AGE-STRUCTURE, GROWTH AND REPRODUCTION OF STOUT WHITING *Sillago robusta* AND JAPANESE MARKET TRIALS

Adam Butcher and Dr. Ian Brown

DPI QUEENSLAND DEPARTMENT OF PRIMARY INDUSTRIES

FISHERIES RESEARCH & DEVELOPMENT CORPORATION

QFMA Queensland Fisheries Management Authority

Final report to the Fisheries Research and Development Corporation

and

the Queensland Fish Management Authority

AGE-STRUCTURE, GROWTH AND REPRODUCTION OF STOUT WHITING *Sillago robusta* AND JAPANESE MARKET TRIALS

FRDC 92/101

Adam Butcher and Dr. Ian Brown

November 1995

Fisheries Services

Queensland Department of Primary Industries

Contents

PROJECT INFORMATION [FRDC No 92/101]

Project Title: Age structure, growth and reproduction of stout whiting, *Sillago robusta,* and Japanese market trials.

Research Organisation: Natural Resource Management
Queensland Department of Primary Industries
GPO Box 2454
BRISBANE QLD 4001
Telephone (07) 3817 9580 Fax (07) 3817 9555

Principal Investigator: Dr. Ian W. Brown
Senior Fisheries Biologist

Project Leader: Adam Butcher
Fisheries Biologist

Project Staff: Dr. David Die, Dr. Juan-Pablo Pertierra
Mr. Wayne Hagedoorn, Ms. Kate Yeomans,
Mr. John Mclaughlin-Karr, Mr. David Trama,
Mr. Peter Pardoe

Duration of Project: 1992 - 1995

Cooperating Agencies: Fisheries Research and Development Corporation
Queensland Fish Management Authority
Queensland Finfishers Association

OBJECTIVES

The specific objectives of this project were:

a) To describe basic biological parameters necessary for effective management of a trawl fishery for stout whiting.

b) To examine alternative strategies to market stout whiting in Japanese supermarkets.

During 1993, the opportunity arose to expand the second objective and examine test marketing of stout whiting on the domestic market as well, in conjunction with an FR&DC funded project into market trials of school whiting, *Sillago bassensis flindersii.*

EXECUTIVE SUMMARY

Stout whiting, *Sillago robusta*, is one of the most abundant harvestable finfish species in south-east Queensland waters. However, over the past 10 years the fishery for this resource has been irregular. During the 1980's access to the fishery remained effectively unlimited and annual landings increased. In 1991, the Queensland Fish Management Authority set up a limited entry developmental finfish trawl fishery with 6 endorsements. They established a pilot research program to examine the history of the fishery, catch and effort, bycatch considerations and the basic biological parameters of the target species. The results from the pilot project gave an indication of age composition of the fished stock, but more data on age structure, distribution and catchability were required to follow changes in age structure and stock abundance during the development of the fishery. In 1992 The Fishing Research and Development Corporation funded a 3 year project to estimate the biological parameters necessary for effective management of the stout whiting trawl fishery and to examine alternative strategies to market them in Japan.

The commercial catch has been sampled during the past 4 years and additional data has been obtained from a stratified research sampling regime in waters off Double Island Point. Methods to estimate the age of stout whiting were developed by staff at the Southern Fisheries Centre (SFC) during 1992-93, after consultation with staff at the Central Ageing Facility, Queenscliff, Victoria. Reading whole otoliths was the most accurate technique. Fifty-one percent of all fish examined could not be confidently aged. Of the fish that were aged 32% had only one annual mark and 37% had none, indicating that the majority of the catch comprised young fish. The oldest fish observed had 4 annual marks on its otoliths. Stout whiting lay down a single annulus on the otolith every year in late winter, coinciding with the fall in sea surface temperature. Differences in age structure between male and female stout whiting were insignificant and the data from both sexes were combined to estimate the growth parameters. Stout whiting have von Bertalanffy growth parameters of; $L_\infty = 22.3$ cm and $k = 0.46$.

Between 1991 and 1994, the reproductive cycle of stout whiting was examined by monitoring the average gonosomatic index of a sample of females every month. Female stout whiting have a protracted spawning season with a peak in reproductive activity during the summer months. The overall sex ratio of males to females in stout whiting was found to be 1.19:1. The smallest reproductively mature female observed had a fork length of 12.1 cm, although the smallest size class at which 50% of the population were reproductively mature was 14.5 cm. As long as the average size of the commercial catch remains above this length, then the chance of recruitment overfishing can be diminished. Fecundity estimates range from less than 5,000 in a fish of 15.2 cm fork length to nearly 50,000 in a fish of 19.8 cm fork length with a linear relationship between fork length and estimated fecundity.

The catch and effort data from the past 4 years of study was modelled in a virtual population analysis to estimate the biomass of the stock. The model required the input of several seeded parameters and catch and effort data from the past 4 years. The seeded values were estimated using the best available methods, but, various assumptions associated with these methods are

not fully met by the stout whiting fishery. Fishing mortality was optimised from the initial seeded value during the analysis of each year's data.

In 1991 the total catch was about 526 tonnes. The average age was 2.3 years and the average length was 17.3 cm. The total area fished was 1086 nm^2. The biomass was estimated at about 1750 tonnes ± 553 tonnes (SD). By 1992, the commercial catch had increased to around 926 tonnes and a further 124 tonnes were caught as bycatch outside the season. Both average length and average age of the catch had declined to 2.2 years and 16.7 cm respectively. However, as the area fished had increased by around 40% to 1513 nm^2 and the estimate of mean biomass also increased to 3104 tonnes ± 886 tonnes. During 1993 there was a marginal increase in catch, effort and area fished. The catch was around 1002 tonnes with a further 198 tonnes taken as bycatch outside the fishery. The area fished increased to 1550 nm^2. The average age of the catch had declined to 1.9 years and the average length was only 16.3 cm. The estimated mean biomass for 1993 also declined to 2237 tonnes ± 629 (SD). In 1994 there was a significant increase in catch, effort and area fished. The catch was about 2414 tonnes, with a further 120 tonnes taken outside the fishery as bycatch. The area fished increased to 3613 nm^2. The average age and length of the catch increased from the 1993 results to 2.1 years and 16.7 cm respectively. The estimated biomass was estimated to be approximately 7240 tonnes ± 2257 (SD).

The overall conclusion from these results is that the fishery has been spatially expanding over the past 4 years. As such it is not possible to compare the yearly estimates of mortality and biomass derived by the model as they refer to sub-stocks from different areas. The 1994 results are most representative of the total fishery area to date. A yield per recruit analysis carried out on the 1994 data indicated that to obtain the maximum possible yield per recruit, the fishing effort would have to be increased by more than 100%. However, the remaining biomass corresponding to this level of yield would be less than 7% of the original virgin biomass - a situation that would probably lead to recruitment overfishing. The (conservative) $F_{0.1}$ harvesting strategy has indicated the need for a reduction of effort in 1995 by about 10% to achieve optimal fishing sustainable yields, if we assume that the original estimate of natural mortality is correct. However, there is considerable uncertainty surrounding our estimates of M, which can have a significant impact on optimal $F_{0.1}$.

Stout whiting are a large volume, low priced export commodity with negligible domestic market presence. Several south-east Asian countries also take a similar species of whiting and are able to glut overseas markets. The successful development of alternative export markets for the Australian product is necessary to stabilise demand. In 1992, negotiations with a marketing agent for Yokohama Reito P/L resulted in a trial shipment of frozen stout whiting being sent to Bangkok for processing into Kisu Hiraki, the Japanese style of butterfly fillet, and then test marketing directly into a Japanese supermarket retail group. The original trial delivered a 45.3% recovery of Kisu Hiraki which was of excellent quality. The processor indicated that for continued demand, a realistic price and continuity of supply of quality product would be the principal determinants. Follow-up orders were anticipated, but an oversupply on the Japanese domestic market in 1991-92 led to a glut in the market and further orders did not eventuate.

