 0.794$) was not significantly different from that in sectioned otoliths ($r = 0.791$; $p = 0.890$).

The correlation between estimated age and otolith weight did not vary with otolith readability. The relationship between otolith weight ($W_o$) and age in yellowfin bream is described by the equations:

$$\text{Age} = -0.7260 + 80.84\ W_o \text{ (whole otoliths), and}$$
$$\text{Age} = -0.8161 + 85.85\ W_o \text{ (sectioned otoliths).}$$

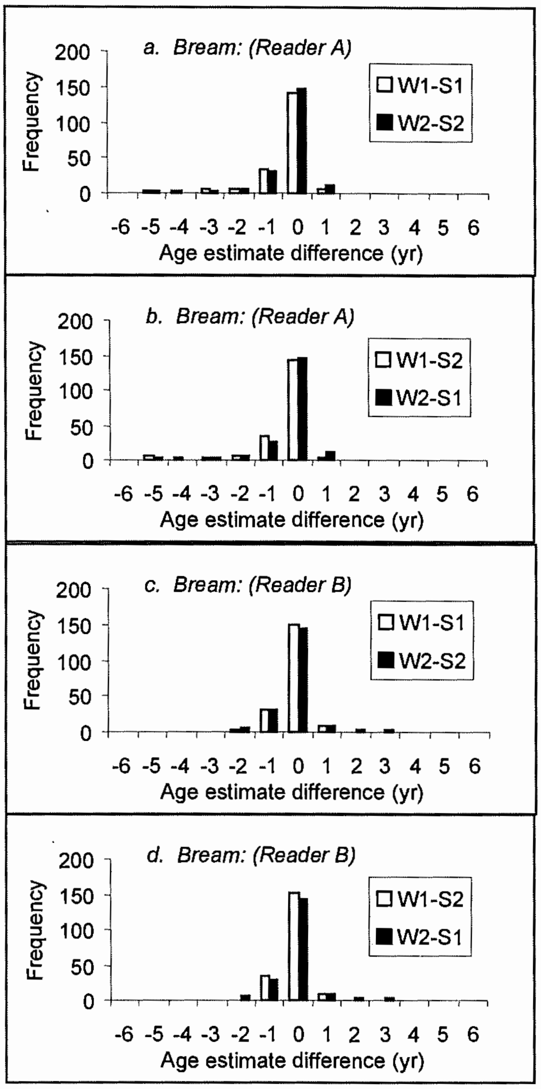



Figure 7.33 Age estimate differences between whole and sectioned bream otoliths for Readers A (a, b) and B (c,d). Legend symbols: W = whole, S = sectioned, 1 & 2 = first and second readings.

#### *7.2.1.2 Sand Whiting*

There was a greater degree of variation in sand whiting than bream between the first and second reading age estimates. This variation was greater for whole otoliths (APE = 30 %) than sectioned (APE = 17%). The more experienced reader (APE = 10.5%) was more consistent than the other (22.7% APE) between sectioned readings but there was no difference between them for whole readings (29.7% vs. 29.4% APE), which suggests that some of the variation between sectioned readings for the less experienced reader was due to learning. Similarly, there was greater agreement between readers for sectioned (19.9% APE) than for whole (59.4% APE) readings.

There was a percentage agreement of 33.6% between whole and sectioned readings, averaged over 2 readings each by 2 readers. Reader A registered a higher level of agreement in ring counts between the two methods than did Reader B (Figure 7.34). There was, nevertheless, a spread of age estimate differences ranging from –3 to +6 (Figure 7.34 a, b).

The modal age estimate difference between methods was zero for Reader A (Figure 7.34 (a), (b)) and +1 for Reader B (Figure 7.34 (c), (d)). This indicates that Reader B was interpreting an additional growth check in the whole otoliths that was not evident in the sections. The figure shows that this (counter-intuitive) situation was more pronounced in the second set of readings than in the first. Because of this, the correlation between whole and sectioned readings was relatively low at 0.776. Bowker's (1948) test of symmetry confirmed that the bias towards counting more translucent zones in whole than sectioned otoliths was highly significant ($p<0.0001$) (Appendix Table 13.4.2), particularly where the sectioned count was low.

There was no distinct seasonal pattern in the agreement between whole and sectioned otolith age estimates. However, a complete yearly cycle was not available in the data, as the *S. ciliata* otoliths used in the experiment were all collected between March and August.

Not surprisingly, the relationship between otolith weight and estimated age was significantly different ($p = 0.24$) between sectioned otoliths ($r = 0.856$) and whole otoliths ($r = 0.832$). Correlation between the number of rings and otolith weight was lower for otoliths of lower readability. The relationship between otolith weight and estimated age is described by the equations:

Age = $0.462 + 12.33\ W_0$ (whole otoliths) and
Age = $-0.257 + 13.46\ W_0$ (sectioned otoliths).

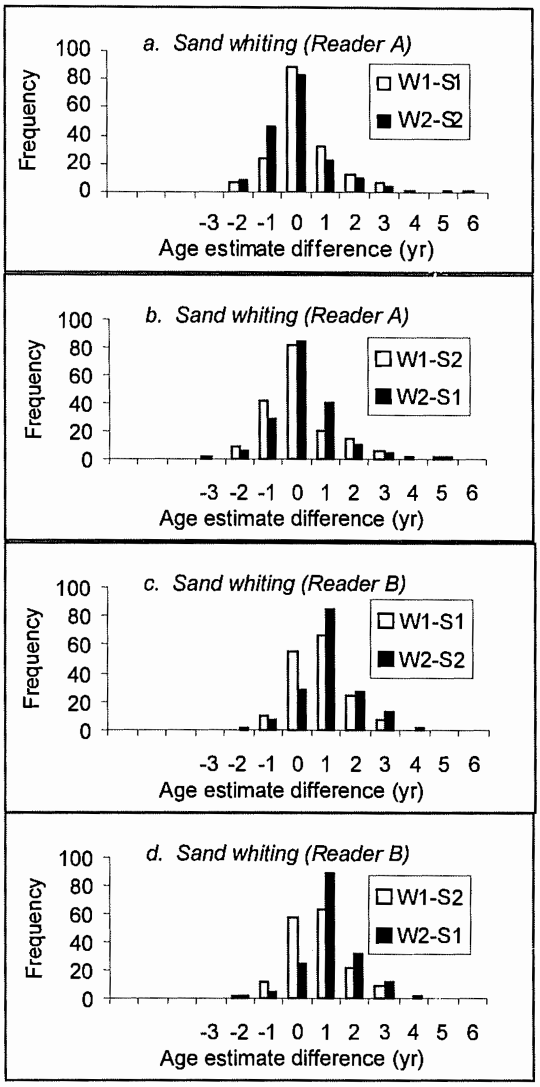



Figure 7.34 Age estimate differences between whole and sectioned sand whiting otoliths for Readers A (a, b) and B (c,d). Legend symbols: W = whole, S = sectioned, 1 & 2 = first and second readings.

### *7.2.1.3 Golden-Lined Whiting*

Age estimates from whole and sectioned otoliths of *Sillago analis* showed similarities in consistency with those of *S. ciliata,* but were characterised by greater bias. Again, ages estimated from whole otoliths tended to be higher than those from sections, as is evident from the general right-skewness of the graphs in Figure 7.35. The discrepancy between estimates from the two methods ranged from –2 to +4 years, with the bulk of the sample lying in the zero and +1 age difference categories.

Bowker's (1948) test of symmetry confirmed that the bias towards counting more translucent zones in whole than sectioned otoliths was highly significant ($p<0.0001$) (Appendix Table 13.4.3), particularly where the sectioned count was low.

Both readers tended to ascribe greater ages to whole otoliths than to sectioned otoliths, the differences being more marked in the second reading than in the first (Figure 7.35).

### *7.2.1.4 Dusky Flathead*

There was considerable variation between first and second estimates of dusky flathead age, both from sectioned otoliths (APE = 17%) and whole (APE = 17% ). Both readers registered this variation in estimated age between first and second readings (APE = 24% and 10% respectively).

The agreement between whole and sectioned readings, averaged over 2 readings each by 2 readers, was 58.25%. However, Bowker's (1948) test of symmetry showed a significant bias ($p<0.0001$) towards higher growth-check counts in whole than in sectioned otoliths (Appendix Table 13.4.4). The data showed some error occurring in both directions, though this varied between readers and readings (Figure 7.36). Both readers tended to ascribe the same age to a given otolith, regardless of whether it

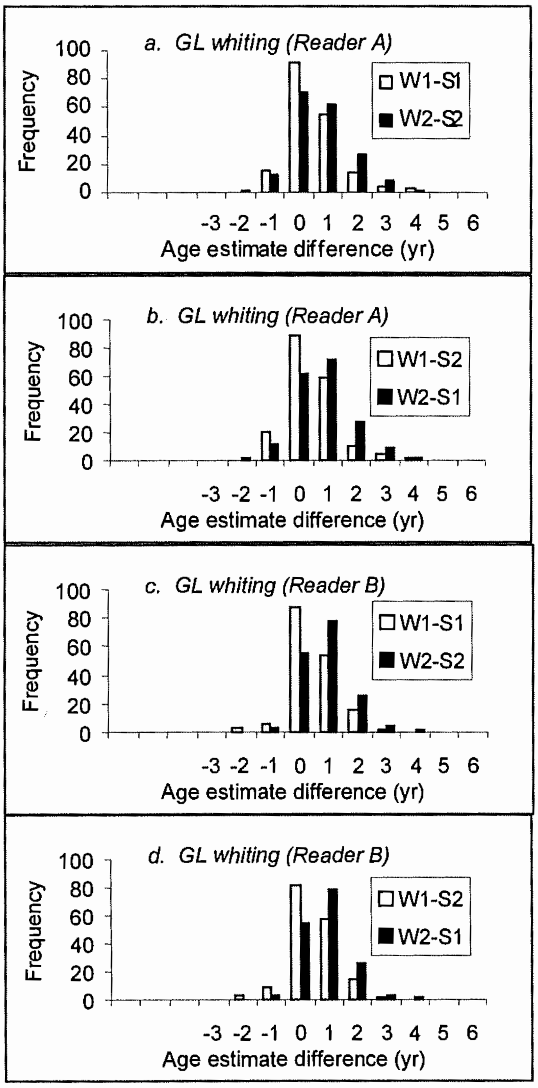



Figure 7.35 Age estimate differences between whole and sectioned golden-lined whiting otoliths for Readers A (a, b) and B (c,d). Legend symbols: W = whole, S = sectioned, 1 & 2 = first and second readings.

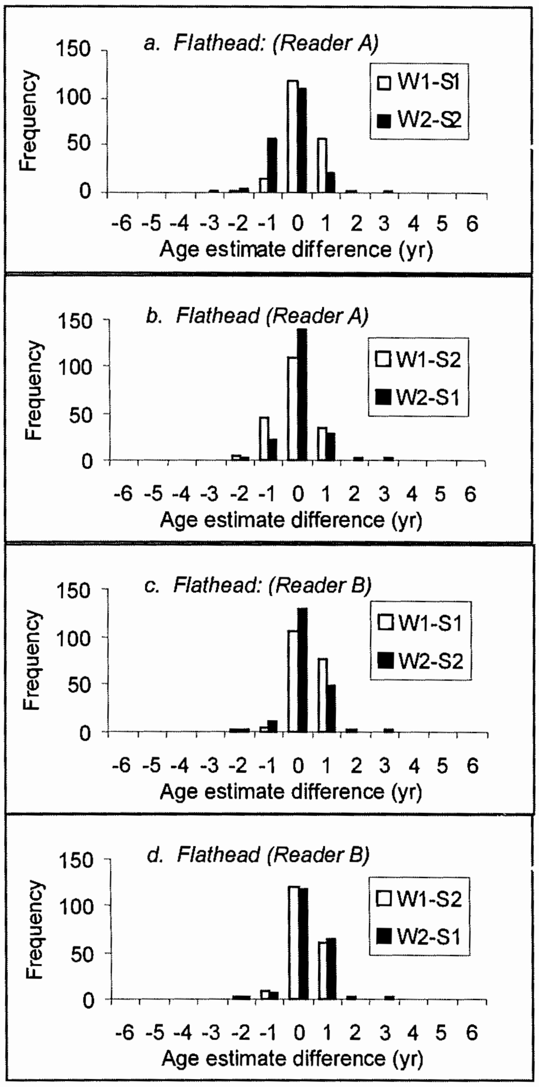



Figure 7.36 Age estimate differences between whole and sectioned flathead otoliths for Readers A (a, b) and B (c,d). Legend symbols: W = whole, S = sectioned, 1 & 2 = first and second readings

had been examined whole or sectioned. However there was some bias, as a significant number of the whole otolith samples were given greater ring counts than sections, especially by Reader B. Reader A did the same on the first reading, but counted more rings in sectioned otoliths at the second reading. There was no observable pattern by month in average agreement between whole and sectioned readings. However, all the dusky flathead otoliths in the experiment were collected between March and August, so there was not a complete yearly cycle in the data set.

The relationship between otolith weight and the number of observed translucent zones was tighter ($p<0.0001$) for whole ($r = 0.890$) than for sectioned ($r = 0.811$) otoliths. Correlation between estimated age and otolith weight was lower for otoliths of lower readability, the relationships being described by the equations:

$$\text{Age} = 0.232 + 30.2\ W_o \text{ (whole otoliths), and}$$
$$\text{Age} = 0.163 + 29.2\ W_o \text{ (sectioned otoliths).}$$

### *7.2.1.5 Tailor*

There was higher degree of variation between age estimates for sectioned (13.9% APE) than for whole (8.8% APE) tailor otoliths. Reader A showed more variation (17.7% APE) than Reader B (5.0% APE). It should be noted here that Reader B scored many more otoliths as being unreadable than did Reader A (e.g. 49.5% vs. 13.5% on the first reading), and there is therefore a considerable difference in the sizes of the samples between the two readers (e.g. Figure 7.37 (a) and (c)).

On average (over 2 readings each by 2 readers) the percentage agreement between rings counts from whole and sectioned readings was 46% (Figure 7.37).

The age estimate differences were not symmetrical about zero, with some sectioned otoliths yielding higher counts than their whole counterparts, producing a left-skewed frequency distribution (Figure 7.37). This effect was greater for Reader A than Reader B, but was reasonably consistent between the first and second readings. Bowker's (1948) test of symmetry confirmed that, averaged over readings and readers (Appendix Table 14.5), the bias was statistically significant ($p<0.0001$).

In 536 age estimate pairs (sectioned and whole for 2 readers by 2 readings) where ages were estimated on both readings, 147 were higher when sectioned and 43 were higher as whole otoliths. The bias was consistent for both readers and readings. There was no significant difference in average agreement between whole and sectioned readings between the months of August and October.

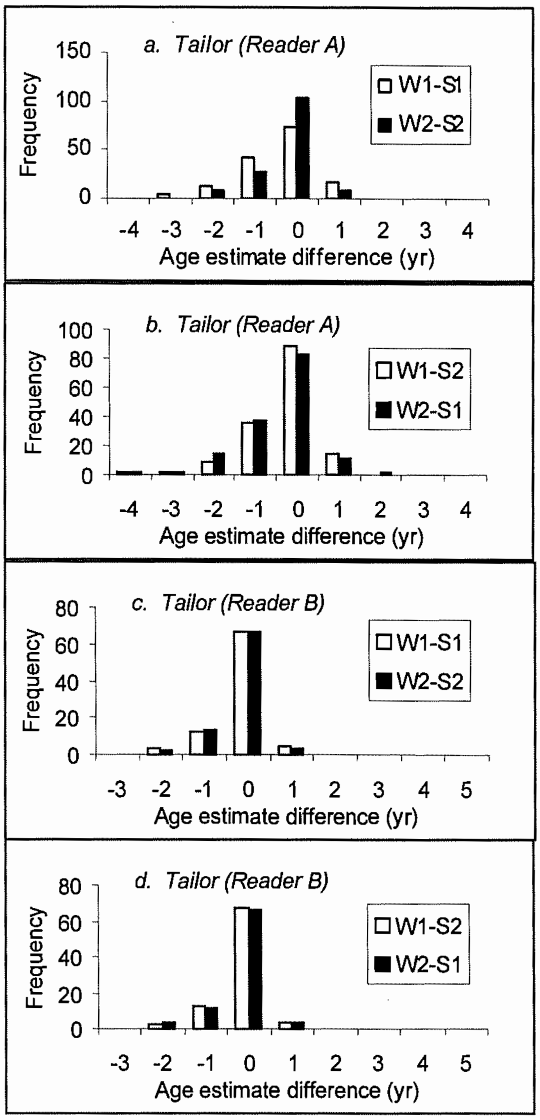



Figure 7.37 Age estimate differences between whole and sectioned tailor otoliths for Readers A (a, b) and B (c,d). Legend symbols: W = whole, S = sectioned, 1 & 2 = first and second readings.

While both readers broadly agreed on interpreting the internal structure of the tailor otoliths, suspicions were raised about their accuracy after the catch-at-age data were used to estimate total mortality rates (see Section 7.4.3.5). The estimates of Z seemed excessive, and

Table 7.11 Coefficients of correlation between pairs of readings of a sample of 100 sectioned tailor otoliths examined by researchers at DPI Queensland (Readers A and B) and W.A. Fisheries (Readers C and D). Note that the Queensland readings were replicated (reading number in parentheses), and that the sample size was reduced in some pairwise comparisons because of otoliths considered unreadable by one or other of the readers.

| | Reader | | | | |
|---|---|---|---|---|---|
| | A (1) | A (2) | B (1) | B (2) | C |
| A (2) | 0.5985 | | | | |
| B (1) | 0.4310 | 0.6436 | | | |
| B (2) | 0.3893 | 0.7483 | 0.7057 | | |
| C | 0.3188 | 0.4874 | 0.5090 | 0.6364 | |
| D | 0.1857 | 0.5504 | 0.2376 | 0.5358 | 0.5433 |

prompted us to seek confirmation of our age estimates from another source. As the National Ageing Facility (Queenscliff) had at that stage not gained any experience with otoliths of this species we sought assistance from Mr R Steckis, currently undertaking a PhD study (including age and growth estimation) of tailor in WA waters. Mr Steckis kindly agreed to examine 100 otolith sections, and also arranged for a second reader to examine the sections.

The results of this otolith exchange showed a lack of conformity between the Qld and WA readers. Both of the WA readers tended to count more growth checks than the Qld readers. Moreover one of the WA readers regularly counted more than his colleague. This lack of consistency is apparent from Table 7.11, which provides a simple pairwise matrix of correlation coefficients between readers and (in the case of Queensland researchers) between readings. The lowest correlations were registered between Reader D and the first readings of Readers A and B, while the highest were between Readers A and B (second series) and between Reader B's replicated estimates.

The relationship between otolith weight and estimated age was tighter ($p = 0.01$) for whole ($r = 0.602$) than for sectioned ($r = 0.410$) otoliths. The correlation between estimated age and otolith weight was lower for otoliths of lower readability, the relationship being described by the equations:

Age = $-0.316 + 59.02\ W_o$, (whole otoliths) and
Age = $0.0811 + 57.85\ W_o$ (sectioned otoliths).

### 7.2.2 Comparison of readability estimates between methods and readers

Otoliths from all five species (*A. australis*, *S. ciliata*, *S. analis*, *P. saltatrix* and *P. fuscus*) were read and interpreted whole, then again after sectioning. Most showed distinct banding patterns. In each species the broader translucent zones (as appearing under reflected light) were interpreted to be the growth zones, and the milky bands to be the growth checks.

Of the five species, *A. australis* showed the most distinct internal structure. The growth zones were opaque and the growth checks thin distinct milky bands. While the distance between growth checks in some bream otoliths was irregular, each individual growth check was counted irrespective of the width of the growth zone.

*P. saltatrix* otoliths were thin and elongated. Growth zones were broad and appeared as bundles of crystalline material. The growth checks were obvious milky bands.

*P. fuscus* otoliths were also elongated, but thicker than those of *P. saltatrix*. They were opaque in appearance. In most cases the thin milky checks were easy to distinguish from the opaque growth zones. There was some crystalline structure visible within the growth zone.

*S. ciliata* and *S. analis* otoliths were thick and rounded, making it almost impossible to interpret them whole. Sections of both species were similar in appearance. Some sections showed good definition, displaying opaque growth zones and thin milky growth checks. However, others were more difficult to interpret, because of poor band definition and difficulty in determining the first growth check.

In this section we examine the differences in readability index (RI) of whole and sectioned otoliths as assessed by two readers (identified as A and B) on two independent occasions. The assessment is designed to indicate whether there are consistent differences between species in the perceived ease of reading otoliths, and whether there was any difference in the ease of reading whole otoliths vs. thin sections.

#### *7.2.2.1 Bream*

Consistency was high between the repeated readings of whole otoliths by each of the two readers. This is shown by the peaked distribution of score differences in Figure 7.38(a), where, for each reader, about 75% of the individual RI scores were identical between occasions 1 and 2, and very few differed by more than ±1 unit. Fig. 7.38(b) shows that the same otoliths were, by and large, scored similarly by the two readers. In other words, readers A and B agreed as to which otoliths were straightforward and which were difficult to interpret. Both readers also agreed that the internal growth structures of by far the majority of whole otoliths were quite clear and unambiguous (Figure 7.38 (c) and (d)). Reader A classified no otoliths with an RI less than three, and Reader B scored very few less than three.

Readability assessments for sectioned bream otoliths were less consistent. Each reader varied more in classifying the readability of the sections than whole otoliths, as indicated by the greater number of score differences in the -1 and +1 categories (Figure 7.39 (a)). Likewise, there were more differences between readers, with over 40% of the scores differing by at least ±1 (Figure 7.39 (b)). Reader A rated almost all sections 4 or 5, with high precision between reading occasions (Figure 7.39 (c)). Reader B also scored the great majority of sections as 4 or 5, but showed a tendency to be more confident on the second reading (Figure 7.39 (d)). Neither observer scored any sections as being unreadable (RI = 1).

#### *7.2.2.2 Sand whiting*

The interpretation of sand whiting (*Sillago ciliata*) otoliths was less straightforward than that of bream. Both readers' (particularly Reader A) readability estimates for whole otoliths varied between the first and second readings (Figure 7.40 (a)), with a significant number of score-pairs differing by up to 2 units. This difference was systematic, and a comparison of the scores between readers (Fig. 7.40 (b)) shows A tending to assign more optimistic RIs than B.

Reader A classed most whole sand whiting otoliths as RI = 2 or 3 (equal proportions), while the modal RI for Reader B was 2 (Fig. 7.40 (c and d)). These low scores indicate the presence of interpretable internal structure, but relatively low confidence in the reader's ability to estimate age. Differences between readings for sectioned sand whiting otoliths showed a similar pattern (Fig. 7.41 (a)), with A showing less precision than B. In the between-reader comparison (Fig. 7.41 (b)) the RIs of Reader A were biased lower than B, suggesting that the former was less confident in the age estimates than the latter. This is confirmed by the frequency-distribution of readability scores which show modal values of 4 for Reader A (Fig. 7.41 (c)) and 5 for Reader B (Fig. 7.41 (d)). Both readers considered sectioned sand whiting otoliths to be more readable than the whole otoliths, but the difference was far more marked in one reader's assessment than the other's.

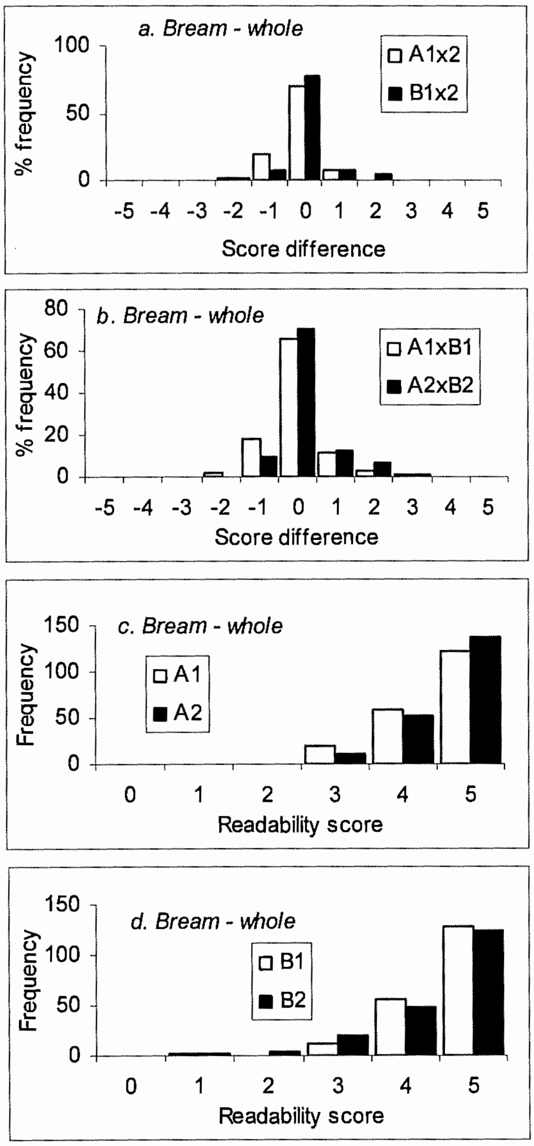



Figure 7.38. Whole bream (*Acanthopagrus australis*) otolith readability comparisons (a & b) and distribution of readability scores (c & d).

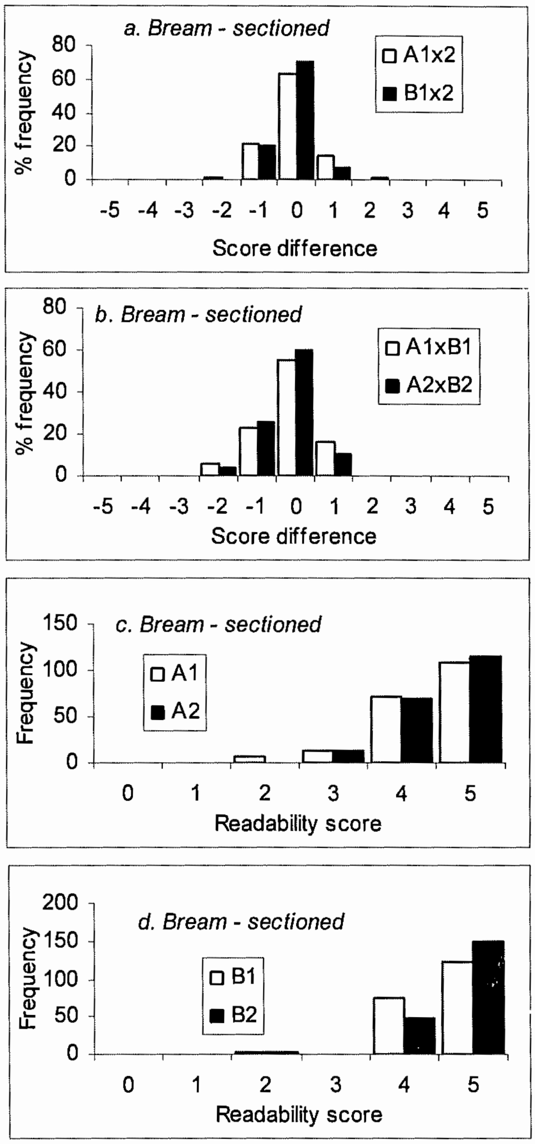



Figure 7.39. Comparison of the readability of sectioned otoliths from bream (*A.. australis*) (a & b), and distribution of readability scores (c & d).

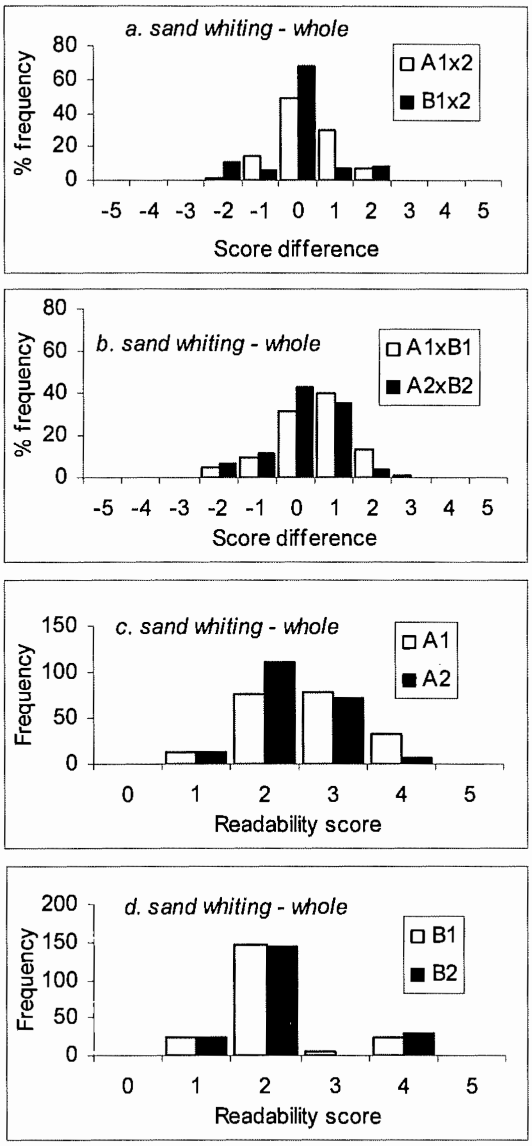



Figure 7.40. Comparison of the readability of whole otoliths from sand whiting (*Sillago ciliata*) (a and b), and distribution of readability scores (c and d).

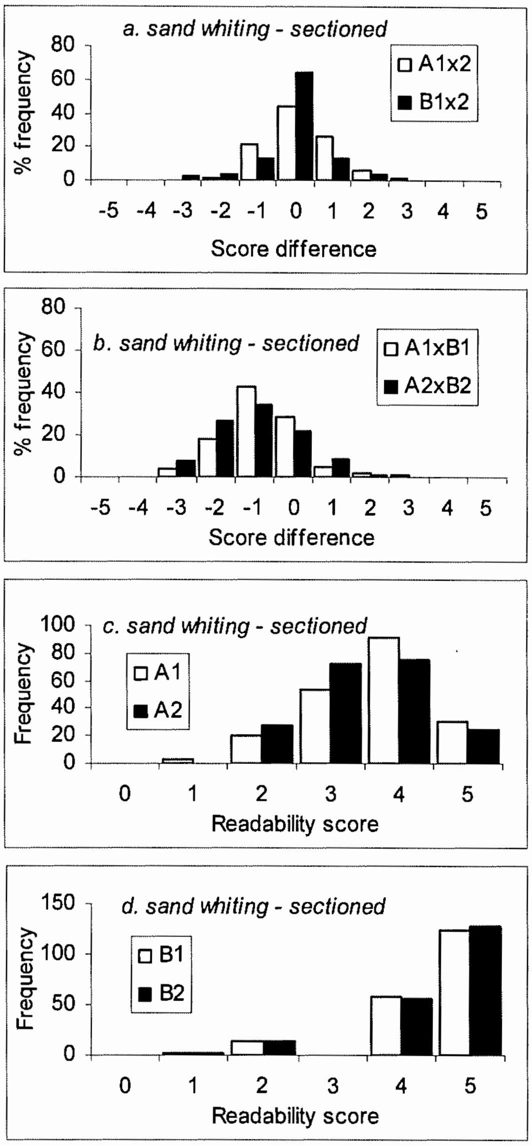



Figure 7.41 Comparison of the readability of sectioned otoliths from sand whiting (*Sillago ciliata*) (a and b), and distribution of readability scores (c and d).

### *7.2.2.3 Golden-Lined Whiting*

The general form of golden-lined whiting (*Sillago analis*) otoliths resembles that of its congener *S. ciliata.* They also show considerable similarity in the clarity and interpretability of their internal structure (Figures 7.42 and 7.43).

Reader B again was more consistent than A in assessing readability of whole otoliths between two independent readings (Fig. 7.42 (a)). As with the other summer whiting species, Reader B assigned lower RI values than A (Fig. 7.42 (b)). This is reflected in the higher modal RI score (3) attributed by A than B (modal RI = 2) on both occasions (Fig. 7.42 (c) and (d)).

Successive readings of otolith sections by Reader B were more consistent than those of Reader A (Fig. 7.43 (a)). At the first reading Reader B was inclined generally to be more confident of the ring counts than was Reader A, but at the second the situation was reversed, with A being the more confident (Fig. 7.43 (b)). This situation was due primarily to Reader A's increasing confidence with the second reading (Fig. 7.43 (c)) rather than a significant decrease in the average score of Reader B (Fig. 7.43 (d)). In contrast to the situation for whole otoliths, neither reader assigned a score of 1 (unreadable) to any of the thin sections.

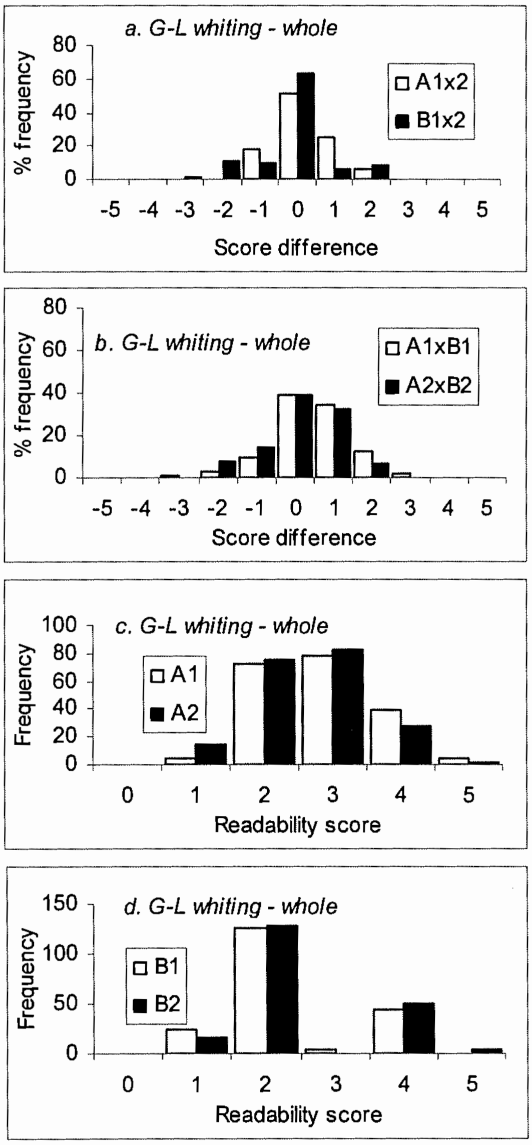



Figure 7.42 Comparison of the readability of whole otoliths from golden-lined whiting (*Sillago analis)* (a and b), and distribution of readability scores (c and d).

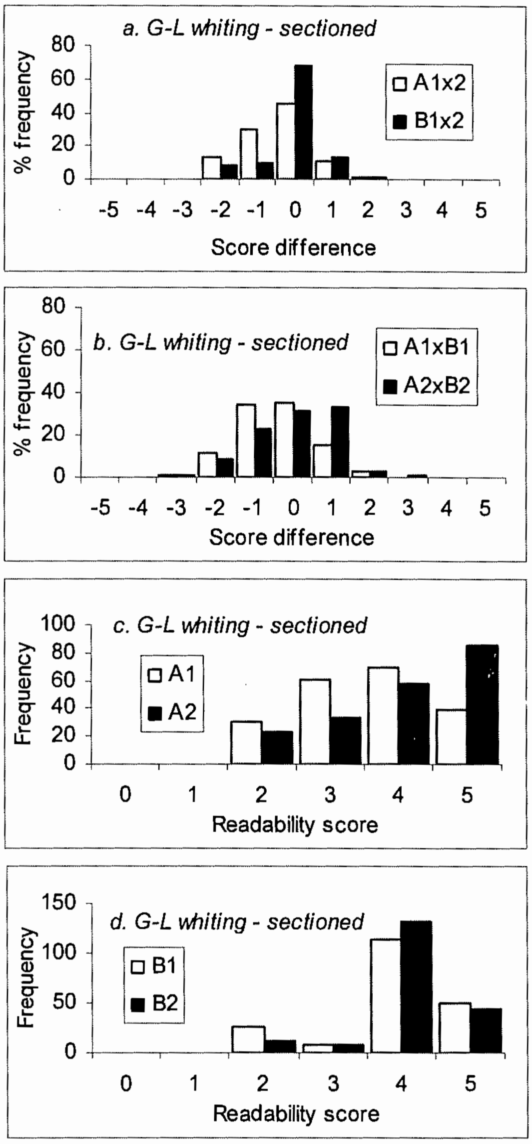



Figure 7.43 Comparison of the readability of sectioned otoliths from golden-lined whiting (*Sillago analis)* (a and b), and distribution of readability scores (c and d).

*7.2.2.4 Dusky Flathead*

The frequency distribution of RI score differences between readings for whole flathead otoliths by Reader B was somewhat skewed (Fig. 7.44 (a)). At the second reading scores were generally higher (more negative differences), indicating increased confidence in ring counts. The results of Reader A showed no temporal bias, but slightly lower precision, with a few RI scores varying by up to 2 units.

There was, however, a consistent bias between readers in RI score for whole otoliths over both readings (Fig. 7.44 (b)), as the modal difference was -1. This indicates that Reader A generally rated the readability of these otoliths about 1 unit lower than Reader B.

Again, this is reflected in the frequency distributions of the actual RI scores. Reader A classified almost all of the otoliths as RI = 3 or 4 (Fig. 7.44 (c)) while Reader B classed most as either 4 (first reading) or 5 (second reading)(Fig. 7.44 (d)). In keeping with these between-reader differences, Reader A rated a few otoliths as unreadable, while Reader B placed some interpretation on all otoliths in the

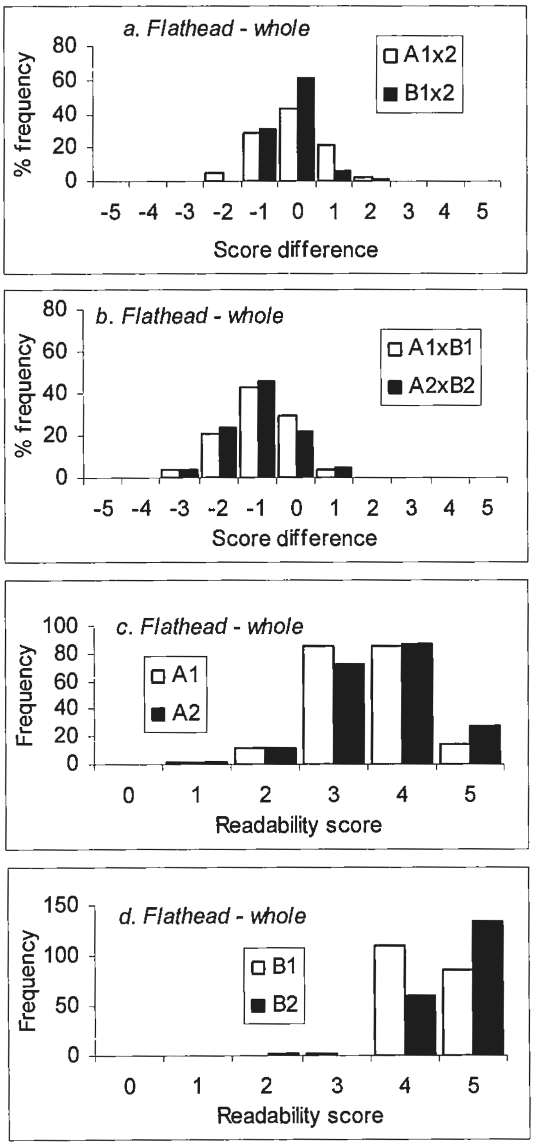



Figure 7.44 Comparison of the readability of whole otoliths from dusky flathead (*Platycephalus fuscus)* (a and b), and distribution of readability scores (c and d).