In late November, 1993, a processor in Western Australia indicated that whiting could be mechanically bulk filleted. Frozen samples were sent to this processor for test filleting into Kisu Hiraki and normal Australian style butterfly fillets, both bare and crumbed. His trials indicated that the filleting machine would be able to process up to 4 tonnes of whiting per day into the Australian style of butterfly fillet at a cost of around $7.50 per kg (wholesale returned to Brisbane) and that the resulting product was most suitable for crumbing. However, both of these Hiraki and Australian style fillets retained the spines from dorsal and ventral fins respectively, making the end product unsuitable for either the export or domestic fillet markets. Further trials with the mechanical filleting process were abandoned.

In early 1994, staff at the National Seafood Centre, in conjunction with a local wholesale/retail operator, were examining the domestic market for "Australian whiting", based on the redspot whiting, *Sillago bassensis flindersii.* This research was based on nonstructured consumer acceptance trials. Following negotiations, arrangements were made to send a sample of fresh chilled stout whiting for similar trials. The results indicated that stout whiting have a marketable shelf life of up to 6 days and were of better quality when kept as fillets rather than whole fish. This information was passed onto the fishers and they were encouraged to enter into commercial negotiations themselves. Unfortunately, the 1994 export market was one of the best experienced in the last 4 years and fishers were able to sell all of their product, in frozen form, to offshore processors at a better price than the domestic market could afford.

While the results of these marketing trials may not appear overly successful, the trials themselves have encouraged interest among the commercial fishers in marketing aspects of the fishery to the point where several of the fishers embarked on a fact finding tour of south-east Asian processing plants in late 1993. The success of this tour was cited by commercial operators as the major reason for the success of the 1994 season. One of the fishers has gone further during 1995 and is developing a specialised value-adding process on board his vessel. At this stage the process is still being developed, but, he anticipates a good return for his substantial financial investment. Value adding is deemed the best method of changing this fishery from a high volume low priced one into a medium volume higher priced fishery.

MANAGEMENT OPTIONS

1. Levels of effort in the fishery:
Over the past 4 years commercial activity within the stout whiting trawl fishery has covered nearly all trawlable grounds. The 1994 level of effort was some 3613 hours which translates into an estimated instantaneous fishing mortality rate of 0.23. Although there is strong evidence of substantial stocks of stout whiting both to the north and south of the existing fishery boundaries, opening these areas to the trawl whiting fleet at a level of effort similar to that in the currently-fished area could lead to significant interaction with the local trawl fisheries.

Virtual Population Analysis (VPA) provides an estimate of total population size, with an indication of exploitation and fishing mortality rates. The reliability of these estimates depends critically on the reliability of estimates of population parameters such as growth rates, natural mortality and terminal F (the rate of fishing mortality on the final age-class in the population). VPA's have been used in this study to estimate the optimum long-term level of fishing mortality (F) on the basis of a commonly-used fisheries management reference point $F_{0.1}$. This reference point corresponds to a fishing mortality beyond which increases in yield-per-recruit, relative to increases in fishing effort, are marginal.

If considered appropriate, fishing mortality could be changed (via manipulation of fishing effort) by extending or contracting the fishing season, by expanding or reducing the number of endorsed vessels, or by expanding or reducing the area available to the fishery. Expansion of the area available to commercial stout whiting trawling activity to the north and/or the south may create adverse interactions between the stout whiting fishers and participants in adjacent fisheries such as prawn trawling, scallop trawling and spanner crabbing. Such processes are better assessed on economic merit than by biological analysis. Our VPA suggests that the optimum yield-per-recruit would occur at a level of F corresponding to about 10% less that that estimated for the 1994 season. However, this estimate of optimal harvest is based on our current estimate of natural mortality (M) which is notoriously difficult to determine accurately in any exploited stock.

Option 1-increase effort
Increasing effort (and consequently F) would be a high-risk policy if our estimate of M is too high. If M is actually less than we currently think, then the exploitation rate is higher than appears from the analysis, and any further increase could potentially lead to recruitment overfishing.

Option 2-maintain effort at present levels
Maintaining current levels of fishing mortality by effort is a medium-risk policy. There is an even chance of M having been underestimated as overestimated. This option would probably not result in recruitment overfishing problems (unless M has been seriously under-estimated), but may preclude potential financial advantages of an increased harvest should M be seriously over-estimated.

Option 3-reduce effort
Reducing effort represents a low risk policy consistent with results of our VPA analysis. A 10% reduction in F would translate to a yield reduction of about 250 tonnes catch which implies an overall revenue loss of between $300,000 - $400,00 (Aust.). Any further decrease in fishing mortality could push the fishery below the point of economic viability. Given the past record of commercial participants for self regulation based on scientific advice of stock exploitation levels, a 10% reduction in effort from the 1994 level represents the most easily achieved and sustainable option.

2. **Extension to the collection of scientific data**
Current VPA techniques provide a relevant starting point for estimated population parameters and biological reference points. However, these techniques do not account for the effects of gear size-selectivity, targeting by commercial fishers, bycatch of stout whiting taken in adjacent trawl fisheries, stock migration or schooling behaviour of stout whiting. These factors will have to be addressed before biomass estimates can be considered reliable.

The continuation of current fishery-dependant research includes collecting monthly commercial catch for age-length and reproductive analysis. These collections, coupled with annual logbook data analysis, will enable further refinement of estimated population parameters and reference points. In addition, commercial fishers have identified stock migration and spawning frequency as areas of interest. A knowledge of spawning frequency will benefit possible future research using fishery-independent methods such as the egg production method of estimating surplus stock biomass. It can be examined by a detailed histological analysis allied with existing sampling regimes. The question of migration is important because of its influence on estimates of total mortality, (Z) and thus natural mortality, (M). Migration is more difficult to assess because stout whiting physiology is not conducive to standard migration assessment techniques such as tag-recapture methods.

Over the past 5 years, funding for research into stout whiting in southeast Queensland has been made available from the appropriate Federal corporation and State management bodies. This funding was based on a large scale research application. The State contribution was funded by the endorsement premiums from commercial participants. All commercial stout whiting endorsed fishers have given a verbal commitment to maintain their endorsements and management will continue to receive the endorsement premiums.

Option 1-Increase research funding
At this stage this option should be considered a medium to high risk policy. At present there does not appear to be a great need for long-term intensive research work in this fishery. Short-term future research plans are directly associated with existing commercial activity and any increase in research funding would not have a favourable cost benefit ratio. Long-term future research programs may require increased funding, but these should be reviewed during their development.

Option 2- maintain research funding

This option is a low risk strategy. Continuation of current fishery dependant research will be crucial in refining the population parameters such as age structure, natural and total mortality estimates and will address the question of spawning frequency. Feedback to commercial participants gives this research a direct application. Commercial participants have given verbal endorsement for the continuation of current research.

Option 3- decrease current funding
This is a medium to high risk policy. Current VPA techniques provide a relevant starting point for estimated population parameters and biological reference points. However, there is a risk in accepting these parameters and reference points without further refinement. All are sensitive to our estimates of M (which is difficult to estimate with so short a time series of data) and further research is necessary to increase the degree of confidence we can place in our estimates.

3. Protection of inshore waters < 20 fathom from commercial finfishing activity.
There is a strong inverse relationship between stout whiting size and depth. Inshore shallow waters (<20 fm) are stout whiting spawning and nursery areas. Commercial finfish trawling activity in these waters may have a detrimental effect on spawning and pre-recruit stocks.