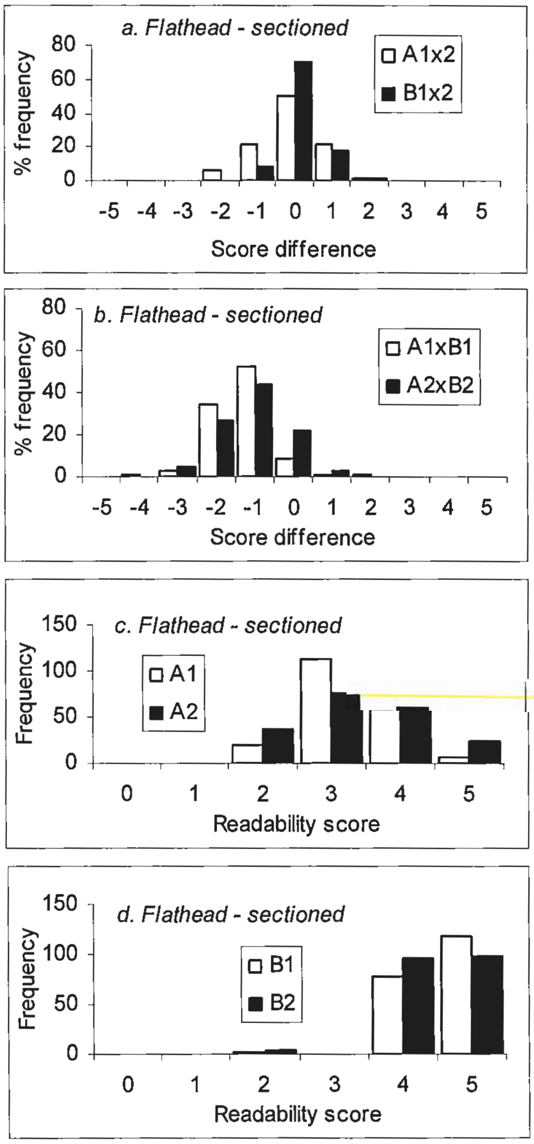



Figure 7.45 Comparison of the readability of sectioned otoliths from dusky flathead (*Platycephalus fuscus)* (a and b), and distribution of readability scores (c and d).

sample.

Readability estimates were slightly more consistent between consecutive readings for sectioned than for whole otoliths (Fig. 7.45 (a)). However, there was still a significant bias between readers (Fig. 7.45 (b)) on both occasions. Reader A consistently reported RIs of 3 or 4 (Fig. 7.45 (c)), while Reader B reported almost all RIs of 4 and 5 (Fig. 7.45 (d)).

### *7.2.2.5 Tailor*

Both readers' readability assessments for whole tailor otoliths were consistent between readings, as shown by the peaked distribution of score differences with a mode at zero. Very few scores differed by more than ±1 unit between occasions (Figure 7.46 (a)). However Reader A generally rated whole otoliths less readable than did Reader B, as can be seen from the substantially negative score-

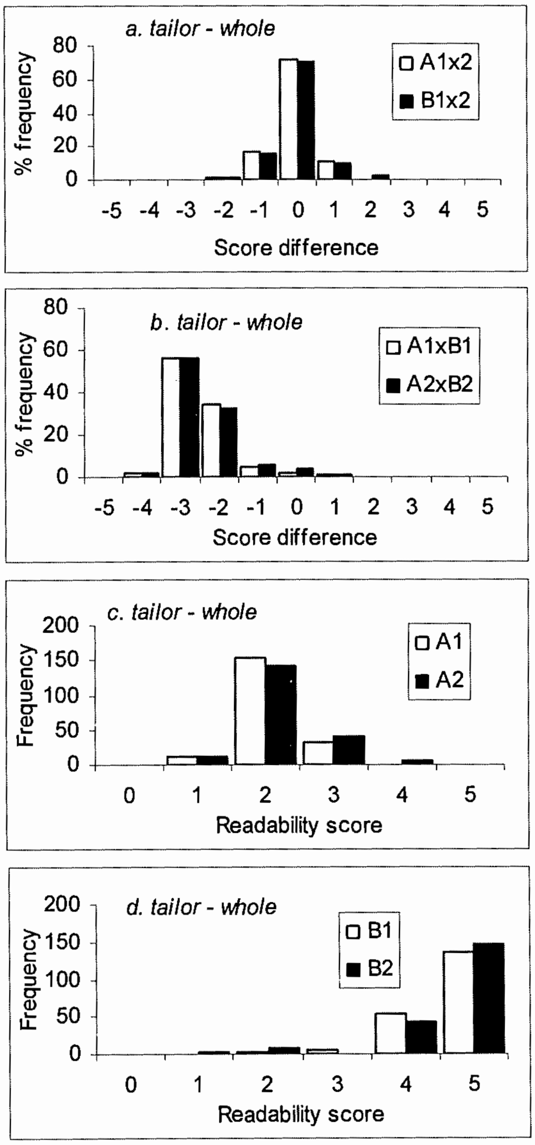



Figure 7.46 Comparison of the readability of whole otoliths from tailor (*Pomatomus saltatrix)* (a and b), and distribution of readability scores (c and d).

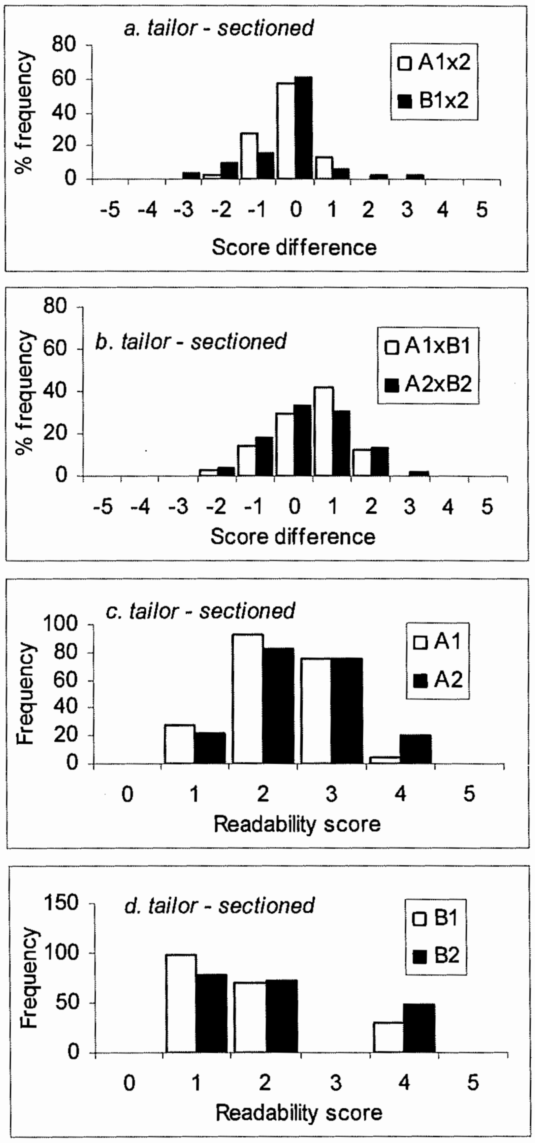



Figure 7.47 Comparison of the readability of sectioned otoliths from tailor (*Pomatomus saltatrix)* (a and b), and distribution of readability scores (c and d).

differences in Figure 7.46 (b). This effect is also apparent from the readability score frequency distributions in Figures 7.46 (c) and (d), with Reader A rating most of the otoliths at 2, while Reader B rated most at 5. This between-reader difference, which was consistent between reading occasions, may have been due to a tendency for Reader A to place readability in the context of all species, while Reader B categorised readability within the one species.

As with whole otoliths, sectioned otolith readability ratings were quite consistent between readings (Figure 7.47 (a)). However, the consistency was slightly lower than that obtained from whole otoliths, some differences being as much as ±3 RI units.

In contrast to the situation with whole otoliths, there was a much closer agreement between readers with sectioned otoliths. Reader A tended, on average, to allocate slightly higher scores than did Reader B (Figure 7.47 (b)). In terms of absolute scores, Reader A considered most sectioned otoliths to have a low to medium readability (RI = 2 or 3) while Reader B attributed mostly very low to low scores (RI = 1 or 2) (Figures 7.47 (c) and (d)). Reader B's modal readability class on both reading occasions was 1 (unreadable), implying that one of the readers would be prepared to attribute a ring count to little more than half of the tailor otolith sections.

### 7.2.3 Age Validation – Marginal Increment Analysis

#### *7.2.3.1 Bream*

Analyses of variation in marginal increment (using general linear modelling (GLM)) showed significant effects due to month (p=0.0002) and year (p=0.0003) for all data, and significant effects due to month (p=0.0001) and band type (p=0.0289) for those otoliths that had been assigned a band type. No other first or second order effects werestatistically significant.

The mean marginal increment showed no consistent pattern of growth, for bream pooled for all ring counts. However, two declines were suggested, at the beginning of winter in May-June and at the end of winter in October (Figure 7.48). October and December were the two lowest points both for bream with 3–4 translucent zones and for those with 5 or more translucent zones. However, the declines to these points were not steep, and there was considerable variation about the mean increments for each month.

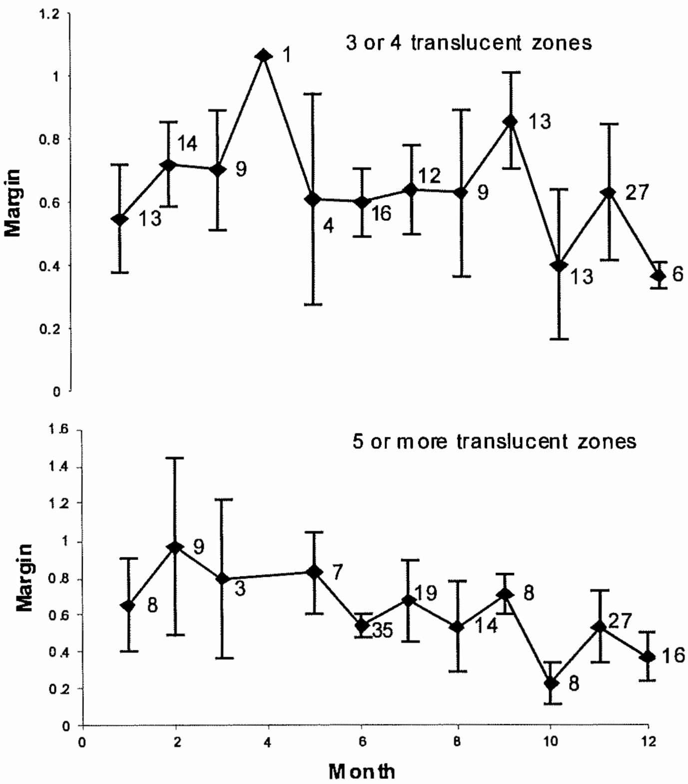



Figure 7.48 Mean monthly marginal increments ±95% CI for sagittal otoliths of bream (*Acanthopagrus australis*). Sample sizes are given for each month.

#### *7.2.3.2 Sand Whiting*

GLM analyses of variation in marginal increment showed a significant interaction between month and number of translucent zones (p=0.0001). Neither sex, year, location, nor any two or three way interactions among these factors, showed significant relationships with marginal increment. Data were pooled across these factors.

The mean marginal increment in sectioned otoliths with one translucent zone increased from 0.23 to 0.47 between February and August, and then fell over three months to 0.06 in November (Figure 7.49). Too few data were available to estimate increments during December and January. The marginal increments in otoliths with 2 translucent zones showed minimum values in October and November that were not significantly different. In otoliths with three or more translucent zones the smallest increment was seen in September-October, with the November increment significantly larger than that of October. Thus the translucent zones become visible earlier in older fish.

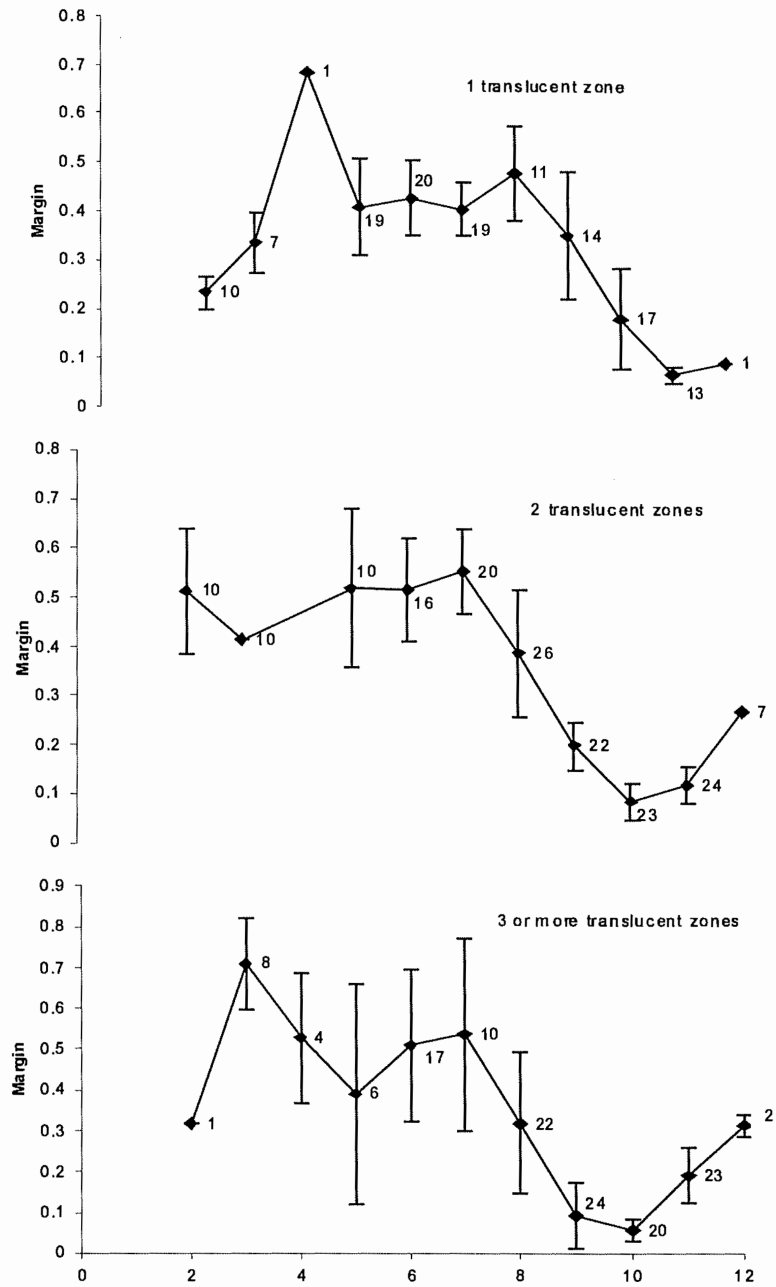



Figure 7.49 Mean monthly marginal increments ±95% CI for sagittal otoliths of *Sillago ciliata*. Sample sizes are given for each month.

### 7.2.3.3 *Golden-Lined Whiting*

Golden-lined whiting otoliths were characterised by a poorly defined boundary between growth checks and intermediate zones. As a result, it was impossible to make accurate measurements on the radial distance of the periodic checks. Marginal increment analysis is not a suitable technique for validating otolith-derived age estimates in this species.

### 7.2.3.4 *Dusky Flathead*

GLM analyses of variation in marginal increment showed significant effects of month and year, and significant interactions between sex and month, and month and number of translucent zones. Sex and number of translucent zone factors were not significant by themselves, but were retained in the model because of their significant interactions.

Further examination of the least squares means showed that the significance of the month * translucent zone interaction was not due to different timing of ring deposition for different ages. The sex * month interaction appeared to result from a slower decline of marginal increment for males than females.

The year effect may have resulted from a significantly larger increment size in 1996 than in 1997, but this is uncertain due to the low level of overlap between months sampled in 1997 and 1998. The month effect was due to the timing of the date of ring deposition.

The mean marginal increment in whole otoliths with one translucent zone varied between 0.50 and 1.16 between May and September, but then fell to 0.22 in October and further to 0.18 before increasing again (Figure 7.50). The marginal increments in otoliths with 2, 3, 4, and 5-8 translucent rings also showed a minimum value in October-November. In all cases but the three translucent zones the steepest decline was between September and October (Figure 7.50).

### 7.2.3.5 *Tailor*

GLM analyses showed significant effects due to month (p=0.0001), number of translucent zones (p=0.0001), and the month * translucent zone interaction (p=0.0005). Neither the year (p=0.7720) nor the year * month interaction (p=0.9435) was statistically significant, so years were pooled in subsequent analyses. Similarly, there were no statistically significant sex (p=0.1896) or sex * month (p=0.2072) effects, so sexes were pooled.

The mean marginal increment in otoliths with one translucent zone increased between February and July from 0.098 to 0.275 (Figure 7.51). From July onwards the margin showed a steady decline, with the largest difference between December and January. In otoliths with two and three or more translucent zones the peak margin size (ignoring months represented by a single otolith) also occurred in the June to October

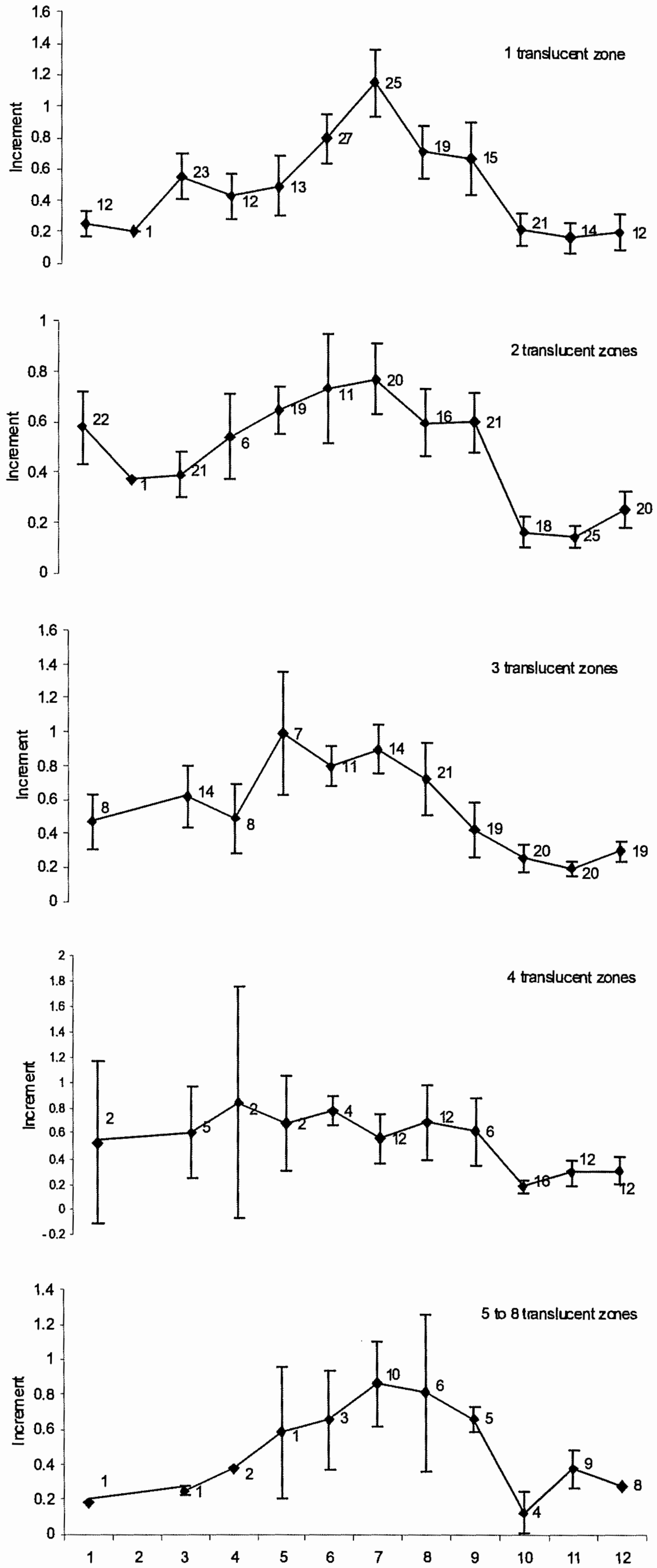



Figure 7.50 Mean monthly marginal increments ±95% CI for sagittal otoliths of *Platycephalus fuscus*, pooled for both sexes. Sample sizes are given for each month.

period. This was followed by a steeper decline during November and December than occurred for the otoliths with a single translucent zone (Figure 7.51).

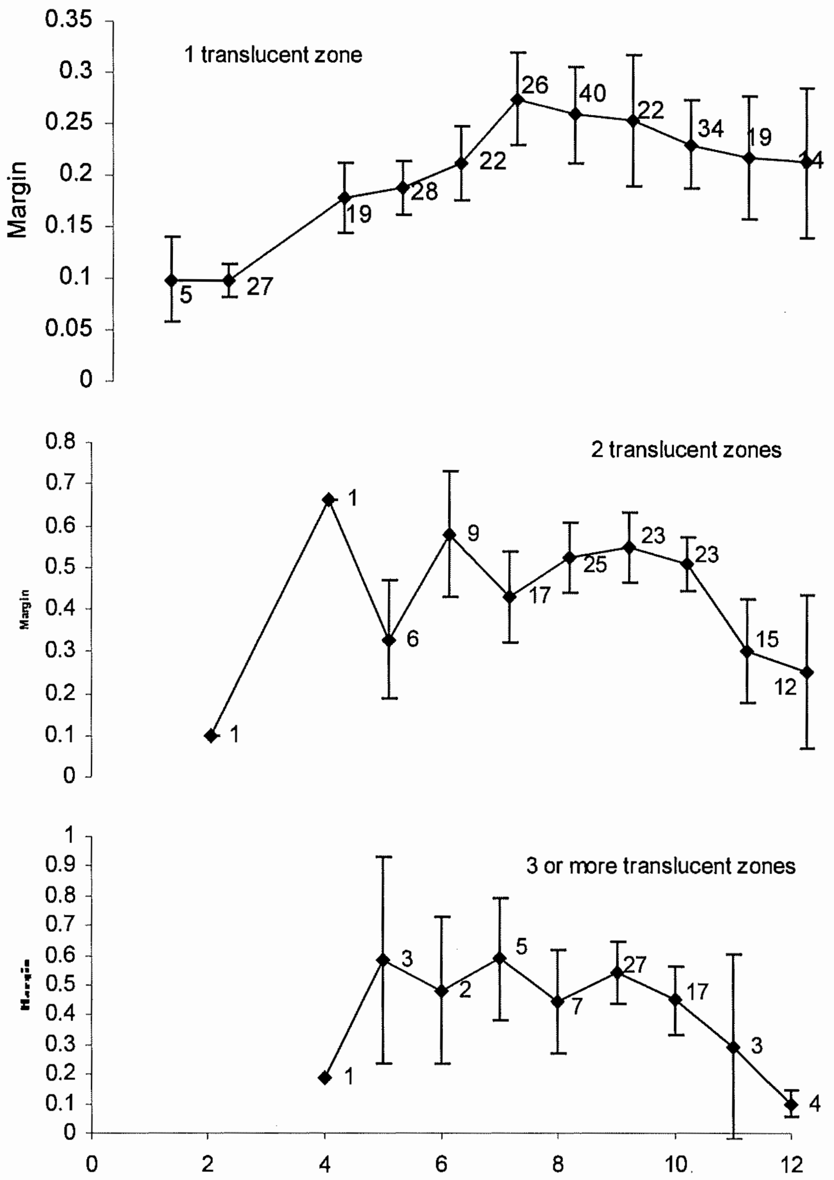



Figure 7.51 Mean monthly marginal increments ±95% CI for sagittal otoliths of *P. saltatrix*. Sample sizes are given for each month.

### 7.2.4 Production sample processing costs

Knowledge of the time taken to process samples for age determination and actually do the readings is of considerable importance to the planning and budgeting of long-term stock monitoring programs that involve the use of catch-at-age data. Each otolith takes approximately 0.5 minutes to weigh, including removal from vial, checking for damage, recording of the weight, and replacement in vial (Table 7.12).

There is little difference between species in this regard. Readings of whole otoliths take about one minute, including removal from vial, adjustment of light source, alcohol-cleaning and replacement in vial. Sectioning (using a low-speed bone saw) is the most time-consuming part of the process, requiring between 4.0 and 6.3 minutes per otolith, depending on species. Those with massive otoliths (e.g. sand whiting) tend to take longer than those with thin otoliths (e.g. tailor). The age-composition of the sample also affected the sectioning time, because large otoliths take slightly longer to cut than small ones.

Table 7.12. Average time (in minutes) taken to process one otolith of each of the various species. Sample sizes are shown in parentheses.

| | Weighing | Whole Reading | Blocking | Sectioning & mounting | Section reading |
|---|---|---|---|---|---|
| Bream | 0.52 (100) | 1.00 (160) | 0.85 (20)* | 4.46 (25) | 0.68 (20) |
| Flathead | 0.52 (100) | 0.94 (100) | | 5.03 (25) | 0.66 (20) |
| Tailor | 0.53 (100) | 0.90 (80) | | 4.00 (25) | 0.62 (20) |
| G-L whiting | 0.48 (100) | 1.10 (100) | | 4.81 (25) | 0.47 (20) |
| Sand whiting | 0.50 (100) | 1.06 (100) | | 6.34 (25) | 0.43 (20) |

* blocking time was calculated on the basis of a mix of species in the 20-pot mould.

For greatest accuracy in age determination it may be necessary to section otoliths rather than reading them whole (this is certainly the case with the two whiting species). However this comes at a considerable cost in time and labour. To process and read a sample of (say) 100 whole otoliths, including weighing, would take about 2.6 hr. On the other hand, to process, section and read the same number of otoliths would take about 11 hr of continuous work. For a single reading, the total sectioning process takes about four times as long as the whole otolith reading. However, once the sections are mounted on slides, the reading time is little more than half of that for whole otoliths. Thus, if there is a need for multiple readings, the time-cost differential between methods would be somewhat reduced.

## 7.3 Growth rate estimation

As a result of the ageing experiment (described previously) we opted to carry out the routine ageing for population age structure, growth rate and mortality rate analyses on the basis of both whole otoliths (for yellowfin bream, dusky flathead and tailor) and sectioned otoliths (for sand whiting and golden-lined whiting). In the case of tailor, Queensland ageing techniques were used.

### 7.3.1 Yellowfin bream

We were unable, using marginal increment analysis, to identify a time when translucent zones appear in the otoliths of yellowfin bream. In Moreton Bay, yellowfin bream spawn during a relatively short period in winter (Dredge 1976, Pollock 1982a, Pollock 1984, Thorogood 1991). We allocated the date of birth around the middle of the spawning season (15 July).

These results suggest that Moreton Bay bream grow to a larger size than Maroochy River bream. Growth curves show a smaller asymptotic length for Maroochy River bream than Moreton Bay bream, for those fish taken by fishery-independent methods (Table 7.13). Growth curves were significantly different ($p<0.0001$). Certainly the average fork length (12.47 cm ± 0.367) and age (3.75 ± 0.117) of the Maroochy River bream samples was smaller than the average size (19.60 cm ± 0.323) and age (2.14 ± 0.134) of the Moreton Bay samples. The Moreton Bay samples were taken using mesh nets and fence nets, while the Maroochy River samples were taken using mesh nets and beam trawls.

Parameter estimates for all Moreton Bay data, combined in the growth bootstrap module of the stochastic yield per recruit model, showed relatively low error reflecting the repeatability of the ageing and the number of samples obtained. Correlations between the parameters are given in Table 7.14. The combined Moreton Bay data appear in Figure 7.52.

Table 7.13 Parameters of von Bertalanffy growth curves for yellowfin bream (*A. australis*).

| Source | Method | $L_\infty$ (cm) | K | $T_0$ |
|---|---|---|---|---|
| Maroochy River | Fishery-independent | 23.3 | 0.373 | -0.302 |
| Moreton Bay | Fishery-independent | 27.3 | 0.341 | -0.499 |
| Moreton Bay | All data – stochastic yield per recruit model | 27.34 (0.65) | 0.347 (0.032) | -0.455 (0.146) |

Table 7.14 Correlation between parameters of the von Bertalanffy growth curve for yellowfin bream (all data).

| | $L_\infty$ | K | $T_0$ |
|---|---|---|---|
| $L_\infty$ | 1 | -0.909 | -0.709 |
| K | -0.909 | 1 | 0.905 |
| $T_0$ | -0.709 | 0.905 | 1 |

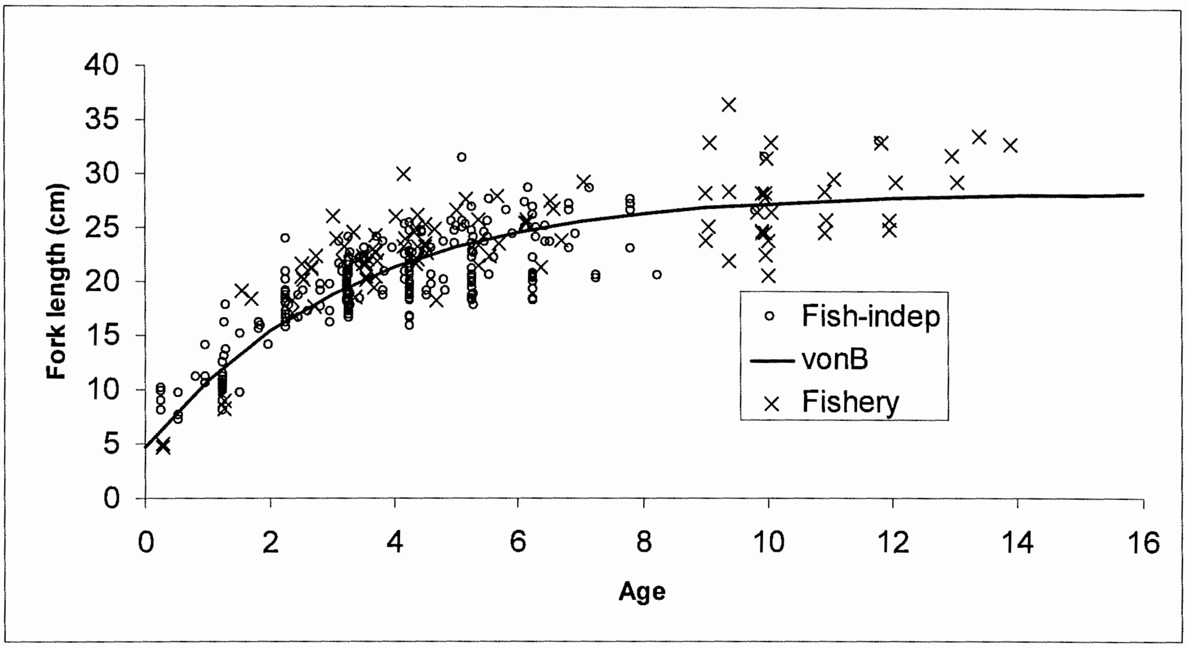



Figure 7.52 Growth curve for Moreton Bay bream, based on a combination of fishery data for fish aged 9 or older, and fishery-independent data.

### 7.3.2 Sand whiting

Sand whiting in Queensland spawn over an extended seven-month period between September and March, and may spawn more than once during this period (Morton 1982). Translucent zones appear in the otoliths between August and October. We therefore designated 1 October as the birth date of sand whiting. When fishery-independent and fishery data from all regions were combined, mean length at age of female whiting was consistently higher, by up to 5 centimetres, than for males, except for 0+ age fish (Table 7.15). However, there was considerable overlap in length at age between the sexes. No evidence for sex reversal has been found for sand whiting. Comparison of the maximum likelihood parameter estimates, for fish >5 years old from Moreton Bay and fishery independent Maroochy data, showed a significant improvement (p=0.0004) in the overall model fit if males and females were modelled separately.

Table 7.15 Length at age for sand whiting – pooled data from all areas and fishing methods

| | Male | | | | Female | | | |
|---|---|---|---|---|---|---|---|---|
| Age | Average | SD | Min | Max | Average | SD | Min | Max |
| 0 | 18.00 | 1.01 | 17.0 | 19.5 | 16.53 | 0.23 | 16.4 | 16.8 |
| 1 | 21.74 | 2.52 | 17.0 | 27.3 | 21.76 | 2.86 | 16.8 | 25.7 |
| 2 | 23.73 | 2.60 | 19.0 | 27.7 | 25.57 | 2.80 | 21.3 | 29.4 |
| 3 | 26.60 | 4.99 | 21.3 | 31.2 | 30.43 | 2.54 | 24.5 | 32.7 |
| 4 | 28.08 | 3.18 | 22.8 | 32.4 | 29.56 | 3.03 | 25.3 | 34.7 |
| 5 | 26.31 | 3.90 | 21.2 | 35.5 | 30.46 | 3.95 | 21.3 | 37.0 |
| 6 | 27.92 | 4.17 | 22.5 | 33.1 | 31.87 | 4.03 | 25.6 | 39.6 |
| 7 | 29.73 | 4.06 | 26.2 | 35.5 | 34.78 | 1.40 | 32.7 | 37.0 |
| 8 | 32.50 | 0.58 | 32.0 | 33.0 | 33.56 | 2.83 | 29.3 | 37.0 |

sand whiting from the Maroochy River, obtained using fishery-independent methods, appeared to grow faster than fish obtained from other areas using different methods. Too few fishery-independent samples were available from other areas for direct comparison over all age classes, and similarly there were few samples from commercial fisheries in the Maroochy River. Length at age data from the recreational fishery in the Maroochy River were supplied by the QDPI Coastal Streams Project (O'Neill 1999). A growth curve was calculated based on these recreational data and the fishery independent data already described.

Mean lengths-at-age were calculated from fishery-based data for the 3 regions from which at least 5 fishery-based catches had been taken (Gold Coast, Moreton Bay, and Hervey Bay; see Figure 7.53). In Hervey Bay there was very little change in mean length with increasing age, in contrast with the Gold Coast and Moreton Bay, where length increased with age. The average length of 129 fish obtained from Hervey Bay was less than 25cm for all age classes, and significantly less than Moreton Bay for age classes 1 to 6 ($p<0.01$), apart from age 5(ns). The average length of fish in each of the 1–5 year age classes was greater on the Gold Coast than in Moreton Bay ($p<0.01$).

Table 7.16 Parameters of von Bertalanffy growth curves fitted to sand whiting data.

| Region | Parameter | Sex | | |
|---|---|---|---|---|
| | | Combined | Female | Male |
| Gold Coast | $L_\infty$ | 37.5 | 39.7 | 38.5 |
| | K | 0.255 | 0.221 | 0.192 |
| | $t_0$ | -1.27 | -1.38 | -1.77 |
| Moreton Bay | $L_\infty$ | 31.5 | 35.0 | 29.2 |
| | K | 0.380 | 0.293 | 0.379 |
| | $t_0$ | -1.02 | -1.18 | -1.19 |
| Maroochy River – fishery independent | $L_\infty$ | 38.0 | 68.5 | 29.4 |
| | K | 0.285 | 0.105 | 0.394 |
| | $t_0$ | -1.07 | -1.61 | -1.10 |
| Maroochy River - fishery-dependent | $L_\infty$ | 39.9 | 44.0 | 38.0 |
| | K | 0.372 | 0.333 | 0.353 |
| | $t_0$ | -0.672 | -0.647 | -0.830 |

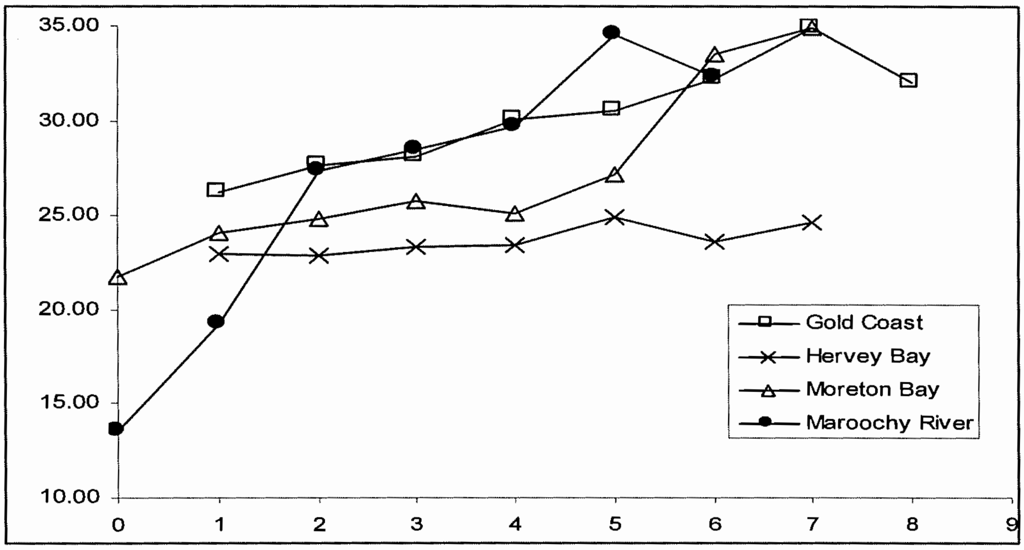



Figure 7.53 Mean lengths at age of sand whiting in four regions.

Von Bertalanffy growth curves were fitted for fish caught using fishery-independent methods in the Maroochy River. These are likely to underestimate lengths at age due to the size selectivity of the fishing methods used—seine nets and beam trawls. The results of the analyses are given in Table 7.16.

Growth rate estimates were difficult to obtain for other areas since the minimum legal size imposed size selectivity on younger age classes. A compromise was to combine fishery-independent data from the Maroochy River with fishery data from other areas (Moreton Bay and the Gold Coast). Only fish aged as 5 years or more by at least one reader were used from the fishery data, and only fish aged as 3 or less by at least one reader were used from the Maroochy data.

Ageing was very uncertain for summer whiting, and all estimated ages were included in the growth curve estimating process (weighted to give equal emphasis to each individual sand whiting). This meant that a number of fish from Moreton Bay with one or more age estimates less than 5 were included, along with several fish from Maroochy River with an age estimate greater than 3. Parameters from von Bertalanffy growth curves fitted to the data for fish from Moreton Bay and the Gold Coast, combined with Maroochy River, are given in Table 7.16, and the growth curve for Moreton Bay is displayed in Figure 7.54.

### 7.3.3 Golden-lined whiting

We did not carry out marginal increment analysis with golden-lined whiting otoliths, and no reproductive

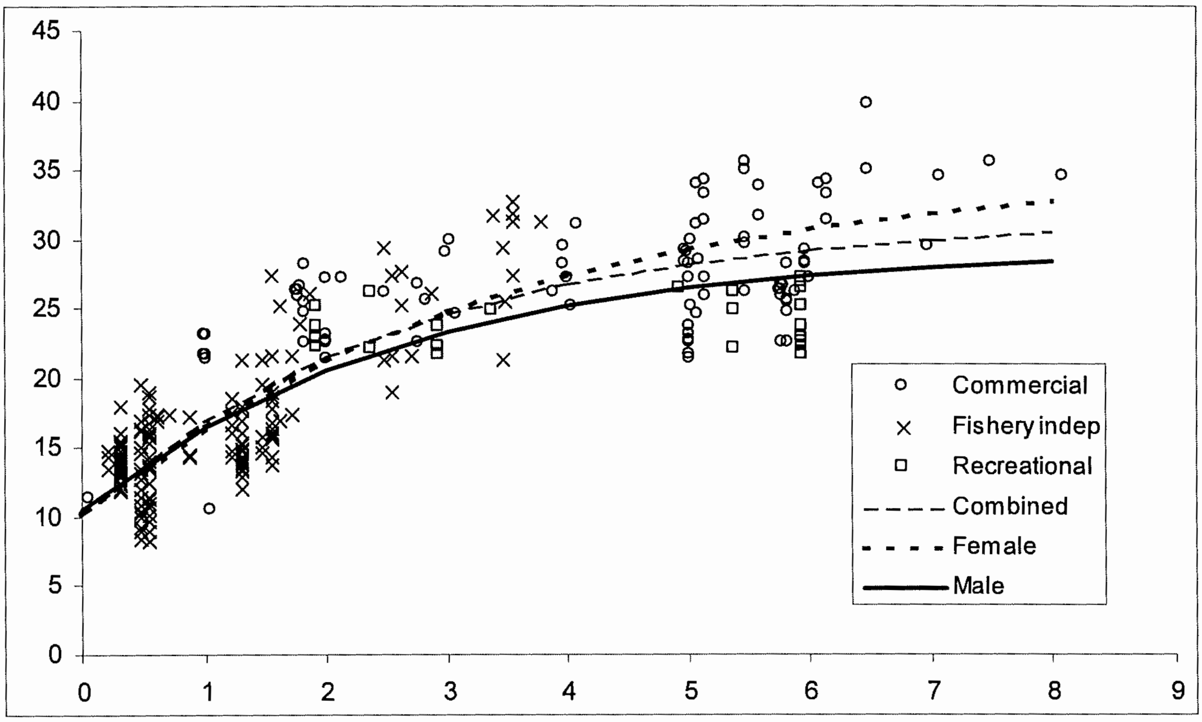



Figure 7.54 Lengths at age of sand whiting (*S. ciliata*) from Moreton Bay (commercial and recreational samples) and the Maroochy River (fishery independent samples).

studies have been carried out on golden-lined whiting in southern Queensland. Gunn (1978) found that a population in the vicinity of Townsville, north Queensland, had an extended breeding season, beginning in July and continuing to March. We chose the middle of this period, 1 November, as the birth date.

Data from the fishery were pooled with data collected independently of the fishery. Comparisons between regions could not be made, since only commercial catches were obtained from Moreton Bay, and only one commercial catch from Hervey Bay. A growth curve was estimated for Moreton Bay

Table 7.17: Parameters of growth curve estimated for golden-lined whiting in Moreton Bay

| Parameter | Estimate | Std. error |
|---|---|---|
| $L_{\infty}$ | 30.77 | 1.560 |
| K | 0.499 | 0.090 |
| $T_o$ | -0.524 | 0.185 |

Table 7.18 Estimated growth rates of male and female dusky flathead in Moreton Bay, with standard errors.

| | $L_{\infty} \pm$ se | K | $T_0$ | N |
|---|---|---|---|---|
| Females | $81.7 \pm 1.44$ | $0.234 \pm 0.008$ | $-0.423 \pm 0.035$ | 1499 |
| Males | $81.5 \pm 9.68$ | $0.146 \pm 0.025$ | $-1.234 \pm 0.124$ | 457 |

only (parameter estimates are shown in Table 7.17). Growth curves between sexes, from the few fish sexed, were not significantly different (p=0.186).

### 7.3.4 **Dusky flathead**

Dusky flathead spawn in Moreton Bay over a seven-month period from September to March, with peak activity between September and December (D. Cameron, unpublished data). Translucent zones appear in the otoliths in October. We therefore designated 15 October as the birth date of dusky flathead.

In order to determine the growth rate of dusky flathead, the total lengths of fish caught by commercial fishers and by seine nets in fishery-independent surveys were pooled. From January to March (Appendix Figure A1), the length range of 0+ fish was between 120 and 334 mm (n=30). The 1+ age class ranged from 25 to 47.5 mm (n=188). The 2+ age class ranged from 300mm to 575 mm (n=130), and the 3+ age class from 345 mm to 640 mm (n=68).

Assumptions of random and homoscedastic residuals were not rejected for either males or females. Growth curves derived for male and female dusky flathead (Figure 7.55, Table 7.18) differed significantly (P<0.0001).

The yield per recruit growth bootstrap gave alternative confidence limits on male and female growth parameters, incorporating ageing as well as sampling error (Table 7.19). The distribution of male growth was non-normal, so medians and percentiles are presented as well as means. A parametric randomisation test for difference in growth between the sexes, using the stochastic yield per recruit model, was significant (p<0.001).

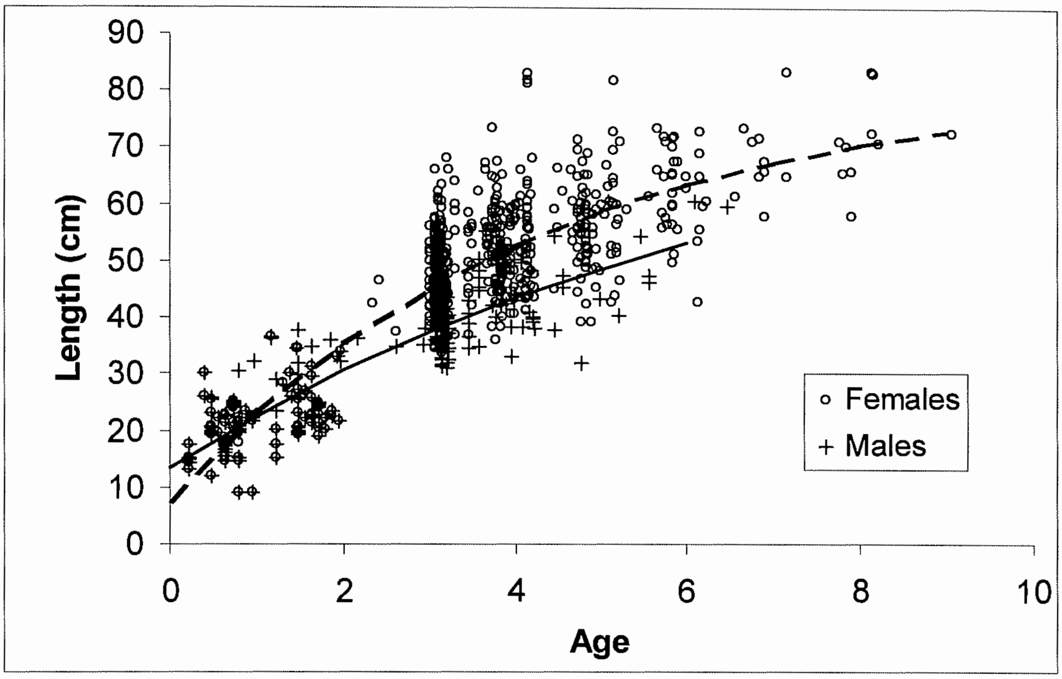



Figure 7.55 Lengths at age of dusky flathead (*Platycephalus fuscus*) from Moreton Bay (commercial and recreational samples) and the Maroochy River (fishery independent samples.).

Table 7.19 Distribution of growth curves for male and female flathead in Moreton Bay, estimated using the stochastic yield per recruit model

| | Male | | | Female | | |
|---|---|---|---|---|---|---|
| | $L_\infty$ | K | $T_0$ | $L_\infty$ | K | $T_0$ |
| Mean | 93.8 | 0.150 | -1.248 | 84.9 | 0.219 | -0.457 |
| SD | 55.2 | 0.059 | 0.276 | 4.7 | 0.023 | 0.096 |
| Median | 81.4 | 0.146 | -1.222 | 84.5 | 0.220 | -0.451 |
| Percentile 2.5 | 58.7 | 0.038 | -1.828 | 76.6 | 0.175 | -0.636 |
| Percentile 97.5 | 224.6 | 0.268 | -0.775 | 95.6 | 0.268 | -0.270 |

### 7.3.5 Tailor

Tailor appear to spawn over a protracted period, with some activity throughout the year but peak activity between August and November. Based on marginal increment analysis, translucent zones tend to appear in the otoliths between October and January. We therefore designated 1 November as the birth date of tailor.

The average age at length from the fishery of males was consistently greater than females across all 2 cm size classes (SAS GLM, $p<0.0001$) by 0.14 years on average. This result held for recreationally and commercially caught fish, and for the years 1996 and 1997. Similarly, average length at age was lower for males than for females for all available age classes (see Table 7.20). However, comparison of age length keys pooled over the period of the study showed no significant difference between males and females in the distribution of age at length ($\chi^2=96.1$, $n=113$, $p=0.87$).

In order to estimate the growth rate of tailor, we pooled the lengths of fish caught by commercial fishers and recreational anglers, and those caught independently of the fishery.

Table 7.20 Average length at age for tailor caught in the commercial and recreational fisheries

| | Average (and SD) of fork length (cm) | | |
|---|---|---|---|
| Age | Female | Male | Unsexed |
| 0 | 29.6 (2.5) | 28.0 (2.1) | 27.3 (3.5) |
| 1 | 33.0 (3.1) | 32.1 (2.7) | 32.5 (3.1) |
| 2 | 38.6 (4.3) | 36.9 (3.8) | 37.6 (4.4) |
| 3 | 43.7 (9.6) | 39.9 (6.5) | 40.3 (9.1) |
| 4 | 46.2 (8.2) | 44.6 (9.3) | 60.0 (n=1) |
| 5 | 63.0 (n=1) | 41.00 (n=1) | 29.0 (n=1) |

Table 7.21 Parameters of growth curves estimated for male and female tailor

| Parameter | M | F |
|---|---|---|
| $L_\infty$ | 79.5 | 12750 |
| K | 0.116 | 0.000537 |
| $T_0$ | -2.26 | -2.62 |

Table 7.22 Distribution of growth rate estimates for pooled male and female tailor data estimated using the stochastic yield per recruit model.

| Statistic | $L_\infty$ | K | $T_0$ |
|---|---|---|---|
| Mean | 45.6 | 0.507 | -0.894 |
| SD | 4.36 | 0.130 | 0.346 |
| Median | 44.6 | 0.517 | -0.820 |
| Percentile 2.5 | 41.0 | 0.224 | -1.796 |
| Percentile 97.5 | 57.3 | 0.742 | -0.434 |

Table 7.23 Correlation between estimates of tailor growth curve parameters in stochastic yield per recruit model

| Parameter | $L_\infty$ | K | $T_0$ |
|---|---|---|---|
| $L_\infty$ | 1 | -0.871 | -0.857 |
| K | -0.871 | 1 | 0.911 |
| $T_0$ | -0.857 | 0.911 | 1 |

Growth curves were fitted both for pooled male and female data (with fish of unknown sex excluded) and for each sex separately, and the fit compared using maximum likelihood techniques (Kimura 1980). Separate growth curves gave better fit to the data (p=0.00014) than a combined curve.

Growth curves were fitted with fishery-sourced data for ages less than 3 years excluded, leaving only fish from fishery-independent sampling in this age-range. This excluded fish from the most highly size-selected age classes in the fishery. Fish of unknown sex were included if they were smaller than the size at which fish could generally be sexed (25 cm). The von Bertalanffy parameters of best fit for males and females are given in table 7.21. The female growth curve showed no tendency towards an asymptotic length, and was well approximated by a straight line ($y = ax + b$) with the parameters $a = 6.86 \pm 0.27$, and $b = 17.94 \pm 0.69$. The yield per recruit growth bootstrap gave alternative confidence limits on pooled growth parameters, incorporating ageing as well as sampling error (Table 7.22). The distribution of growth rate estimates was non-normal, so medians and percentiles are presented as well as means. Parameter estimates were highly correlated (Table 7.23).

## 7.4 Population modelling

### 7.4.1 Population length structure (estuarine species)

#### *7.4.1.1 Yellowfin bream*

Significant variation in length structure was associated with catch sample for bream caught in Moreton Bay in 1997 (F=6.62, p<0.0001, 12 mesh net catches and 11 tunnel net catches). However, gear type (mesh net or tunnel net) was not associated with a statistically significant difference in length (F=0.14, p=0.7117). Catch explained approximately 26% of the variation in length for bream caught in mesh nets, and 16.6% for bream caught in tunnel nets. Average lengths were 23.39 for mesh net, and 23.56 for tunnel net. Length frequency distributions of fish from the two net types are shown in Figure 7.56.

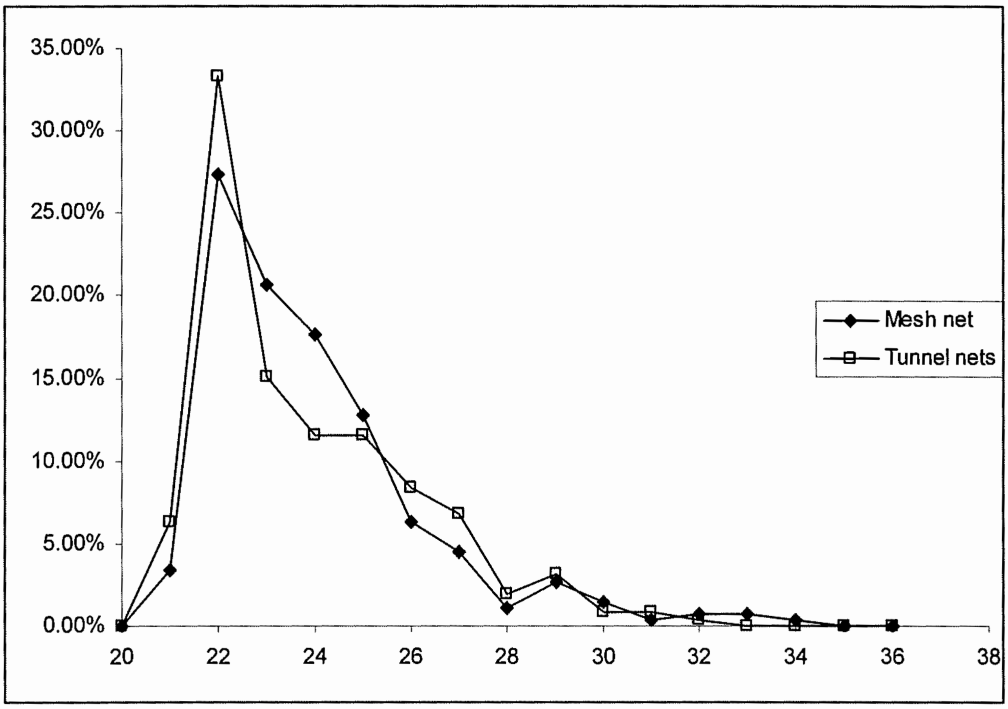



Figure 7.56 Length frequency distribution of yellowfin bream sampled from Moreton Bay catches in 1997.

There was no statistically significant difference in length between the few Moreton Bay mesh net catches obtained in 1996 and those from 1997 (F=0.37, p=0.5437, 3 catches in 1996, 12 in 1997).

#### *7.4.1.2 Sand whiting*

There was significant variation between catch samples in the length of sand whiting caught in 1997 (F=8.46, p<0.0001). There was also a significant difference between mesh nets and tunnel nets (F=71.07, p<0.0001, 7 catches by tunnel net, 8 by mesh net). Sand whiting caught in mesh nets were larger (least squares mean = 25.37 cm) than those caught in tunnel nets (lsm = 24.32). Data from 1996 also showed a significant difference in length between catches (F = 19.03, p<0.0001) but not between gear types (F = 0.44, p=0.5061). Catch sample explained approximately 23% of the variance when gear type was taken into account.

An analysis of variance using showed significant variation between regions. However, the 7 tunnel net catches in 1996 came from only 2 fishers, and the 10 mesh net catches from 6 fishers, suggesting that the observed regional variation may be due to differences between fishers. In 1997 the 7 tunnel net catches came from 4 fishers, and 8 mesh net catches from 7 fishers. Year did not make a significant contribution to the variance (F=0.94, p=0.3337).

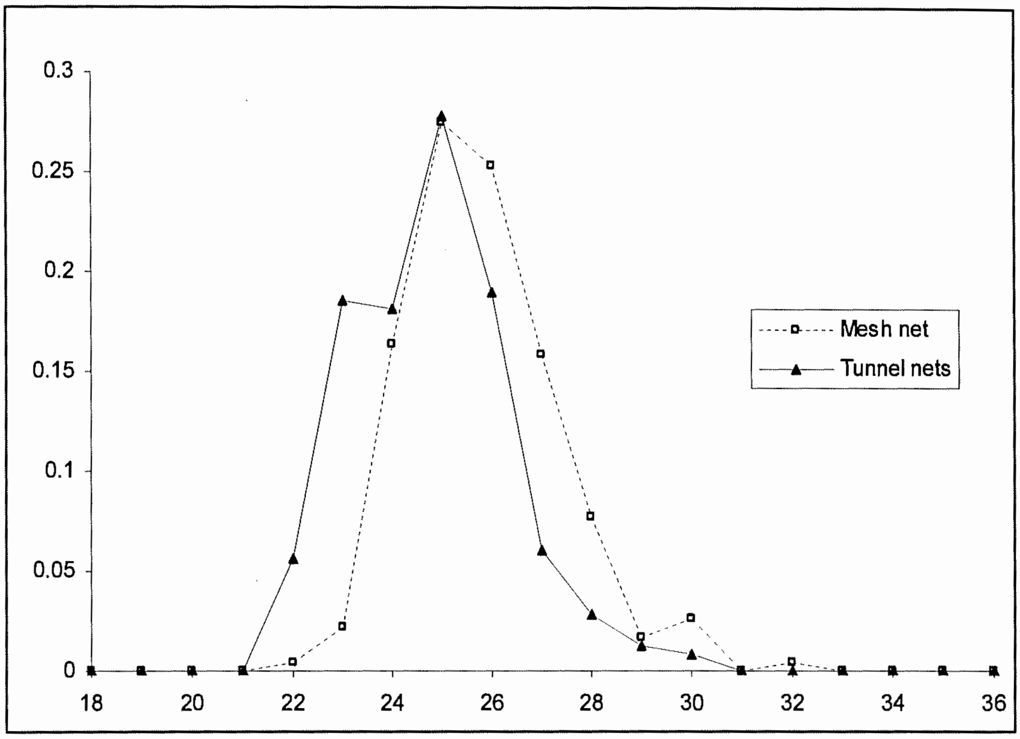



Figure 7.57 Length frequency distribution of commercial sand whiting catch in Moreton Bay in 1997, by fishing method.

Length frequency distributions for sand whiting taken in Moreton Bay by tunnel and mesh nets in 1997 are given in Figure 7.57.

### *7.4.1.3 Golden-lined whiting*

There was significant variation between catch samples in the length of golden-lined whiting caught by mesh-net in 1996 (n catches=6) and 1997 (n catches=4) ($F=38.84$, $p<0.0001$). However, the average lengths for the two years were not significantly different ($F=0.02$, $p=0.8879$). The small sample sizes made it difficult to detect any differences that might have existed. Too few tunnel net catches were obtained to compare with mesh net catches. Catch explained approximately 49% of the variance.

### *7.4.1.4 Dusky flathead*

There was significant variation in the length of flathead between mesh-net catches in 1996 (41 catches) and 1997 (15 catches) ($F=14.57$, $p<0.0001$), and between the two years ($F=13.50$, $p=0.0002$). Average length in 1996 was 46.1 cm, and 43.9 cm in 1997. Catch explained 28% of the variation in length of mesh net catches, and year explained 0.5%.

The lengths of flathead taken in the tunnel net catch also varied between years ($F=4.36$, $p=0.0376$) but in the opposite direction, with average length larger in 1997 (45.3 cm, 6 catches) than in 1996 (41.4 cm, 7 catches). There was also variation in length between catches for tunnel net catches ($F=3.46$, $p<0.0001$). Catch explained 9.5% of the variation in length for tunnel net catches, and year explained 1%. The average length was greater for the tunnel net catch than the mesh net catch in 1996 ($F=56.78$, $p<0.0001$) but not in 1997 ($F=0.66$, $p=0.4156$). It should be noted that in this species there is a substantial difference in growth rate between the sexes, with females growing faster than males (see Section 7.3.4). It is not surprising, therefore, to find that population size-frequencies also differ between sexes. In the 1996–97 commercial catches from Moreton Bay, the modal size of females was at least 10 cm greater than that of males (Figure 7.58).

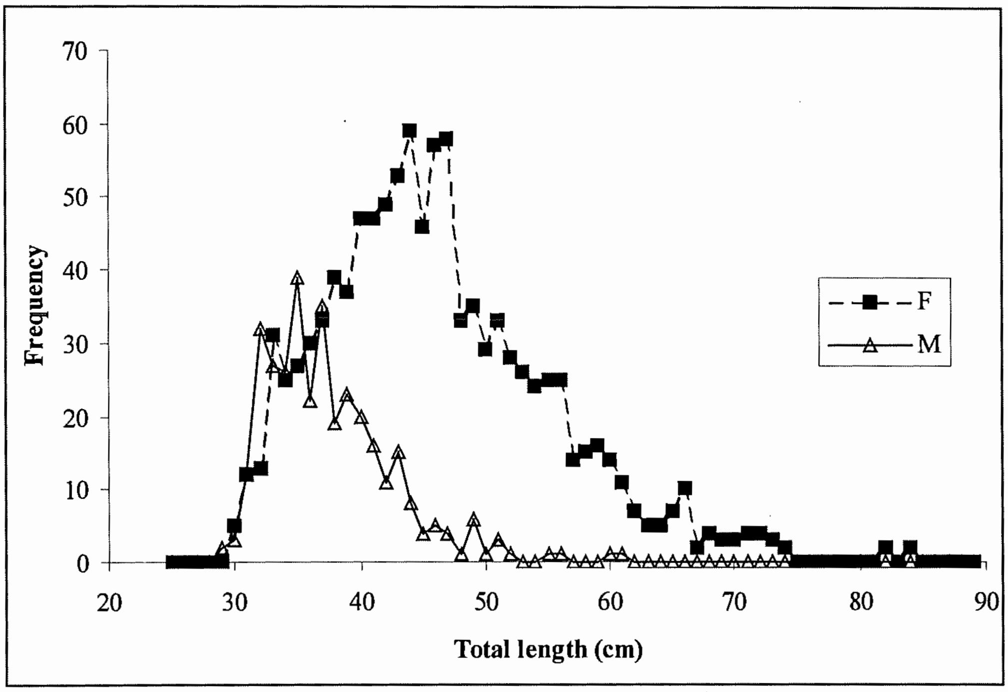



Figure 7.58 Length-frequency distribution of male and female dusky flathead from the Moreton Bay commercial catch during 1996 and 1997.

## 7.4.2 Population length structure (coastal species – tailor)

### *7.4.2.1 Commercial gear selectivity*

The average length of tailor caught in tunnel nets was significantly smaller than for gill nets (t test, $p<0.0001$) (Table 7.24).

Table 7.24 Mean length of tailor in commercial catches sampled in 1996 and 1997. No beach seine catches were obtained in 1996, but there were 24 gill net and 4 tunnel net catches. All but two of 21 catches in 1997 were beach seine catches.

| | 1996 | | | 1997 | | |
|---|---|---|---|---|---|---|
| Gear | Mean | S.D. | N | Mean | S. D. | N |
| Beach seine | | | | 33.60 | 4.86 | 648 |
| Gill net | 33.87 | 3.45 | 929 | 33.55 | 3.78 | 18 |
| Tunnel nets | 32.31 | 3.86 | 119 | 31.00 | 1.72 | 11 |

### *7.4.2.2 Length distribution of the commercial catch*

After correction, the modal length in 1997 was 31cm (Figure 7.59). The distribution contained more small fish than did the recreational catch for the same year.

### *7.4.2.3 Length distribution of recreational catch*

Differences between years are apparent in the graphs of recreational catch length frequency. The modal length in 1995 was 32 cm (Figure 7.60). In 1996 this decreased to 30 cm (Figure 7.61), but in 1997 the modal length had increased to 36 cm (Figure 7.62).

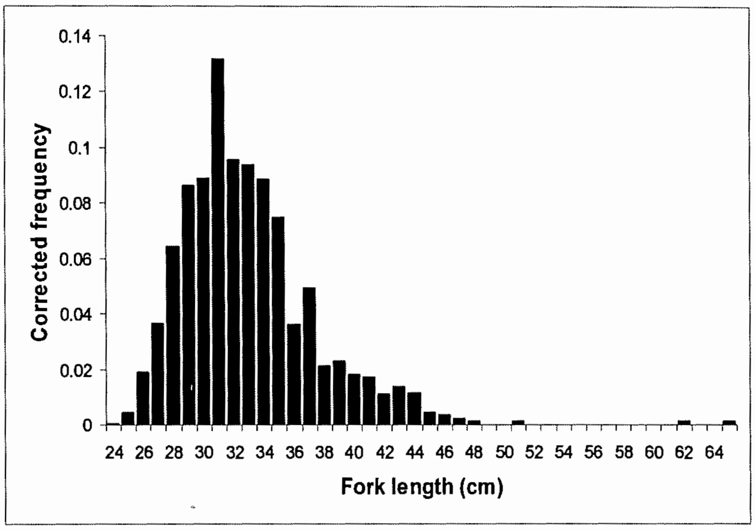



Figure 7.59 Length frequency distribution of the commercial tailor catch in 1997, corrected for month and location of capture.

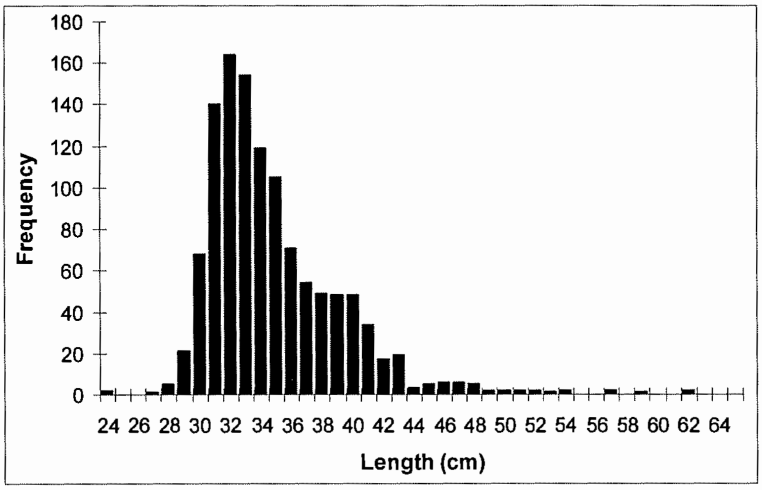



Figure 7.60 Length frequency of the recreational tailor catch in 1995.

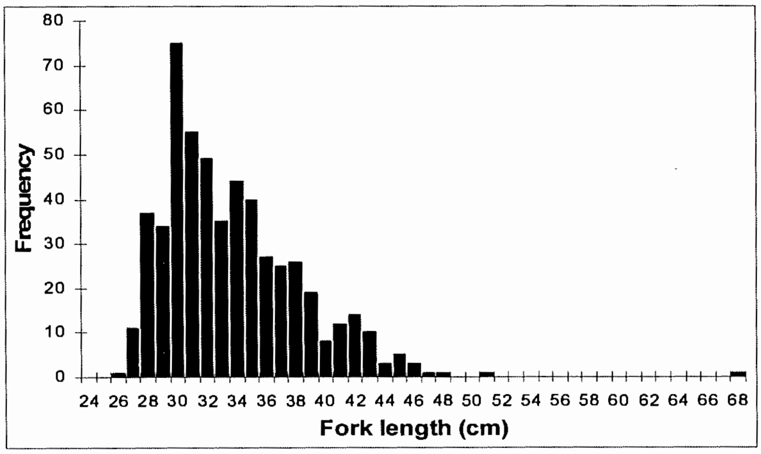



Figure 7.61 Length frequency of the recreational tailor catch in 1996.

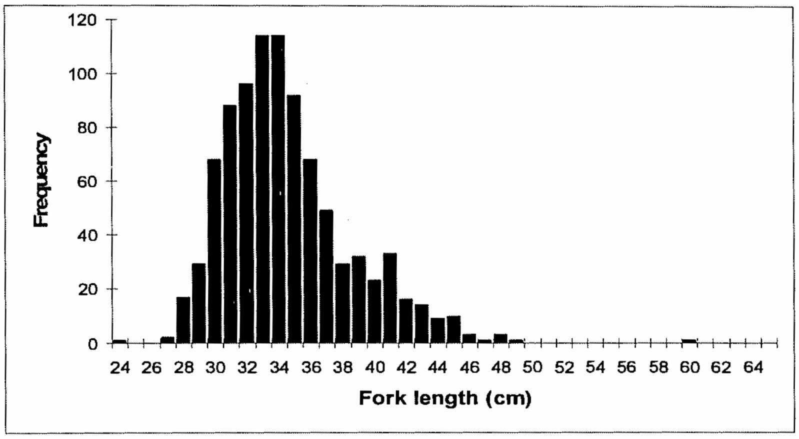



Figure 7.62 Length frequency of the recreational tailor catch in 1997.

No other length modes are clearly apparent. The mode at 42 cm in 1996 can be attributed to sampling variation. However, all three graphs show a levelling off of the decline in frequency in the region of 40 cm.

Table 7.25 Results from general linear modelling of length for NSW early morning shore-based recreational tailor catches.

| Source | DF | Type III SS | Mean Square | F | Pr > F |
|---|---|---|---|---|---|
| Platform | 2 | 230 | 115 | 9.38 | 0.0001 |
| Platform (site) | 32 | 2519 | 78.7 | 6.43 | 0.0001 |
| Quarter | 3 | 24.9 | 8.3 | 0.68 | 0.5666 |
| Platform*quarter | 4 | 215 | 53.9 | 4.4 | 0.0020 |
| Platform*quarter (site) | 15 | 471 | 31.4 | 2.57 | 0.0016 |

*7.4.2.4 Length and age structure with depth and distance from coast*

Analysis of New South Wales shore-based data was carried out using general linear modelling of variation in length. This analysis (Table 7.25) showed a significant interaction effect between fishing platform and quarter when other factors were taken into account, including quarter, site nested within platform, and the interaction between quarter and site nested within platform.

Given this interaction, means must be examined at the platform * quarter level (Table 7.26). Average lengths of fish taken from rock platforms were larger than those taken from the beach and from breakwalls for all quarters except autumn 1994. The largest fish were caught in winter and spring of

Table 7.26 Average lengths, sample sizes, and standard deviations of length by platform and quarter for early morning shore-based recreational catches.

| PLATFORM | Quarter/year | N | Mean | SD |
|---|---|---|---|---|
| Beach | Autumn 1994 | 26 | 29.9 | 3.2 |
| Beach | Winter 1994 | 39 | 29.1 | 5.1 |
| Beach | Summer 1994/95 | 7 | 31.6 | 2.1 |
| Rock | Autumn 1994 | 25 | 29.8 | 2.2 |
| Rock | Winter 1994 | 51 | 37.3 | 6.4 |
| Rock | Spring 1994 | 4 | 39.0 | 4.8 |
| Rock | Summer 1994/95 | 66 | 32.2 | 3.7 |
| Wall | Autumn 1994 | 29 | 29.0 | 4.5 |
| Wall | Winter 1994 | 9 | 29.2 | 6.1 |
| Wall | Summer 1994/95 | 7 | 22.9 | 9.3 |

1994. For boat-based catches of tailor, there were significant differences in the lengths of fish caught between quarters and sites, and a significant interaction between site and quarter (Table 7.27). Means were therefore examined at the site * quarter level.

Table 7.27 Results from general linear modelling of length for NSW boat-based recreational tailor catches.

| Source | DF | Type III SS | M S | F | Pr > F |
|---|---|---|---|---|---|
| Site | 8 | 4451.3 | 556.4 | 17.09 | 0.0001 |
| Quarter | 7 | 802.9 | 114.7 | 3.52 | 0.0010 |
| Quarter * site | 36 | 5495.6 | 152.7 | 4.69 | 0.0001 |

The average length of fish taken by boat-based anglers was greatest in the two winter quarters of 1994 and 1995 (Table 7.28). The overall average of 35.96 ± 0.25 (std. err.) was larger than for rock anglers. However when the 1994 data were separated out, for comparison with the rock platform data, the average was 34.98 ± 0.37 which was similar to the rock platform catch (Table 7.29).

Table 7.28 Average lengths, sample sizes, and standard deviations by quarter for boat-based recreational catches of tailor

| Quarter | N | Mean | SD |
|---|---|---|---|
| Autumn 1994 | 169 | 34.21 | 7.22 |
| Autumn 1995 | 207 | 34.38 | 5.72 |
| Spring 1993 | 72 | 35.74 | 9.34 |
| Spring 1994 | 12 | 33.42 | 4.01 |
| Summer 1993 | 83 | 34.39 | 8.25 |
| Summer 1994 | 50 | 33.48 | 4.06 |
| Winter 1994 | 105 | 37.11 | 6.98 |
| Winter 1995 | 167 | 40.78 | 7.21 |

Table 7.29 Overall average length, standard error and sample sizes for early morning shore-based recreational catches.

| Platform | Average | SE | N |
|---|---|---|---|
| Ocean Beach | 31.11 | 0.47 | 57 |
| Breakwall | 31.17 | 0.71 | 30 |
| Rocks | 34.15 | 0.45 | 140 |

For the North American bluefish catch, the average length caught by boat-based methods (charter, party/charter, and private/rental) was considerably larger than for non-boat methods (man-made, beach/bank, and shore) (Table 7.30).

#### *7.4.2.5 Length variation between catches*

During the Fraser Is sampling, there was considerable variation in average fish length between catches (Figure 7.63). This variation was both temporal (over a relatively short time-span) and spatial (over a relatively small section of the island coast.

General linear modelling showed significant differences in length for the date*location interaction term ($F=8.32$, $p<0.0001$), and for catch when date and location were taken into account ($F=16.69$, $p < 0.0001$).

Similarly, there were significant differences between lengths of fish in commercial catches when month and year were taken into account (F=40.16, p<0.0001).

Table 7.30 Average length by platform for *Pomatomus saltatrix* taken in the USA by recreational anglers. Data from the US National Marine Fisheries Service's Marine Recreational Fisheries Statistics Survey.

| FISHING PLATFORM | MEAN LENGTH (cm) |
|---|---|
| Man-made | 30.90 |
| Beach-bank | 35.65 |
| Shore | 28.42 |
| Charter | 41.76 |
| Party/charter | 52.60 |
| Private/rental | 48.14 |

*7.4.2.6 Change through time – average length from recreational catch records*

Results from the general linear modelling indicated significant differences in mean weight of tailor caught between clubs, and a significant interaction between month and location (Table 7.31). There was a significant increasing trend in average weight through time, though variation was better explained on a year by year basis (Table 7.32).

*7.4.2.7 Trends in recreational fishing effort – DEH Fraser Island access data*

The tourism numbers during the off-season were 65% of numbers during the tailor season. We therefore made the ad hoc assumption that the difference (35%) in passenger numbers during the tailor season was due to tailor fishers. The annual rate of increase during the tailor season was 4.5%, and the average increase outside the tailor season was 5.3%. Assuming that the difference was due to a slower rate of increase for tailor fishing, that rate was estimated as 3.4% per annum.

Table 7.31 Results of general linear modelling of tailor fork length by club, year, location, and month (all as classification variables) based on recreational fishing club data.

| Source | DF | Type III SS | MS | F | Pr > F |
|---|---|---|---|---|---|
| Location | 28 | 10.38 | 0.3708 | 2.32 | 0.0004 |
| Month | 11 | 3.09 | 0.2811 | 1.76 | 0.0632 |
| Location*month | 41 | 12.81 | 0.3124 | 1.96 | 0.0013 |
| Club | 273 | 60.63 | 0.2221 | 1.39 | 0.0069 |
| Year | 17 | 12.90 | 0.7587 | 4.75 | 0.0001 |

Table 7.32 Results of general linear modelling of tailor fork length with club, location, and month as classification variables and year as a linear covariate, based on recreational fishing club data.

| Source | DF | Type III SS | Mean Square | F | Pr > F |
|---|---|---|---|---|---|
| Location | 29 | 10.122 | 0.3490 | 1.71 | 0.017 |
| Month | 11 | 3.172 | 0.2884 | 1.41 | 0.168 |
| Location*month | 41 | 13.017 | 0.3175 | 1.56 | 0.024 |
| ClubKey | 273 | 70.327 | 0.2576 | 1.26 | 0.036 |
| Year | 1 | 0.894 | 0.8941 | 4.39 | 0.037 |

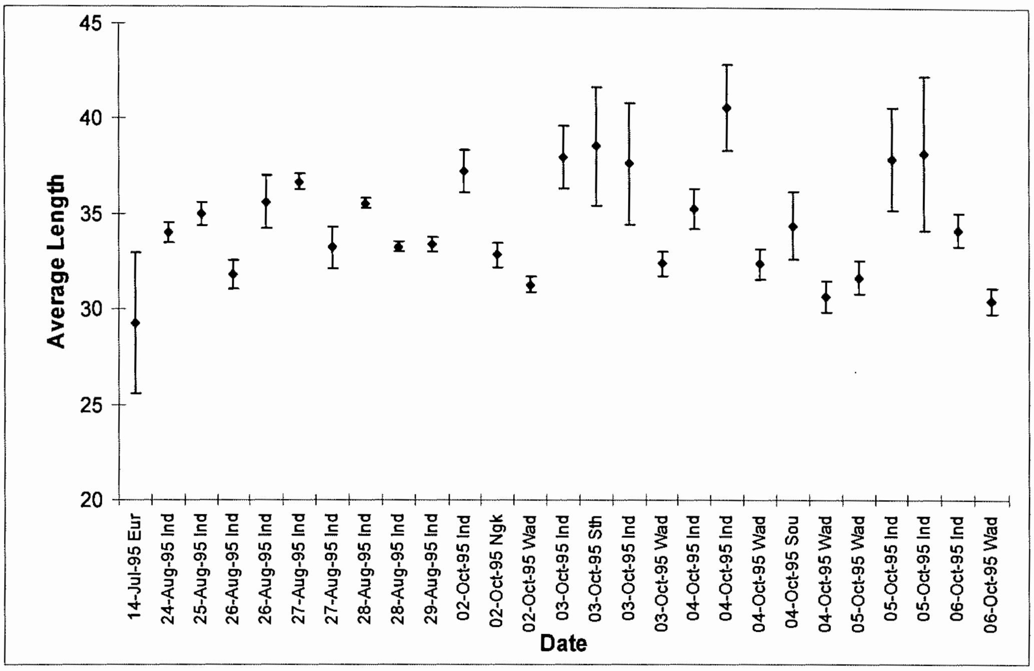



Figure 7.63 Average fork length (cm) of tailor in catch by catch date and location, with 95% confidence limits on average length. Location codes: Eli – Eli Creek, Inh – Indian Head, Ngk – Nagkali Rocks, Wad – Waddy Pt, Sou – South Rocks.

### 7.4.3 **Population age structure and total mortality rate**

#### *7.4.3.1 Bream*

The bream fishery takes fish from a wide range of age classes. The oldest age estimated was a single ageing each of 16 years for two bream from Hervey Bay (one also estimated at 15, 15, and 15, the other also aged as 12, 13, and 14). The oldest estimates from Moreton Bay were two fish each estimated on both readings to be 13 years old.

The catch curves show similar rates of total mortality for Hervey Bay and Moreton Bay (Figure 7.64). Although the Moreton Bay rate appeared higher, the difference was not statistically significant. There was also the appearance of a greater age at full recruitment for Hervey Bay. The growth rate data from Moreton Bay suggested 7 years as age of full recruitment, whereas the age structure data appeared to show an age at full recruitment of 4 years. We were unable to use the same technique for Hervey Bay without fishery-independent data from that region. Both total mortality estimates (Table 7.33) are calculated using an age at full recruitment of 7 years.

Standard error given here refers only to the statistical error in calculating the slope, and underestimates the true uncertainty associated with ageing error and sampling error. These are incorporated in the stochastic yield-per-recruit model.

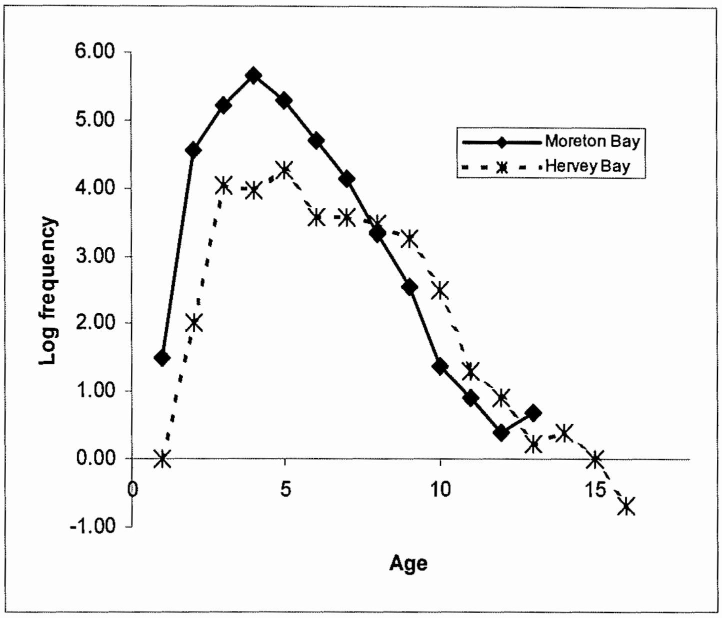



Figure 7.64 Catch curves for bream from Moreton Bay and Hervey Bay. Data from all years are pooled. Negative values of log frequency are obtained when frequency is between 0 and 1 – this occurs because age estimates are weighted to equalise the contribution of fish to the analysis.

Table 7.33 Estimates of total mortality for bream in Moreton Bay and Hervey Bay.

| Location | Moreton Bay | Hervey Bay |
|---|---|---|
| Mortality | 0.638 | 0.510 |
| Std Error | 0.087 | 0.040 |

#### *7.4.3.2 Sand whiting*

The growth curve for Moreton Bay suggested an age at full recruitment of approximately 4 years. This is supported by the shape of the catch curve, which shows a consistent slope after the age of 4 years (Figure 7.65).

Table 7.34 Estimates of total mortality for sand whiting on the Gold Coast, Hervey Bay, and Moreton Bay.

| Location | Gold Coast | Hervey Bay | Moreton Bay |
|---|---|---|---|
| Mortality | 0.62 | 0.99 | 1.45 |
| Std Error | 0.11 | 0.15 | 0.14 |

Moreton Bay appeared to have a higher total mortality rate than the Gold Coast or Hervey Bay (Table 7.34). The Gold Coast samples came from seine netting in the Broadwater and recreational angling in the Nerang river, while the Moreton Bay samples came from anglers, tunnel nets, and mesh nets from a number of areas around the bay. Rod and line-caught samples from Moreton Bay were significantly smaller than those from the Gold Coast. Commercially caught whiting from Hervey Bay were significantly smaller than those from Moreton Bay.