Option 1-maintain current inshore boundary along the 20 fathom isobath
This is a low risk policy. It will preserve identified nursery areas from fish trawling activity while still allowing commercial finfishers to satisfy market demand for smaller sized fish (<45g) from existing commercial finfish grounds.

Option 2-decrease the current inshore boundary to waters shallower than 20 fathoms
This is a high risk policy as it will allow the fisher to access small fish below the identified size at which 50% of the stock will be sexually mature. Excessive fishing mortality on these stocks could lead to recruitment overfishing.

Option 3-Increase the current inshore boundary to waters greater than 20 fathoms
This is a medium risk policy. Current analysis indicates that the average size of the commercial catch is above that of the size at which 50% of the stock are sexually mature. If fishers are not able to access current stocks to satisfy the market demand for smaller sized fish (<45g) there is a real risk of market collapse and the subsequent conversion of effort by fishers into adjacent trawl fisheries. There is no identifiable need for this policy.

1. INTRODUCTION

Background

Trawl caught seafoods account for approximately 70% of the total annual value of seafood production in Queensland. The trawl catch comprises four main target categories; prawns, scallop, bugs and finfish, as well as several lesser bycatch categories; crabs, squid, lobsters etc. In 1994, the Queensland East Coast Trawl fishery (ECT) had 851 endorsee's. A further thirty-four concessional zone endorsements allowed several northern New South Wales (Tweed Coast) fishers to access southern Queensland waters below the northern tip of Fraser Island. The Queensland Fish Management Authority (QFMA) is actively pursuing long-term management strategies that will reduce the size and effort of this large ECT fleet with minimal deleterious economic impact on the current endorsee's. The QFMA's policies include a 2-for-1 replacement policy for new entrants into the ECT, a non-split policy for joint ECT - Northern Prawn Fishery (NPF) endorsed vessels and ECT - Commonwealth fishery endorsed vessels, and diversification of the ECT fleet into other fisheries. Contemporary management strategies support the development of new fisheries as the most practical way of diversifying the existing fleet.

Stout whiting, *Sillago robusta*, are one of the most abundant fish species occurring on trawl grounds between 23^0S and 30^0S. In the past, they have been taken both by prawn trawl fishermen (as marketable bycatch) and by fish trawlers targeting the species. However, the fishery for this resource has been irregular, with annual landings in Queensland varying between zero and 2700 tonnes during the past 10 years (Butcher, 1991). Variation in landings is closely linked to market conditions. They are a large volume, low priced marine commodity. In 1994 they accounted for approximately 30% of total Queensland trawl caught landings by weight, but only 5% by value (Lightowler, *pers. comm.*). Stout whiting are not marketed extensively in Australia; most of the catch is frozen (normally at sea) in 10 kg boxes and shipped to south-east Asian countries for further processing. Ultimately the end-product is sold in Japan. Given the complexities of this operation and the relatively low prices which fishermen can obtain for the unprocessed product, there is little room for market price variation before the fishery loses economic viability. Unfortunately for the local industry, south-east Asian fishing operations appear to take similar species of whiting, periodically glutting the Japanese market and depressing prices. When this occurs Australian fisheries cannot compete, and stop supplying their traditional market outlets. During the past decade, the fishery has been controlled by the fluctuating export market in Japan. The successful development of alternative export target markets and marketing strategies for the processed product is necessary to stabilise demand, provide participants with greater income security and allow participants to plan the future commercial development from a more secure economic base.

Technical Background to the Research Need

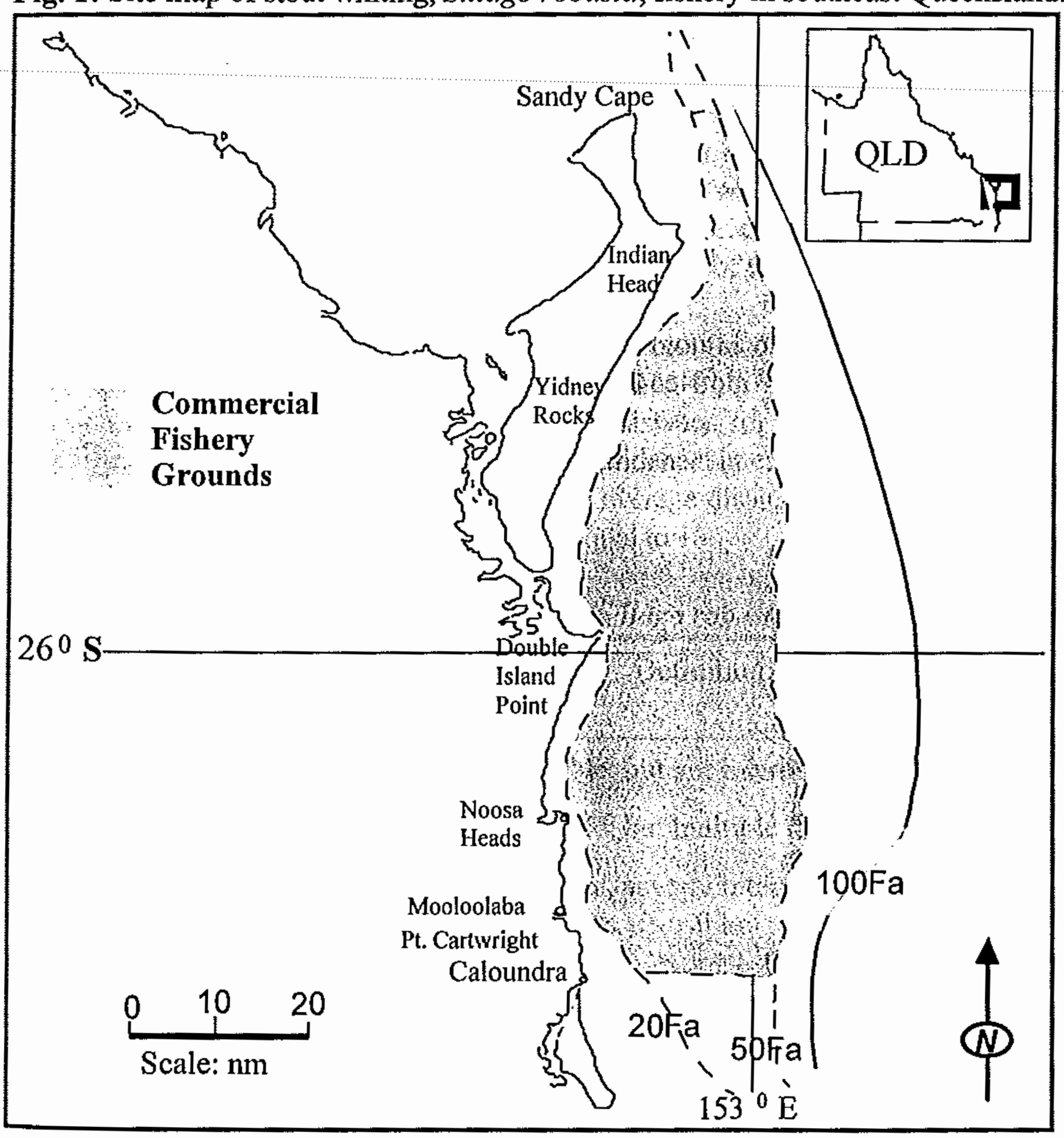
The targeting of whiting for the Japanese kisu market began in the very early 1980's. By mid 1984, there were up to 7 vessels supplying wholesalers with trawl caught whiting, but, few boats had the capacity or on-deck facilities to handle the volume of product adequately. Most landed their catch fresh and it was sorted on-shore before being frozen and sent to Japan. In the mid 1980's, cheaper south-east Asian product flooded the Japanese market and the south-east Queensland fishery, unable to compete, stopped supplying the Asian markets. The market revived in 1986, when a purpose built fish trawler began targeting stout whiting exclusively. Access to the fishery remained effectively unrestricted in the '80s and by 1990 11 vessels were targeting stout whiting. Annual landings increased from 200 tonnes in 1986 to 1700 tonnes in 1990. In February 1991, the Queensland Fish Management Authority, taking a conservative approach, gazetted the stout whiting fishery as a limited entry, developmental fishery and restricted the number of endorsements to six. These vessels were permitted to use sweeps to fish between Sandy Cape and Caloundra in depths between 20 and 50 fathoms during the finfish season of April 1st to December 31st. The Authority also instituted a pilot study to examine and document the fishery's history, catch and effort status, bycatch considerations and the basic biological parameters of the target species (Butcher 1991). In 1991 the Japanese market was again swamped by southeast Asian whiting. This coincided with a change in processing geography as Japanese wholesalers moved offshore to the cheaper southeast Asian labour markets in Thailand and China. The southeast Queensland market experienced its second recession in less than 10 years, but, as had previously occurred, the market revived within 18 months, in the latter half of 1992 (Butcher, 1992). Thus the prevailing situation in the early 1990's offered an almost unique opportunity to obtain age structure and abundance data on a relatively lightly-exploited stock. Hilborn and Walters (1992) have pointed out how valuable and important early age and stock abundance data is for future stock assessment, particularly in terms of obtaining estimates for natural mortality rates and virgin stock biomass. In the pilot study referred to above, indicative data on age composition of the fished stock was obtained. However, further data on age structure, distribution and catchability was required in order that changes in age composition and, if possible, stock abundance, could be followed during the development of the fishery and effective stock management can be implemented.