As for the bream, standard error given here refers only to the statistical error and underestimates the true uncertainty associated with ageing error and sampling error. There was considerable ageing error with both whiting species.

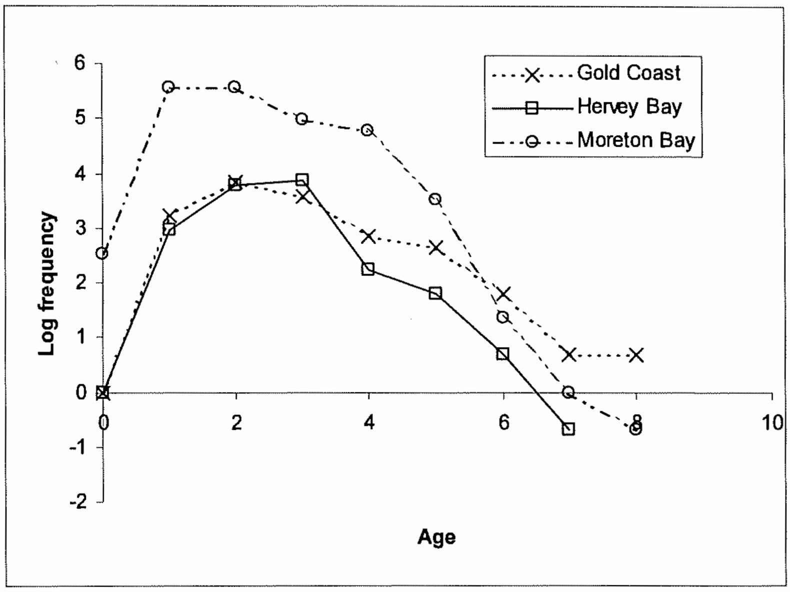



Figure 7.65 Catch curves for sand whiting from Hervey Bay, the Gold Coast, and Moreton Bay.

#### *7.4.3.3 Golden-lined Whiting*

Although estimates of total mortality for golden-lined whiting were calculated from catch curves (Figure 7.66 and Table 7.35), too few samples were obtained and aged to place much confidence in the results: only 121 fish in one catch from Hervey Bay, and 105 in 2 commercial and 11 fishery-independent catches from Moreton Bay. This is particularly so given the difficulty, and degree of error, involved in ageing golden-lined whiting.

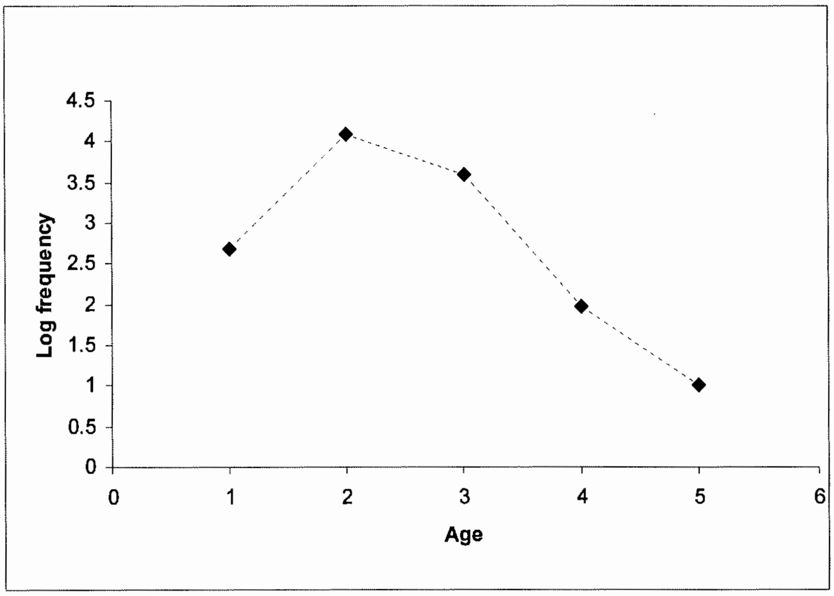



Figure 7.66 Catch curve for golden-lined whiting in Hervey Bay.

#### *7.4.3.4 Dusky flathead*

The flathead fishery was dominated by one, two, and three-year old fish. Consistent with the appearance of growth rings during winter, the proportion of one-year olds in the catch decreased substantially between July-August and November-December 1997, with a corresponding increase in the proportion of two and three-year old fish (Appendix Figure 1).

Mortality rates were estimated separately for males and females in the three areas from which sufficient samples were obtained (Figure 7.67; Table 7.36). Total mortality rate was estimated to be significantly higher for males than females on the Gold Coast and in Moreton Bay, but not significantly different in Hervey Bay.

### *7.4.3.5 Tailor*

The tailor fishery was dominated by fish aged as 1 and 2 years old, with very few fish aged as more than 3 years old in the catch (Figure 7.68). No marked changes in size and age distribution were observed through time (Appendix Figure 6). The 1995 and 1996 data show a fairly clear division into age classes by size, though there is a suggestion of ageing error in the 2nd peak of one-year olds in the 3rd quarter of 1995. The total mortality rate for tailor estimated from the catch curve was 2.03 ± 0.24.

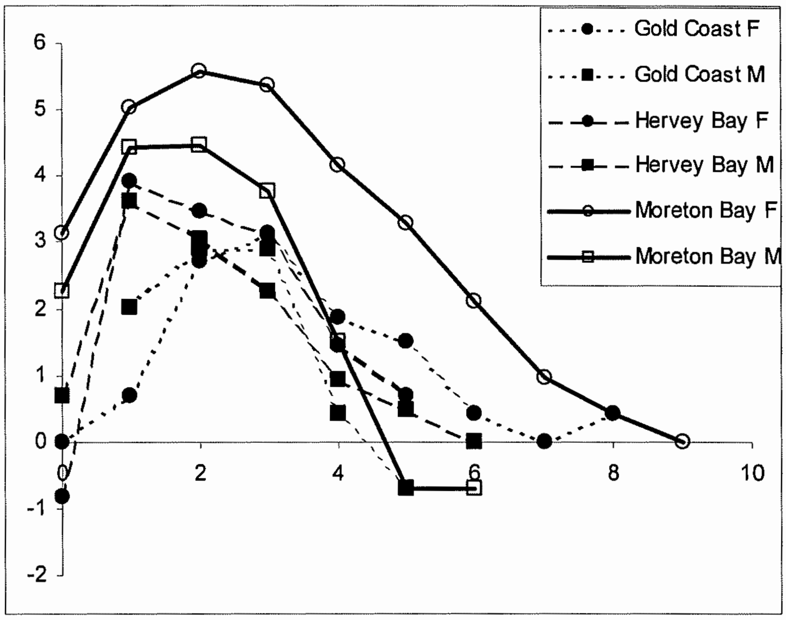



Figure 7.67 Catch curves for dusky flathead by sex and location (Gold Coast, Hervey Bay, and Moreton Bay).

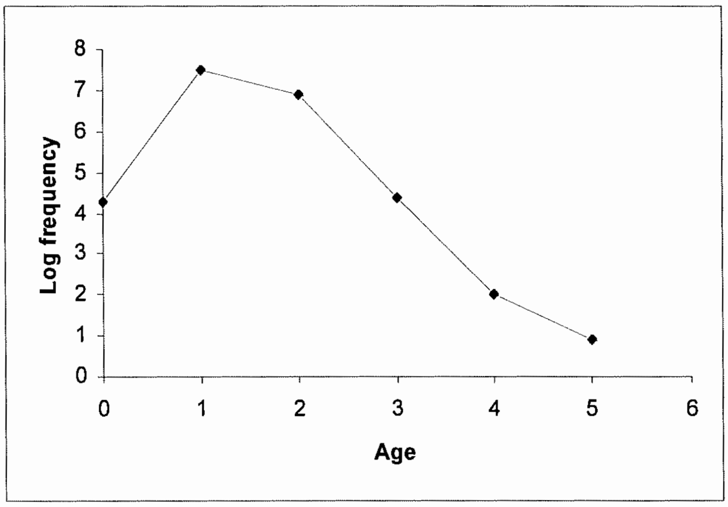



Figure 7.68 Catch curve for tailor from combined commercial and recreational data for all years.

## 7.4.4 Yield-Per-Recruit Analysis

### *7.4.4.1 Bream*

The deterministic yield per recruit model suggested that the ideal minimum legal size was strongly dependent on current fishing pressure (Figure 7.69). Due to the large amount of error inherent in the data-based estimates of natural and fishing mortality, as well as error in estimates of growth rate, a stochastic yield per recruit model was preferred.

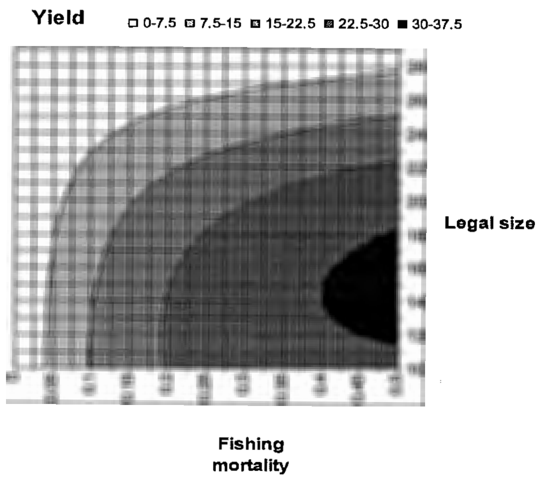



Figure 7.69 Isopleth diagram of bream yield per recruit at a range of legal sizes and fishing mortalities.

The stochastic yield per recruit model, when run with natural mortality predicted by Pauly's (1980) method, gave an average prediction of optimum legal size of only 12.2 (± 1.75) centimetres fork length at current levels of fishing mortality. However, there was a strong negative correlation between predicted legal size and natural mortality (rho=-0.710), even with the low level of variation in M permitted by Pauly's method for estimating M (mean of 0.421 and standard deviation of 0.028). The true uncertainty in M is greater than this, since the model does not take into account the inaccuracy of Pauly's method, which is only a rule of thumb.

We therefore ran the model a second time with natural mortality distributed with an arbitrary mean of 0.35 and standard deviation of 0.1. With this input the model recommended a minimum legal size of 14.7 cm ± 3.4 fork length. The correlation between M and legal size in this case was –0.968, indicating the importance of the natural mortality estimate. Values given below are estimated with the second version of the model.

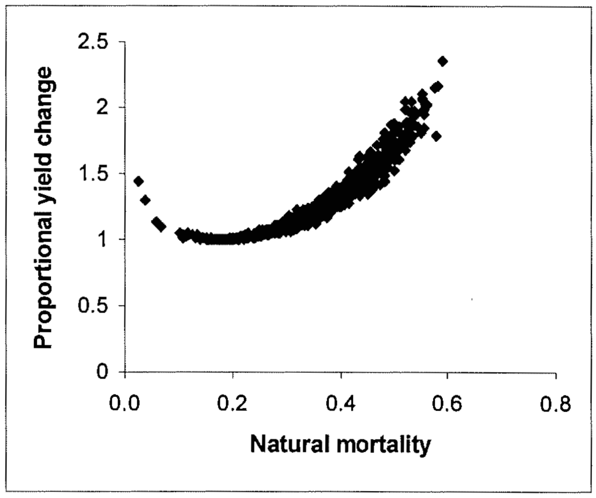



Figure 7.70 Distribution of potential yield changes for bream, given optimum minimum legal size, at various levels of natural mortality.

Given this close relationship between natural mortality and the legal size that will maximise yield at the current level of fishing mortality, we estimated the natural mortality for which the current legal size would maximise yield. This value was 0.193. Therefore, if M was less than 0.193 then the fishery would probably benefit if legal size was raised. If M is greater than this a decrease in the MLS would benefit the fishery in yield per recruit terms. However, this does not take into account egg production, the relative commercial and recreational value of small and large fish, or the effort involved in processing them.

Figure 7.70 shows the potential benefit from optimising MLS in terms of proportional increase in yield. The benefits are greatest if the true value of natural mortality is considerably lower or considerably higher than the estimate currently considered most likely.

The model estimates the current level of total mortality, based on estimates of age distribution in the fishery, as 0.66 ± 0.06. This places an upper limit on values of M. The value has fairly tight confidence intervals compared to the estimate of fishing mortality, which is estimated as 0.31+- 0.12.

Growth parameters were estimated as $L_\infty$=27.4+-0.6, K=0.35+-0.03, $T_0$=-0.458+-0.138.

We assessed the fit of the model to the data for age classes 3 and over (n=9) using the sum of the $\chi^2$ values for these age classes. The fit was not particularly good, with a p value of less than 0.05 in 62.5% of cases. Ages less than 3 gave a poor fit, with considerably more fish caught in age classes 1 and 2 than were predicted by the model.

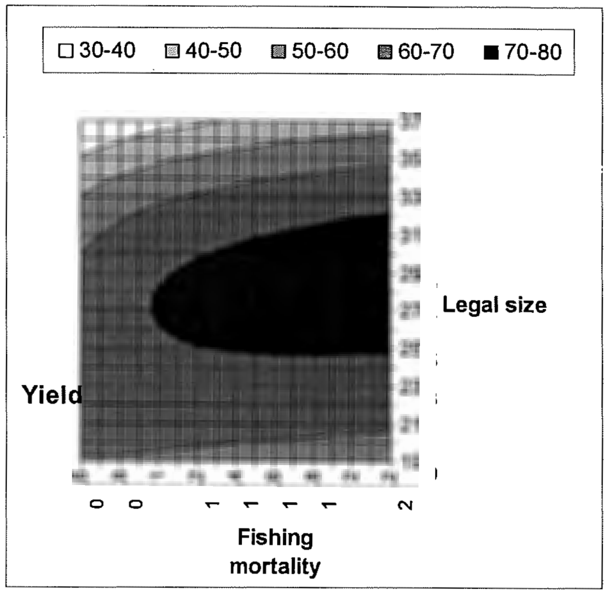



Figure 7.71 Isopleth diagram from deterministic yield per recruit model for sand whiting – Maroochy River.

### *7.4.4.2 Sand and golden-lined whiting*

Deterministic yield per recruit models were developed for both sand and golden-lined whiting. The current minimum legal size of 23 cm total length for whiting is equivalent to 21.5 cm fork length for sand whiting and 21.9 cm fork length for golden-lined whiting. The results suggested that, purely on the basis of yield per recruit, this MLS is too small for sand whiting from the Maroochy river (Figure 7.71), and possibly low also for sand whiting from Moreton Bay (Figure 7.72). The results suggest that for Moreton Bay fish the MLS should be one centimetre larger, but seven centimetres larger for Maroochy river whiting.

The current legal size may be a little too large for golden-lined whiting (Figure 7.73) . However this result is very uncertain given the ageing and sampling error in the parameter estimates for this species.

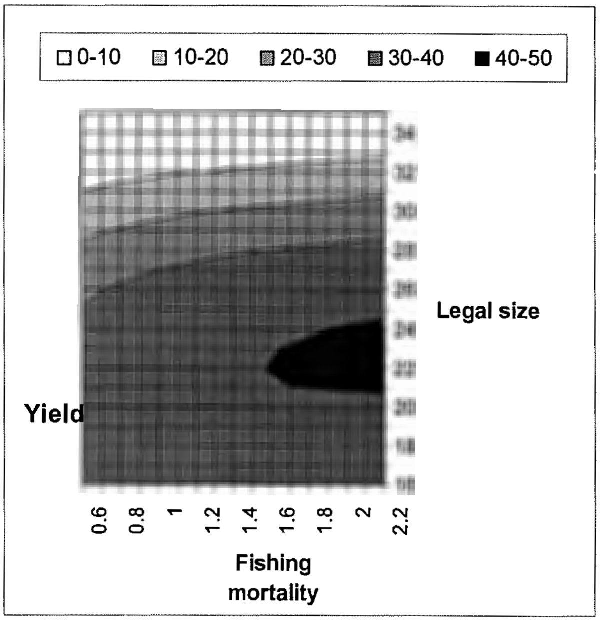



Figure 7.72: Isopleth diagram from deterministic yield per recruit model for sand whiting – Moreton Bay.

### *7.4.4.3 Dusky flathead*

The recommended minimum legal size from the deterministic yield per recruit model was relatively insensitive to the estimate of current fishing mortality. However, there was considerable uncertainty associated with many aspects of the data and analysis. In order to assess the effects of this on results, the stochastic yield per recruit model was adapted to flathead.

The model was adapted to deal with the two sexes separately, given their differing growth rates, and to allow for varying catchability with size.

The model estimated natural mortality as 0.201 ± 0.032 based on Pauly's (1980) method for estimating mortality from growth rate and mean water temperature.

The von Bertalanffy growth curve for females was estimated with the following parameters (mean (median) ± standard deviation, N=1000): $L_\infty$ = 851 (847) ± 46 mm, K = 0.218 (0.218) ± 0.023, and $T_0$ = -0.454 (-0.450) ± 0.097. The male growth curve was determined with less precision, with the parameters $L_\infty$ = 934 (824) ± 454 mm, K = 0.148 (0.143) ± 0.059, and $T_0$ = -1.25 (-1.24) ± 0.28.

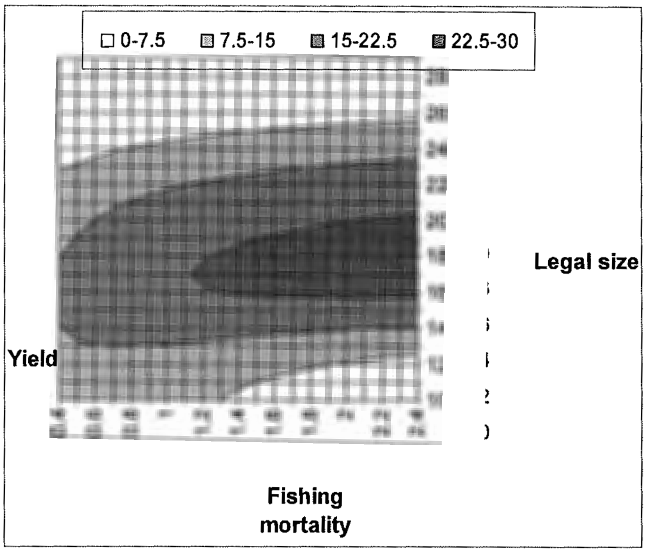



Figure 7.73 Isopleth diagram from deterministic yield-per-recruit model for golden-lined whiting.

The current fishing mortality estimated for each age class is given in Table 7.37. The decline in these values with increasing age is the result of a size selectivity curve that is estimated by the model based on frequency at age of both sexes. The results suggest that flathead become less vulnerable to fishing as they grow. Female flathead have lower fishing mortality than males, because their faster growth means they are at the most vulnerable lengths for a shorter period.

Table 7.37 Fishing mortality at age estimated from flathead stochastic yield per recruit model. The mean and standard deviation of fishing mortality are given for both sexes for ages 4 to 10.

| | Age | 4 | 5 | 6 | 7 | 8 | 9 | 10 |
|---|---|---|---|---|---|---|---|---|
| Females | Mean | 0.66 | 0.51 | 0.41 | 0.35 | 0.31 | 0.28 | 0.25 |
| | SD | 0.18 | 0.21 | 0.22 | 0.22 | 0.22 | 0.22 | 0.21 |
| Males | Mean | 0.98 | 0.78 | 0.65 | 0.55 | 0.48 | 0.43 | 0.39 |
| | SD | 0.14 | 0.16 | 0.19 | 0.21 | 0.23 | 0.23 | 0.23 |

The model estimates a sex ratio at birth of 3.04 ± 1.12 females to 1 male.

The model estimates that the greatest yield per recruit from both sexes combined would be achieved by increasing the minimum legal size to a mean of 550 ± 63 mm (SD) (Figure 7.74). The mean (± SD) yield per recruit achieved in this case would be 1550 ± 860 g, or an average increase of 92 ± 41%

However, given that it is not possible to estimate the exact MLS that will give the absolute maximum value of yield, we must select an MLS and assess the probable change in yield. If we change the minimum legal size to 550 mm, the model estimates that yield would increase by 86 ± 37%.

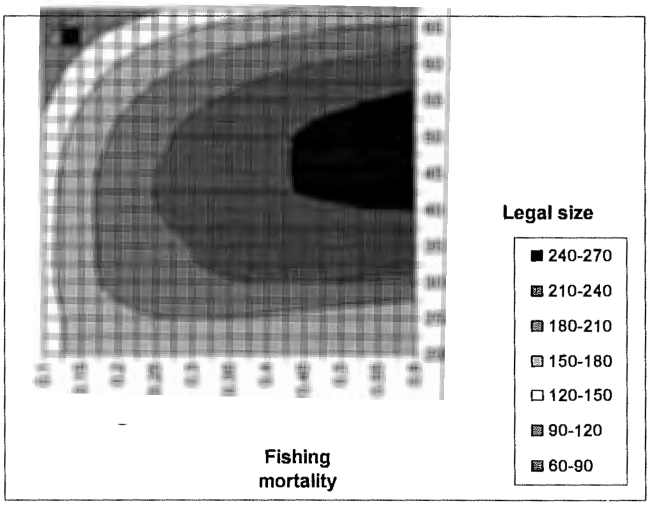



Figure 7.74 Isopleth diagram for dusky flathead yield per recruit model. The highest yields are available in the dark area on the middle right of the diagram.

*7.4.4.4 Tailor*

The tailor fishery was also modelled using both deterministic and stochastic yield per recruit models. The deterministic model (Figure 7.75) gives the impression that yield per recruit would not be improved by increasing the current legal size.

The stochastic model, on the other hand, suggests that a slight increase in legal size to about 32.7 cm fork length or 36 cm total length would give better yield. However, the magnitude of the increased yield is likely to be low, with a greater than 50% chance that it would be 5% or less.

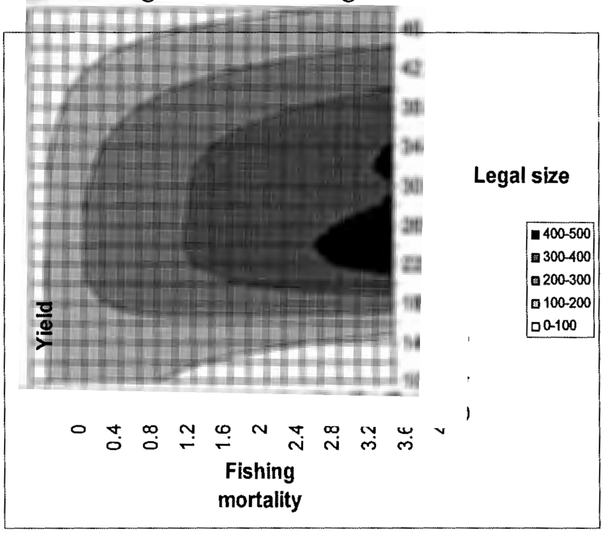


Figure 7.75 Isopleth diagram based on deterministic yield per recruit model of tailor. The graph shows predicted yield based on fishing mortality and minimum legal size (fork length in cm.).

### 7.4.5 Catch sampling results: length-weight relationships

To aid in the comparison of growth and size-structure statistics between different studies as well as provide a conversion to weight for incorporation into the yield-per-recruit analyses, we estimated the regression parameters between various pairs of morphometric characteristics for each of the species (Table 7.38). Also included are data for the winter or trumpeter whiting (*Sillago maculata*) although this species was not included formally in the suite of species addressed by the Project. The convention adopted in Table 7.38 was to provide the slope (B) and intercept (A) of either the linear regression (for length-length conversions) or exponential regression (for length-weight conversions).

Length-weight relationships use the formula: Weight = $e^{B} \times \text{Length}^{A}$.

Length conversion relationships have the form: $\text{Length}_1 = \text{slope} \times \text{Length}_2 + \text{intercept}$.

The error values included in the table are standard errors of the estimates.

Table 7.38 Length-weight and length conversion relationships.

| Parameter | | *A. australis* | *S. ciliata* | *S. analis* | *S. maculata* | *P. fuscus* | *P. saltatrix* |
|---|---|---|---|---|---|---|---|
| Fork to wt | A | 2.856 | 3.063 | 3.203 | 3.043 | | 3.005 |
| | Error | 0.058 | 0.038 | 0.055 | 0.049 | | 0.022 |
| | B | -3.295 | -4.777 | -5.189 | -4.736 | | -4.290 |
| | Error | 0.182 | 0.124 | 0.174 | 0.135 | | 0.076 |
| Total to weight | A | 2.838 | 3.076 | 3.164 | 3.034 | 3.079 | 2.982 |
| | Error | 0.060 | 0.039 | 0.052 | 0.045 | 0.034 | 0.025 |
| | B | -3.585 | -5.018 | -5.206 | -4.883 | -5.333 | -4.503 |
| | Error | 0.194 | 0.129 | 0.168 | 0.125 | 0.129 | 0.087 |
| Standard to weight | A | 2.869 | 2.978 | 3.061 | 2.872 | 3.033 | 2.894 |
| | Error | 0.056 | 0.038 | 0.055 | 0.047 | 0.035 | 0.024 |
| | B | -2.913 | -4.161 | -4.355 | -3.941 | -4.728 | -3.594 |
| | Error | 0.167 | 0.119 | 0.168 | 0.123 | 0.129 | 0.078 |
| Total to fork | Intercept | 0.112 | -0.094 | 0.571 | 0.326 | | 0.057 |
| | Error | 0.188 | 0.142 | 0.195 | 0.193 | | 0.129 |
| | Slope | 0.882 | 0.941 | 0.933 | 0.925 | | 0.905 |
| | Error | 0.007 | 0.005 | 0.008 | 0.012 | | 0.004 |
| Standard to fork | Intercept | 0.157 | 0.792 | 1.109 | 1.071 | | 1.197 |
| | Error | 0.250 | 0.123 | 0.190 | 0.181 | | 0.102 |
| | Slope | 1.150 | 1.085 | 1.081 | 1.042 | | 1.071 |
| | Error | 0.013 | 0.005 | 0.009 | 0.013 | | 0.004 |
| Total to standard | Intercept | 0.681 | -0.722 | -0.176 | -0.565 | -0.473 | -1.032 |
| | Error | 0.271 | 0.162 | 0.246 | 0.138 | 0.174 | 0.122 |
| | Slope | 0.738 | 0.863 | 0.851 | 0.878 | 0.879 | 0.844 |
| | Error | 0.011 | 0.006 | 0.010 | 0.008 | 0.004 | 0.003 |
| N | | 220 | 209 | 230 | 202 | 202 | 198 |

## 7.5 Bootstrapping recreational catch confidence intervals – comparison of methods.

The coverage results (Table 14.3.7) are presented as the proportion of replicates where the confidence interval encloses the expected value (ideally 0.90 in most cases). The coverages of the individual tails (Tables 14.3.8 and 14.3.9) are presented as the proportion of replicates where the true value lies in the tail (ideally 0.05). These proportions are binomially distributed (n=4000) so comparisons between trials must take account of this error ($\sigma = \sqrt{pq / n}$).We also compare the performances of the different types of bootstrap confidence interval using the same set of data. Table 14.3.10 gives the width of the confidence intervals.

The various bootstrap methods produced intervals in the following order of decreasing accuracy for both parameters: bootstrap-t, BCa, BC, percentile, bootstrap normal, hybrid (see Table 14.3.7). The bootstrap-t intervals were substantially better than the other methods, particularly for estimating total catch. The BCa confidence interval had greater coverage than BC for catch rate, but only marginal improvement for total catch.

Coverage of catch rate was mostly less than the nominal level. However, some of these 'nominal' coverages were in fact unevenly distributed across the tails, as were all of the non-nominal coverages. Error was in all these cases greater than the nominal level for the upper limit (Table 14.3.9) and less at the lower limit (Table 14.3.8). Where tails were unbalanced the difference was always lowest for the bootstrap-t intervals. The width of the intervals (Table 14.3.10) was also much greater for the bootstrap-t method.

The same pattern occurred for total catch as for catch rate.

Changing the alpha level did not substantially alter the accuracy of any of the intervals.

The size of resample proved to be important. The most accurate intervals for both mean catch and total catch were given by resampling n/2 or 50 items under the bootstrap-t method (see Figures 7.76 and 7.77). For this scenario the BCa method also gave coverage not significantly different (at the 5% level) from the nominated level of 90%, but its intervals were unbalanced with 9.1% of the error in the upper tail. The intervals given by the bootstrap-t method were the closest approach to nominal and balanced coverage achieved by any of the trialed methods. The errors (with binomial standard error) associated with this method for catch rate and total catch at the lower confidence limit were 0.0398 (0.0031) and 0.0385 (0.0030), and at the upper confidence limit were 0.0690 (0.0079) and 0.0660 (0.0077), respectively.

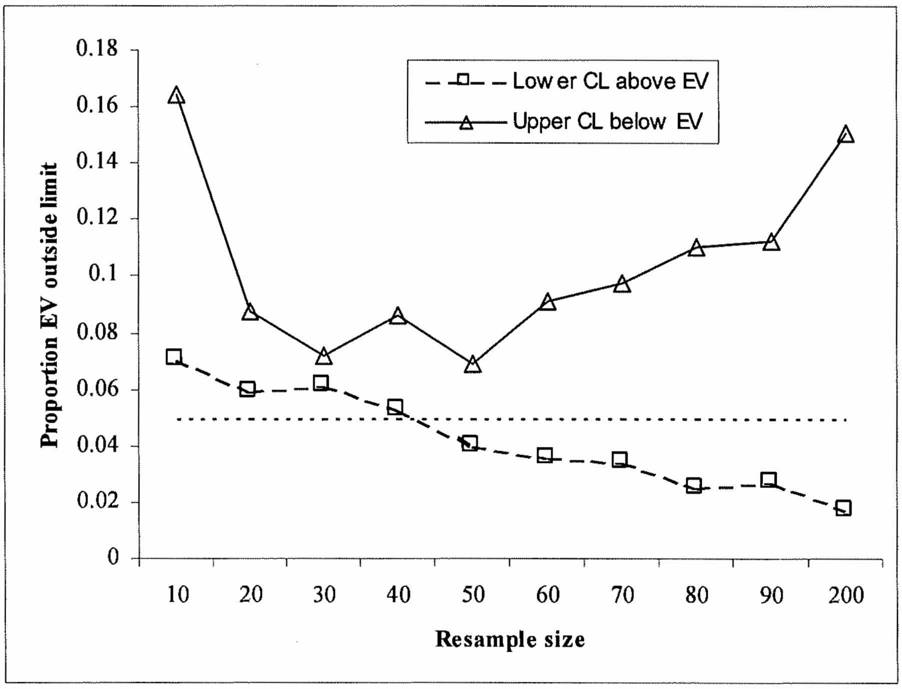



Figure 7.76 Coverage of the upper and lower confidence limits of catch rate for a range of resample sizes. The ideal level is marked with a dotted line.

The error rate of the lower CL increased in an approximately linear fashion as resample size dropped from 100 to 10. At a resample size of between 50 and 40 its error rate approached nominal levels. The error rate of the lower confidence limit increased, also in a roughly linear way, over the interval from 100 to 50. However, after resample size had reached 50 the CL's error rate stopped increasing, and below 30 began to decline rapidly. A resample size of 50, or n/2, was therefore the best option in this case.

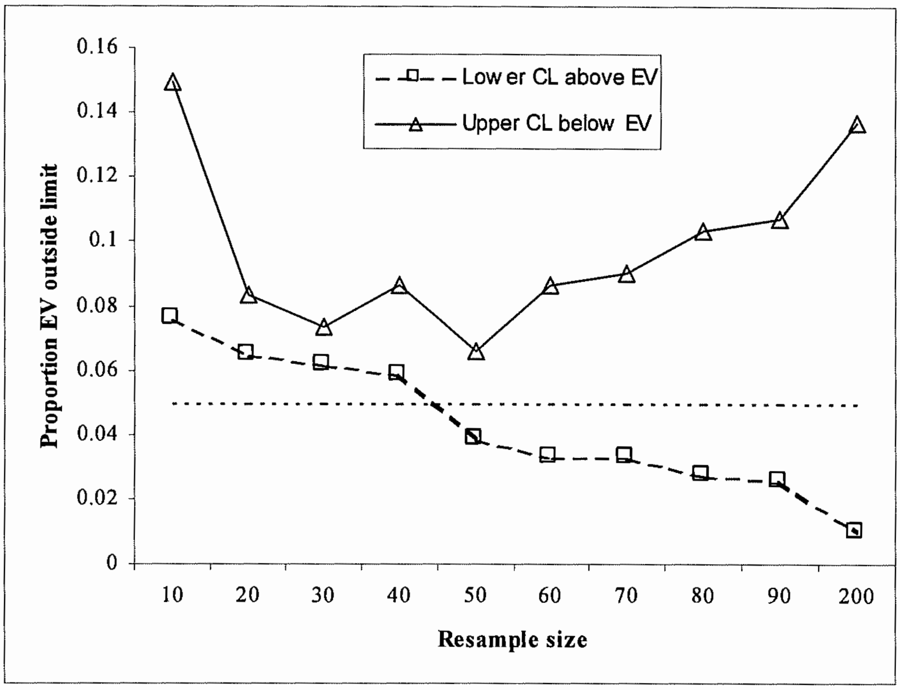



Figure 7.77 Coverage of the upper and lower confidence limits of total catch for a range of resample sizes. The ideal level is marked with a dotted line.

Changing the number of observations in the initial sample had a substantial effect on the width and coverage of the intervals. With 200 observations the bootstrap-t interval's width almost halved, and accuracy improved at both ends. However, all the intervals remained unbalanced with the bootstrap-t the best for catch rate at 0.034 (0.003) and 0.083 (0.004).

As expected, reducing the proportion of zeros in the population improved the coverage of the intervals. When the source distribution for catch rate was Normal, the coverage of all intervals on catch rate reached nominal levels. However, for total catch all but the bootstrap-t intervals still showed considerable lack of balance between the tails.

Changing the relative standard error of effort did not have a significant effect on the coverage or bias of the intervals.

## 7.6 DEPM as an alternative assessment method for tailor

A total of 1027 eggs and 2185 larvae were identified from the plankton samples: 429 eggs and 746 larvae in were found in the 1997 annual egg survey; and 306 eggs and 1132 larvae in the 1998 survey.
There was considerable spatial variation between the two years' surveys. In 1997 the highest egg counts were made to the east of Indian Head (Fig. 7.78), but very few were found there in 1998 (Fig. 7.79). Few eggs and larvae were found north of Indian Head (Figures 7.80 and 7.81).

Eggs were found throughout the year, with a peak in the period from August to October (Fig. 7.82). Larvae were mainly found between July and September, with very low numbers also found at other times of the year (Fig. 7.83).

Larvae appeared to be found further inshore than eggs (Figures 7.84 and 7.85). General linear modelling of larval density by latitude, longitude, and period showed a statistically significant difference between longitudes ($p<0.0001$) and latitudes ($p=0.03$), with a significant interaction ($p=0.0006$), and no significant difference between periods ($p=0.15$). Investigation of the least squares means showed that of the twelve estimates of mean larval density by latitude and longitude, the three highest were in the middle longitude. Egg density differed significantly by longitude ($p=0.04$) and period ($p=0.04$), but showed no statistically significant interactions. The highest egg densities were in the outer longitude range. Overall means are shown in Figure 7.86.

Under non-parametric one-way analyses of variance, eggs showed significant variation across longitudes for two of four periods, and across latitudes for two of four periods. For larvae the equivalent figures were three of four for longitudes and one of four for latitudes.

The distribution of larvae also appeared to be more aggregated than that of eggs, since the standard deviation was higher (F test, $F=1.45$, $p<0.0001$). Considering only presence and absence of larvae (present in 41.3% of samples) and eggs (43.9%), and ignoring the higher average densities of larvae, the proportions of zeroes were not significantly different (binomial test of homogeneity, $p=0.276$).

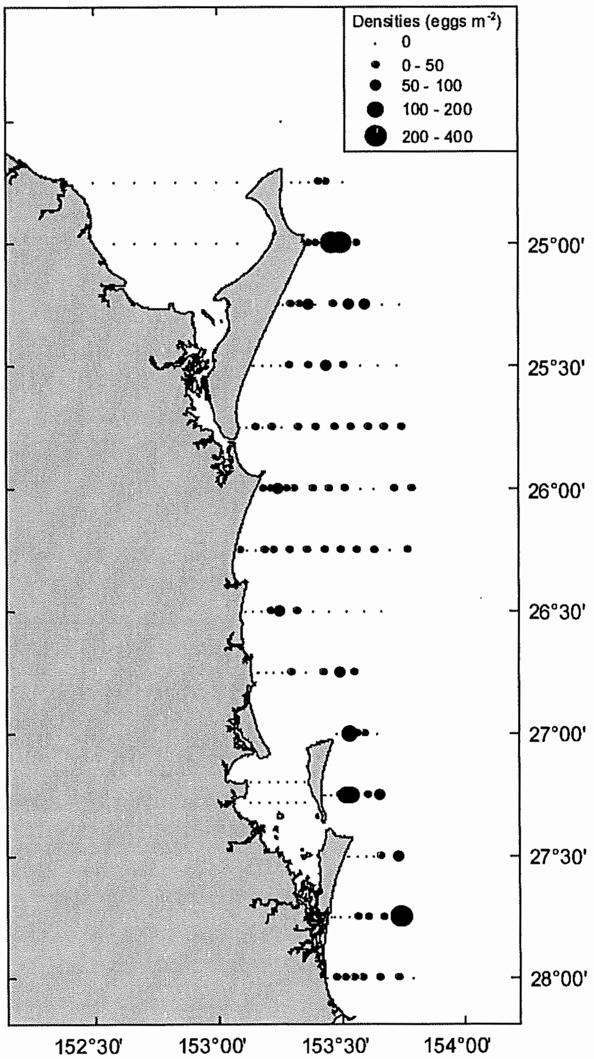



Figure 7.78 Tailor egg densities (eggs $m^{-2}$) during 1997 annual egg survey.

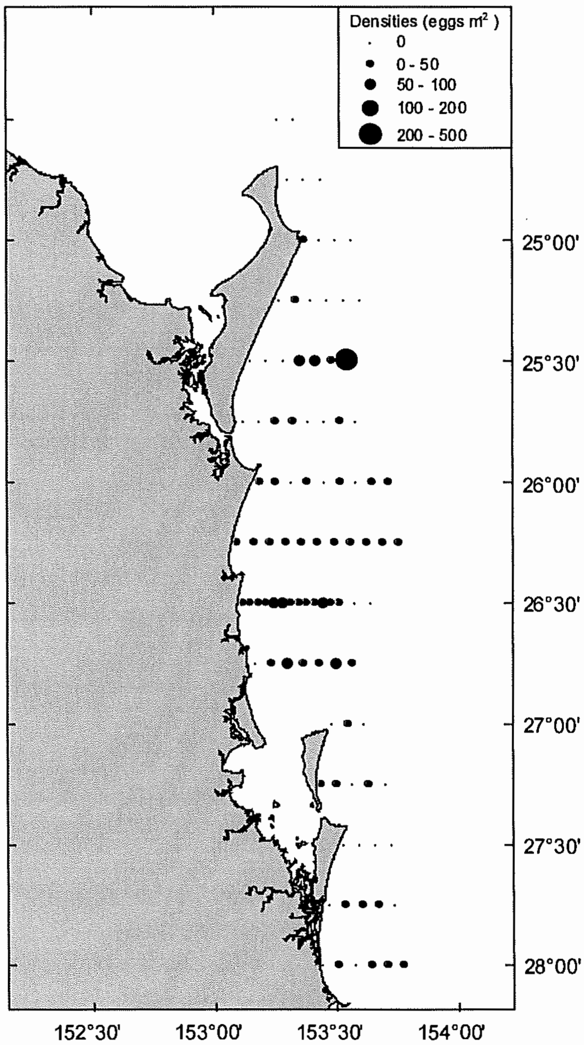



Figure 7.79 Tailor egg densities (eggs $m^{-2}$) during 1998 annual egg survey.

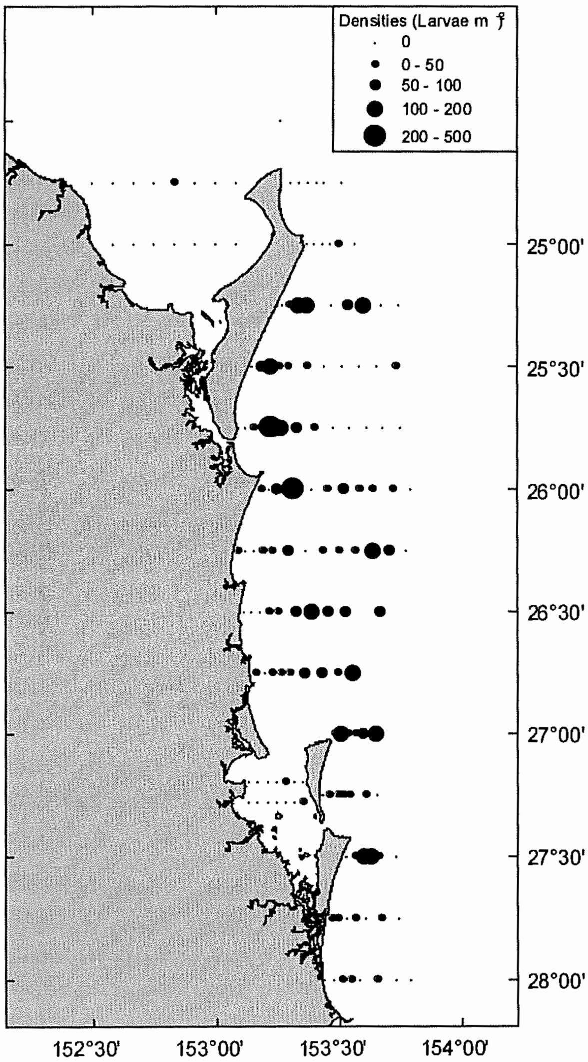



Figure 7.80 Tailor larval densities ($m^{-2}$) during 1997 annual egg survey.

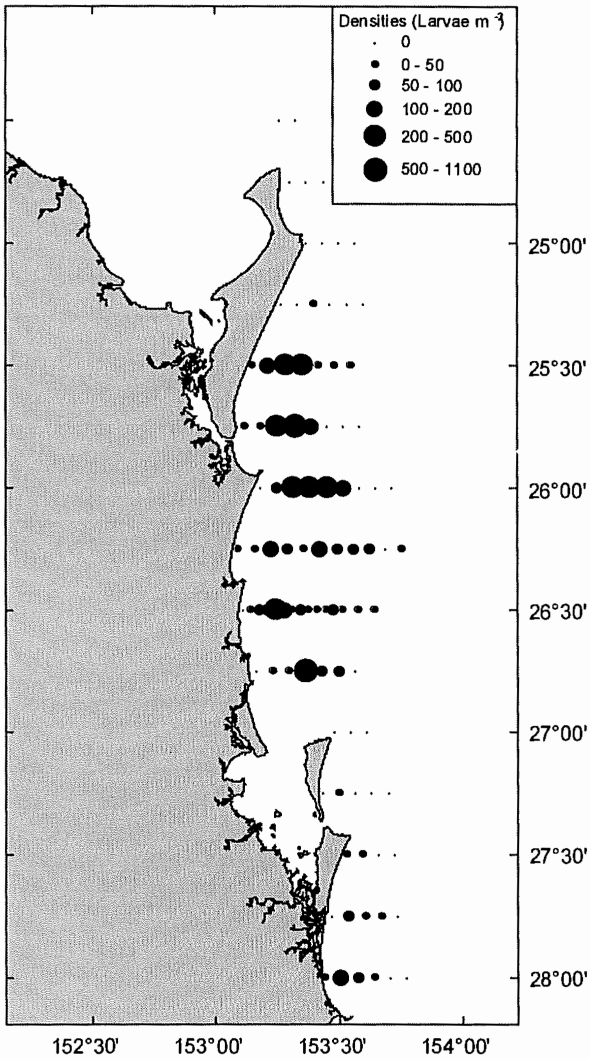



Figure 7.81 Tailor larval densities ($m^{-2}$) during 1998 annual egg survey.

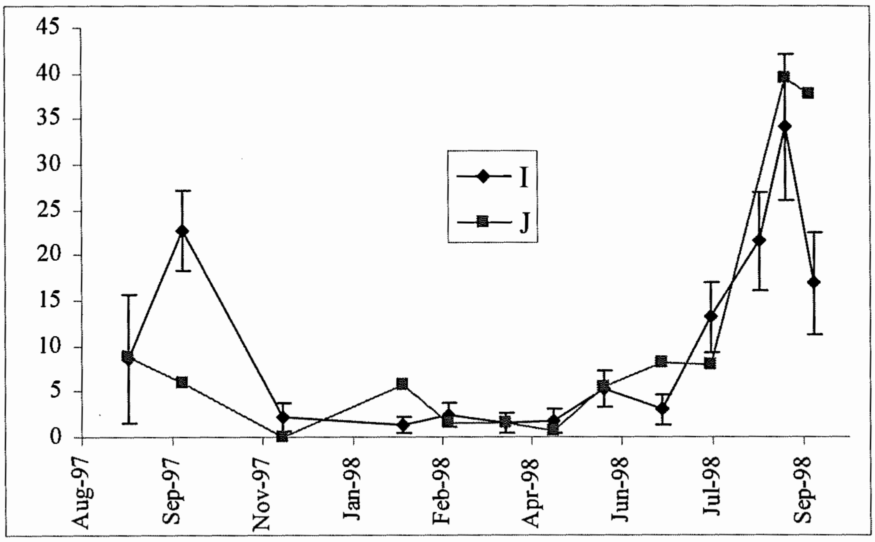



Figure 7.82 Seasonal patterns in abundance of tailor eggs along two transects off the south Queensland coast.

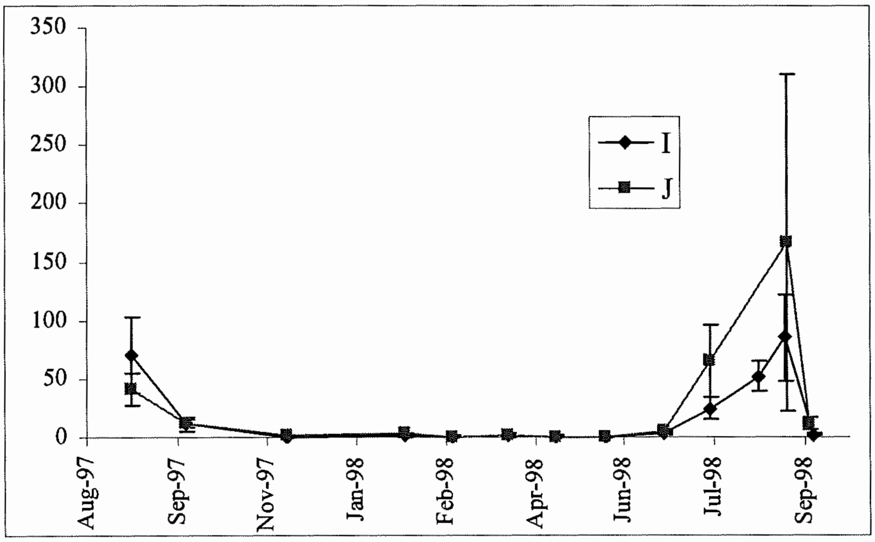



Figure 7.83 Seasonal changes in abundance of tailor larvae along two transects off the south Queensland coast.

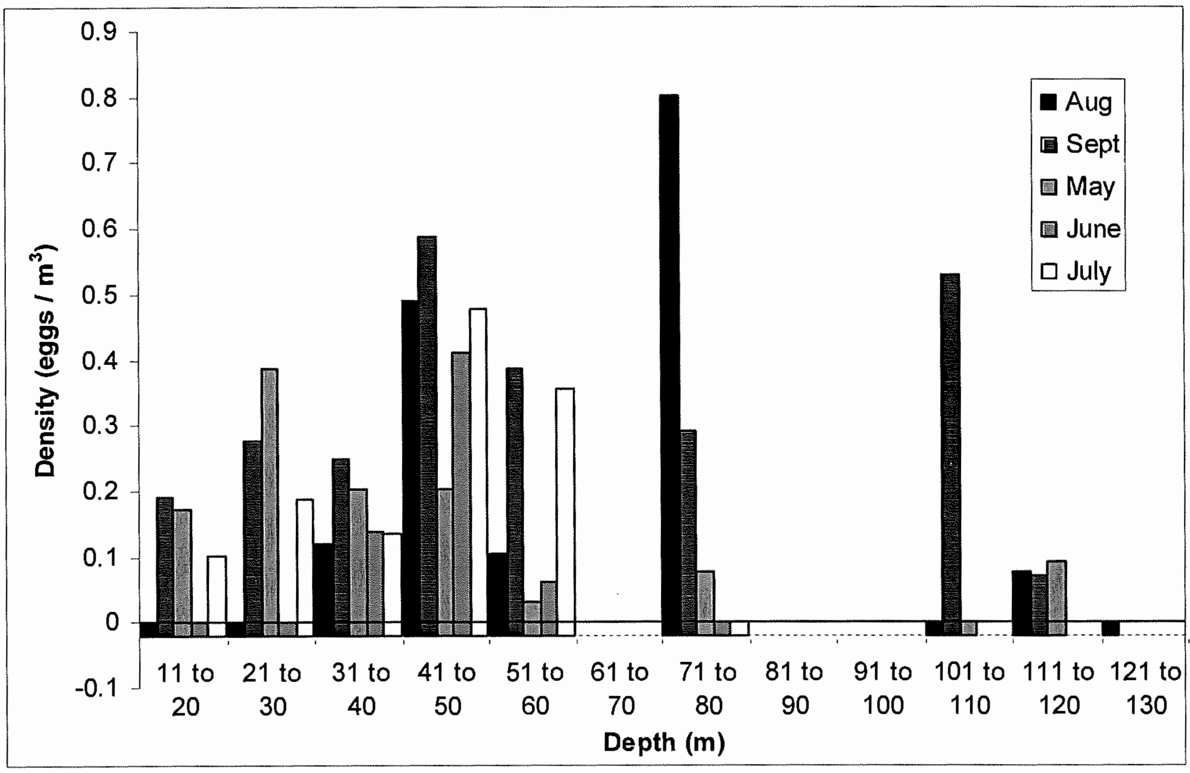



Figure 7.84 Abundance (density) of tailor eggs by depth and month.

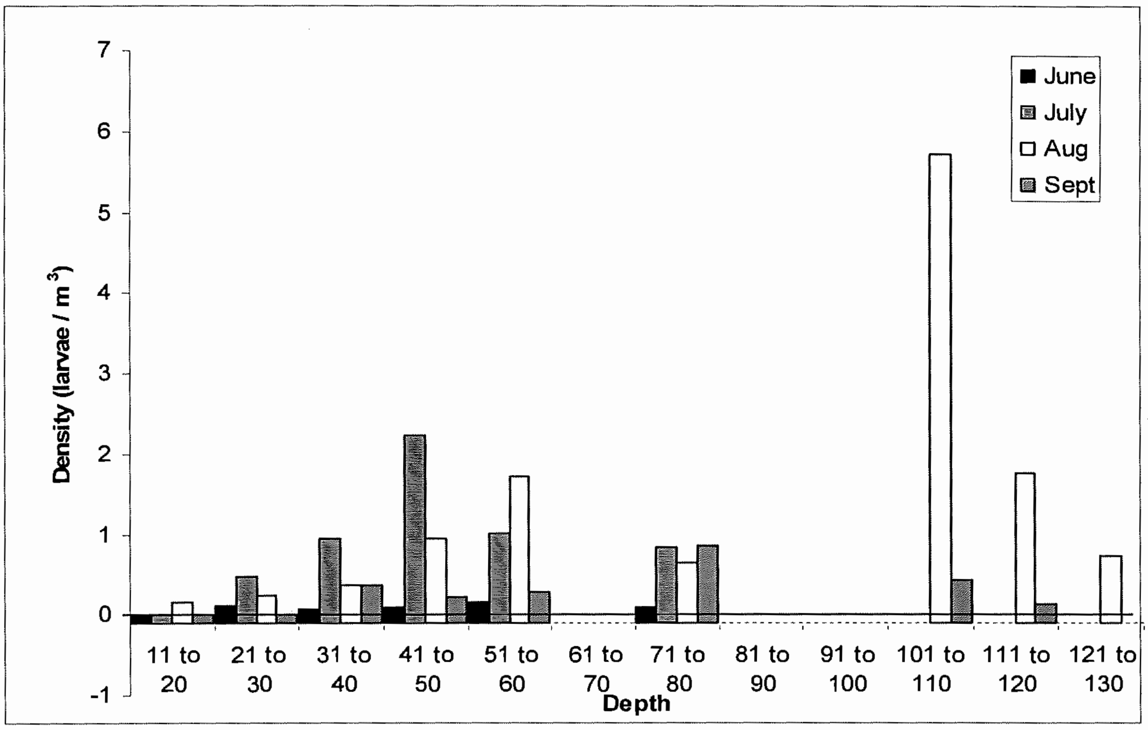



Figure 7.85 Density of tailor larvae by depth between August 1997 and July 1998.

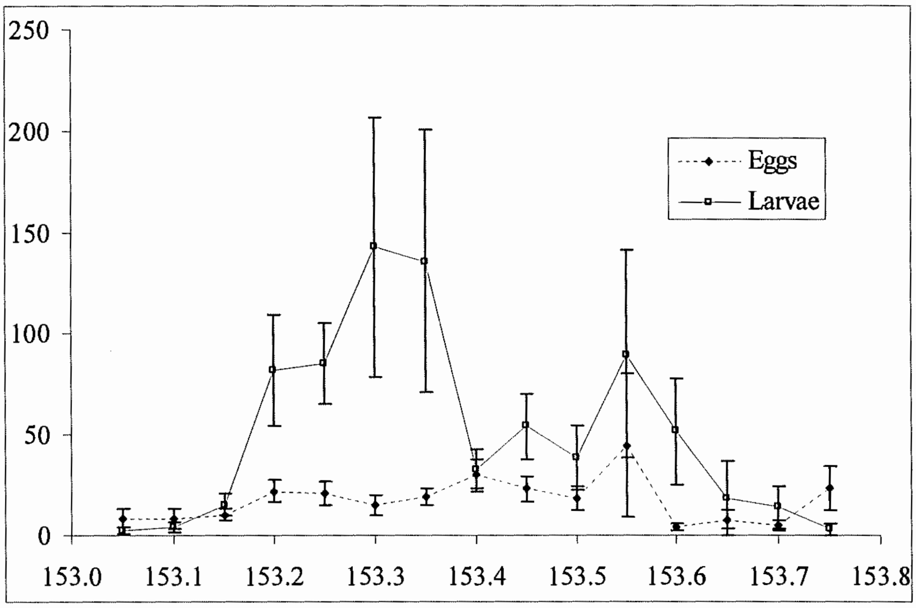



Figure 7.86 Average density of tailor eggs and larvae per square metre of surface, by longitude.

# 8 DISCUSSION

A summary of the detailed material contained in the discussion, together with some overall conclusions, is given in the executive summary. The discussion below follows the structure of the results section.

## 8.1 The CFISH commercial fishery database

### 8.1.1 Data management issues

The CFISH data set is extensive and comprehensive, and is in many respects the central resource for stock assessment and monitoring of Queensland's fisheries. However, there is room to make the system considerably more useful in some areas.

A major potential enhancement, particularly with respect to the ocean beach fishery, would be to separate records of mullet and tailor catches taken by haul net in the ocean beach fishery from those taken in estuarine mesh and tunnel nets. These are quite separate fisheries which are difficult to distinguish under current arrangements.

Inclusion of searching effort in the database would also improve assessments for tailor and mullet. A large part of the effort in the haul net fishery for migratory schooling species consists of searching or spotting. A further enhancement would be to allow determination of the size or number of crews involved in any fishing operation. Beach crews are able to join forces on an *ad hoc* basis, which clearly has an influence on effective effort.

Greater liaison with fishers, together with improved range checking, would greatly improve data quality. 'Effort' indices such as mesh size and net length are included in the logbook, but in very many instances the data are not recorded or are unreliable. It is often impossible to determine what units the mesh sizes are expressed in (i.e. inches, centimetres or millimetres), and there are uncertainties about the net length units as well.

An issue common to multi-species fisheries is the effect of target fishing. The CFISH database would be enhanced by recording which, if any, of the species caught were targeted on a particular operation. Zero catches should also be recorded. If a single species approach is undertaken to calculate effort, the effect of ignoring zero-catch records is to bias the effort down, and correspondingly bias catch rates upward. If the incidence of zero catches where the vessel was fishing and targeting the species of interest, or not targeting any fish specifically, then the relative catch rate index can be misinterpreted. This causes serious problems for the interpretation of CPUE as an index of abundance. Since catch rate is based only on catches where the species is reported, it can be substantially affected by price and the degree of targeting.

The database should separate the catches of flathead, bream, and whiting to their individual species, and use the coding categories already available. Although reasonably confident inferences can be made for dusky flathead and yellowfin bream, this is not the case for whiting. Summer and trumpeter whiting have very distinct life histories and population dynamic characteristics, so it is essential that their catch and effort be treated separately.

The database must also indicate which gear type is used within the net mesh fishery, since the gear types are very distinct. Gear type can currently be inferred through a set of rules using month, location, vessel sequence number of beach seine endorsed fishery, and net length, but this can lead to interpretational errors. The new logbook has a field for recording this information, but as yet it has not been observed in the database. Stock assessment and monitoring would benefit if industry was urged to be much more precise in recording their catch, fishing method and location by species, gear type, and latitude and longitude.

For the above reasons it is essential that the reader be aware that in any graphic or tabular presentation of commercial Queensland haul-net or set-net effort or its derivatives (e.g. catch-per-unit-effort), or in any discussion of these measures, there is a very high degree of inherent uncertainty.

### 8.1.2 The estuarine and ocean beach fisheries

Bream, flathead, whiting and tailor constitute the basis of a multi-species mixed-gear estuarine fishery (using gill, mesh and tunnel nets) in southern Queensland. Tailor are also the secondary focus of a seasonal haul-net fishery, primarily for sea mullet on the ocean beaches. It has not been possible to determine the extent to which fishers target particular species during their fishing operations; this depends on the type of net in use, how it is deployed, knowledge of the presence of particular species and of their behavioural patterns. It appears that fishers probably target bream and whiting, and capture flathead and perhaps tailor incidentally.

The catches of the gill and tunnel net fisheries tend to be small, and characterised by an assemblage of different species. Most of the vessels in the netting fleet recorded less than five days effort per year, and only about 20% of the vessels caught more than 1 tonne of any species in a year. Bream are caught mainly by gill net in Moreton Bay and Hervey Bay, during the winter months, when they congregate near the mouths of rivers and on bars to spawn. Most of the flathead are taken by gill netters in Moreton Bay throughout the year, with highest catch rates in winter. Tailor are mainly caught by the ocean beach fishery on the offshore aggregations along the beaches of Moreton Bay Island and Fraser Island during winter and spring. Both the tunnel and gill net fisheries catch most of the summer, sand, and unspecified whiting throughout the year, mainly in Moreton Bay.

### 8.1.3 CPUE as an index of abundance

Catch per unit effort (CPUE) can be used as an index of abundance in some fisheries. However, many factors can alter CPUE apart from abundance, so it is important to consider such issues directly with respect to each fishery and species. They include the degree of aggregation of the stock, since CPUE on an aggregated patch may not decline at the same rate as abundance; effort creep, in which fishing power gradually increases with advances in technology; changes in price and the amount of targeting in the fishery, since catches of a targeted species will be larger than those of a bycatch species; variation through time or between areas in logbook compliance, or the accuracy of logbook compliance; and variation between areas or times in the scale of fishing operations.

Of the five species only bream and flathead were suitable for analysis of catch per unit effort. As described above, whiting could not be separated into species. Tailor CPUE was too flawed by the lack of search effort data, the lack of information about fishing type (haul net versus gill net) and the effect of price on fishing effort.

Although the bream and flathead analyses appeared successful, we cannot be sure how much some potential problems have affected the results. The majority of the bream catch is taken during the spawning season, when the fish aggregate on surf bars. It is possible that catch rates on these aggregations could be maintained despite a decline in overall stocks. The lack of target species data also causes concern. For example, although Moreton Bay and Hervey Bay had the highest bream commercial catch rates, this could be based only on catches containing bream, and catches where bream was targeted but not caught could not be included. Thus factors other than fish abundance may have affected the result.

Standardisation was effective, and removed spurious time trends in CPUE data for both bream and flathead. The most important factor in the analyses was vessel sequence number, indicating that there is more variability in catch rates between vessels than for each individual vessel. Effort standardisation of this kind is clearly necessary to maintain comparability of data through time, as technological developments and other fishery changes affect catch rates and obscure changes in abundance.

## 8.2 Age determination

Bream otoliths had a clear internal structure, which made them easy and unambiguous to interpret. There was little variation between readers or readings, though sections were aged with slightly less error. On this basis, and due to the cost of sectioning, it may be more cost-effective to age yellowfin bream otoliths whole, as we did in our study. However, sectioned otoliths tended to be aged slightly older than whole otoliths. If this difference is due to better interpretation of sectioned otoliths, particularly at the edge, then ageing of sections may be preferable, depending on the application. Validation of ring annularity using marginal increment analysis was not successful. However, validation using oxytetracycline in NSW (D. Ferrell personal communication) has shown both annual band deposition and growth rates similar to those found in this study. He also found such variable timing of ring deposition among individuals as to make marginal increment analysis difficult without very large sample sizes.

Sand whiting otoliths were almost impossible to interpret when whole, and required sectioning. Even for sectioned otoliths, average percent error was quite high at 17% between readings by the same reader. Marginal increment analysis validated the annual timing of growth band deposition for otoliths with between 1 and 3 bands. Validation has been carried out for sand whiting in New South Wales using oxytetracycline-marked otoliths from tagged and recaptured fish (D. Ferrell personal communication). Further validation in Queensland using this technique may also be worthwhile given the different conditions of temperature variation.

Golden-lined whiting otoliths were even more difficult to interpret than those of sand whiting. Due to the poor readability of the otoliths marginal increment analysis was not carried out for this species.

Dusky flathead otoliths were not particularly easy to interpret either whole or after sectioning. There was relatively high variation between readers and readings for both methods, and it was unclear which ageing method was more accurate.

Sections are often considered to be generally more accurate, partly because the methods can permit bands on the edge to be seen and counted more easily, resulting in higher, more accurate ages (Hyndes *et al.* 1992). However, with dusky flathead whole otoliths tended to be aged older than sections, suggesting that biases were not due to edge interpretation. Supporting this, marginal increment analysis using whole otoliths validated the timing of growth band deposition for otoliths with between 1 and 8 bands, which suggested that bands at the edges of whole otoliths were correctly interpreted. Readers allocated similar estimates of readability to both methods, but the relationship between otolith weight and estimated age was closer for whole than for sectioned otoliths. We chose to read otoliths whole, due to this closer relationship and the greater number of otoliths that could be read whole in the time available. Further work, using tag and release of flathead marked with oxytetracycline, is currently under way in Queensland to better validate ageing and determine which method is more reliable.

Tailor otoliths were also unclear, and the positions of bands were difficult to determine. Whole and sectioned otoliths tended to be read differently, with sectioned otoliths read as older on average, but not consistently so. One reader judged that otoliths were easier to read whole than sectioned, while the other found the opposite. A third experienced reader agreed with the first reader, that whole otoliths appeared more useful. Given that there was also a closer relationship between otolith weight and estimated age for whole otoliths than for sections, and that whole otoliths were much less time and cost-intensive to age, we chose to use whole otoliths for our production ageing. However, there is clearly a need for further investigation of ageing methods for tailor, and this is currently under way as part of an FRDC-funded project.

The lack of a tailor fishery outside the main season prevented us from obtaining tailor otolith samples year-round for marginal increment analysis. The data we obtained suggest that bands are laid down annually, towards the end of the year. However, we did not observe a well-defined minimum as in, for example, flathead. This was partly because of the poor definition of the bands, and may also be due to variation between individuals in the time when bands become visible.

## 8.3 Age/growth parameterisation

- Yellowfin bream

Our results accord more closely with the slow growth (Munro 1944; Dredge 1976) than the fast growth (Henry 1983; Pollock 1982) model, with the growth curve estimating an average age at 20 cm FL of 3.40 ± 0.08 years (standard error) for Moreton Bay bream using the yield per recruit model estimates. This is not unexpected since our ageing techniques were similar to those used by Dredge (1976).

- Sand Whiting

There were considerable differences in the length at age data between our results and those of Cleland (1947) and Dredge (1976). Our Moreton Bay data showed little increase in length from age 1 to 3. This may be a result of bias introduced by the size selectivity of the fishery, and also unreliable ageing.

Sand whiting otoliths were very difficult to interpret accurately and repeatably. Dredge (1976) had difficulty in interpreting the banding pattern in whole otoliths. We found that sectioned otoliths were easier to interpret than whole otoliths, though still difficult. Therefore our ageing and growth curve are likely to be more accurate than that of Dredge. Due to the validation described above, we can be reasonably confident that the observed bands do represent annual increments.

We found considerable variation in length within age classes. Some of this was probably due to ageing error. Because of the difficulty we had in ageing, we cannot address the issue of variation in growth rate between individuals or between years.

The observed sex differences in growth rate were statistically significant. Females appeared to have a greater asymptotic length ($L_\infty$) and a smaller growth coefficient (K) than males. However, differences were not large enough to have a major effect on management of the fishery. Similar small differences between sexes in growth rate have been found for the Australian whiting species *S. bassensis*, *S. burrus*, *S. schomburkii*, and *S. vittata* (Hyndes *et al.* 1998). Differences of this type imply similar length at age for most age classes, with most divergence in the older age classes. Although the difference may reflect a slight variation in life history strategy or investment in growth between the sexes, sampling effects due to a behavioural difference cannot be ruled out.

There appeared to be a difference between growth rates in the Maroochy River and Moreton Bay. A similar result was found by O'Neill (1999), who observed greater lengths at age for sand whiting from the Maroochy River (based on the same Maroochy data set used here) than from Pumicestone Passage or the Burnett River. Our data suggesting this difference are not from directly comparable sources however. Only recreational fishery and fishery independent data were available from Maroochy River, while Moreton Bay had only three recreational catches out of 35.

The difference might be explained if the length at age of recreational catches was consistently larger than commercial catches, or if recreational catches contained larger fish than commercials. However, the few recreational catches from Moreton Bay were actually smaller, on average, than the commercial catches though the differences were not significant (2 sample t-test on mean lengths of catches, $p=0.44$). Mean lengths at age of fish caught by recreational anglers were also consistently smaller than those taken by commercial fishers for the few Moreton Bay recreational catches obtained.

The difference that the data suggests may be worth further study. A number of possible reasons can be hypothesised for such a difference, such as the conditions for growth, removal of fast-growing individuals in an area with high fishing pressure, or emigration of large fish, leaving behind small, slow-growing individuals.

The Hervey Bay data show little increase in mean length with increasing age. This was probably due to the size selectivity in the catches, since only 5 catches were obtained and all had a small average size.

- Golden-Lined Whiting

The lengths at age in this study differ from those of Gunn (1978) in Townsville, in having a greater mean length at age for all available age classes. It is not appropriate to conclude that a difference actually exists though, because the results are uncertain due to a combination of size selectivity and ageing error. Fish were size-selected by the mesh nets used in the fishery independent sampling and by the legal size applied in the commercial fishery.

A number of factors contributed to uncertainty in the growth curve for golden-lined whiting. Ageing was difficult, with much variation between repeated readings of the same otolith. Sample sizes were small, with all but two catches in Moreton Bay coming from fishery-independent sampling. Thus the growth curve is very uncertain.

- Dusky Flathead

Marginal increment analysis suggests that growth increments on otoliths appear at the roughly the same time as spawning occurs. The estimated birth date can therefore be considered fairly robust.

The bootstrap growth curve showed considerably more uncertainty than the standard von Bertalanffy curve fit, as expected since the uncertainty estimate includes error in ageing as well as lack of fit in the model.

The length at age estimates had reasonably low standard errors. This reflects the reliability and repeatability of ageing flathead, as well as the sample sizes and the number of age classes that were sampled.

Females appeared to grow considerably faster than males; a result that was statistically significant based on Kimura's (1980) method for comparing growth curves using maximum likelihood. The confidence intervals on the bootstrap results may appear to indicate that male and female growth curves are not significantly different. However, asymptotic length ($L_{\infty}$) and growth rate (K) are closely correlated, and the parameter estimates should not be used in isolation. A randomisation test based on the yield per recruit model confirmed that female flathead grow faster than males, but that asymptotic lengths are not significantly different.

This may appear to contrast with what has been found for *Platycephalus speculator* females, which have a greater asymptotic length than males but similar growth coefficients (Hyndes *et al.* 1992). However, both species are similar in that length at age is larger for females than males in the older age classes. With no large males in our samples, we could not determine asymptotic length with any precision. The strong correlation between the two parameters K and $L\infty$ suffices to explain the apparent discrepancy (between *P. fuscus* and *P. speculator*) as probably due to chance. For *P. indicus* in Kuwait waters females were also found to have a greater mean length at age, modelled in this case as greater asymptotic mean length and smaller growth coefficient (Bawazeer 1989).

- Tailor

Our egg survey work, together with that of Miskiewicz *et al.* (1996), indicates that some spawning occurs throughout the year, although there is an obvious pulse between August and October. There is also evidence of protracted spawning in North and South American populations (Smith *et al.* 1994, Haimovici and Krug 1996). If the formation of growth bands on the otoliths is associated with spawning, or with change in temperature and food availability during spawning run, a wide range of dates of band formation might also be expected. For this reason, the 'birth date' assigned to tailor is somewhat arbitrary.

The average age at length of males was consistently slightly greater than that of females. The fact that this result held for recreationally and commercially caught fish, and for two years (1996 and 1997), suggests that this was not a statistical artefact of the sampling process. A difference between sexes in growth rate has not previously been identified for tailor. The reasons for this observation are difficult to establish, because fish are sampled from those fish in the spawning run that are close to the beach, and samples are therefore not necessarily representative of the whole tailor population. Females mature at larger size than males (Bade 1977), so more small males of a given age may join the spawning run.

There was a great deal of uncertainty in the growth curve due to both considerable ageing error, and uncertainty about the representativeness of the sampling. The surprising lack of large, old fish in the samples, and the flattening in the growth curve due to ageing error, resulted in a very low estimate of asymptotic mean length.

## 8.4 Sampling strategies

### 8.4.1 Length structure of estuarine species

The primary focus of these analyses was to assess the extent and sources of variation in fish length within commercial catches. This information was used to determine ways of obtaining representative age and length samples.

All four species showed significant length variation between individual catches within a single fishing method, year, and region. This has implications for sampling, in that many catches must be sampled, with limited numbers of fish coming from each individual catch.

In all cases with sufficient data, catch explained more of the variance for mesh netting than for tunnel netting. This was due to the greater size selectivity of mesh nets than tunnel nets, leading to less within-catch variance relative to between-catch variance. However, the overall size distribution of mesh net catch was generally similar to that of the tunnel net catch. This was presumably due to the range of mesh sizes used in the fishery, and the greater variety of location types fished with mesh nets.

There was no size difference between the two gear types for bream, but there were for sand whiting in 1997 and flathead in 1996. However, these differences were not consistent between years. It may therefore be the case that the different lengths are due to random factors associated with the small sample sizes of fishers and catches, rather than the selectivity of the methods.

It was notable that catch explained 49% of the variance for golden-lined whiting. This indicated very consistent length within catch sample, and therefore presumably either within schools of golden-lined whiting, or within the locations targeted by each catch.

These analyses demonstrate the potential problems associated with fishery-dependent sampling from a fishery of limited size. The sampling unit,individual fish,is nested within catch, which is further nested within both gear type and fisher. Fishers may vary the gear type they use and the locations in which they fish. Each has a particular set of favoured fishing grounds, and the species and size targeted vary both with season and changes in the market. If we wish to observe change in size or age structure in the overall fishery between years, sampling must be precisely targeted given the number of potentially confounding variables.

### 8.4.2 Coastal species —tailor

#### *8.4.2.1 Length and age structure with depth and distance from coast*

The spatial length distribution of adult tailor is very important for stock assessment, since the fishery only targets tailor in shallow waters close to shore. If this group is not representative of the length and age distribution of the stock then only limited conclusions about the overall stock can be drawn from fishery samples.

It is suggested by the results of the pilot egg survey that tailor spawn across the shelf during the main spawning season (see below). Small numbers of tailor are caught as bycatch in the trawl whiting fishery (A. Butcher, personal communication), using a slow-moving trawl not well suited to catching fast-swimming tailor. Similar anecdotal evidence from commercial fishing operators (J. Blaney personal communication) suggests that tailor are present offshore to some extent. Despite this, recreational catch rates of tailor on Queensland's offshore reefs are low. This may be due in part to large tailor biting through traces, which has occurred in Western Australia (R. Steckis, personal communication), but the anecdotal evidence suggests that this is unlikely. Another explanation may be the targeting of fishing methods, since anglers do not usually target tailor on offshore reefs, and catches of this species are coincidental.

Length variation with distance offshore is known from other tailor stocks. In southern Brazil, larger and older *P. saltatrix* adults migrate further from the coast (Haimovici and Krug 1996), and this has also been observed in north Africa (Conand 1975; Champagnat 1983). In Western Australia, average and maximum length appear to increase substantially with distance offshore (Lenanton *et al.* 1996).

Similarly, recreational catch data from the United States suggest that bluefish caught from boats, offshore, are larger than those caught from the shore.

We have not been able to test the hypothesis that tailor increase in length or age with distance offshore in Queensland, mainly due to difficulty in obtaining samples of fish caught offshore. However, there is some evidence of larger length offshore from New South Wales recreational catch data.

We therefore consider it quite possible that beach-caught samples of tailor do not represent the stock's overall length distribution. This begs an important question: how do the age distribution and the numbers of tailor vary with distance offshore?

If beach-caught tailor are not representative, then our estimates of total mortality have been biased upwards, and the situation may not be as bad as it appears from the ageing data. However, with data neither on the age distribution of offshore tailor nor the proportion of fish offshore relative to the onshore stock, it is not possible to estimate total mortality 'correctly'.

For future monitoring, we must determine if length and age distributions vary with distance or depth or habitat offshore. If they do, estimates of total mortality would require both representative samples of each 'distance' category, and estimates of the proportion of fish in each category. This is clearly not possible with current technology and available funds. We therefore could not estimate total mortality, which is one of the main purposes of age-based monitoring. However, such monitoring could be used to estimate an annual recruitment index, by noting the relative proportions of tailor in each age class.

#### *8.4.2.2 Length variation between catches*

The average length of tailor in individual catches varies greatly between catches. We suggest several possible reasons for this. Each catch comes mainly from a single school of fish, and tailor tend to school with others of a similar length.

This implies that for age structure analyses tailor must be obtained from a number of different catches and schools. Given the behaviour of tailor and the nature of the fishery, sampling from Fraser Island should comprise several separate short trips, rather than a single long trip. Sampling from numerous fishers in the same area will tend to sample the same school, which is not appropriate. To sample from a range of schools it is necessary to make several trips for short periods, and sample along the length of the island each time.

#### *8.4.2.3 Change through time – average length from recreational catch records*

Evidence of increased fishing pressure can sometimes be seen in reduced average length of fish in the catch, as higher total mortality rates reduce the proportion of older, larger age classes. The data on average length in the catches of competitive club anglers do not indicate such a decline between 1973 and 1991. Annual variation in average length is apparent, with an increasing trend overall.

A number of factors may have contributed to the variation and the overall trend. Variation in recruitment between years results in variable year-class strength, which can cause the average length of fish in the catch to vary. The gear used by tailor anglers has improved, with four-wheel drive vehicles enabling anglers to reach less accessible sites more easily and quickly. Equipment prices have dropped, and improvements in gear mean that fishermen can cast further, possibly accessing larger tailor in deeper water. Pilchards have become the most common bait, replacing sea gar and horse mackerel for many anglers, although anecdotal evidence is that pilchard baits tend to catch smaller fish.

#### *8.4.2.4 Trends in recreational fishing effort – DEH Fraser Island access data*

The Department of Environment and Heritage Fraser Island access data demonstrate an increasing trend in visits to Fraser Island. Any link between this and recreational tailor fishing effort is very tentative. The data have been included partly to demonstrate the poor quality of existing information.

Information on such effort is very important for management of the stock. Effort controls, through seasonal and spatial closures, constitute the main methods of managing the stock, along with output controls such as bag limits.

However, information on effort will be as difficult to define as it is to obtain. Just as 'spotting' time must be included in estimates of commercial tailor and mullet fishing effort, it is important in recreational effort. Increasingly, media-based spotters on television, radio, and in daily newspapers advise anglers of the current best places to catch various species (including tailor), and thereby increase the effectiveness of fishing effort. The market-share of four-wheel drive vehicles is also increasing, improving access and so removing spatial refuges.

### 8.4.3 Overall goals of sampling

The goal of the length and age sampling was to obtain samples characteristic of the fishery. The ultimate reason for getting samples characteristic of the fishery is to use the data in a model of the fishery to draw inferences about the stock. Examples of this kind of model include virtual population analysis, delay difference, and length-based virtual population analysis models. The alternative goal of obtaining samples representative of the stock (for example from a fishery-independent survey) can also be used with similar types of model. Both approaches require a parallel time series of total catch and catch per unit effort.

Without representative samples of either the total fishery, including recreational and commercial components, or the total stock, along with annual estimates of total catch and CPUE, it is not possible to develop a VPA-style age structured model.

An alternative goal is to obtain annual indices of the age and/or size-structure of the population. These indices are sampled in an equivalent way over a long period and can be used in modelling. For example, they can be used in a biomass-dynamic model. They can also be used as biological reference points, and the Subtropical Finfish Management Plan uses such indices as trigger points for management action. If the sampling is well enough targeted to give some estimate of the overall age structure of the population, all the better. Such an estimate can be used to get a general impression of the fishing pressure on the stock.

A decline in the average length of fish in the long term, particularly after an increase in fishing intensity, may indicate overfishing. In some circumstances, it can indicate change in the genotype of the stock, due to selection against large size. Size variation in the short term, particularly in long-established fisheries such as those described here, is more likely to be due to the movement through the fishery of strong and weak year classes.

### 8.4.4 What is achievable?

The goal of obtaining representative samples of the overall fishery was compromised by lack of sampling from recreational fishery. This is particularly true since, as recent angler survey information shows (Higgs 1999), the recreational fishery is larger than the commercial fishery. This ratio is likely to increase in the future. Another problem with sampling the commercial fishery was its very fragmented nature. A large proportion of the catch is taken by a mixed fishery, where the species we are considering are caught without being specifically targeted. Many of these are small catches of a few kilograms each, which generally do not reach the fish markets but are sent directly to fish shops and restaurants. However, they make up a large proportion of the catch. Other factors affecting sampling of the catch meant that we were unable to obtain representative samples of the commercial fishery even within Moreton Bay. These factors included the frequent sending of high quality fish to the Sydney Fish Markets, sorting of fish by size, and other markets that occasionally emerge such as a demand for large whiting exported live.

We found that obtaining representative samples even of the commercial fishery was not practically achievable, so that VPA-style age-structured modelling was not feasible. The next goal was to determine the best method for obtaining a long-term index of population age and size structure, that could be efficiently sampled in an equivalent way each year.

### 8.4.5 Long-term indices of size and/or age

The important issue to consider here is how consistent indices through time could be obtained. Should sampling focus on the recreational or commercial fishery, or should there be fishery-independent sampling? If the commercial fishery is targeted, should sampling occur across all gear types, or focus on one gear type? In addition, it is important to consider which areas should be targeted, either as indicators or because they contain discrete stocks.

#### 8.4.5.1 *Indices from commercial catches*

We found serious problems with obtaining indices of size and age from commercial catch data for the estuarine fisheries. Commercial catch samples can be obtained either directly from fishers or from the fish markets. It is not practical to sample catch direct from fishers, due to the small size of catches and the expense of purchasing adequate quantities of fish directly. Sampling at fish markets is therefore the most efficient option.

However, it is not possible to sample all the markets to which fishers send their product. Higher quality product such as large bream is often sent to the Sydney Fish Markets where it commands higher prices, and many fishers have contracts with fish shops and restaurants that take their product directly. Thus only a small subset of markets could be sampled.

The issue of sorting, and the effect of price on the availability of fish of different size, causes obvious problems for an index of size from the commercial catch. As well as bream, whiting are also often sorted by size. Size indices from the commercial fishery are therefore vulnerable to changes in markets, which can alter the size distribution of fish available for sampling, as well as the sizes targeted.

Obtaining a representative size/age index requires a large number of samples with representation across each of the important variables. Investigations of length distributions showed that gear type, catch, region, and individual fisher were important variables.

The nature of the estuarine fisheries made it difficult to obtain large numbers of catches from a range of fishers, regions, and gear types. Each of the fisheries is relatively small, with the 1997 catch comprising only 162 t of bream, 268 t of whiting, and 55 t of flathead. This catch is spread across a number of regions, although the majority comes from Moreton Bay. Although a large number of days of fishing effort report catch of each species, much of this is taken as incidental catch.