A principal concern in the maintenance of this fishery was the particularly sensitive export market. Japan has one of the highest consumption rates of fishery products, both in aggregate and per capita, of any country in the world (FAO, 1987) . The Japanese have traditionally included considerable quantities of fishery products in their diets as a result of productive seas surrounding Japan and the restricted availability of arable land (Kingston et *al.,* 1990, Chapman, 1990). As with any commodity, successful marketing requires the ability to differentiate the commodity from competitors. This can be achieved through significant price differentials (the usual method in Asian markets due to cheaper labour costs) or through a real or perceived differences in the product (quality, freshness, value-adding). Target marketing to better satisfy consumer needs is another way of increasing demand for Australian seafood. Discussions with representatives of a Japanese supermarket supplier, regarding the problems of the south-east Queensland whiting trawl fishery, identified the need for test marketing of processed stout whiting direct to a supermarket chain. Such a test marketing trial would identify consumer requirements, relay these requirements to industry and allow industry to respond with the establishment of a niche market for Queensland producers.

Study Area

The results presented in this report are derived from commercial and research samples caught in southeast Queensland waters between Sandy Cape (24^{0}42'S., 153^{0}16'E.), and Cape Moreton (27^{0}02'S., 153^{0}28'E.), in depths ranging from 8 - 50 fathoms (Fig. 1). Within this area, samples of stout whiting were collected from commercial finfish trawlers, at monthly intervals along with the location and time of fishing activity and total catch statistics. Most of these samples came from depths between 25 - 30 fm. These samples were collected between April and December of each fishing season. Further samples were collected between January and March, each year, from prawn trawlers to assist in the reproductive biology research. A bi-monthly stratified research survey was conducted in waters east of Yidney Rocks (25^{0}21'S., 153^{0}12'E), east of a point 7 miles south of Double Island Point (26^{0}09'S., 153^{0}07'E.) and east of Pt Cartwright (26^{0}41'S., 153^{0}08'E.) in depths of 10, 20 and 30 fathoms.

Fig. 1: Site map of stout whiting, *Sillago robusta*, fishery in southeast Queensland.



2. Age and Growth Estimates

Materials and Methods

Samples of *S. robusta* were collected from a fish trawl research survey carried out in 1993-4 in waters of Double Island Point, south-east Queensland. In the laboratory, each sample was thawed and length frequency measurements were taken. A sub-sample of 5 fish from each 0.5 cm size class was weighed (± 0.01g) and measured (±1mm FL), and otoliths excised. Scales were collected from behind the ventral fins. All otoliths and scales were cleaned in alcohol and dried. Otoliths were individually weighed (±0.001g) and both scale and otoliths were stored dry in marked 5 ml vials.

(a) Otolith Preparation and Reading

Preliminary investigations were conducted to determine the ageing method most applicable to stout whiting. These included the reading of whole otoliths and scales, heated cracked and whole otoliths and cut and polished transverse otolith sections. All of these otolith preparations were examined under low power (X15) microscope with either transmitted or reflected light. Whole otoliths were examined after immersion in a bath of vegetable oil. Scales were mounted on a microfiche reader (X5) for viewing. Each scale, whole otolith or otolith section was read once and assigned an age, according to the number of discernible growth checks, and an arbitrary readability value ranging from 1 to 5 (Table 2.1). All samples were read a second time, by the same reader, after an interval of 4-10 weeks. At each reading the reader was provided with no information other than the identification number of the sample.

To assess reader consistency, one-hundred otoliths of various age were selected from a sample collected in July 1993. The distance from nucleus to first growth check was measured in each otolith. The average distance for each age group was then plotted against age along with their 95% confidence intervals. If readings were consistent between different age groups, then the average distance to first annulus for each group would be in a straight line with slope equal to 1.

Table 2.1: Readability scale for ageing *Sillago robusta* otoliths.

Readability Value	Definition
1	Internal structure visible, but not interpreted
2	Internal structure visible, but multiple interpretations possible
3	Internal structure visible, several interpretations possible, but confident that only one is plausible
4	Internal structure visible, little chance of mis-interpretation
5	Internal structure visible, only one interpretation possible

(b) Validation

Marginal increment analysis was used to determine the periodicity of the growth checks (annuli). All whole otoliths which had a readability value of 3 or greater were examined a third time under a dissecting microscope at low power (10X) using image enhancing software (Optimas^R). Measurements were taken from the otolith nucleus to each annulus and to the margin at a point adjacent to the rostrum (Morales-Nin, 1992). The method of Staples (1970) and Hobday and Wankowski (1986) was used to analyse the seasonal changes in marginal increment (MI). The relative marginal increment is given as;

$$MI = \frac{r - r_n}{r_n - r_{n-1}}$$

where R-r_n is the distance between the otolith margin and the last annular growth check, and r_n - r_{n-1} is the distance between the outermost annulus and the penultimate annulus. This method determines marginal increment as a proportion of otolith diameter irrespective of age, and thus 1+, 2+ and 3+ age groups could be pooled for analysis. The average monthly sea surface temperatures for waters off Double Island Point are provided on the same graph.

(c) Growth

Growth was estimated using the von Bertalanffy growth function (VBGF)

$$L_t = l_\infty (1\text{-}\exp(\text{-}k(t\text{-}t_0)))$$

where L_t is the fork length at age t, L_∞ is the asymptotic fork length, K is a parameter describing how rapidly L_∞ is achieved and t_0 is the hypothetical age at length zero. The fork lengths of a sub-sample of 400 stout whiting were plotted against age and the VBGF was fitted using the FAO-ICLARM package Fisat.