A long-term index requires a consistent mix of gear types if there is a difference in the size of fish or the areas targeted by the fishing methods. Mesh nets are used to fish a wide range of habitat types, including, for example, bream spawning aggregations at surf bars in winter where larger fish would be expected, while tunnel nets are used exclusively to fish tidal flats. We found it easier to obtain mesh net catches since more fishers use this technique. Tunnel nets are less size-selective, requiring fewer samples. However, the small number of tunnel netters, the restricted areas in which they are able to fish, and the difficulty of sampling enough catches from them ruled them out as a long-term source of samples.

In addition, the commercial fishery is smaller than the recreational fishery for all these species. Sampling programs should attempt to sample across the majority of the fishery. The recreational fishery is very likely to increase in the future with the growth of southeast Queensland's population and increased access to trailer boats. If the commercial fishery becomes correspondingly smaller, it will become more difficult to maintain appropriate sampling.

Commercial sampling can only be applied in restricted areas. Some areas where the allocation of fisheries resources has particular social significance, such as Pumicestone Passage or the Maroochy River, are either closed to or fished irregularly by commercial fishers.

Costs of obtaining commercial catches from the market are lower than for recreational catches. However, for the reasons outlined above they are unlikely to consistently represent the true age or size distribution of the population for bream, whiting, or flathead.

As discussed above, sampling the tailor catch must also be aimed at obtaining an index of age structure. The fragmented nature of the stock into estuarine and ocean-beach components makes it impractical to obtain samples representative of the overall commercial catch. In addition, the possible existence of an unavailable offshore component, the unknown migration between these components, and the lack of estimates of recreational catch from each component, makes most modelling approaches inappropriate. Sampling is probably best aimed at estimating an annual index of recruitment to the ocean beach fishery.

Bearing this in mind, commercial sampling of the ocean-beach component of the tailor fishery is more achievable than sampling the estuarine fisheries for bream, whiting, and flathead. There are not many licensed ocean beach fishers, making it possible to sample most of the fishery. The fishery is also assumed to come from a single migrating stock, so geographical variation in size may be ignored. Individual catches tend to be large and consist of mostly tailor. However, sampling still suffers some problems. There appears to be some size variation through time, requiring sampling to be represented across the tailor season. There is a certain amount of sale of fish to the Sydney Fish markets, and this may be influenced by the quality or size of the tailor. Price strongly influences the catch, so that catches may be difficult to obtain at some times. The recreational catch is considerably larger than the commercial catch (Higgs 1999), so this segment of the fishery cannot be ignored.

Sampling to estimate an annual index of recruitment can be achieved by maintaining regular contact with the main ocean beach fishers, determining their markets, and arranging to collect fish for ageing either directly or via the fish markets.

#### *8.4.5.2 Indices from recreational catches*

The recreational fishery, which is larger than the commercial fishery for each of these species, may provide samples more representative of the status of the stock and at lower cost. This approach was taken for estuarine species by another DPI project, "Assessment of fish stocks in coastal streams" (O'Neill 1999). This project operated in parallel with the ISAMP project, and we were therefore able to assess the practicality of its techniques.

Recreational sampling has the advantage that large numbers of individuals are obtaining independent catch samples, in many areas, at all hours of every day. This high number of catches is very important when the catch, rather than individual fish, must be considered as the statistical sampling unit.

Anglers can be approached on the water or on the beach, which provides information about both fishing location and effort. Recreational catch rate information can be obtained at the same time, information that can be at least as useful as the indices of size and age, provided problems with skewness of the catch distribution can be overcome.

Small areas such as the Maroochy River or Pumicestone Passage can be sampled separately and discrete indices obtained at biologically meaningful spatial scales.

Markets do not influence the size or species of fish available or targeted, though fashion, species availability, and gear development do to some extent.

A problem with sampling recreational catch is the difficulty of sampling over large areas, such as Moreton Bay. However, representative areas can be selected and sampling carried out in these areas, such as Jumpinpin or the area around Mud Island. This is more reliable than commercial sampling of large areas, which depends on the choices of individual commercial fishers about where they set their nets. However, if disturbance changes the distribution of recreational fishing and catch rates in the chosen areas drop, it may become difficult to obtain samples.

A further potential problem is catch-and-release fishing, which can bias the size distribution of fish available for measuring if anglers choose to keep fish based on size. This type of fishing is currently minor but may increase. Moves overseas to ban it on animal ethics grounds may make an appearance in Queensland in the future, and affect further growth.

Finally, obtaining representative samples of frames from recreationally caught fish can be difficult (except in the case of tailor where fish are often filleted on the beach). Although it is straightforward to obtain samples suitable for developing an age length key (which can then be combined with size distribution for an index of age structure), the variability of size at age revealed by this and other studies reduces the usefulness of such keys.

Sampling to obtain indices of size and age distribution alone could be achieved for approximately $10 000 per area. The costs of processing samples and entering data are treated separately. Larger sample sizes are needed for indices of catch rate, at a total estimated cost of $20 000 per area. This amount represents the cost of employing a contractor to interview anglers on the water. Such sampling would cover all the major species recreationally targeted in the area. Further costs would be involved in supervising the contractors and entering and processing the data. Further details about this sampling methodology are available in O'Neill (in press).

The alternative method of creel surveys at boat ramps may be cheaper, but it lacks spatial precision, and makes it difficult to target particular areas. Factors such as changing catch rates in particular areas, or improved boat technology, can alter the areas fished by users of a particular boat ramp. This may also alter the size and age structure of the samples (e.g. serial depletion).

Tailor sampling from the recreational fishery can be carried out on the ocean beaches of Stradbroke, Moreton, and Fraser Island during the tailor season. Since at least 20 separate schools of tailor must be sampled, five or more short trips should be undertaken. This will involve approximately 40 person days, or \$8000 at 1/6th of a salary plus vehicle and travel costs.

#### *8.4.5.3 Indices from fishery-independent sampling*

Fishery-independent sampling was rejected as part of ISAMP apart from specifically targeting small tailor for growth curves, since we did not have sufficient resources to obtain the necessary sample sizes. Some fishery-independent samples were also obtained from a separate project focusing on the Maroochy River.

Fishery-independent sampling can be compared to commercial sampling in that it employs similar techniques. However it has various advantages and disadvantages over commercial catch sampling. Its advantages are that a) problems with sorting and market-driven size selectivity are avoided, b) any area can be sampled, and areas sampled will be consistent through time, c) gear types are reliably known and consistent, d) catches of all sizes can be obtained, e) frames are available for ageing.

The expense of this method is greater than sampling recreational catches. As with commercial sampling, at least 20 catches of each species must be obtained from each area. As with recreational catch sampling, an index of catch rate in an area is obtained, though the statistical power of estimates using these methods is unknown. One advantage over fishery-dependent sampling is that all size classes can be obtained, so some fishery-independent sampling is needed to develop growth curves. In addition, fishery-independent indices are not affected by changes in legal size.

An approximation of the cost of obtaining at least 20 catches of 15 fish per species per area is \$8–10 000 per species per area, or \$20—25 000 per area for bream, sand whiting, and flathead. This represents 160 person days per area, or 2/3 of a salary, plus on-costs, travel, and costs of gear purchase and maintenance.

#### *8.4.5.4 Commercial, recreational, or fishery-independent sampling for size and age structure?*

In summary, we consider that it will be preferable to sample recreational catches, rather than sampling the commercial fishery, to examine the size and age structure of bream, whiting, and flathead. It is difficult and expensive to obtain representative commercial samples from even a few fishing areas, and unseen biases can occur due to changes in markets, regulations, and the behaviour of the individual fishermen. Such biases limit the value of commercial catch sampling for these species.

Fishery-independent sampling is also a suitable method for obtaining indices of size, age structure, and catch rate, although costs are considerably greater than sampling the recreational fishery.

#### *8.4.5.5 Areas to target.*

It is important to break down the fishery into appropriate regions, because although some fish move between regions most do not do so. Thus fishing in one area will affect the age and size structure, and abundance in that area more than elsewhere.

The finest level of detail available over any length of time in the CFISH database is the 30 minute grid square. However, these grid squares do not tally very well with appropriate levels for considering fish 'stocks'. For example, Moreton Bay contains grid squares W37 and W38, but these grids also extend to the east of Moreton and Stradbroke Islands. Pumicestone Passage occupies both W36 and W37. In considering areas as management units for ISAMP, we therefore chose to focus on geographical entities, such as Moreton Bay, the Maroochy River, and Hervey Bay. These groupings were used for the estuarine species bream, sand whiting, golden-lined whiting, and flathead. Tailor were considered all as one management unit, since they are considered to mostly move along the coast, and are not clearly separable into units.

Movement between estuarine areas is known to occur for bream and flathead, based on tagging data (O'Neill in press). However, although the level of movement may be sufficient to link the stocks genetically, it may not significantly mix the age-classes or spread the effect of fishing mortality. With available resources, we were unable to determine the extent of such mixing, and chose to ignore it in our analyses.

## 8.5 Population modelling

### 8.5.1 Total mortality rates

Care is necessary when estimating total mortality rates from catch curves; one must be aware of size selectivity and the effects of strong year classes. Catch curves work on the assumption that the samples are representative of the population, but the samples actually represent the age distribution of the catch. If the largest animals are less represented in the catch, which can happen for many reasons, then total mortality can be overestimated. If, on the other hand, catchability increases with size, or large animals are more sought after by the fishery, total mortality can be underestimated. Strong year classes moving through the fishery require sampling through a number of years, or attention to the rate at which particular year classes decline with time.

Bream total mortality did not appear to be high in either Moreton Bay or Hervey Bay. The presence of fish to the ages of 11 and 15 years respectively also indicated healthy fisheries. Ageing appeared to be reliable and sample sizes were acceptable, which lends credence to this conclusion. The main point of uncertainty associated with the ageing was whether whole otoliths were as reliable as sections, but the tendency of sections to give slightly higher ages would only reduce estimates of total mortality.

Sand whiting mortality rates were higher than bream. The average size of sand whiting from the Gold Coast was consistently larger than the other locations where sampling occurred, and the total mortality estimate was considerably lower (0.62 versus 0.99 and 1.45 for Hervey and Moreton Bays). This compares with estimates for the Maroochy River, Pumicestone Passage, and the Burnett River of 0.63, 0.66, and 1.06 (O'Neill 1999). The Moreton Bay estimate seems very high in this context. It may be due to higher fishing pressure, or higher natural mortality if conditions are less favourable. It may also be due to emigration of larger, older fish.

Golden-lined whiting mortality rates appeared to be high, along with fast growth rates. However, sample sizes were low and ageing was very uncertain, which suggests that caution should be exercised in accepting these estimates.

Dusky flathead mortality rates were also uncertain. The Moreton Bay samples clearly showed a higher mortality rate for males than females. The number of catches sampled was probably too low for estimates from the Gold Coast and Hervey Bay to be reliable. The assumption of catch curve analysis, that samples represent the age structure of the stock once fully recruited, is open to doubt in this species. There is some evidence that large flathead become less catchable, which would reduce the level of fishing mortality to which they are subject. Such a feature might explain the apparent higher level of fishing mortality on male flathead, since they grow more slowly and thus spend longer at a more catchable size.

The estimated mortality rates were very high for tailor, at a level that suggested overfishing, and indicated concern for the stock. This, together with the value of the fishery, makes further investigation, and possibly management action, high priorities. Further investigation is warranted because of the considerable doubt about two aspects of this mortality rate estimate. First, the ageing on which it is based contains a high degree of uncertainty and possibly some bias. Second, the implicit assumption of catch curve analysis, that samples represent the age structure of the stock, is open to question.

The estimated mortality rates for Moreton Bay for all species are higher than those estimated for Hervey Bay. Estimates of mortality rate on the Gold Coast were lower than in other areas for sand whiting and female dusky flathead. The total mortality rate for male flathead from the Gold Coast was not significantly different from that in other areas.

### 8.5.2 Yield-per-recruit analysis

#### *8.5.2.1 Bream*

The model suggests that the current level of yield per recruit is about 25% below its potential, and could be higher with more fishing effort and a lower minimum legal size. These conclusions together suggest that growth overfishing is unlikely to be a problem for bream populations.

However, reducing the legal size would not only fail to substantially increase yield per recruit, but could also affect recruitment, and would be commercially impractical due to the cost of processing small bream. Such costs are relevant but are beyond the scope of this analysis. There is already some pressure from processors for an increase in the legal size, due to processing costs. Such costs may be managed via market prices, rather than government regulation.

The results also suggest that if natural mortality were less than 0.193, the fishery would probably benefit if legal size were raised. However, convention in the form of Pauly's method suggests that such low natural mortality is not the case, and that bream are therefore unlikely to be growth overfished.

#### *8.5.2.2 Sand and golden-lined whiting*

Deterministic yield per recruit models suggested that the current legal size is too small for sand whiting, particularly in the Maroochy River, but too large for golden-lined whiting, if the aim is to maximise yield per recruit. However, the golden-lined whiting result is very uncertain given the ageing and sampling error in the parameter estimates for the species. The inability of many fishers to distinguish between the species suggests that the same minimum legal size should continue to apply to both species.

The results suggest that for Moreton Bay fish an MLS of 24 cm (total length) would maximise yield, but 30 cm would be best for Maroochy River whiting. The difference between areas, in appropriate legal sizes to maximise yield, is due solely to differences in estimated growth rate. Sand whiting appear to grow faster in the Maroochy River, so they can be targeted at a larger size. O'Neill's (1999) yield per recruit modelling used the same Maroochy River data to reach similar conclusions about minimum legal size. It is impractical to have different size limits for the same species in separate closely spaced locations however.

Although we did not model yield per recruit using Gold Coast sand whiting data, lengths at age here were similar to the Maroochy River. We therefore expect that a similar minimum legal size would maximise yield.

O'Neill (1999) found smaller length at age in the Burnett River and Pumicestone Passage than in the Maroochy River, but was unable to estimate growth rate. The appropriate minimum legal size to maximise yield per recruit in these areas would therefore probably be somewhere between 24 cm and 30 cm total length.

Raising the legal size would reduce catch rate in the first years, since fewer whiting would be available for capture. However, the model suggests that over the next few years the catch would increase and soon exceed current levels, as fish grew to the new legal size. Catch rate would remain lower than at present, but the greater average size would more than compensate for this in terms of the overall weight of the catch.

Other issues that must be considered when determining legal size are: compatibility with New South Wales, where the minimum legal size for whiting is 27 cm; and the value that anglers place on the experience of catching large whiting. A further issue is the greater processing effort for smaller fish. If this were considered, then a higher legal size would be further justified.

A major source of error in this analysis was natural mortality rate, about which there was very little information. If natural mortality is higher than we have assumed (0.40 for sand whiting and 0.65 for golden-lined whiting), then legal size should be lower than we have estimated. If it is lower, then we have underestimated the appropriate minimum legal size.

#### *8.5.2.3 Dusky flathead*

The stochastic yield per recruit model estimated that changing the MLS from the current 30 cm to 55 cm could increase the equilibrium yield by 86 ± 37%. This is a considerable increase and warrants serious consideration. At the current legal size, flathead appear to be seriously growth overfished. Such an increase in legal size would also increase spawning biomass a great deal. This conclusion supports the suggestion of the Queensland Fishery Management Authority's draft management plan for subtropical finfish species, that a change in minimum legal size may be warranted for flathead.

Increasing the minimum legal size would however cause an initial decline in yield, since many flathead would be unavailable to the fishery until they grew beyond the new legal size. Further modelling is required to estimate the length of time the change would take to occur, and whether a smaller increase in legal size might increase yield by almost as much, but sooner.

The stochastic yield per recruit model was a considerable improvement on the deterministic model, because it was able to include both sexes in the one model, as well as uncertainty in parameter estimates.

Male and female growth rates were found to be different. Differences between sexes in growth rate have also been estimated for *Platycephalus indicus* in the Persian gulf (Bawazeer 1989) and for *P. speculator* in Western Australia (Hyndes *et al.* 1992).

Catchability seemed to decrease with length. This may be due to the selectivity of the gear used, or to habitat usage by different sized flathead. Although it would be helpful to estimate fishing selectivity experimentally, the various fishing methods used in the fishery are likely to have different selectivities. If selectivity does not in fact increase with length, optimum legal size would be even larger than we have estimated. The main conclusion of this modelling exercise would therefore not be affected by this assumption.

Natural mortality was estimated using Pauly's method. This is subject to considerable model error, which we were not able to include in the model.

The growth rate estimated for males was less precise than the female growth rate, because considerably fewer males than females were found in the catch samples. The observed sex ratio may represent an actual bias. However, higher natural mortality for males than females prior to recruitment is an alternative hypothesis, as is a difference in behaviour between males and females such that males become less vulnerable to fishing than females as they age. An example of such a behavioural change would be a size-linked change in habitat use by males to an area where less fishing occurs.

#### *8.5.2.4 Tailor*

The stochastic model suggests that a slight increase in equilibrium yield per recruit might be obtained by increasing the legal size to 36cm total length. The deterministic model estimates a lightly lower optimal legal size, but the stochastic model must be given priority since it considers a range of possible situations, while the deterministic model considers only one. The slight yield increase associated with a larger legal size would, more significantly, be accompanied by an increase in spawning biomass.

However, the yield per recruit model also demonstrates the importance of uncertainty in the estimates, associated with the ageing of tailor and the observed age and size distributions. Given this uncertainty, the predicted increase in yield is not large.

The most significant issue for spawning biomass is model error—the unmodelled possibility that the actual total mortality and growth rates are not as we have estimated. A clear possibility is that, as fish age, they become less available to the fishery. If this is the case, our estimates of $L_\infty$ are probably too low, and our estimates of natural mortality are too high. Nevertheless, such error would not affect the conclusions with respect to yield per recruit, since emigration affects yield in the same way as mortality does. Similarly, increased $L_\infty$ will not affect yield if few fish grow large in the fishery. The main implications of such a situation are for spawning biomass. If large tailor become unavailable to fishing but keep spawning, there is little need to increase spawning stock by raising the legal size. The evidence for this scenario is tentative however.

There are also drawbacks with raising minimum legal size. Raising the legal size would increase the number of fish dying after capture and release. Release mortality for line-caught tailor is probably low, based on previous QDPI tagging experiments and a trial carried out at a fishing competition (R. Steckis, personal communication). Release mortality for seine-netted tailor is likely to be high however, and this loss might itself more than offset any yield increase from raising the legal size.

Raising the legal size would seriously affect commercial tailor fishers, since seine nets are not size-selective and tend to catch most of the fish in a school. The cost of sorting out undersized fish in large quantities could make tailor fishing uneconomic for many beach netters.

Finally, there are costs as well as benefits to recreational fishers of catching and releasing undersized fish, and there may also be animal ethics considerations. These issues are beyond the scope of this modelling exercise but should be considered before changing the minimum legal size.

## 8.6 Bootstrapping confidence intervals

Appropriate confidence intervals are very important where uncertainty is incorporated into stock assessments. The nature of the fisheries examined here makes it vital that uncertainty is explicitly considered. As previously discussed, recreational catch rate information is likely to be used as an index of abundance, and total catch used as a fishery reference point and incorporated into biomass dynamics models.

Many different methods are available for calculating bootstrap confidence intervals. If all gave similar results, the choice would not be important, but as we have shown they may not. Most of the methods we used did not calculate accurate confidence intervals for our highly skewed data. The upper limit was usually grossly underestimated, and the lower limit also underestimated.

We have shown that the bootstrap-t method produces the most accurate confidence intervals with these data. It gave the most accurate and least biased coverage in each of the scenarios examined. However, as predicted theoretically (Shao and Tu 1995), the intervals were much longer than those produced by other methods.

For the bootstrap-t method, the best intervals were produced using a resample size of n/2. The bootstrap works, in the sense of providing consistent estimates of distributions, if and only if the limiting distribution is Normal - that is, when the central limit theorem holds. When the central limit theorem does not apply, one can get consistency by using a resample size smaller than n. This problem has been treated by a number of authors since Beran and Srivastava (1985) first noticed it. However, most work to date has been of a theoretical nature (Peter Hall, personal communication), whereas in this case the "m-out-of-n bootstrap" is important in practice.

In the case of our recreational catch data, the extreme skewness of the data means that the Normal distribution does not provide a good approximation to the limiting distribution of the statistic. In effect, the central limit theorem does not apply. However, consistency is recovered by using a smaller resample size.

The plethora of bootstrapping methods begs the question of which characteristics of the data make one method superior to another. In the particular case of recreational catch data, one must ask which features of the data affect the coverage of the bootstrap-t method. The most notable feature of the distribution of catch rate was the very high frequency of zeroes, which may be characterised as sampling zeroes and structural zeroes (Gaston and McArdle 1994). These zeroes had a number of sources: the trailer boat not being used for fishing; the trailer boat used for fishing but not for the species of interest; the species being sought but not encountered; the species being encountered but not caught.

The resulting skewness in the distribution was handled poorly by all the bootstrapping techniques except the bootstrap-t. All methods produced better confidence intervals when the skewness of the original data was lower. Similarly, all methods produced better confidence intervals when more data were available. The width of the bootstrap-t intervals was very sensitive to the amount of data. Doubling the number of data points halved the width of the intervals.

Shao and Tu (1995) state that bootstrap-t and BCa methods are second order accurate, while the other methods used here are only first-order accurate. However, the BCa and bootstrap-t methods rely on the availability of good estimators for the acceleration parameter and standard error respectively. The superiority of the bootstrap-t method over the other methods in this case was presumably due to the fact that a good estimator of variance was available, whereas the BCa was less successful because acceleration was not well estimated by the jackknife method.

A distribution produced by multiplying two variables can be difficult to characterise parametrically, since the multiplication adds skewness. Total catch was the product of two variables — the Normally distributed effort (number of boats), and the observed highly skewed distribution of catch rate. Thus, more problems were observed in characterising total catch than catch rate. Even in the scenario where catch data were from a Normal distribution only the bootstrap-t gave balanced coverage of total catch, while all methods provided balanced intervals for catch rate.

A related problem when multiplying two variables is lack of independence between the two parameters. In the situation represented here the boats' catch rates and the number of boats were not correlated, so their product provided an unbiased estimate of total catch. However, methods such as multiplying 'catch per trip' by 'number of trips per boat' by the 'number of boats' (e.g. Brown 1993) can suffer from failure of the assumption of independence. This is an example of the fallacy of averages (Welsh *et al.* 1988): the false assumption that the mean of a function of several variables equals the function of the mean of those variables. Catch per trip will in some situations be related to trips per boat, if catch rate influences decisions on whether to make fishing trips, or where boats that make more trips contain more experienced fishers, who tend to catch more fish.

Non-Normal modelling approaches are also possible. Statistical modelling of zero-inflated distributions has been addressed by Welsh *et al.* (1996), in the context of abundance of rare species. They employed a conditional model, where the probability of a non-zero count was modelled with the logistic distribution, and the non-zero count itself was modelled with a truncated Poisson or negative binomial distribution. Faddy (1998) developed a model based on the Markov chain, in which the probability of catching additional fish depended partly on the number of fish already caught. There are also models based on a variance-mean relationship (eg. Gaston and McArdle 1994).

Another bootstrap method, the iterated bootstrap, has been shown in simulation studies to be more accurate than the methods used here in some situations (Shao and Tu 1995). However, it requires very heavy computation since two bootstraps must be run, one nested inside the other. It is also not as generally available in statistical packages as are the methods presented here.

We recommend the use of bootstrapping in recreational fisheries, as it allows workers to place more accurate confidence intervals on their results. Alternatively, it can allow more efficient sampling, since workers can obtain accurate (though wide) confidence intervals with relatively small sample sizes. Appropriate methodology is important where data collection is constrained by lack of resources, and where data are very skewed. We also recommend simulation of potential bootstrapping methods in order to select the method with the best coverage for particular situations. Code for such simulations is provided in the Appendix.

## 8.7 Tailor egg surveys – investigation of an alternative assessment method

The broad distribution of spawning, and the long period over which it occurred, demonstrated that egg production methods would not be appropriate for estimating tailor spawning biomass. However, the study produced some significant results.

One of the most important questions for assessment of tailor stocks is whether there are larger fish offshore than are caught in the beach-based tailor fishery. Although we cannot use these data to address the issue of size, they do indicate that there is a considerable amount of spawning offshore, across the inner continental shelf, and there is no evidence for a concentration of spawning in the latitudes between Indian Head and Waddy Point on Fraser Island.

### 8.7.1 Spawning location

Tailor worldwide are confined mostly to inner-shelf waters, and their eggs are distributed by a mixture of major oceanographic currents and shoreward processes (Lenanton *et al.* 1996). In eastern Australia these processes include the East Australian Current (EAC) and prevailing winds.

The data display several interesting features that require explanation: a) eggs are relatively evenly distributed across the shelf and along the coast; b) the density of larvae increases relative to egg density closer to the coast; and c) larvae appear to aggregate more than eggs.

The presence of eggs indicates spawning within about 48 hours (Deuel *et al.* 1966). The even distribution of eggs suggests two hypotheses: either tailor are evenly distributed across the shelf in their spawning, or spawning is localised and eggs are rapidly distributed to observed locations by currents. During the period of peak egg numbers, the EAC flows in a southerly direction, so that eggs and larvae would be transported south. However, the lack of a north-south difference between egg and larval distribution suggests that widespread spawning, rather than current flow, is the explanation for the widespread egg distribution.

The data support the assumption that there is very little spawning north of Fraser Island.

The observed pattern of larvae being closer to the shore than eggs also suggests several explanations. Either larvae are carried close to shore by south-westerly moving currents patterns around Fraser Island; or larval behaviour or position in the water column results in them moving closer to shore.

Wind-assisted movement of surface waters could be important. Tailor eggs are highly buoyant (Wilk 1977), and larvae occupy the surface layers of the water (Kendall and Naplin 1981, Miskiewicz *et al.* 1996, Muelbert and Sinque 1996, Lenanton *et al.* 1996). They are therefore subject to transport by wind-driven surface currents. Prevailing winds during August are south-westerly and therefore offshore. During September they tend to turn towards the south-east, which is an onshore direction, and may remain in this direction for some time. It is unclear how eggs spawned during the south-westerly periods would reach the coast to recruit, but wind direction does vary considerably, and there can be onshore periods at any time of year.

Serial spawning is an appropriate life history strategy where temporal uncertainty in the environment affects the likelihood of recruitment. The serial spawning pattern of tailor may work as insurance against offshore winds during the spawning period.

The higher observed variation, on a local scale, in larval density than egg density suggests that larvae tend to aggregate. This is particularly so since larvae remain in the plankton for about 3 weeks, while eggs only metamorphose after about 2 days (Deuel *et al.* 1966). The higher observed number of larvae than eggs is consistent with longer existence in this state.

In 1997 eggs were denser where the shelf is narrow (to the east of Fraser and Moreton Islands). In 1998 this was not observed. The 1997 observation suggests that spawning may occur at a consistent level per latitude, so that where the shelf is narrower, spawning becomes more concentrated. A parsimonious explanation for this is to postulate a constant rate of migration with constant spawning throughout migration. Tailor may be spread out over shelf, moving north and returning south.

### 8.7.2 Spawning timing

The results suggest that some spawning occurs throughout the year, with spawning rising from June to reach a major peak in September, and the suggestion of a further minor peak in January. Larvae numbers also peak in September but few were seen outside this period. Survival of eggs and larvae may be low outside the peak spawning season.

## 9 BENEFITS

The outcomes of the Project are of primary benefit in the areas of resource monitoring and assessment. As one of the investigated species (tailor) is a "straddling stock" between Queensland and NSW, the relevant growth and age structure data should be of interest to NSW Fisheries, even though tailor is not currently viewed as a high priority stock in that State. Our increased understanding of the population dynamics (growth, age-structure and total mortality rates) of yellow-fin bream, sand whiting, golden-lined whiting, dusky flathead and tailor must be of benefit in any attempt to evaluate the status of the resources.

While we may never be able to use virtual population analysis to assess stocks of any of these species in Queensland, indices of age and size composition will provide the next-best alternative. Our conclusions about minimum legal sizes are very relevant to management issues currently under consideration. Our recommendations about optimal methods for placing confidence intervals on estimates of total recreational catch, will improve the usefulness of the results from the RFISH process.

## 10 FURTHER DEVELOPMENT

The primary outcome of this research was the development of a long-term monitoring program for fishery stocks in southern Queensland. During the course of the Project a number of developments occurred, including the running of a joint QDPI/QFMA workshop to determine priorities for monitoring and assessment. Prioritisation was seen as essential, given that financial resources to do this sort of work would be very limited until a greater level of cost-recovery from industry is negotiated. Much of the impetus for the establishment of the new QDPI Monitoring Program (which covers the whole of the State) was due specifically to the present project work, that of a related project in north Queensland (Tropical Resource Assessment Program) and the employment of an experienced stock assessment scientist based at the Southern Fisheries Centre. All three of these "projects" were directly funded by FRDC.

We believe that, primarily through the FRDC-funded Stock Assessment Review Workshop (SFC, August 1998), the results of the present study have been communicated thoroughly to industry and management. The findings have been used also in the stock prioritisation process, insofar as it was necessary not only to rank the "importance" of the stocks, but also to identify the methodological logistics, to determine what level of monitoring and assessment would actually be feasible.

There are, as would be expected, several areas where our results were inconclusive and deserving of further research effort. Perhaps the most critical of these was the question of our estimates of the total mortality rates of tailor. These were so high that doubts were cast on the accuracy of the ageing data and/or the representativeness of the catch-at-age samples. The Stock Assessment Review Workshop (see Dichmont *et al.* 1999) identified these issues as the most in need of resolution from the point of view of resource management and ESD requirements. As a direct consequence of the Review Workshop's recommendations we developed a follow-up project proposal specifically to address these questions. We are pleased that FRDC has agreed to provide financial support for the Tailor Age Validation study.

## 11 CONCLUSIONS

Our general conclusions from this Project are as follows:

- Otoliths provide a useful means of ageing all five species examined.
- For production ageing, cost savings can be achieved by reading tailor, flathead, and possibly bream otoliths whole (rather than sectioned). However because of their thickness, the otoliths of both whiting species must be sectioned before reading.
- Marginal increment analysis has provided a basic validation of the ageing procedures used for sand whiting, dusky flathead, and tailor. Bream marginal increment analysis was equivocal, but

our readings are consistent with those obtained from a tetracycline-mark validation study in NSW bream.

- We estimated total mortality for bream, flathead, and sand whiting, from catch curves. Mortality rates for bream, sand whiting, and flathead were found to vary by location, possibly as a result of differing levels of fishing pressure. Mortality rates for these species were higher in Moreton Bay than in Hervey Bay. Bream total mortality rates were moderate and suggested little cause for concern. Sand whiting mortality rates were higher, but error in ageing reduced confidence in these estimates. Flathead mortality was also moderately high, with higher rates for males than females in Moreton Bay.

- Tailor mortality rates suggested cause for concern, but also doubt about the assumptions used in estimating these rates. Data on other tailor stocks, and anecdotal evidence, suggest that samples from the recreational and commercial tailor fisheries may not represent the age and size structure of whole population. This hypothesis is currently being investigated by an FRDC-funded project motivated by the ISAMP results.

- Growth curves were estimated for bream, sand whiting, dusky flathead, and tailor. All species showed a wide range of length at age. Growth rates showed significant differences between the sexes for dusky flathead and sand whiting. Dusky flathead males grew more slowly than females but asymptotic lengths were not significantly different. Sand whiting females grew slightly faster than males but with slightly smaller asymptotic length. Female tailor were slightly longer at a given age than males, which may be due to differences in either size of availability to the fishery or growth rate. As with sand whiting this difference was not large enough to affect management.

- All estuarine species showed significant variation between catches in size structure, implying that catch should be regarded as an important sampling unit, and many catches should be sampled. Mesh nets were more size selective than tunnel nets, requiring more catches for a statistically valid index of size or age structure.

- Tailor also showed considerable size variation between schools of fish, as defined by groups of catches taken from a particular area and time. Size variation between schools implies that, to obtain age and size indices of recreational catch, sampling should target as many different schools as possible. Many schools can be targeted by sampling a number of times at intervals of several weeks, and covering as much ocean beach as possible each time.

- No evidence was found for a reduction in the average size of tailor caught by recreational club anglers, associated with increased fishing pressure. There was considerable variation between years. This was probably due to annual variation in tailor recruitment, which results in strong and weak age classes passing through the fishery. The very slight increase in average size may have been due to changes in the technology available to anglers, and an increased level of expertise in targeting large fish.

- It was not possible to sample, in a representative way, the size and age distribution of the total commercial catch of yellowfin bream, dusky flathead, golden-lined whiting, sand whiting, or tailor. This was because of the small scale and extremely subdivided nature of the fisheries, the variability of the catch in time and space, and our inability to sample a large proportion of the catch.

- VPA-type modelling methods require representative samples from all sections of the fishery – recreational as well as commercial. They also require annual estimates of total catch. These methods are therefore not practical for the ISAMP fisheries. Thus future monitoring will rely on a) CPUE from the commercial and/or recreational fisheries to index the stock size, b) indices of age and size structure from a subsection of the fishery (preferably recreational), to identify year class strength and changes in age or size structure.

- If the QFMA's recreational fishing survey program (RFISH) can provide reliable estimates of total annual recreational catch, biomass dynamic modelling may eventually be used to estimate stock size, though this requires annual catch estimates, and at least 5 years of data are required to even begin modelling.

- For total recreational catch estimates to be most useful for stock assessment and as stock status indicators, confidence intervals on total catch and CPUE from the RFISH program should be estimated using the bootstrap-t method, since our analyses show these estimates are the most reliable. For stock assessment modelling, annual catch estimates, and estimates by location of catch instead of angler postcode, are also required.
- Age and size structure indices will be obtained more reliably, with greater geographical precision and with greater statistical validity, from the recreational than the commercial fishery for all species investigated. It is not practical to obtain reliable long-term age and size-structure indices from the commercial fishery. Fishery-independent sampling would also achieve useful results but at a greater cost than recreational catch sampling.
- Yield per recruit modelling suggested that the dusky flathead fishery could obtain considerably more yield in the long term from an increase in legal size. This would also greatly increase spawning biomass, and the average size of flathead captured. A value of 550 mm total length is most likely to give optimal yield (in weight) with an estimated increase at equilibrium of 86 ± 37%. However, a smaller increase of legal length to 450 mm would increase yield almost as much.
- Yield per recruit modelling suggested that yield (in weight) from the sand whiting fishery could increase with a greater minimum legal size. A value of 27 cm total length is suggested. This would also increase the spawning biomass and the average size of fish captured. However, there is considerable uncertainty about this estimate.
- Yield per recruit modelling of yellowfin bream and tailor indicated that current minimum legal sizes for these species are not inappropriate from a yield perspective.
- Tailor egg distribution was relatively even, suggesting that spawning is distributed 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. Larvae were on average distributed slightly closer to the shore than eggs. Some spawning occurred throughout the year, rising in June to reach a peak in September and declining again by November.
- Data on other tailor stocks, and anecdotal evidence, suggest that samples from the recreational and commercial tailor fisheries may not represent the age and size structure of whole population. This hypothesis is currently being investigated by an FRDC-funded project motivated by the ISAMP results.

Long-term monitoring of stocks of the species examined in this study will continue to rely (at least partially) on commercial catch and effort statistics. Our investigations have revealed inadequacies in the commercial logbook system that, unless remedied, will severely compromise the value of these statistics as reliable indicators of stock abundance. Some of the main areas for development are:

- precision in the specification of "fishing method" codes.
- validation and appropriate range-checking at data entry.
- follow-up to correct reporting errors, such as fishing methods that are inappropriate for the reported species or location, and incorrect units of measurement, e.g. for net lengths and mesh sizes.
- adequate and appropriate effort statistics, particularly in fisheries such as the ocean beach haul-net fishery where searching time is a very important component of actual fishing effort.
- provision for recording species targeted in a particular fishing operation.
- time-series of wharf-price or market value information.

In the original Project Application we identified that the success or otherwise of this work would be judged by (i) the utility and timeliness of the information it provides to the QFMA, (ii) critical reviews of the project's outputs by the QFMA and the Queensland Commercial Fishermen's Organisation

(QCFO), and (iii) by a commitment on the part of the Queensland Government to adopt the work process as a core program, with the provision of appropriate resources.

There have been many occasions on which the QFMA and its management advisory committees have been informed directly of progress of the Project, and output in the form (for example) of the Estuarine and Coastal Finfish Fishery Situation Statement. These situation statements were discontinued when QDPI established a "Fisheries Condition and Trend" unit, specifically charged with providing regular reports of a similar type.

The Stock Assessment Review Workshop (Dichmont *et al.* 1999) was used as the major forum for reviewing the outcomes from this Project, and those of other local projects with a stock assessment focus. The Workshop included research staff from around Australia who had appropriate experience with the species under review, as well as stock assessment experts, statisticians, representatives of the QFMA, QCFO, and relevant Management Advisory Committees, and fishermen with direct involvement in the various fisheries. The workshop was highly successful, providing an open forum for critical evaluation of the Project, and presented a number of conclusions which have already been acted upon.

Perhaps the most valuable outcome of the project has been the recognition by QDPI not only that stock assessment if essential, but also that good assessments depend on reliable data, and that (in many cases) this may only be forthcoming from a fishery-independent monitoring program. The fact that the Department has recently committed dedicated funding to such a program cannot be attributed entirely to the present Project, but there is no doubt that the continuous lobbying by our Project staff played a very significant part.

## 12 ACKNOWLEDGMENTS

Many people assisted with the conduct of this Project in diverse ways. We especially acknowledge:

- staff of Raptis Pacific Seafoods (particularly John and Bernie) who assisted us in measuring fish on the auction floor and obtaining samples from the filleting room, and
- staff of the Wynnum Fish Market (especially Joe and Ray), Sade's Fish Market, the Scarborough Fish Market, the Fish Factory, Southern Cross Fisheries, the Sandgate Fish Co-op, Q-Fish, Bart's Place, Morgan's Seafoods, Markwells (Chinderah), and Markwells (Southport) for providing fish samples.

In addition, many commercial and recreational fishers cooperated with Project staff by providing samples, and/or advice based on their experience and knowledge of the fisheries. We particularly thank Jeff Blaney, Billy Michel, Peter Hancock, John Page, Don Clark, John Stone, Raymond Hincks, Martin Cowling and John Longhurst.

Without the assistance of these companies and individuals, our ability to achieve the objectives of the Project would have been severely compromised.

Many members of the Southern Fisheries Centre staff helped with the Project work. Their help involved field operations (including visiting fish processing works at a very early hour of the morning), laboratory processing of fish and otoliths, otolith age estimation, data acquisition from the CFISH database, and report reviewing and editing. To these people we extend our sincere thanks.

We are also grateful to the following people: Aldo Steffe (New South Wales Fisheries, tailor data); Doug Ferrell (NSW Fisheries, ageing advice); Richard Steckis (Western Australian Fisheries, tailor ageing assistance); Julian Pepperell (tailor data); Cameron Baker, StJohn Kettle and the staff of the QFMA (CFISH data acquisition); Darren Cameron (QDPI, now Great Barrier Reef Marine Park Authority, mackerel data for bootstrap); Jonathan Staunton-Smith (QDPI, tailor egg and larval survey data); Anne Gason & Simon Conron (Marine and Freshwater Resources Institute, Victoria, bootstrapping assistance); Barry Pollock (QDPI, tailor data).

Finally we acknowledge the valuable advice and commentary provided at the August 1998 Stock Assessment Review Workshop by the participants in the Sections 6 (Tailor) and 7 (Bream, whiting and flathead) working groups. Of particular value was the contribution of the workshop facilitator, Dr Malcolm Haddon (Dept Fisheries, AMC, Launceston).

## 13 REFERENCES

Anon. (1992). State Government Inquiry into Recreational Fishing. Report of the Recreational Fishing Consultative Committee. Brisbane, Queensland. 96 p + appendices.

Anon. (1993). Discussion Paper "Queensland Fisheries Policy and Legislation. Fisheries: managing for the future." Issued under the authority of the Hon. E Casey MLA, Minister for Primary Industries, Brisbane. August 1993. 24 p + appendices.

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

Bannerot, S. P., Fox Jr., W. W., and Powers, J. W. (1987). Reproductive strategies and the management of snappers and groupers in the Gulf of Mexico and Caribbean,. In 'Tropical Snappers and Groupers: Biology and Fisheries Management'. (Eds. J. J. Polovina and S. Ralston.) pp.561–605. (Westview Press: London.)

Barger, L. E. (1990). Age and growth of bluefish *Pomatomus saltatrix* from the northern Gulf of Mexico and U.S. South Atlantic coast. *Fishery Bulletin*, **88**, 805–9.