Results

The preliminary investigations demonstrated that of all the techniques examined, reading whole otoliths with diffuse natural light (near a window), augmented by low power reflected light when necessary, was the most consistently reliable technique for estimating age of *S. robusta* from south-east Queensland. Consequently, the otoliths from 879 fish were read and assigned an age and a readability value. Fish ranged from 10.7 to 22.4 cm in fork length and 11.48 to 108.70 g in weight. Otolith weights ranged from 0.032 to 0.197 g. The otolith of stout whiting (Figure 2.1) is an oblong accretion of calcareous tissue. It has an identifiable nucleus which is surrounded by a large region of densely opaque material. In some otoliths irregular spaced growth checks are visible within this region. Several distinct opaque growth checks are visible on the translucent outer portion of the otolith.

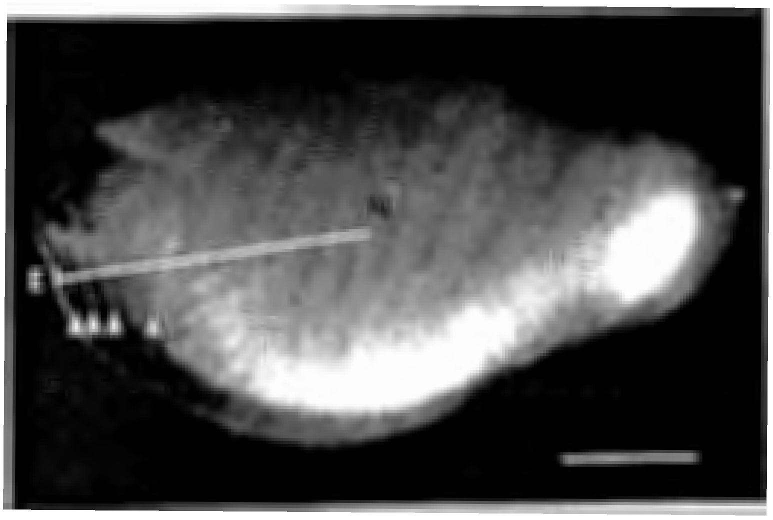


Figure 2.1: Photograph of otolith from a 4+ age group *Sillago robusta* (Fl: 20.7cm), showing the position (arrows) of the four growth checks. The line between N and E is the line used for MI analysis. E; otolith margin, N; otolith nucleus. bar = 2mm

(a) Age Estimation

Over 49% of all fish examined were confidently ageable, i.e. having a readability value of 3 or greater (Table 2.1). There was agreement between the two sets of readings in over 92% (396) of those fish with an initial readability value greater than 2 i.e. those otoliths that could be confidently interpreted during the first reading. There was only 68% agreement between successive readings of otoliths that had a readability value of less than 3 and there was no apparent relationship between size and readability.

S. robusta otoliths used in this study had a maximum of 4 annuli, with 37% having none and 32% having 1 annulus. The average distance from nucleus to each of the four annuli is given in Table 2.2. Approximately 30% of all otoliths examined displayed either opaque or translucent rings within the area bounded by the first annulus. However, the presence/absence and location of these spurious rings appeared to be random, and not interpretable.

Table 2.2: Otolith annulus measurements of *Sillago robusta* from all samples.

Age	Mean distance (mm) ± 95% C.I. from nucleus to last growth check.	n
1+	2.659 ± 0.175	127
2+	3.121 ± 0.196	77
3+	3.382 ± 0.162	41
4+	3.548 ± 0.117	8

The average distance to the first annulus for each age group is given in Figure 2.2. This distance ranged from 2.653 ±0.023 to 2.778 ±0.004 mm and no significant differences in variance of means of age groups 1+ - 4+ ($F=0.356$, d.f.=51, $p=0.05$). However, the sample size of the 4+ age group was small (4) and otoliths from this age group were not used in the marginal increment analysis. As analysis of variance in length at age indicated no significant differences between males and females ($F=1.87$, d.f.=379, $p=0.05$), data for the two sexes were pooled for age validation and growth estimation.

Figure 2.2: Mean distance (mm) from otolith nucleus to first annulus for separate age groups of *Sillago robusta* collected in July 1993. Bars show 95% confidence intervals. n=23 for age group1+, 17 for age group2+, 10 for age group 3+ and 4 for age group 4+.

(b) Validation of age estimate interpretations

Marginal increment indices for age classes 1 to 3 (Figure 2.3) indicate that a small proportion of the *S. robusta* stock begin laying down the opaque annulus on the margin of their otoliths by late June. This is shown by a decrease in the relative marginal increment between April and June. The proportion of otoliths with an opaque margin increases to a maximum in late August. Subsequently, there is translucent growth on the margin of the otoliths of an increasing number of fish and the marginal increment increases into December. The marginal increment analysis indicates that annulus formation is an annual event occurring in late winter and coinciding with a fall in average sea surface temperature.

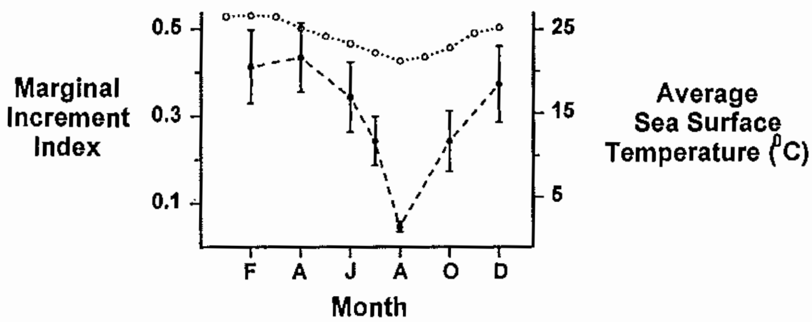


Figure 2.3: Yearly cycle of marginal increment on the whole otolith of *Sillago robusta*. Bars represent 95% confidence intervals.
···O···; mean sea surface temperature (^{0}C) (supplied by Met. Bureau, Darwin)
---I---; Marginal Increment index for combined age groups 1+ to 3+.

(c) Growth

Estimates of the parameters of the von Bertalanffy growth equation (L_∞, k and t_0) were derived from the pooled length-at-age data for male and female stout whiting (Figure 2.4). Non-integer ages were obtained by adding the time interval (months) between annulus formation (late Winter) and time of capture, onto the estimated age. Such that;

non-integer age = no. of annuli + number of months between last annulus formation and capture

Von Bertalanffy growth estimates for stout whiting are; $L_\infty = 22.29$ cm, $K = 0.459$ and $t_0 = -1.03$. The L_{max} observed during this study was 22.6 cm which is a reasonable comparison with the estimated L_∞.

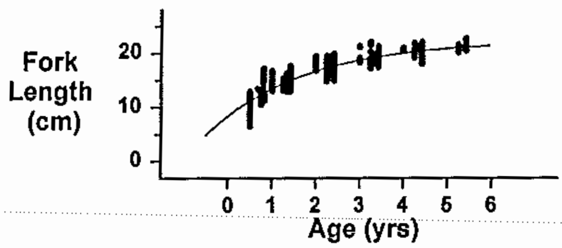


Figure 2.4: Length at age data for combined sexes of *Sillago robusta*. Line represents von Bertalanffy Growth curve with the following parameters; $L_\infty = 22.29$ cm, $k = 0.459$, $t_0 = -1.03$.