Bawazeer, A. S. (1989). The stock and fishery biology of Indian flathead (wahar) *Platycephalus indicus* (Linnaeus), family Platycephalidae in Kuwait waters. Eighth Shrimp and Fin Fisheries Management Workshop, (Salmiya) (Kuwait), 2–4 Feb 1987. *Kuwait Bulletin of Marine Science*, **10**, 169–78.

Beamish, R. J., and Fournier, D. A. (1981). A method for comparing the precision of a set of age determinations. *Canadian Journal of Fisheries and Aquatic Sciences*, **38**, 982–3.

Beamish, R. J., and McFarlane, G. A. (1983). The forgotten requirement for age validation in fisheries biology. *Transactions of the American Fisheries Society*, **112**, 735–43.

Beran, R., and Srivastava, M. S. (1985). Bootstrap tests and confidence regions for functions of a covariance matrix. *The Annals of Statistics*, **13**, 95–115.

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

Brown, C. A. (1993). Catch estimation utilizing simulation modeling and bootstrapping methodology. *Collective volume of scientific papers. International Commission for the Conservation of Atlantic Tunas/Recueil de documents scientifiques. Commissio internationale pour la Conservation des Thonides de l'Atlantique/Coleccion d documentos cientificos*, **40**, 249–53.

Brown, I. W., Doherty, P., Ferreira, B., Keenan, C., McPherson, G., Russ, G., Samoilys, M., and Sumpton, W. (1994). 'Growth, reproduction and recruitment of Great Barrier Reef food fish stocks'. Final Report on Project 90/18 to the Fisheries Research and Development Corporation. 154 pp.

Butterworth, D. S., Punt, A. E., Borchers, D. L., Pugh, J. B., and Hughes, G. S. (1989). 'A manual of mathematical techniques for linefish assessment'. South African National Scientific Programmes Report No. 160. (Foundation for Research Development: Pretoria, South Africa).

Cameron, D. S. and Begg, G. (1999). Fisheries biology and interaction in the northern Australian small mackerel fishery. Draft final report on Projects 92/144 and 92/144.02 to the Fisheries Research and Development Corporation. 219 pp and Appendices.

Champagnat, C., Fontana, A., Caveriviere, A., Conand, C., Cury, P., Durand, J. R., Fonteneau, A., Freon, P., and Samba, A. (1983). 'Bluefish (*Pomatomus saltator*, Linnaeus, 1766) fishery, biology, and dynamics on the coasts of Senegal and Mauritania'. (Institut Français de Recherche Scientifique pour le Development en Cooperation: Paris, France.)

Chang, W. Y. B. (1982). A Statistical Method for Evaluating the Reproducibility of Age Determination. *Canadian Journal of Fisheries and Aquatic Sciences*, **39**, 1208–9.

Changeux, T., and Zylberblat, M. (1993). Analysis of fishing gear fishery statistics in the Rhone River basin: Part one: Study of the catch. *Bulletin Francais de la Pêche et de la Pisciculture*,, 271–94.

Chiarella, L. A., and Conover, D. O. (1990). Spawning season and first-year growth of adult bluefish from the New York Bight. *Transactions of the American Fisheries Society*, **119**, 455–62.

Clarke, J. R., and Buxton, C. D. (1989). A survey of the recreational rock-angling fishery at Port Elizabeth, on the south-east coast of South Africa. *South African Journal of Marine Science*, **8**, 183–94.

Cleland, K. W. (1947). Studies on the economic biology of the sand whiting (*Sillago ciliata* C.& V.). *Proceedings of the Linnean Society of New South Wales*, **72**, 215–28.

Conand, C. (1975). Maturite sexuelle et fecondite du tassergal, *Pomatomus saltator* (L. 1766), poissons - Pomatomatidae. *Bull. Inst. Fondam. Afr. Noire, Ser. A*, **37**, 395–466.

Cordue, P. L., and Francis, R. (1994). Accuracy and choice in risk estimation for fisheries assessment. *Canadian Journal of Fisheries and Aquatic Sciences*, **51**, 817–29.

Deuel, D. D., Clark, J. R., and Mansueti, A. J. (1966). Description of embryonic and early life stage of bluefish, *Pomatomus saltatrix*. *Transactions of the American Fisheries Society*, **95**, 264–71.

Dredge, M. C. L. (1976). Aspects of the ecology of three estuarine dwelling fish in south-east Queensland. MSc Thesis. University of Queensland.

Ebbers, M. A. (1987). Vital statistics of a largemouth bass population in Minnesota (USA) from electrofishing and angler-supplied data. *North American Journal of Fisheries Management*, **7**, 252–9.

Efron, B. (1979). The 1977 Rietz Lecture. Bootstrap methods: another look at the Jackknife. *The Annals of Statistics*, **7**, 1–26.

Efron, B. (1981). Nonparametric standard errors and confidence intervals (with discussions). *Canadian Journal of Statistics*, **9**, 139-172.

Efron, B. (1987). Better bootstrap confidence intervals. *Journal of the American Statistical Association*, **82**, 171–85.

Efron, B., and Tibshirani, R. (1986). Bootstrap methods for standard errors, confidence intervals and other measures of statistical accuracy. *Statistical Science*, **1**, 54–77.

Efron, B., and Tibshirani, R. J. (1993). 'An Introduction to the Bootstrap'. (Chapman and Hall: London.)

Faddy, M. J. (1998). Stochastic models for analysis of species abundance data. In 'Statistics in Ecology and Environmental Monitoring, Dunedin, June 1996'. (Eds. D. J. Fletcher, L. Kavalieris and B. F. J. Manly.) pp.33–40. (University of Otago Press: Dunedin.)

Fletcher, D., and Webster, R. (1996). Skewness-adjusted confidence intervals in stratified biological surveys. *Journal of Agricultural, Biological, and Environmental Statistics*, **1**, 120–30.

Francis, R. I. C. C., and Shotton, R. (1997). "Risk" in fisheries management: a review. *Canadian Journal of Fisheries and Aquatic Sciences*, **54**, 1699–715.

Gaston, K. J., and McArdle, B. H. (1994). The temporal variability of animal abundances: measures, methods and patterns. *Philosophical Transactions of the Royal Society of London, Series B*, **345**, 335–58.

Goodyear, C. P. (1996). Minimum sizes for red grouper: Consequences of considering variable size at age. *North American Journal of Fisheries Management*, **16**, 505–11.

Govender, A. (1996). Mark-recapture models for determination of mortality, migration and growth in *Pomatomus saltatrix* (Teleostei). PhD. Dissertation. University of Natal (Durban).

Gunn, J. S. (1978). A study of the feeding, growth and reproduction of three species of the family Silliganidae in the Townsville region, north Queensland. Honours Thesis. James Cook University, Townsville.

Haimovici, M., and Krug, L. C. (1996). Life history and fishery of the enchova, *Pomatomus saltatrix*, in southern Brazil. *Marine and Freshwater Research*, **47**, 357–63.

Hall, P. (1992). 'The Bootstrap and Edgeworth Expansion'. (Springer-Verlag: New York.)

Hardy, J. D. (1978). Pomatomidae – Bluefishes, in 'Development of fishes of the Mid-Atlantic Bight, an atlas of egg, larval, and juvenile stages, v3, Aphredoderidae through Rachycentridae'. (Fish and Wildlife Service, US Department of the Interior: Fort Collins, Colorado).

Henry, G. W. (1983). Biology and fisheries of yellowfin bream *Acanthopagrus australis* (Teleostei: Sparidae) in Tuggerah Lakes, NSW. MSc Thesis. University of New South Wales.

Higgs, J. B. (1999). Experimental Recreational Catch Estimates for Queensland Residents, RFISH Technical Report #2, Results from the 1997 Diary Round. (Queensland Fisheries Management Authority: Brisbane, Queensland).

Hilborn, R. (1979). Comparison of fisheries control systems that utilize catch and effort data. *Journal of the Fisheries Research Board of Canada*, **36**, 1477–89.

Hilborn, R., and Walters, C. J. (1992). 'Quantitative Fisheries Stock Assessment: Choice Dynamics and Uncertainty'. (Chapman and Hall: New York.)

Hjorth, J. S. U. (1994). 'Computer-Intensive Statistical Methods'. (Chapman and Hall: London.)

Hoenig, J. M. (1983). Empirical use of longevity data to estimate mortality rates. Fish. Bull. NOAA/NMFS, 81 (4): 898–903.

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**, 364–8.

Hughes, G. S. (1986). Examining methods of fitting age/length data to the von Bertalanffy growth curve with a view to applying a simplified version of the Beverton and Holt yield per recruit model. Department of Applied Mathematics, University of Cape Town, South Africa, 70 pp. Unpublished report.

Hyland, S. (1993). 'Fisheries resources of the Sunshine Coast - Cooloola region'. (Queensland Fish Management Authority: Brisbane Australia.)

Hyndes, G. A., Loneragan, N. R., and Potter, I. C. (1992). Influence of sectioning otoliths on marginal increment trends and age and growth estimates for the flathead *Platycephalus speculator*. *Fishery Bulletin*, **90**, 276–84.

Hyndes, G. A., Platell, M. E., Potter, I. C., and Lenanton, R. C. J. (1998). Age composition, growth, reproductive biology, and recruitment of King George whiting, *Sillaginoides punctata*, in coastal waters of southwestern Australia. *Fishery Bulletin*, **96**, 258–70.

Jones, C. M., Robson, D. S., Lakkis, H. D., and Kressel, J. (1995). Properties of catch rates used in analysis of angler surveys. *Transactions of the American Fisheries Society*, **124**, 911–28.

Kailola, P. J., Williams, M. J., Stewart, P. C., Reichelt, R. E., McNee, A., and Grieve, C. (1993). 'Australian Fisheries Resources'. (Bureau of Resource Sciences, Department of Primary Industries and Energy, and the fisheries Research and Development Corporation: Canberra, Australia.)

Kendall, A. W., Jr., and Naplin, N. A. (1981). Diel-depth distribution of summer icthyoplankton in the middle Atlantic bight. *Fishery Bulletin*, **79**, 705–26.

Kerby, B. M., and Brown, I. W. (1994). 'Bream, whiting and flathead in south-east Queensland: a review of the literature'. QI94028. (Queensland Department of Primary Industries: Brisbane, Queensland.)

Kimura, D. K. (1980). Likelihood methods for the Von Bertalanffy equation. *Fishery Bulletin*, **77**, 765–76.

Kokko, H., and Lindstrom, J. (1998). Seasonal density dependence, timing of mortality, and sustainable harvesting. *Ecological Modelling*, **110**, 293–304.

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

Lenanton, R. C., Ayvazian, S. G., Pearce, A. F., Steckis, R. A., and Young, G. C. (1996). Tailor (*Pomatomus saltatrix*) off Western Australia: Where does it spawn and how are the larvae distributed? *Marine and Freshwater Research*, **47**, 337–46.

Lucy, J. A., and Barr, C. G. (1994). Experimental monitoring of Virginia artificial reefs using fishermen's catch data. *Fifth International Conference On Aquatic Habitat Enhancement*, **55**, 524–37. 5. Int. Conf. on Aquatic Habitat Enhancement, Long Beach, CA (USA), 3–7 Nov 1991; BULL.-MAR.-SCI. vol. 55, no. 2–3.

Ludwig, D., and Walters, C. J. (1985). Are age-structured models appropriate for catch-effort data? *Canadian Journal of Fisheries and Aquatic Sciences*, **42**, 1066–72.

Manly, B. F. J. (1997). 'Randomization, Bootstrap and Monte Carlo Methods in Biology', 2nd ed. (Chapman and Hall: London.)

Mason, D. L., and Manooch III, C. S. (1985). Age and growth of mutton snapper along the east coast of Florida. *Fisheries Research (Amsterdam*, **3**, 93–104.

McGlennon, D., and Branden, K. L. (1994). Comparison of catch and recreational anglers fishing on artificial reefs and natural seabed in Gulf St. Vincent, South Australia. *Fifth International Conference On Aquatic Habitat Enhancement*, **55**, 510–23. 5. Int. Conf. on Aquatic Habitat Enhancement, Long Beach, CA (USA), 3–7 Nov 1991; BULL.-MAR.-SCI. vol. 55, no. 2–3.

McKay, R. J. (1992). 'Sillaginid fishes of the world (Family Sillaginidae). An annotated and illustrated catalogue of the sillago, smelt or Indo-Pacific whiting species known to date', Vol. 14. vol. 14, no. 125. (Fao: Rome-Italy.)

McPherson, G. (1981). Research helps track spanish mackerel. *Australian Fisheries*, 6, 9–13.

Miskiewicz, A. G., Bruce, B. D., and Dixon, P. (1996). Distribution of tailor (*Pomatomus saltatrix*) larvae along the coast of New South Wales, Australia. *Marine and Freshwater Research*, **47**, 331–6.

Moore, N. (1986). 'Recreational fishing in Hervey Bay and Great Sandy Strait'. no. Q189021. (Queensland Department of Primary Industries: Brisbane, Queensland.)

Morton, R. M. (1982). Reproductive biology and tagging studies of sand whiting, *Sillago ciliata* (C.&V.) at Bribie Island. MSc Thesis. University of Queensland (Brisbane).

Muelbert, J. H., and Sinque, C. (1996). Distribution of bluefish (*Pomatomus saltatrix*) larvae along the continental shelf off southern Brazil. *Marine and Freshwater Research*, **47**, 311–4.

Munro, I. R. S. (1944). The economic biology of the Australian black breams (*Roughleyia australis* (Gunther)). M.Sc. Thesis. University of Queensland.

O'Neill, M. (1999). 'Fishery Assessment of the Burnet River, Maroochy River and Pumicestone Passage'. Project Report QO99011. (Department of Primary Industries: Brisbane, Queensland).

Parma, A. M., and Deriso, R. B. (1990). Dynamics of age and size composition in a population subject to size-selective mortality: Effects of phenotypic variability in growth. *Canadian Journal of Fisheries and Aquatic Sciences*, **47**, 274–89.

Pauly, D. (1980). On the interrelationships between natural mortality, growth parameters, and mean environmental temperature in 175 fish stocks. *Journal du Conseil International Pour L'Exploration De La Mer*, **39**, 175–92.

Pelletier, D., and Gros, P. (1991). Assessing the impact of sampling error on model-based management advice: Comparison of equilibrium yield per recruit variance estimators. *Canadian Journal of Fisheries and Aquatic Sciences*, **48**, 2129–39.

Pollock, B. R. (1980). Surprises in Queensland angling study. *Australian Fisheries*, **April**, 117–9.

Pollock, B. R. (1982a). Movements and migrations of yellowfin bream, *Acanthopagrus australis*

(Guenther), in Moreton Bay, Queensland as determined by tag recoveries. *Journal of Fish Biology*, **20**, 245–52.

Pollock, B. R. (1982b). Spawning period and growth of yellowfin bream, *Acanthopagrus australis* (Guenther), in Moreton Bay, Australia. *Journal of Fish Biology*, **21**, 349–55.

Pollock, B. R. (1984). Relations between migration, reproduction and nutrition in yellowfin bream *Acanthopagrus australis*. *Marine Ecology Progress Series*, **19**, 17–23.

Pollock, B. R., and Williams, M. J. (1983). An assessment of the angling fishery for yellowfin bream, *Acanthopagrus australis* (Guenther), in Moreton Bay, Australia. *Journal of Fish Biology*, **22**, 125–32.

Pollock, K. H., Jones, C. M., and Brown, T. L. (1994). 'Angler Survey Methods and Their Applications in Fisheries Management'. (American Fisheries Society: Bethesda, Maryland.)

Poole, D., Givens, G. H., and Raftery, A. E. (1999). A proposed stock assessment method and its application to bowhead whales, *Balaena mysticetus*. *Fishery Bulletin*, **97**, 144–52.

Punt, A. E. (1992). 'PC-Yield II User's Guide Version 2.2'. (University of Cape Town: Cape Town.)

Quinn, R. H. (1992). 'Fisheries Resources of the Moreton Bay Region'. (Queensland Fish Management Authority: Brisbane.)

Rawlings, J. O. (1988). 'Applied regression analysis, a research tool'. (Wadsworth & Brooks/Cole Advanced Books & Software: Pacific Grove, California).

Restrepo, V. R., and Fox, W. W. (1988). Parameter Uncertainty and Simple Yield-per-Recruit Analysis. *American Fisheries Society*, **117**, 282–9.

Restrepo, V. R., Hoenig, J. M., Powers, J. E., Baird, J. W., and Turner, S. C. (1992). A simple simulation approach to risk and cost analysis, with applications to swordfish and cod fisheries. *Fishery Bulletin*, **90**, 736–48.

Robins, C. M., Wang Y. G., and Die D. (1998). The impact of global positioning systems and plotters on fishing power in the northern prawn fishery, Australia. *Canadian Journal of Fisheries & Aquatic Sciences*, **55**, 1645–51.

Rosenberg, A. A., and Restrepo, V. R. (1994). Uncertainty and risk evaluation in stock assessment advice for U.S. marine fisheries. *Canadian Journal of Fisheries and Aquatic Sciences*, **51**, 2715–20.

Roughley, T. C. (1951). 'Fish and Fisheries of Australia'. (Angus and Robertson: Sydney).

SAS Institute (1996). SAS/STAT and SAS/BASE. Statistical Analysis Software v 6.12. SAS Institute Inc., North Carolina USA.

Shao, J., and Tu, D. (1995). 'The Jackknife and Bootstrap'. (Springer-Verlag: New York.)

Smith, S. J. (1997). Bootstrap confidence limits for groundfish trawl survey estimates of mean abundance. *Canadian Journal of Fisheries and Aquatic Sciences*, **54**, 616–30.

Smith, W., Berrien, P., and Potthoff, T. (1994). Spawning patterns of bluefish, *Pomatomus saltatrix* in the northeast continental shelf ecosystem. *Bulletin of Marine Science*, **54**, 8–16.

Steffe, A. S., Staines, J. F., and Murphy, J. (1996). Recreational use of fisheries resources in Northern New South Wales. New South Wales Fisheries Research Institute.

Terceiro, M., and Ross, J. L. (1993). A comparison of alternative methods for the estimation of age from length data for Atlantic coast bluefish (*Pomatomus saltatrix*). *Fishery Bulletin*, **91**, 534–49.

Thorogood, J. A. (1991). Aspects of the reproductive biology of the yellowfin bream, *Acanthopagrus australis* (Gunther), with a view to its mariculture. Ph.D. Thesis. University of Queensland.

van der Elst, R. (1976). 'Game fish of the east coast of southern Africa. I. the biology of the elf, *Pomatomus saltatrix* (Linnaeus) in the coastal waters of Natal', Vol. Investigational Report No. 44. (South African Association for Marine Biology Research, Oceanographic Research Institute: Durban.)

Welsh, A. H., Peterson, A. T., and Altmann, S. A. (1988). The fallacy of averages. *American Naturalist*, **132**, 277–88.

Welsh, A. H., Cunningham, R. B., Donnelly, C. F., and Lindenmayer, D. B. (1996). Modelling the abundance of rare species: Statistical models for counts with extra zeros. *Ecological Modelling*, **88**, 297–308.

West, I. F., and Goode, R. H. (1986). Postal surveys of anglers fishing for sea-run chinook salmon on the Rakaia river, Canterbury, New Zealand, 1973/74 and 1974/75. *New Zealand Journal of Marine and Freshwater Research*, **20**, 345–54.

Wilk, S. J. (1977). 'Biological and fisheries data on Bluefish, *Pomatomus saltatrix* (Linnaeus)', Technical Series Report No 11. Sandy Hook Laboratory, NOAA. 56 p.

Williams L. (1993). Moreton Bay Fisheries. In 'Moreton Bay in the balance'. pp.71–9. (Department of Primary Industries, Queensland: Brisbane).

Williams, L. E. (1997) 'Queensland's fisheries resources: current condition and recent trends 1988–1995'. (Department of Primary Industries, Queensland: Brisbane).

Wilson, C. W., Beamish, R. J., Brothers, E. B., Carlander, K. D., Casselman, J. M., Dean, JM, Jearld Jr, A., Prince, E. D., and Wild, A. (1987). Glossary, pp. 527–530. In Summerfelt, R. C. and Hall, G. E. (eds), Age and Growth of Fish. (Iowa State University Press: Ames, Iowa).

# 14 APPENDIXES

## 14.1 Appendix 1: Intellectual Property

There are no intellectual property rights considerations arising from this Project, in terms of patentable products or processes.

## 14.2 Appendix 2: Staff

| | |
|---|---|
| Principal Investigator: | Mr Simon Hoyle (Fisheries Biologist and Modeller) |
| Co-Investigator: | Dr Ian Brown (Principal Fisheries Scientist) |
| Co-Investigator: | Ms Cathy Dichmont (Senior Stock Assessment Scientist) |
| Project Fisheries Technicians: | Ms Michelle Sellin |
| | Mr Michael Cosgrove |
| | Mr Mark McLennan |
| Administrative support: | Ms Trish McDonald |
| | Ms Elaine Hewitt |
| Biometrical support: | Mr David Mayer |

## 14.3 Appendix 3: Tables

Table 14.1: Ages of bream as determined by reading whole and sectioned otoliths. Bold numbers are where the two methods agree.

| | | Sectioned age | | | | | | | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | | 0 | 1 | 2 | 3 | 4 | 5 | 6 | 7 | 8 | 9 | 10 | 11 | 12 | 13 | 14 | 15 | 16 |
| Whole | 0 | **3** | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| age | 1 | 0 | **12** | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| | 2 | 0 | 0 | **56** | 26 | 2 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| | 3 | 0 | 0 | 6 | **149** | 14 | 5 | 1 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| | 4 | 0 | 0 | 0 | 3 | **115** | 29 | 2 | 1 | 0 | 5 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| | 5 | 0 | 0 | 0 | 0 | 1 | **83** | 20 | 3 | 0 | 2 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| | 6 | 0 | 0 | 1 | 3 | 0 | 3 | **60** | 4 | 1 | 2 | 0 | 0 | 3 | 0 | 0 | 0 | 0 |
| | 7 | 0 | 0 | 0 | 0 | 0 | 1 | 5 | **29** | 9 | 4 | 0 | 1 | 3 | 0 | 0 | 0 | 0 |
| | 8 | 0 | 0 | 0 | 0 | 0 | 1 | 1 | 4 | **40** | 9 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| | 9 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 3 | **15** | 2 | 2 | 0 | 0 | 0 | 0 | 0 |
| | 10 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 1 | 3 | **6** | 5 | 1 | 0 | 0 | 0 | 0 |
| | 11 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 1 | 0 | **5** | 4 | 0 | 0 | 0 | 0 |
| | 12 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 1 | 0 | 0 | **6** | 0 | 0 | 3 | 0 |
| | 13 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 3 | **2** | 1 | 1 | 0 |
| | 14 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 1 | 0 | **1** | 4 | 0 |
| | 15 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 1 | **3** | 0 |
| | 16 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 2 | **0** |

Table 14.2: Ages of sand whiting as determined by reading whole and sectioned otoliths. Bold numbers are where the two methods agree.

Sectioned age

| | | 0 | 1 | 2 | 3 | 4 | 5 | 6 | 7 | 8 | 9 |
|---|---|---|---|---|---|---|---|---|---|---|---|
| Whole | 0 | **60** | 12 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| age | 1 | 51 | **46** | 25 | 4 | 0 | 0 | 0 | 0 | 0 | 0 |
| | 2 | 6 | 57 | **54** | 33 | 3 | 0 | 0 | 0 | 0 | 0 |
| | 3 | 0 | 32 | 63 | **56** | 11 | 3 | 0 | 0 | 0 | 0 |
| | 4 | 0 | 18 | 25 | 29 | **29** | 8 | 6 | 0 | 0 | 0 |
| | 5 | 0 | 2 | 11 | 11 | 10 | **15** | 3 | 1 | 0 | 0 |
| | 6 | 0 | 0 | 0 | 1 | 1 | 6 | **4** | 2 | 1 | 0 |
| | 7 | 0 | 1 | 1 | 1 | 4 | 2 | 1 | **2** | 1 | 0 |
| | 8 | 0 | 1 | 1 | 1 | 4 | 2 | 0 | 0 | **0** | 0 |
| | 9 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | **0** |

Table 14.3: Ages of golden-lined whiting as determined by reading whole and sectioned otoliths. Bold numbers are where the two methods agree.

| | | Sectioned age (yr) | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|
| | | 0 | 1 | 2 | 3 | 4 | 5 | 6 | 7 | 8 | 9 |
| Whole | 0 | **39** | 10 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| Age | 1 | 23 | **68** | 11 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| | 2 | 5 | 79 | **115** | 9 | 3 | 0 | 0 | 0 | 0 | 0 |
| | 3 | 0 | 38 | 97 | **75** | 7 | 1 | 0 | 0 | 0 | 0 |
| | 4 | 1 | 6 | 24 | 56 | **12** | 4 | 0 | 0 | 0 | 0 |
| | 5 | 0 | 3 | 11 | 17 | 7 | **6** | 0 | 0 | 0 | 0 |
| | 6 | 0 | 0 | 2 | 3 | 1 | 2 | **0** | 0 | 0 | 0 |
| | 7 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | **3** | 0 | 0 |
| | 8 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 1 | **0** | 0 |
| | 9 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | **0** |

Table 14.4: Ages of dusky flathead as determined by reading whole and sectioned otoliths. Bold numbers are where the two methods agree.

Sectioned age

| | | 0 | 1 | 2 | 3 | 4 | 5 | 6 | 7 | 8 |
|---|---|---|---|---|---|---|---|---|---|---|
| | 0 | **20** | 12 | 2 | 0 | 2 | 0 | 0 | 0 | 0 |
| | 1 | 57 | **167** | 24 | 7 | 5 | 0 | 0 | 0 | 0 |
| | 2 | 1 | 53 | **111** | 24 | 2 | 0 | 0 | 0 | 0 |
| Whole | 3 | 3 | 1 | 55 | **88** | 17 | 1 | 0 | 0 | 0 |
| Age | 4 | 1 | 2 | 1 | 34 | **57** | 6 | 0 | 0 | 0 |
| | 5 | 0 | 0 | 1 | 1 | 7 | **16** | 4 | 0 | 0 |
| | 6 | 0 | 0 | 0 | 0 | 0 | 0 | **6** | 0 | 0 |
| | 7 | 0 | 0 | 0 | 0 | 0 | 1 | 0 | 0 | 0 |
| | 8 | 0 | 0 | 0 | 0 | 0 | 1 | 0 | 0 | 0 |

Table 14.5: Ages of tailor as determined by reading whole and sectioned otoliths. Bold numbers are where the two methods agree.

Sectioned age

| | | 0 | 1 | 2 | 3 | 4 | 5 | 6 |
|---|---|---|---|---|---|---|---|---|
| Whole | 0 | **0** | 5 | 0 | 2 | 0 | 0 | 0 |
| age | 1 | 4 | **236** | 73 | 23 | 6 | 2 | 0 |
| | 2 | 2 | 32 | **119** | 33 | 7 | 0 | 0 |
| | 3 | 0 | 2 | 5 | **2** | 1 | 0 | 0 |
| | 4 | 0 | 0 | 0 | 0 | **0** | 0 | 0 |
| | 5 | 0 | 0 | 0 | 0 | 0 | **0** | 0 |
| | 6 | 0 | 0 | 0 | 0 | 0 | 0 | **0** |

Table 14.6: Frequency distribution of survey data, used as source for bootstrap simulation. Add column and row headers together to obtain size of catch for a given frequency. Total number of catches (diary quarters) recorded was 2844.

| | 0 | 20 | 40 | 60 | 80 | 100 | 120 |
|---|---|---|---|---|---|---|---|
| 0 | 2530 | 3 | 0 | 0 | 0 | 0 | 0 |
| 1 | 100 | 2 | 0 | 0 | 0 | 0 | 1 |
| 2 | 49 | 4 | 0 | 0 | 0 | 0 | |
| 3 | 38 | 1 | 1 | 0 | 0 | 0 | |
| 4 | 21 | 1 | 1 | 0 | 1 | 0 | |
| 5 | 13 | 0 | 1 | 1 | 0 | 0 | |
| 6 | 11 | 0 | 0 | 0 | 0 | 0 | |
| 7 | 6 | 0 | 0 | 0 | 0 | 0 | |
| 8 | 9 | 3 | 0 | 0 | 0 | 0 | |
| 9 | 7 | 0 | 0 | 0 | 0 | 0 | |
| 10 | 2 | 1 | 2 | 0 | 0 | 0 | |
| 11 | 5 | 1 | 0 | 0 | 0 | 0 | |
| 12 | 1 | 0 | 0 | 0 | 0 | 0 | |
| 13 | 3 | 1 | 0 | 0 | 0 | 0 | |
| 14 | 3 | 0 | 0 | 0 | 0 | 0 | |
| 15 | 4 | 0 | 0 | 0 | 0 | 0 | |
| 16 | 3 | 1 | 0 | 0 | 1 | 0 | |
| 17 | 5 | 2 | 0 | 0 | 0 | 0 | |
| 18 | 3 | 0 | 0 | 0 | 0 | 0 | |
| 19 | 2 | 0 | 0 | 0 | 0 | 0 | |

Table 14.7: Coverage of bootstrap estimators – the proportion of simulations for which the confidence intervals covered the population mean. Results for the standard method (alpha =0.1, resample size = 100, observed distribution, RSE=15%) are in bold. Coverage should ideally be 0.9, except for 'Alpha' where the ideal is (1-alpha).

| | | Analysis | | | | | Data | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | | | Alpha | | Resample | | Initial sample | | | RSE of boat numbers | | |
| Name | Method | **Std** | 0.05 | 0.20 | n/2 | 2n | 50 | 200 | P(0)=0.5 | 5 | 25 | Norm. |
| Catch rate | Trad. normal | **0.746** | NA | NA | NA | NA | NA | NA | NA | NA | NA | NA |
| | B normal | **0.729** | 0.788 | 0.583 | 0.824 | 0.636 | 0.665 | 0.792 | 0.832 | 0.739 | 0.739 | 0.898 |
| | BC | **0.766** | 0.826 | 0.600 | 0.879 | 0.642 | 0.687 | 0.812 | 0.843 | 0.772 | 0.771 | 0.894 |
| | BCa | **0.789** | 0.870 | 0.600 | 0.903 | 0.652 | 0.726 | 0.834 | 0.854 | 0.803 | 0.800 | 0.895 |
| | Hybrid | **0.697** | 0.741 | 0.577 | 0.765 | 0.630 | 0.634 | 0.768 | 0.821 | 0.710 | 0.711 | 0.897 |
| | Percentile | **0.744** | 0.807 | 0.583 | 0.846 | 0.636 | 0.675 | 0.798 | 0.836 | 0.750 | 0.750 | 0.896 |
| | Boot – t | **0.852** | 0.911 | 0.675 | 0.891 | 0.832 | 0.792 | 0.883 | 0.885 | 0.856 | 0.856 | 0.903 |
| Total catch | Trad. normal | **0.730** | NA | NA | NA | NA | NA | NA | NA | NA | NA | NA |
| | B normal | **0.733** | 0.781 | 0.589 | 0.822 | 0.663 | 0.670 | 0.794 | 0.851 | 0.736 | 0.744 | 0.893 |
| | BC | **0.772** | 0.844 | 0.606 | 0.886 | 0.658 | 0.705 | 0.825 | 0.871 | 0.773 | 0.801 | 0.895 |
| | BCa | **0.773** | 0.845 | 0.605 | 0.886 | 0.658 | 0.712 | 0.825 | 0.871 | 0.787 | 0.801 | 0.895 |
| | Hybrid | **0.692** | 0.727 | 0.576 | 0.761 | 0.650 | 0.634 | 0.761 | 0.827 | 0.713 | 0.699 | 0.895 |
| | Percentile | **0.746** | 0.816 | 0.584 | 0.851 | 0.659 | 0.684 | 0.808 | 0.856 | 0.752 | 0.765 | 0.895 |
| | Boot - t | **0.858** | 0.919 | 0.679 | 0.896 | 0.853 | 0.801 | 0.886 | 0.903 | 0.858 | 0.878 | 0.9 |

Table 14.8: Proportion of lower confidence limits that were above the expected value. Results for the standard method (alpha =0.1, resample size = 100, observed distribution, RSE=15%) are in bold. Values should ideally be 0.05, except for 'Alpha' where the ideal is alpha/2.

| Analysis | | | Data | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | | | Alpha | | Resample | | Initial sample | | | RSE of boat numbers | | |
| Name | Method | Std | 0.05 | 0.20 | n/2 | 2n | 50 | 200 | P(0)= 0.5 | 5 | 25 | Norm. |
| Catch rate | Trad. normal | **0.003** | NA | NA | NA | NA | NA | NA | NA | NA | NA | NA |
| | B normal | **0.004** | 0.001 | 0.025 | 0.000 | 0.038 | 0.002 | 0.005 | 0.012 | 0.004 | 0.004 | 0.048 |
| | BC | **0.020** | 0.006 | 0.054 | 0.001 | 0.069 | 0.015 | 0.026 | 0.033 | 0.018 | 0.023 | 0.049 |
| | BCa | **0.035** | 0.026 | 0.068 | 0.006 | 0.096 | 0.037 | 0.050 | 0.047 | 0.034 | 0.042 | 0.050 |
| | Hybrid | **0.001** | 0.000 | 0.020 | 0.000 | 0.028 | 0.000 | 0.003 | 0.007 | 0.002 | 0.002 | 0.050 |
| | Percentile | **0.010** | 0.002 | 0.030 | 0.000 | 0.052 | 0.006 | 0.016 | 0.022 | 0.010 | 0.012 | 0.049 |
| | Boot - t | **0.027** | 0.008 | 0.067 | 0.040 | 0.017 | 0.018 | 0.034 | 0.040 | 0.025 | 0.030 | 0.047 |
| Total catch | Trad. normal | **0.003** | NA | NA | NA | NA | NA | NA | NA | NA | NA | NA |
| | B normal | **0.001** | 0.000 | 0.020 | 0.000 | 0.023 | 0.001 | 0.003 | 0.007 | 0.004 | 0.001 | 0.018 |
| | BC | **0.021** | 0.006 | 0.057 | 0.002 | 0.070 | 0.016 | 0.030 | 0.033 | 0.020 | 0.021 | 0.019 |
| | BCa | **0.022** | 0.006 | 0.057 | 0.002 | 0.071 | 0.018 | 0.030 | 0.033 | 0.026 | 0.021 | 0.019 |
| | Hybrid | **0.000** | 0.000 | 0.015 | 0.000 | 0.013 | 0.000 | 0.001 | 0.003 | 0.002 | 0.000 | 0.017 |
| | Percentile | **0.008** | 0.003 | 0.031 | 0.000 | 0.045 | 0.006 | 0.011 | 0.020 | 0.010 | 0.008 | 0.017 |
| | Boot - t | **0.024** | 0.008 | 0.062 | 0.039 | 0.010 | 0.019 | 0.032 | 0.038 | 0.024 | 0.023 | 0.052 |

Table 14.9: Proportion of upper confidence limits that were below the expected value. Results for the standard method (alpha =0.1, resample size = 100, observed distribution, RSE=15%) are in bold. Values should ideally be 0.05, except for 'Alpha' where the ideal is alpha/2.

| Analysis | | Data | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | | | Alpha | | Resample | | Initial sample | | | RSE of boat numbers | | |
| Name | Method | **Std** | 0.05 | 0.20 | n/2 | 2n | 50 | 200 | P(0) =0.5 | 5 | 25 | Norm. |
| Catch rate | Trad. normal | **0.268** | NA | NA | NA | NA | NA | NA | NA | NA | NA | NA |
| | B normal | **0.267** | 0.212 | 0.273 | 0.176 | 0.326 | 0.334 | 0.204 | 0.156 | 0.257 | 0.257 | 0.055 |
| | BC | **0.215** | 0.168 | 0.228 | 0.120 | 0.289 | 0.299 | 0.162 | 0.124 | 0.210 | 0.206 | 0.057 |
| | BCa | **0.177** | 0.104 | 0.214 | 0.091 | 0.252 | 0.237 | 0.116 | 0.100 | 0.164 | 0.159 | 0.056 |
| | Hybrid | **0.303** | 0.259 | 0.285 | 0.235 | 0.343 | 0.366 | 0.229 | 0.172 | 0.288 | 0.287 | 0.054 |
| | Percentile | **0.247** | 0.191 | 0.269 | 0.154 | 0.313 | 0.320 | 0.187 | 0.143 | 0.241 | 0.239 | 0.056 |
| | Boot - t | **0.121** | 0.082 | 0.139 | 0.069 | 0.151 | 0.190 | 0.083 | 0.075 | 0.120 | 0.114 | 0.051 |
| Total catch | Trad. normal | **0.252** | NA | NA | NA | NA | NA | NA | NA | NA | NA | NA |
| | B normal | **0.267** | 0.219 | 0.273 | 0.178 | 0.314 | 0.330 | 0.203 | 0.142 | 0.260 | 0.255 | 0.090 |
| | BC | **0.207** | 0.150 | 0.219 | 0.112 | 0.272 | 0.279 | 0.145 | 0.097 | 0.208 | 0.178 | 0.087 |
| | BCa | **0.206** | 0.149 | 0.220 | 0.112 | 0.272 | 0.270 | 0.145 | 0.097 | 0.187 | 0.178 | 0.087 |
| | Hybrid | **0.308** | 0.274 | 0.290 | 0.240 | 0.337 | 0.366 | 0.238 | 0.170 | 0.286 | 0.301 | 0.090 |
| | Percentile | **0.246** | 0.182 | 0.266 | 0.149 | 0.296 | 0.311 | 0.181 | 0.124 | 0.238 | 0.228 | 0.089 |
| | Boot - t | **0.118** | 0.074 | 0.140 | 0.066 | 0.137 | 0.180 | 0.083 | 0.059 | 0.119 | 0.100 | 0.048 |

Table 14.10: Average length of confidence intervals. Results for the standard method (alpha =0.1, resample size = 100, observed distribution, RSE=15%) are in bold.

| Analysis | | | Data | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | | | Alpha | | Resample | | Initial sample | | | RSE of boat numbers | |
| Name | Method | **Std** | 0.05 | 0.20 | n/2 | 2n | 50 | 200 | P(0)= 0.5 | 5 | 25 |
| Catch rate | Trad. normal | **1.36** | NA | NA | NA | NA | NA | NA | NA | NA | NA |
| | B normal | **1.30** | 1.56 | 1.03 | 1.82 | 0.91 | 1.63 | 1.00 | 3.07 | 1.30 | 1.32 |
| | BC | **1.35** | 1.61 | 1.10 | 1.93 | 0.93 | 1.68 | 1.03 | 3.14 | 1.35 | 1.37 |
| | BCa | **1.50** | 2.13 | 1.14 | 2.28 | 1.01 | 2.03 | 1.16 | 3.28 | 1.53 | 1.55 |
| | Hybrid | **1.27** | 1.49 | 1.01 | 1.73 | 0.91 | 1.58 | 0.99 | 3.05 | 1.27 | 1.29 |
| | Percentile | **1.27** | 1.49 | 1.01 | 1.73 | 0.91 | 1.58 | 0.99 | 3.05 | 1.27 | 1.29 |
| | Boot - t | **3.33** | 4.83 | 2.33 | 5.64 | 2.28 | 7.08 | 1.66 | 4.01 | 3.36 | 3.48 |
| Total catch | Trad. normal | **13.70** | NA | NA | NA | NA | NA | NA | NA | NA | NA |
| | B normal | **13.69** | 16.50 | 10.88 | 18.98 | 10.04 | 16.91 | 10.91 | 36.11 | 13.11 | 15.04 |
| | BC | **14.51** | 17.40 | 11.59 | 20.69 | 10.46 | 17.97 | 11.45 | 37.40 | 13.68 | 16.30 |
| | BCa | **14.57** | 17.48 | 11.57 | 20.73 | 10.47 | 18.51 | 11.47 | 37.38 | 14.38 | 16.25 |
| | Hybrid | **13.29** | 15.96 | 10.62 | 17.89 | 9.92 | 16.21 | 10.68 | 35.62 | 12.83 | 14.45 |
| | Percentile | **13.29** | 15.96 | 10.62 | 17.89 | 9.92 | 16.21 | 10.68 | 35.62 | 12.83 | 14.45 |
| | Boot - t | **35.40** | 50.80 | 24.39 | 58.58 | 24.57 | 74.12 | 18.09 | 47.32 | 33.93 | 40.49 |