Discussion

Maclean (1969) and Smith (pers. comm.) have remarked on the difficulty of interpreting whiting otoliths from eastern Australian waters. *S. robusta* otoliths have also proven to be difficult to interpret, especially in the inner region around the nucleus. To minimise reader bias, all otoliths were examined in random order in the absence of any auxiliary information. Although there was up to 92% agreement between multiple readings, less than half (45%) of the sample could be aged with confidence. This difficulty in interpreting stout whiting otoliths may be related to water temperatures in south-east Queensland. Gauldie *et al.* (1990) observed a seasonal variation in otolith mineral:protein ratio associated the opaque and translucent regions of the otolith and Kelley (1988) noted that unbroken growth can occur over winter in warmer environments resulting in no distinct annulus formation. The samples of *S. robusta* used in this research came from an area between Fraser Island and Caloundra where Bureau of Meteorology records show that seasonal mean monthly sea surface temperatures in this area vary by less than 6C^0 (26.5^{0}C Jan 94, 21.2^{0}C Aug 94). The juveniles occur in the shallow inshore waters (Butcher unpublished data) where ambient bottom temperature is more closely related to sea surface temperatures. Otolith annulus formation may be more strongly influenced by factors such as fluctuation in food resources and reproductive activity than seasonal temperature variation.

The inner zone, preceding the first annulus is difficult to interpret in many stout whiting, often being clouded by one or several irregularly distributed thick opaque bands. Similar banding has been observed in snapper, *Pagrus auratus* (Gauldie, 1990), stock fish, *Merluccius capensis* (Morales-Nin, 1992) and winter whiting, *S. maculata* (MacLean, 1969). Gauldie (1990) attributed the banding to episodes of somatic growth which were not necessarily annual and MacLean (1969) attributed them to changes in feeding patterns and diet of the juveniles. Camp (1954) and Krishnayya (1968) noted that the annuli in otoliths of sand whiting *(S. sihama)* and the Gangetic whiting *(S. panijus)* were laid down during periods of stress associated with ecophysiological disturbances such as lack of food or spawning activity. Burchmore et al. (1988) reported differences in feeding strategies between juvenile and adult stout whiting which they attributed to habitat partitioning between the two age groups. In southeast Queensland, *S. robusta,* also have differences in prey selection between juveniles and adults (Butcher, unpublished data). If Maclean is correct in his assumptions on the origins of inner otolith marks in winter whiting, then this could also account for similar marks on the inner regions of otoliths from stout whiting.

Marginal increments were examined as a means of validating the ages of stout whiting. Annulus formation is an annual event occurring in mid to late winter, which coincides with the cooler months of the year. Although Krishnamurthy and Kaliyamurthy (1981) reported similar growth patterns in the otoliths of *S. sihama* from tropical Indian waters, this is earlier than was expected in stout whiting from south-east Queensland waters. One would not expect the annulus to become clearly visible until later in the year, when sea temperatures begin to increase and growth commences again. Such was the case for school whiting from eastern Victoria (Hobday and Wankowski, 1986) which lay down a annulus on the scale in spring or early summer. Either ambient water temperature has a stronger influence on the time of growth check formation than has been previously thought, or growth check formation occurs earlier in otoliths of stout whiting than in the scales.

Hobday and Wankowski (1986) used length-frequency analysis to validate their age estimates of school whiting from eastern Victoria, as did MacLean (1969) for *S. maculata* from Moreton Bay, Queensland. However, Maclean noted that *S. maculata* spawn as many as four times per year, and lay down two annuli per annum, relating to periods of reproductive activity and slow somatic growth. He observed two distinct modal pulses in the annual length-frequency analysis which supported his age interpretation. Observations on the reproductive behaviour of *S. robusta* indicate that they have an extended spawning period which will probably mask modal pulses in the length-frequency data.

Stout whiting are relatively short-lived. Maximum observed age is 5 years (Butcher, unpublished data) and most fish are recruited into the fishery by the end of the first 12 months. Most of the fish aged in this study belonged to age classes 0 and 1. The VBGF estimated L_∞ value of 22.29 cm compares closely with the observed L_{max} of 226 cm.

3. Reproduction

Methods

General procedure
Samples of *S. robusta* were collected from commercial fish trawl catches between 1991-94, prawn trawl bycatch samples collected between 1991-93, and a finfish research survey carried out in 1993-4 in waters off Double Island Point, south-east Queensland. In the laboratory, each sample was thawed and length frequency measurements were taken. A sub-sample of 5 fish from each 0.5 cm size class was weighed (± 0.01g), measured (±1mm FL) and sexed.

(a) Determining spawning season
The gonads from all individually examined stout whiting were removed, washed and weighed (+0.01g) . They were then classified by their macroscopic appearance according to a revised version (Table 3.1) of the staging criteria used by Morton (1985) and fixed in 50 ml jars containing Bouin's fluid. After a minimum fixation period of 48 hours, 30 samples from each macroscopic stage were prepared for histological examination. Thin sections (6μm) were cut from the anterior, medial and posterior regions of each gonad, stained with Mayers haematoxylin-eosin and mounted on slides for light microscopy. The microscopic characteristics present were compared against the macroscopic classification to ensure continuity between macroscopic and microscopic classification.

A gonosomatic index (GSI) was determined for each fish using a modified version of the method of Hobday and Wankowski (1987) where Gonosomatic Index = Gonad weight / (total weight - gonad weight). The sample average GSI, using females only, was then plotted against time to ascertain the peaks in spawning activity over the past 4 years. After size at first maturity had been determined (see below), the average GSI was re-calculated using those females of length greater than the estimated size at first maturity.

(b) Size at first maturity
Size at first maturity was resolved after the peak spawning periods had been determined (see 3a, above). During the months of peak spawning activity, ovaries were removed from individual females, washed, weighed (±0.01g) and macroscopically staged according to the criteria in Table 3a. All females with macroscopically determined ovaries later than stage 2 (ripe or approaching ripe) were deemed to be sexually mature for the season. Any fish with ovaries at stage 2 or less were described as sexually immature. All the fish were grouped into 0.5 cm size classes and the percent of sexually mature fish was plotted against size class to find the lowest size at which 50 % of the females would be sexually mature.

(c) Fecundity estimates
The ovaries from 29 ripe females were collected during the peak spawning period. The ovaries from each fish were washed, dried and then weighed (±0.001g). A small sample was dissected from the middle of each ovary, weighed and then placed in a petri dish of seawater. The ova were gently teased from the connective tissue. The ova were counted three times. The sampling of each ovary was repeated 5 times. The total number of eggs in each ovary was then extrapolated from the average count using the formula developed by Moe (1969) where total number of eggs in ovary = average number of eggs in sample mean / weight of sample mean X

total ovary weight. The resulting estimates were plotted against fork length, weight and gonad weight to establish if any relationship exists between the parameters.

Table 3.1. Distinguishing features of the various stages of development in *Sillago robusta* gonads

Stage	Testes	Macroscopic features	Microscopic features
1	Immature virgins	testes in thin grey strip	Lobules poorly defined Spermatogonia predominate
2	Developing virgins & resting adults	grey-white triangular in cross section, extend $^1/_2$ -way along body cavity	Primary and secondary spermatocytes predominate, spermatids present
3	Ripe	White, occupy $^3/_4$ of body cavity, milt extruded by abdominal pressure	Spermatozoa predominant
4	Spent	not observed	not observed
	Ovary		
1	Immature virgins	ovaries appear as thin translucent strips, sex difficult to determine	Type A and B oocytes, mostly type A. Ovary wall thin and folded
2	Developing virgins & resting adults	Pale yellow colour, small whitish ova visible, gonads extend $^1/_2$-way along body cavity	Type A & B and a few type C oocytes present.
3	Ripe	Pale yellow colour, gonad fills $^3/_4$ of abdominal cavity giving fish swollen appearance	All types oocytes present, types D & E predominate.
4	Running ripe	As above but eggs extruded abdominal pressure.	All types present, type E predominates
5	Spent	not observed	not observed

Results

Overall, some 5500 fish were individually examined. The sex ratio was 1.19:1 males to females. Externally, the stout whiting sexes are indistinguishable, unless running ripe. They both have a gonopore located just posterior to the anus on the ventral surface. In juvenile male stout whiting the testes are paired fine silver-black tube-like organs (<1mm dia.) that lie dorsally in the coelom beneath the swim bladder and kidneys. They are connected to the anterior wall of the coelom by individual mesentery sheathed blood vessels and posteriorly by mesentery sheathed ducts and blood vessels that fuse together anterior to the gonopore. The gonad rarely extends more than 1/3 the length of the coelom in virgin males. As the male fish mature, the gonads change colour to a pale cream-white, thicken and elongate to 4/5 the length of the coelom when ripe. In cross section, the testes become triangular with the onset of maturity. Both testes remain similar in size throughout maturation. When fish are running ripe, milt may be freely expressed from the gonopore by applying abdominal pressure by hand.

Juvenile female stout whiting have a dull orange-grey pair of ovaries (<1mm dia.) that lie dorsally in the coelom. They are joined to the anterior coelom wall by a pair of mesentery sheathed blood vessels and posteriorly by a pair of mesentery sheathed ducts and blood vessels that fuse together just anterior to the gonopore. In virgin female juveniles, the gonads extend less than 1/3 the length of the coelom. As the females mature, the gonads change colour to a orange-yellow, expand and elongate to 3/4 the length of the coelom. Throughout the maturation process they retain their cylindrical shape and the servicing blood vessels dilate. Individual oocytes become visible through the ovary wall. As with the males, gametes are freely expressed from the gonopore of running ripe females by applying abdominal pressure by hand.

(a) Determining the spawning season
Microscopic examination of the sections of female gonads made throughout the year indicated that ova at various stages of development, as defined by Treasurer and Holliday (1981), are present in the developing ovary throughout the year and that the observed densities of each stage correspond to initial macroscopic assessments of gonad staging as defined by Morton(1985). Subsequently, the GSI was determined for all females based on macroscopic assessment of their gonads. The average GSI from each sample was obtained, along with its 90% c.i., and plotted against time from May 1991 to May 1993. GSI was very irregular in its distribution over time except that it was highest during the summer months and lowest during early winter. After the size at first maturity had been determined (see section c, below), the average GSI was re-calculated using females greater than estimated size at first maturity (Figure 3a). Again the distribution was very irregular. In 1991 there are definite depression in spawning activity during the months of late May and early June, after which there is a suggestion of a rise up to January-February 1992. The spawning activity then falls away to a minimum in June-July of 1992, but rises again sharply by September of that year. It again falls slowly until July of 1993 and does not seem to rise substantially until December 1994.

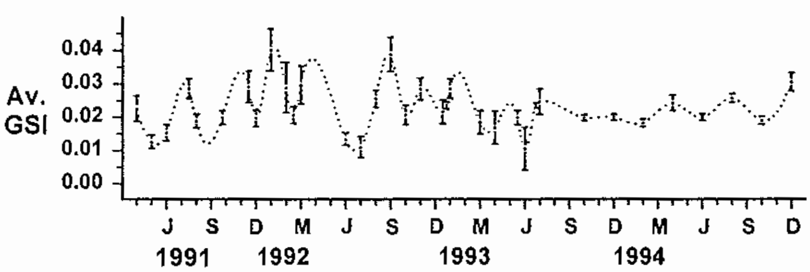


Fig. 3a: Average GSI of female *S. robusta*, > size at first maturity (14.5 cm), from April 1991 to December 1994. Bars represent 95% c.i.

(b) Size at first maturity

Peak spawning activity was recorded in the early to late summer months. Consequently the gonads from some 540 female stout whiting caught during that time period in 1992-93 were examined and staged macroscopically. The smallest female observed with ripe ovaries was 12.1 cm in fork length (FL). However, most fish of this size or smaller were very difficult to sex or stage. The smallest fish that could be sexually differentiated was 10.4 cm FL. The size at which 50 % of the female population was sexually mature was determined as 14.5 cm FL (Figure 3b).

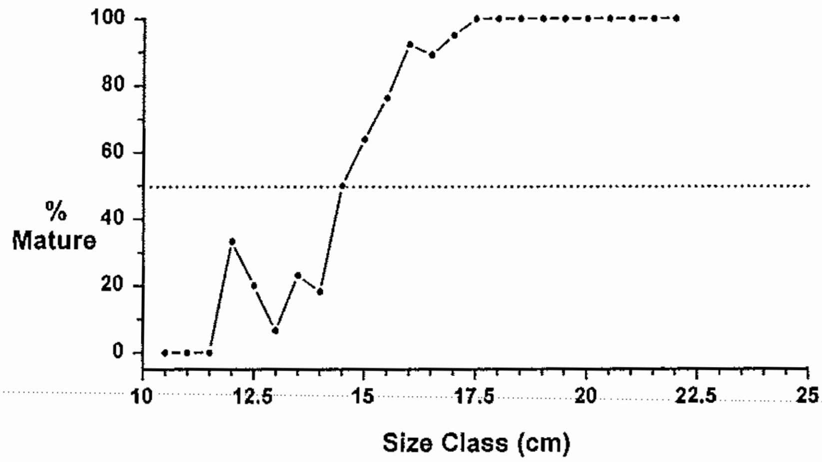


Fig 3b: Size at which *S. robusta* are first sexually mature.

(c) Fecundity estimates

The 29 fish examined ranged in size from 12.8 - 20.9 cm (FL) and from 28.37 - 90.91 g respectively. The ovaries examined ranged in weight from 0.2686 - 3.0407g from fish of 14.4 to 19.8 cm FL respectively. The minimum estimated number of mature oocytes for any ovary was 4890 ± 562 (FL 15.2 cm) while the maximum was 48,822 ±4669 (19.8 cm). There is a distinct linear relationship between fork-length and estimated fecundity (Figure 3c). This relationship is expressed as;

the estimated fecundity = 4581 X FL (cm) - 58918. ($r^2 = 0.72$)

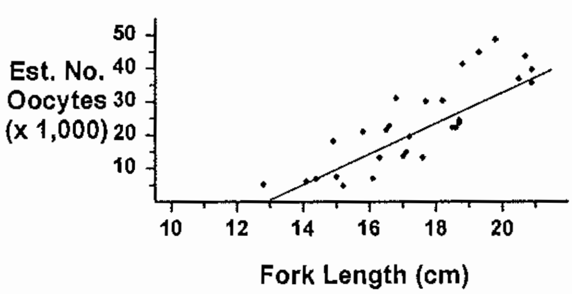


Fig. 3c: Relationship between fork length (cm) and estimated fecundity in sexually mature *S. robusta*.