Table 14.11 Age-length key for bream, Hervey Bay 1996

Age (yr)

| Length class | 2 | 3 | 4 | 5 | 6 | 7 | 8 | 9 | 10 | 11 | 12 | 13 | 14 | 15 | 16 | N |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| 20 | 1.9% | 27.8% | 14.8% | 25.9% | 14.8% | 11.1% | 0.0% | 3.7% | 0.0% | 0.0% | 0.0% | 0.0% | 0.0% | 0.0% | 0.0% | 27 |
| 21 | 5.4% | 18.9% | 16.2% | 25.3% | 9.8% | 6.1% | 10.8% | 7.4% | 0.0% | 0.0% | 0.0% | 0.0% | 0.0% | 0.0% | 0.0% | 74 |
| 22 | 1.0% | 24.0% | 23.6% | 15.4% | 12.2% | 10.9% | 5.8% | 5.3% | 1.9% | 0.0% | 0.0% | 0.0% | 0.0% | 0.0% | 0.0% | 52 |
| 23 | 1.3% | 11.5% | 12.8% | 23.7% | 15.4% | 17.9% | 2.6% | 7.7% | 5.8% | 0.0% | 0.6% | 0.6% | 0.0% | 0.0% | 0.0% | 39 |
| 24 | 1.7% | 5.8% | 5.8% | 10.0% | 15.0% | 24.2% | 24.2% | 5.0% | 8.3% | 0.0% | 0.0% | 0.0% | 0.0% | 0.0% | 0.0% | 30 |
| 25 | 0.0% | 3.7% | 13.0% | 12.0% | 13.0% | 9.3% | 18.5% | 13.9% | 10.2% | 1.9% | 4.6% | 0.0% | 0.0% | 0.0% | 0.0% | 27 |
| 26 | 0.0% | 0.0% | 0.0% | 0.0% | 2.8% | 8.3% | 27.8% | 33.3% | 5.6% | 0.0% | 5.6% | 0.0% | 5.6% | 8.3% | 2.8% | 9 |
| 27 | 0.0% | 0.0% | 0.0% | 9.6% | 26.9% | 1.9% | 17.3% | 26.9% | 9.6% | 0.0% | 1.9% | 1.9% | 1.9% | 0.0% | 1.9% | 13 |
| 28 | 0.0% | 0.0% | 0.0% | 0.0% | 0.0% | 5.0% | 15.0% | 20.0% | 26.7% | 33.3% | 0.0% | 0.0% | 0.0% | 0.0% | 0.0% | 5 |
| 29 | 0.0% | 0.0% | 0.0% | 0.0% | 0.0% | 6.3% | 43.8% | 25.0% | 12.5% | 12.5% | 0.0% | 0.0% | 0.0% | 0.0% | 0.0% | 4 |
| 30 | 0.0% | 0.0% | 0.0% | 0.0% | 0.0% | 12.5% | 37.5% | 0.0% | 0.0% | 0.0% | 0.0% | 12.5% | 25.0% | 12.5% | 0.0% | 2 |
| 31 | 0.0% | 0.0% | 0.0% | 16.7% | 0.0% | 16.7% | 0.0% | 0.0% | 0.0% | 33.3% | 8.3% | 16.7% | 8.3% | 0.0% | 0.0% | 3 |
| 32 | 0.0% | 0.0% | 0.0% | 0.0% | 0.0% | 100% | 0.0% | 0.0% | 0.0% | 0.0% | 0.0% | 0.0% | 0.0% | 0.0% | 0.0% | 1 |

Table 14.12 Age-length key for bream, Moreton Bay 1997

| | Age | | | | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| Length class | 1 | 2 | 3 | 4 | 5 | 6 | 7 | 8 | 9 | 10 | 11 | 12 | 13 | N |
| 19 | 5.00% | 20.00% | 20.00% | 20.00% | 17.50% | 10.00% | 7.50% | 0.00% | 0.00% | 0.00% | 0.00% | 0.00% | 0.00% | 20 |
| 20 | 1.38% | 25.86% | 22.76% | 33.79% | 10.00% | 5.52% | 0.34% | 0.00% | 0.34% | 0.00% | 0.00% | 0.00% | 0.00% | 145 |
| 21 | 0.60% | 11.98% | 24.55% | 28.14% | 16.47% | 11.98% | 5.39% | 0.60% | 0.30% | 0.00% | 0.00% | 0.00% | 0.00% | 167 |
| 22 | 0.00% | 6.58% | 13.16% | 42.11% | 17.54% | 13.16% | 4.82% | 1.75% | 0.88% | 0.00% | 0.00% | 0.00% | 0.00% | 114 |
| 23 | 0.00% | 4.65% | 15.12% | 23.26% | 25.58% | 20.93% | 5.81% | 3.49% | 0.58% | 0.58% | 0.00% | 0.00% | 0.00% | 86 |
| 24 | 0.00% | 0.00% | 6.43% | 25.71% | 26.43% | 13.57% | 15.00% | 5.71% | 5.00% | 0.71% | 1.43% | 0.00% | 0.00% | 70 |
| 25 | 0.00% | 0.00% | 0.00% | 29.63% | 31.48% | 11.11% | 13.89% | 11.11% | 0.93% | 0.93% | 0.93% | 0.00% | 0.00% | 54 |
| 26 | 0.00% | 0.00% | 2.86% | 11.43% | 28.57% | 18.57% | 21.43% | 14.29% | 0.00% | 2.86% | 0.00% | 0.00% | 0.00% | 35 |
| 27 | 0.00% | 0.00% | 0.00% | 15.38% | 38.46% | 11.54% | 19.23% | 7.69% | 7.69% | 0.00% | 0.00% | 0.00% | 0.00% | 13 |
| 28 | 0.00% | 0.00% | 2.94% | 8.82% | 17.65% | 8.82% | 29.41% | 8.82% | 20.59% | 2.94% | 0.00% | 0.00% | 0.00% | 17 |
| 29 | 0.00% | 0.00% | 0.00% | 0.00% | 31.25% | 31.25% | 12.50% | 12.50% | 0.00% | 0.00% | 12.50% | 0.00% | 0.00% | 8 |
| 30 | 0.00% | 0.00% | 25.00% | 0.00% | 50.00% | 0.00% | 0.00% | 25.00% | 0.00% | 0.00% | 0.00% | 0.00% | 0.00% | 4 |
| 31 | 0.00% | 0.00% | 0.00% | 0.00% | 33.33% | 0.00% | 33.33% | 0.00% | 0.00% | 0.00% | 0.00% | 33.33% | 0.00% | 3 |
| 32 | 0.00% | 0.00% | 0.00% | 0.00% | 0.00% | 0.00% | 0.00% | 0.00% | 0.00% | 0.00% | 0.00% | 0.00% | 100.0% | 1 |
| 33 | 0.00% | 0.00% | 0.00% | 0.00% | 0.00% | 0.00% | 0.00% | 0.00% | 25.00% | 25.00% | 0.00% | 0.00% | 50.00% | 2 |
| 34 | 0.00% | 0.00% | 0.00% | 0.00% | 0.00% | 0.00% | 0.00% | 0.00% | 0.00% | 0.00% | 0.00% | 0.00% | 0.00% | 0 |
| 35 | 0.00% | 0.00% | 0.00% | 0.00% | 0.00% | 0.00% | 0.00% | 0.00% | 0.00% | 0.00% | 0.00% | 0.00% | 0.00% | 0 |
| 36 | 0.00% | 0.00% | 0.00% | 0.00% | 0.00% | 0.00% | 0.00% | 0.00% | 100.0% | 0.00% | 0.00% | 0.00% | 0.00% | 1 |

Table 14.13 Age-length key for sand whiting, Moreton Bay 1997

| | Age | | | | | | | |
|---|---|---|---|---|---|---|---|---|
| Length class | 0 | 1 | 2 | 3 | 4 | 5 | 6 | N |
| 21 | 28.6% | 28.6% | 42.9% | 0.0% | 0.0% | 0.0% | 0.0% | 7 |
| 22 | 0.0% | 28.2% | 48.7% | 17.9% | 5.1% | 0.0% | 0.0% | 39 |
| 23 | 2.7% | 52.7% | 30.4% | 10.1% | 4.1% | 0.0% | 0.0% | 74 |
| 24 | 1.1% | 38.9% | 36.1% | 20.4% | 3.6% | 0.0% | 0.0% | 140 |
| 25 | 0.5% | 30.5% | 41.0% | 21.0% | 6.5% | 0.5% | 0.0% | 100 |
| 26 | 0.0% | 20.1% | 39.6% | 29.9% | 9.7% | 0.7% | 0.0% | 67 |
| 27 | 0.0% | 14.6% | 29.2% | 39.6% | 16.7% | 0.0% | 0.0% | 24 |
| 28 | 0.0% | 5.0% | 25.0% | 40.0% | 20.0% | 10.0% | 0.0% | 10 |
| 29 | 0.0% | 0.0% | 10.0% | 50.0% | 20.0% | 15.0% | 5.0% | 10 |
| Grand Total | 1.27% | 32.80% | 36.73% | 21.76% | 6.58% | 0.74% | 0.11% | 471 |

Table 14.14 Age-length key for golden-lined whiting, Hervey Bay 1996

| | Age | | | | | |
|---|---|---|---|---|---|---|
| Length class | 1 | 2 | 3 | 4 | 5 | N |
| 20 | 36.4% | 45.5% | 18.2% | 0.0% | 0.0% | 11 |
| 21 | 19.2% | 49.0% | 30.8% | 0.0% | 1.0% | 26 |
| 22 | 20.2% | 39.3% | 25.0% | 15.5% | 0.0% | 21 |
| 23 | 7.5% | 47.5% | 33.8% | 3.8% | 7.5% | 20 |
| 24 | 0.0% | 57.1% | 32.1% | 10.7% | 0.0% | 21 |
| 25 | 0.0% | 51.7% | 48.3% | 0.0% | 0.0% | 15 |
| 26 | 0.0% | 75.0% | 5.0% | 20.0% | 0.0% | 5 |
| Grand Total | 12.39% | 49.58% | 30.46% | 6.09% | 1.47% | 119 |

Table 14.15 Age-length key for dusky flathead, Moreton Bay 1996 females

| | Age | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|
| Length class | 0 | 1 | 2 | 3 | 4 | 5 | 6 | 7 | N |
| 30 | 22.2% | 77.8% | 0.0% | 0.0% | 0.0% | 0.0% | 0.0% | 0.0% | 5 |
| 32 | 46.6% | 52.6% | 0.8% | 0.0% | 0.0% | 0.0% | 0.0% | 0.0% | 14 |
| 34 | 41.1% | 50.0% | 0.0% | 8.9% | 0.0% | 0.0% | 0.0% | 0.0% | 5 |
| 36 | 5.6% | 80.2% | 8.6% | 5.6% | 0.0% | 0.0% | 0.0% | 0.0% | 18 |
| 38 | 0.0% | 46.1% | 43.7% | 1.1% | 9.1% | 0.0% | 0.0% | 0.0% | 11 |
| 40 | 0.0% | 70.1% | 29.9% | 0.0% | 0.0% | 0.0% | 0.0% | 0.0% | 15 |
| 42 | 0.0% | 35.9% | 57.3% | 5.0% | 1.8% | 0.0% | 0.0% | 0.0% | 14 |
| 44 | 0.7% | 47.7% | 31.8% | 12.3% | 7.4% | 0.0% | 0.0% | 0.0% | 15 |
| 46 | 0.0% | 16.2% | 67.4% | 13.8% | 2.6% | 0.0% | 0.0% | 0.0% | 13 |
| 48 | 0.0% | 7.6% | 32.9% | 53.0% | 6.5% | 0.0% | 0.0% | 0.0% | 19 |
| 50 | 0.0% | 8.3% | 15.7% | 64.5% | 10.5% | 0.9% | 0.0% | 0.0% | 12 |
| 52 | 0.0% | 1.4% | 46.9% | 38.3% | 13.3% | 0.0% | 0.0% | 0.0% | 23 |
| 54 | 0.0% | 2.1% | 18.0% | 36.5% | 42.7% | 0.7% | 0.0% | 0.0% | 16 |
| 56 | 0.0% | 0.0% | 38.9% | 40.7% | 13.0% | 7.4% | 0.0% | 0.0% | 6 |
| 58 | 0.0% | 0.0% | 0.0% | 40.2% | 42.6% | 17.2% | 0.0% | 0.0% | 13 |
| 60 | 0.0% | 0.0% | 0.0% | 62.5% | 37.5% | 0.0% | 0.0% | 0.0% | 3 |
| 62 | 0.0% | 0.0% | 0.0% | 0.0% | 88.9% | 11.1% | 0.0% | 0.0% | 1 |
| 64 | 0.0% | 0.0% | 0.0% | 40.0% | 0.0% | 40.0% | 20.0% | 0.0% | 5 |
| 66 | 0.0% | 0.0% | 0.0% | 48.1% | 48.1% | 3.7% | 0.0% | 0.0% | 3 |
| 70 | 0.0% | 0.0% | 0.0% | 0.0% | 33.3% | 51.9% | 11.1% | 3.7% | 3 |
| 72 | 0.0% | 0.0% | 0.0% | 0.0% | 0.0% | 55.6% | 44.4% | 0.0% | 1 |
| Grand Total | 5.03% | 28.46% | 26.35% | 23.88% | 12.03% | 3.37% | 0.83% | 0.05% | 215 |

Table 14.16 Age-length key for dusky flathead, Moreton Bay 1997 unknown sex

| | Age | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|
| Length class | 0 | 1 | 2 | 3 | 4 | 5 | 6 | 7 | 8 | N |
| 28 | 0.0% | 66.7% | 33.3% | 0.0% | 0.0% | 0.0% | 0.0% | 0.0% | 0.0% | 3 |
| 30 | 33.3% | 66.7% | 0.0% | 0.0% | 0.0% | 0.0% | 0.0% | 0.0% | 0.0% | 3 |
| 32 | 0.0% | 50.0% | 50.0% | 0.0% | 0.0% | 0.0% | 0.0% | 0.0% | 0.0% | 3 |
| 34 | 20.0% | 0.0% | 40.0% | 40.0% | 0.0% | 0.0% | 0.0% | 0.0% | 0.0% | 5 |
| 36 | 50.0% | 0.0% | 50.0% | 0.0% | 0.0% | 0.0% | 0.0% | 0.0% | 0.0% | 2 |
| 38 | 0.0% | 0.0% | 50.0% | 50.0% | 0.0% | 0.0% | 0.0% | 0.0% | 0.0% | 2 |
| 40 | 0.0% | 0.0% | 75.0% | 25.0% | 0.0% | 0.0% | 0.0% | 0.0% | 0.0% | 4 |
| 44 | 0.0% | 0.0% | 12.5% | 75.0% | 12.5% | 0.0% | 0.0% | 0.0% | 0.0% | 4 |
| 46 | 0.0% | 0.0% | 66.7% | 16.7% | 16.7% | 0.0% | 0.0% | 0.0% | 0.0% | 3 |
| 48 | 0.0% | 0.0% | 100.0% | 0.0% | 0.0% | 0.0% | 0.0% | 0.0% | 0.0% | 2 |
| 50 | 0.0% | 0.0% | 0.0% | 100.0% | 0.0% | 0.0% | 0.0% | 0.0% | 0.0% | 1 |
| 52 | 0.0% | 0.0% | 33.3% | 0.0% | 33.3% | 16.7% | 16.7% | 0.0% | 0.0% | 3 |
| 56 | 0.0% | 0.0% | 0.0% | 0.0% | 0.0% | 25.0% | 50.0% | 25.0% | 0.0% | 2 |
| 60 | 0.0% | 0.0% | 0.0% | 0.0% | 0.0% | 0.0% | 0.0% | 50.0% | 50.0% | 1 |
| 62 | 0.0% | 0.0% | 0.0% | 0.0% | 50.0% | 50.0% | 0.0% | 0.0% | 0.0% | 2 |
| 66 | 0.0% | 0.0% | 0.0% | 0.0% | 0.0% | 100.0% | 0.0% | 0.0% | 0.0% | 1 |
| 68 | 0.0% | 0.0% | 0.0% | 0.0% | 0.0% | 100.0% | 0.0% | 0.0% | 0.0% | 1 |
| 84 | 0.0% | 0.0% | 0.0% | 0.0% | 0.0% | 0.0% | 50.0% | 0.0% | 50.0% | 1 |
| Grand Total | 6.98% | 12.79% | 34.88% | 19.77% | 6.98% | 9.30% | 4.65% | 2.33% | 2.33% | 43 |

Table 14.17 Age-length key for dusky flathead, Moreton Bay 1997 males

| | Age | | | | | | | |
|---|---|---|---|---|---|---|---|---|
| Length class | 0 | 1 | 2 | 3 | 4 | 5 | 6 | N |
| 28 | 0.0% | 100.0% | 0.0% | 0.0% | 0.0% | 0.0% | 0.0% | 3 |
| 30 | 11.5% | 76.9% | 11.5% | 0.0% | 0.0% | 0.0% | 0.0% | 13 |
| 32 | 6.5% | 52.2% | 30.4% | 10.9% | 0.0% | 0.0% | 0.0% | 23 |
| 34 | 3.4% | 24.1% | 60.3% | 12.1% | 0.0% | 0.0% | 0.0% | 29 |
| 36 | 0.0% | 25.0% | 62.5% | 12.5% | 0.0% | 0.0% | 0.0% | 20 |
| 38 | 6.3% | 18.8% | 33.3% | 37.5% | 4.2% | 0.0% | 0.0% | 24 |
| 40 | 0.0% | 26.9% | 19.2% | 46.2% | 7.7% | 0.0% | 0.0% | 13 |
| 42 | 0.0% | 0.0% | 26.9% | 65.4% | 7.7% | 0.0% | 0.0% | 13 |
| 44 | 0.0% | 25.0% | 0.0% | 75.0% | 0.0% | 0.0% | 0.0% | 4 |
| 46 | 0.0% | 0.0% | 25.0% | 75.0% | 0.0% | 0.0% | 0.0% | 2 |
| 48 | 0.0% | 0.0% | 33.3% | 33.3% | 33.3% | 0.0% | 0.0% | 3 |
| 50 | 0.0% | 0.0% | 16.7% | 83.3% | 0.0% | 0.0% | 0.0% | 3 |
| 60 | 0.0% | 0.0% | 0.0% | 0.0% | 0.0% | 50.0% | 50.0% | 1 |
| Grand Total | 3.64% | 30.46% | 36.09% | 26.49% | 2.65% | 0.33% | 0.33% | 151 |

Table 14.18 Age-length key for dusky flathead, Moreton Bay 1997 females

| | Age | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|
| Length class | 0 | 1 | 2 | 3 | 4 | 5 | 6 | 7 | 8 | 9 | N |
| 28 | 0.0% | 100.0% | 0.0% | 0.0% | 0.0% | 0.0% | 0.0% | 0.0% | 0.0% | 0.0% | 1 |
| 30 | 23.1% | 65.4% | 11.5% | 0.0% | 0.0% | 0.0% | 0.0% | 0.0% | 0.0% | 0.0% | 13 |
| 32 | 16.1% | 58.9% | 23.2% | 1.8% | 0.0% | 0.0% | 0.0% | 0.0% | 0.0% | 0.0% | 28 |
| 34 | 8.9% | 39.3% | 35.7% | 16.1% | 0.0% | 0.0% | 0.0% | 0.0% | 0.0% | 0.0% | 28 |
| 36 | 0.0% | 40.8% | 52.6% | 6.6% | 0.0% | 0.0% | 0.0% | 0.0% | 0.0% | 0.0% | 38 |
| 38 | 2.6% | 17.9% | 57.7% | 21.8% | 0.0% | 0.0% | 0.0% | 0.0% | 0.0% | 0.0% | 39 |
| 40 | 0.0% | 15.2% | 44.6% | 40.2% | 0.0% | 0.0% | 0.0% | 0.0% | 0.0% | 0.0% | 46 |
| 42 | 0.0% | 15.4% | 48.5% | 30.8% | 3.1% | 1.5% | 0.8% | 0.0% | 0.0% | 0.0% | 65 |
| 44 | 0.0% | 7.8% | 51.0% | 33.3% | 7.8% | 0.0% | 0.0% | 0.0% | 0.0% | 0.0% | 51 |
| 46 | 0.0% | 11.6% | 47.3% | 33.9% | 5.4% | 1.8% | 0.0% | 0.0% | 0.0% | 0.0% | 56 |
| 48 | 0.0% | 0.0% | 33.3% | 55.0% | 11.7% | 0.0% | 0.0% | 0.0% | 0.0% | 0.0% | 30 |
| 50 | 0.0% | 7.6% | 37.9% | 42.4% | 7.6% | 4.5% | 0.0% | 0.0% | 0.0% | 0.0% | 33 |
| 52 | 0.0% | 4.5% | 20.5% | 47.7% | 20.5% | 2.3% | 4.5% | 0.0% | 0.0% | 0.0% | 22 |
| 54 | 0.0% | 0.0% | 27.5% | 57.5% | 10.0% | 0.0% | 5.0% | 0.0% | 0.0% | 0.0% | 20 |
| 56 | 0.0% | 0.0% | 13.6% | 54.5% | 22.7% | 9.1% | 0.0% | 0.0% | 0.0% | 0.0% | 11 |
| 58 | 0.0% | 0.0% | 15.0% | 35.0% | 30.0% | 10.0% | 10.0% | 0.0% | 0.0% | 0.0% | 10 |
| 60 | 0.0% | 0.0% | 0.0% | 11.1% | 55.6% | 22.2% | 11.1% | 0.0% | 0.0% | 0.0% | 9 |
| 62 | 0.0% | 0.0% | 0.0% | 30.0% | 10.0% | 60.0% | 0.0% | 0.0% | 0.0% | 0.0% | 5 |
| 64 | 0.0% | 0.0% | 0.0% | 7.1% | 35.7% | 28.6% | 7.1% | 21.4% | 0.0% | 0.0% | 7 |
| 66 | 0.0% | 0.0% | 0.0% | 30.0% | 10.0% | 50.0% | 10.0% | 0.0% | 0.0% | 0.0% | 5 |
| 68 | 0.0% | 0.0% | 0.0% | 12.5% | 37.5% | 25.0% | 25.0% | 0.0% | 0.0% | 0.0% | 4 |
| 70 | 0.0% | 0.0% | 0.0% | 0.0% | 0.0% | 75.0% | 0.0% | 25.0% | 0.0% | 0.0% | 2 |
| 72 | 0.0% | 0.0% | 0.0% | 0.0% | 0.0% | 33.3% | 0.0% | 0.0% | 33.3% | 33.3% | 3 |
| 80 | 0.0% | 0.0% | 0.0% | 0.0% | 75.0% | 25.0% | 0.0% | 0.0% | 0.0% | 0.0% | 2 |
| 82 | 0.0% | 0.0% | 0.0% | 0.0% | 0.0% | 0.0% | 0.0% | 50.0% | 50.0% | 0.0% | 1 |
| Grand Total | 2.08% | 17.11% | 37.90% | 29.77% | 7.28% | 3.69% | 1.23% | 0.47% | 0.28% | 0.19% | 529 |

Table 14.19 Age-length key for tailor, by year, both sexes combined. The null hypothesis that males and females have the same distribution of age at length was not rejected for any of the three years of the study (1995: $\chi^2 = 54.49$, df = 52, p = 0.380; 1996: $\chi^2 = 46.11$, df = 44, p = 0.385; $\chi^2 = 76.20$, df = 72, p = 0.345).

| | | Age class | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|
| | Length class | 0 | 1 | 2 | 3 | 4 | 5 | 6 | N |
| 1995 | 26 | 42.4% | 57.6% | 0.0% | 0.0% | 0.0% | 0.0% | 0.0% | 11 |
| | 28 | 4.5% | 89.8% | 5.7% | 0.0% | 0.0% | 0.0% | 0.0% | 54 |
| | 30 | 0.5% | 89.0% | 10.4% | 0.0% | 0.0% | 0.0% | 0.0% | 95 |
| | 32 | 1.1% | 84.3% | 14.4% | 0.3% | 0.0% | 0.0% | 0.0% | 95 |
| | 34 | 0.0% | 67.3% | 29.9% | 2.1% | 0.7% | 0.0% | 0.0% | 70 |
| | 36 | 0.0% | 45.1% | 51.6% | 3.3% | 0.0% | 0.0% | 0.0% | 66 |
| | 38 | 0.0% | 27.1% | 72.1% | 0.8% | 0.0% | 0.0% | 0.0% | 66 |
| | 40 | 0.0% | 14.0% | 83.1% | 3.0% | 0.0% | 0.0% | 0.0% | 62 |
| | 42 | 0.0% | 8.3% | 88.3% | 3.3% | 0.0% | 0.0% | 0.0% | 30 |
| | 44 | 0.0% | 2.4% | 90.5% | 7.1% | 0.0% | 0.0% | 0.0% | 14 |
| | 46 | 0.0% | 0.0% | 69.7% | 30.3% | 0.0% | 0.0% | 0.0% | 11 |
| 1996 | 26 | 12.0% | 83.7% | 4.3% | 0.0% | 0.0% | 0.0% | 0.0% | 23 |
| | 28 | 6.4% | 86.5% | 7.1% | 0.0% | 0.0% | 0.0% | 0.0% | 73 |
| | 30 | 2.4% | 90.6% | 7.1% | 0.0% | 0.0% | 0.0% | 0.0% | 85 |
| | 32 | 0.0% | 89.8% | 10.2% | 0.0% | 0.0% | 0.0% | 0.0% | 54 |
| | 34 | 0.0% | 70.3% | 27.3% | 2.3% | 0.0% | 0.0% | 0.0% | 64 |
| | 36 | 0.0% | 42.4% | 52.9% | 4.7% | 0.0% | 0.0% | 0.0% | 43 |
| | 38 | 0.0% | 26.8% | 67.9% | 5.4% | 0.0% | 0.0% | 0.0% | 28 |
| | 40 | 0.0% | 26.5% | 72.4% | 1.2% | 0.0% | 0.0% | 0.0% | 17 |
| | 42 | 0.0% | 4.5% | 86.4% | 9.1% | 0.0% | 0.0% | 0.0% | 11 |
| 1997 | 26 | 30.7% | 65.8% | 3.5% | 0.0% | 0.0% | 0.0% | 0.0% | 57 |
| | 28 | 6.8% | 84.5% | 7.5% | 0.8% | 0.0% | 0.5% | 0.0% | 200 |
| | 30 | 2.5% | 83.5% | 12.7% | 1.3% | 0.0% | 0.0% | 0.0% | 375 |
| | 32 | 1.4% | 78.9% | 17.7% | 1.8% | 0.2% | 0.0% | 0.0% | 421 |
| | 34 | 0.3% | 59.8% | 39.2% | 0.7% | 0.0% | 0.0% | 0.0% | 371 |
| | 36 | 0.0% | 40.9% | 55.0% | 3.9% | 0.2% | 0.0% | 0.0% | 219 |
| | 38 | 0.0% | 30.3% | 63.4% | 5.9% | 0.4% | 0.0% | 0.0% | 119 |
| | 40 | 0.0% | 12.4% | 80.5% | 6.2% | 0.5% | 0.5% | 0.0% | 105 |
| | 42 | 0.0% | 3.4% | 88.1% | 8.5% | 0.0% | 0.0% | 0.0% | 59 |
| | 44 | 0.0% | 1.6% | 87.5% | 10.9% | 0.0% | 0.0% | 0.0% | 32 |
| | 46 | 0.0% | 0.0% | 76.9% | 15.4% | 7.7% | 0.0% | 0.0% | 13 |

## 14.4 Appendix 4: Figures

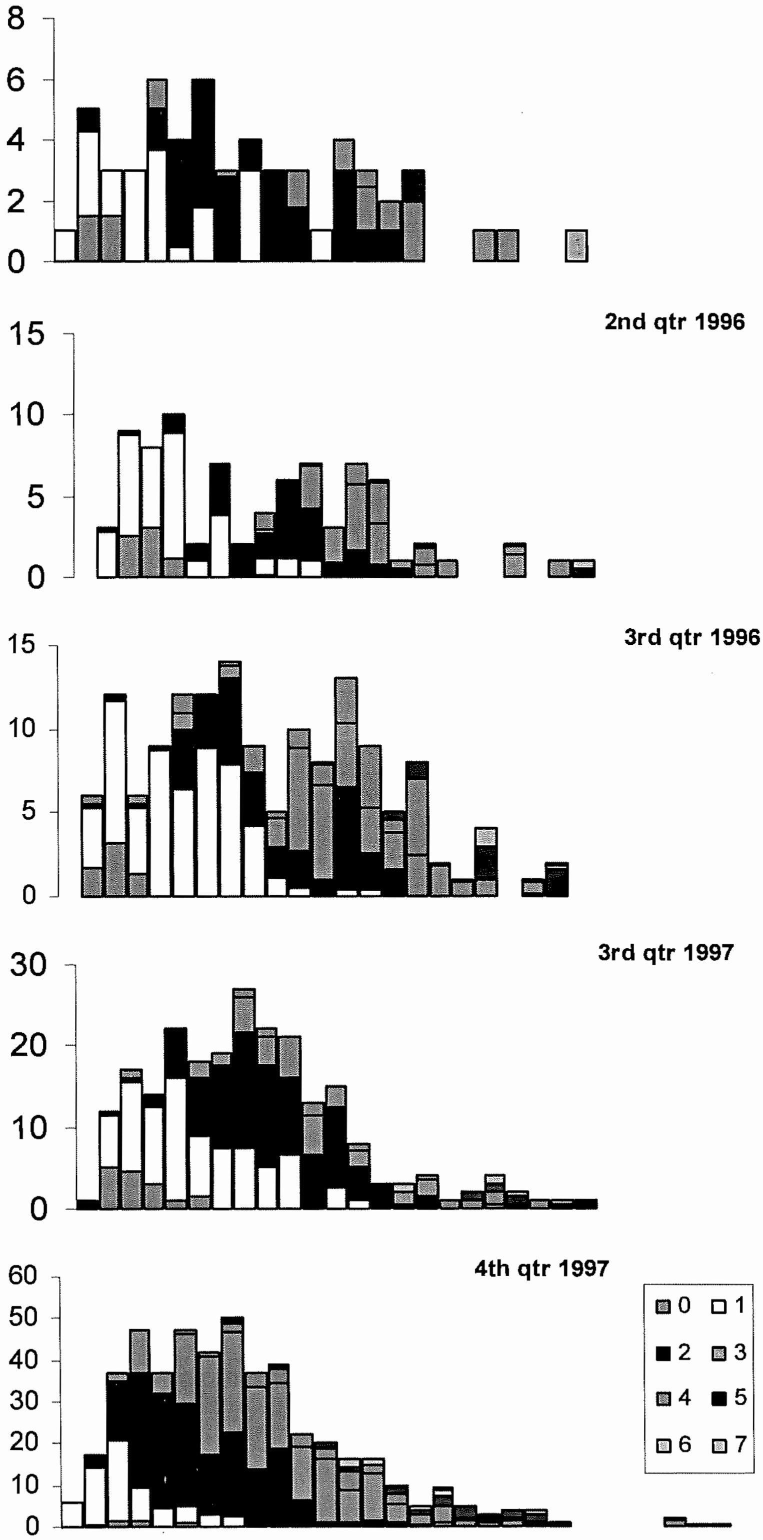



Figure 14.1 Seasonal change in length and age-frequency of dusky flathead sampled from Moreton Bay.

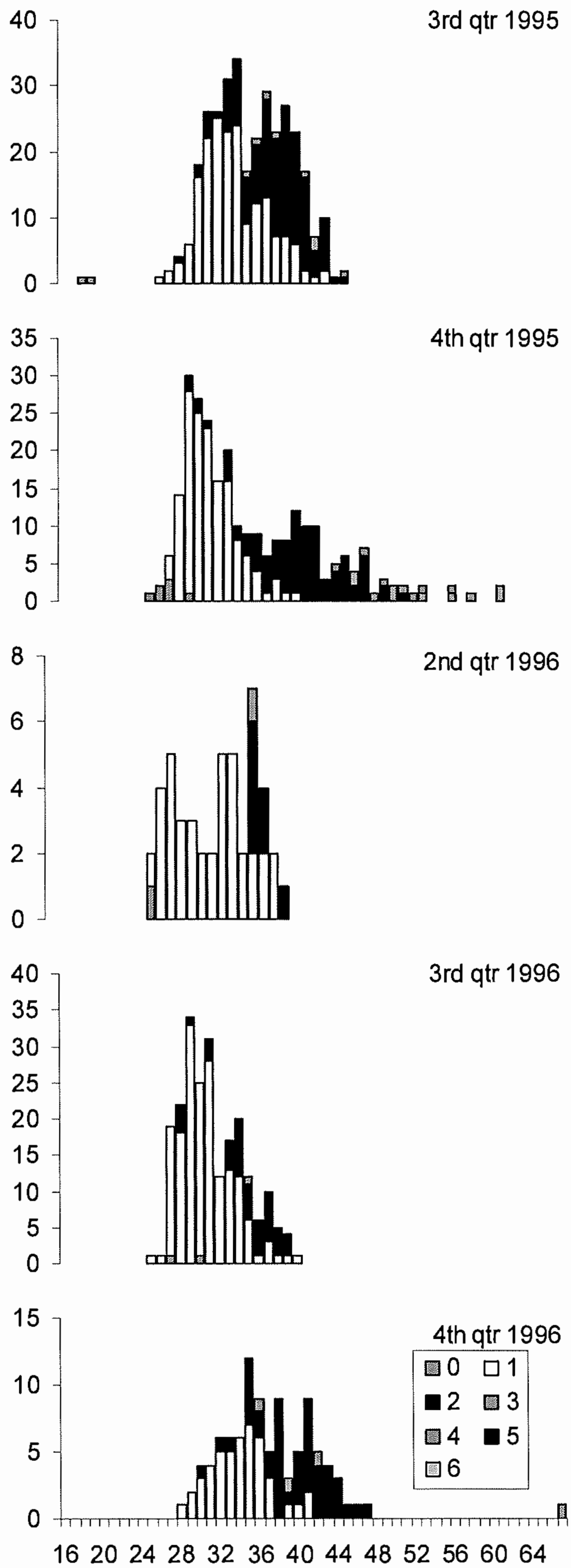



Figure 14.2. Seasonal change in length and age frequency of tailor sampled from recreational and commercial fisheries – 1995 to 1996.

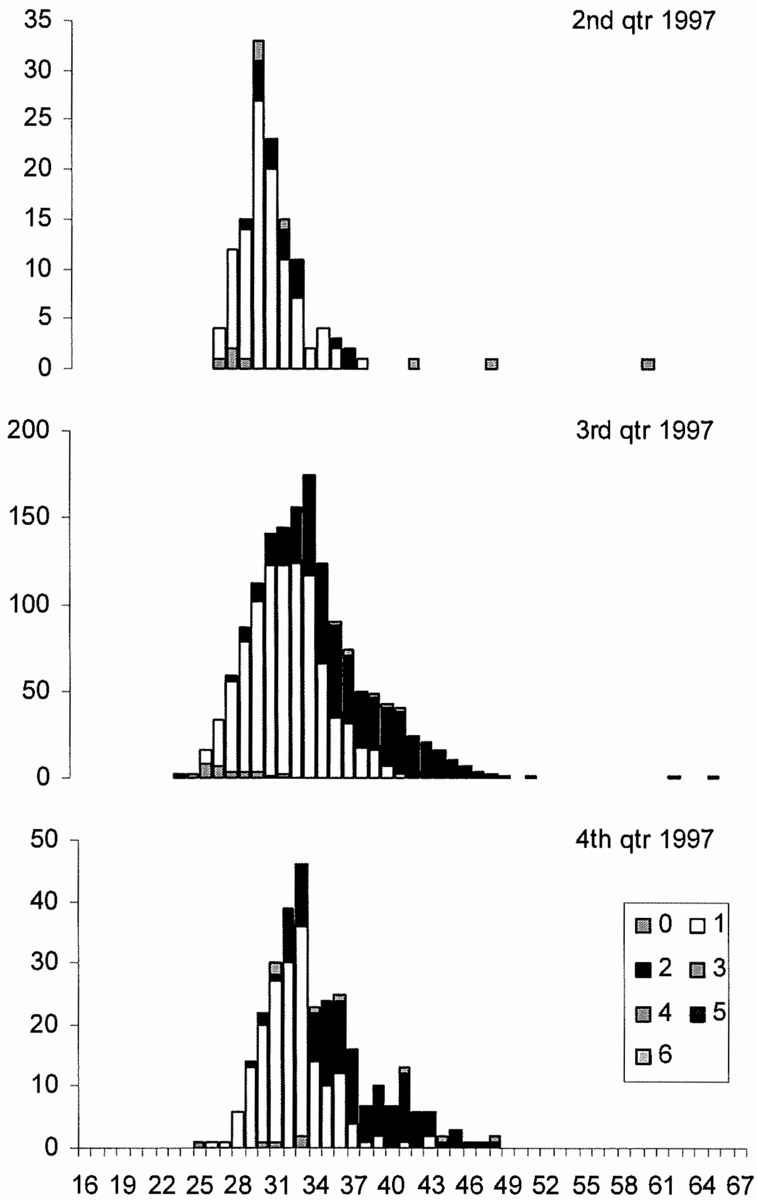



Figure 14.3 Seasonal change in length and age frequency of tailor sampled from recreational and commercial fisheries - 1997.

## 14.5 Appendix 5: SAS macro code for bootstrap confidence intervals

```
* Simulate bootstrapping recreational survey to check confidence intervals;
* by Simon Hoyle;

options nonotes;
options errors=0;
proc printto log='c:\bootstrap\size100.log';
run;

* Insert bootstrapping macro, obtained from SAS Institute;
%include 'c:\bootstrap\jackboot.sas';

* Set up work library
libname trial 'c:\bootstrap';

* Set options to minimise output for long run;
options nonotes;
proc printto log='c:\bootstrap\trial.txt';

* To aid debugging turn on the following settings;
* options notes source symbolgen mprint;

* Initialise the data-append dataset;
data trial.trial1;
input NAME $ VALUE ALCL AUCL CONFID METHOD $20. N STUDNAME $ _LO _UP _Z0
_ACCEL;
cards;
run;

* Iterate the simulation process 'loops' number of times;
%macro ranloop (loops);
        %do loop=1 %to &loops;
                * Each loop generates input data;
                * Expected value of catch is 0.8017687;
                data catch;
                stboats=10;                        * standard number of boats;
                brse=15;
                rse=brse+(2*normal(-5));           * relative standard error;
                boats=stboats+(stboats*rse/100)*normal(-1234);
                do i=1 to 100;  * generate 100 individual catches;
                        catch1=rantbl(0, 0.889592124, 0.035161744, 0.017229255,
        0.013361463, 0.007383966, 0.004571027, 0.003867792, 0.002109705, 0.003164557,
0.002461322, 0.000703235, 0.001758087, 0.000351617,  0.001054852, 0.001054852,
0.00140647, 0.001054852, 0.001758087, 0.001054852, 0.000703235, 0.001054852,
0.000703235, 0.00140647, 0.000351617, 0.000351617, 0, 0, 0, 0.001054852, 0,
0.000351617, 0.000351617, 0, 0.000351617, 0, 0, 0.000351617, 0.000703235, 0, 0, 0,
0, 0, 0.000351617, 0.000351617, 0.000351617, 0, 0, 0, 0, 0.000703235, 0, 0, 0, 0, 0,
0, 0, 0, 0, 0, 0, 0, 0, 0, 0.000351617, 0, 0, 0, 0, 0, 0, 0, 0, 0, 0, 0, 0, 0, 0, 0,
0, 0, 0, 0.000351617, 0, 0, 0, 0, 0, 0, 0, 0, 0, 0, 0.000351617, 0, 0, 0, 0, 0,
0, 0, 0, 0, 0, 0, 0, 0, 0, 0, 0, 0, 0, 0, 0, 0, 0, 0, 0, 0.000351617);
```

```
			catch=catch1 - 1;
			drop i;
			output;
			end;
		run;
```

* The 'analyze' macro is used by jackboot to deliver the parameters of interest. In this case they are the variables mcatch and mtcatch and their standard errors cstderr and tstderr;

```
		%macro analyze(data=,out=);
			proc means noprint data=&data;
		output out=&out (drop=_freq_ _type_)
			mean(catch boats rse)= mcatch mboats mrse stderr(catch)=cstderr;
			var catch boats rse;
			%bystmt;
			run;

			data &out;
			set &out;
			%if _sample_ ne &by
				%then
					%str(effort=mboats;);
				%else
					%str(effort=mboats+(mboats*mrse/100)*normal(-1234););
			mtcatch=mcatch*effort;
			tstderr=cstderr*effort;
			drop effort;
			run;
			%mend;

		title3 'Bootstrap Analysis';
		%boot(data=catch, samples=4000, random=-123, size=100, stat=mtcatch mcatch,
			alpha=0.10, print=0, chart=0);

		%allci(stat=mtcatch mcatch, student=tstderr cstderr, alpha=0.10, print=0);

		* the results are appended to a dataset
		proc append base=trial.trial1 new=allci force; run;

		%end;
	%mend;
%ranloop(4000)
```