The strength of this relationship is supported by the linear nature of the regression of total weight (Figure 3d) and gonad weight (Figure 3e) against estimated fecundity. The relationship between total weight and estimated fecundity is expressed as;

estimated fecundity of the mature ovary = 648 x total weight (g) - 12,826 $(r^2 = 0.73)$

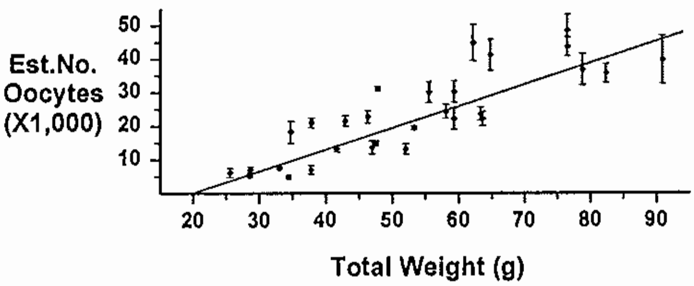


Fig. 3d: Relationship between total weight (g) and estimated fecundity of sexually mature *S. robusta.*

The relationship between gonad weight and estimated fecundity in ripe *S. robusta* is strongly linear $(r^2= 0.91)$and may be expressed as;

estimated fecundity of the mature ovary = 15,989 x gonad weight + 2171 $(r^2 = 0.91)$

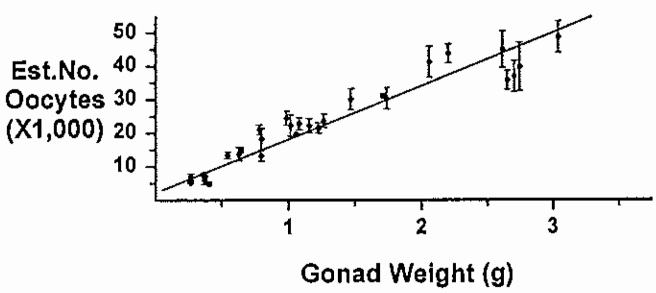


Fig. 3d: Relationship between gonad weight (g) and estimated fecundity of sexually mature *S. robusta.*

However, the strength of this relationship is only apparent in ripe fish during the spawning season. At any other time this relationship will be obscured by somatic growth.

Discussion

As with most sillaginids, the stout whiting gonads are paired structures within the coelom which, when resting or mature, may be sexually differentiated by their colour. They are symmetrical in size and shape as has been observed in *S. sihama* (Palekar and Bal, 1960) although asymmetry is not uncommon in this species. *S. robusta* have an extended spawning period between August and March with a peak in reproductive activity in December through to February. Cockrum and Jones (1992) have reported *Sillaginodes punctata* from South Australia to be serial batch spawners with a spawning period from March to June. Morton (1985) reported a September to March spawning period for *S. ciliata* from Moreton Bay and both Cleland (1947) and Morton (1985) reported 2 spawnings per year by *S. ciliata*. Morton postulated that 2 spawnings per year would reduce inter and intra-specific competition of larvae for limited food resources. Maclean (1969) also observed 2 spawnings per year by *S. maculata* in Moreton Bay and came to a similar conclusion. However, these observations were based on size-frequency distributions of oocytes in selected ovaries, a method which West (1990) has disputed. Hobday and Wankowski (1987) reported a single extended spawning period, between October to March, for *S. bassensis flindersi* from Bass Strait. They noted that ovarian development began in June. Palekar and Bal (1960) observed a narrow spawning period in *S. sihama* between August and October, coinciding with the monsoonal period in India, although the active developing period began in April. Kashiwagi et al. (1987) reported that favourable temperatures strongly influenced the viable hatch rate of *S. japonica* eggs. The peak spawning period of *S. robusta* coincides with periods of warmer sea surface temperatures.

The smallest reproductively mature female *S. robusta* observed was 12.1 cm, but the size at which 50% of females observed were reproductively mature was 14.5 cm. The largest reproductively mature female observed was 20.9 cm. Palekar and Bal (1960) reported the size of 50% sexual maturity for *S. sihama* as being 23.5 cm. They observed sexually mature females in the size range of 12.9 - 35.4 cm. Cockrum and Jones (1992) reported the size at first sexually maturity in *S. punctata* as 31 cm (total length) from a range of 31 - 55 cm (tl). As has been observed in growth rates of stout whiting, clearly some individuals are developing towards sexual maturity at an earlier age than others. Cockrum and Jones (1992) postulated that increased fishing effort would produce selective pressure for fish to spawn at a smaller size. However, the stout whiting fishery has existed for less than 10 years and intense fishing pressure has been restricted to the last 2 years. Whether the variation in size at first reproductive maturity is related to endogenous factors such as individual fish genotype or exogenous factors such as feeding or temperature is not clear.

The estimated fecundity of *S. robusta* has a strong linear relationship with both fork length ($r^2 = 0.72$) and weight ($r^2 = 0.73$). A small female around 14.5 cm (FL) may produce approximately 10,000 eggs while a larger female of around 20.5 cm (FL) may produce about 35,000 eggs. Similar relationships between estimated fecundity and length or weight have been found in other sillaginids such as *S. ciliata* (Cleland, 1947, Morton, 1985), *S. sihama* (Palekar and Bal, 1960), *S. maculata* (Maclean, 1969), *S. punctata* (Cockrum and Jones, 1992) and *S. bassensis flindersi* (Hobday and Wankowski, 1987). However, Hoque and Patra (1987) reported that estimated fecundity was not totally dependant on body weight or length in *S. domina* from Bangladesh, rather it was best described as a function of gonad weight. The relationship between gonad size and estimated fecundity is also stronger in *S. robusta* ($r^2 = 0.91$) and probably many other sillaginids during the peak spawning season. However, the gonad size-fecundity relationship is only accurate during the spawning season when the gonad is ripe and as such, is not a good parameter for estimating fecundity during other parts of the reproductive cycle.

The fishery for *S. robusta* is entirely export market driven and the market requires a small sized fish (less than 45 g). However, as long as the average size of the commercial catch remains above the size at which 50% of *S. robusta* are first mature (14.5 cm), the chance of recruitment overfishing occurring can be diminished.

4. Population Parameters - Virtual Population Analysis

Methods

The commercial catch of *S. robusta* in south-east Queensland was examined monthly during the 1991 - 1994 fishing seasons. Length-frequency data were obtained from random samples of the catch. Further data were obtained by laboratory analysis of sub-samples taken from these catches. At the end of each season the logbook data from each vessel in the fishery were analysed to obtain total catch (kg), effort (hrs bottom time trawling), CPUE (kg/hr) and area trawled. A further analysis of CPUE was also undertaken using only the areas fished during all of the past 4 seasons (1991 - 94).

A Length Cohort Analysis, or LCA (Jones, 1984), was applied for each commercial season: 1991, 1992, 1993, and 1994 using the fisheries analysis program VIT (Leonart and Salat, 1992). Results are based on total landing length frequencies, weights, growth parameters, natural mortality estimate and a terminal fishing mortality value. The analysis estimates numbers, mortalities and weights by length class for the stock at sea. For each season, a set of M and K values were seeded in order to assess the variability of the population biomass estimates. Natural mortality (M) was estimated using a variety of methods including; regressing Beverton and Holt's (1956) Z estimates on effort (f), regressing Beverton and Holt's Z estimates over an area modified effort (f_A), Pauly's (1980) empirical formula relating to average annual sea surface temperature and Rikhter and Efanov's (1976) T_{m50} equation. The average of all four methods was used as the seed value for M and varied within a 0.1 interval for modelling estimates of biomass. Terminal fishing mortality (F_t) was estimated by assuming that the pattern of fishing mortality, as a function of size, follows a sigmoid curve. The estimated value for F_t corresponds to the asymptote of that curve. K, the growth rate constant from the von Bertalanffy growth curve (section II), was seeded within its 95% confidence interval of the calculated mean. Population inputs (growth and recruitment) and outputs (death and catch) as well as turnover rates were provided as a percentage of estimated mean total population biomass to provide an indication of the condition of the fishery.

Finally, a yield per recruit analysis was applied to the 1994 data using the Ricker (1975) model of calculated mean weights. The results are graphically presented for the calculated average natural mortality (M) and its 95% confidence intervals. The yield-per-recruit is compared with the mean biomass-per-recruit on the same figure (4.10) to give an indication of expected biomass for the predicted maximum yield-per-recruit fishing-effort level. A conservative exploitation level for 1995 is predicted using the $F_{0.1}$ harvesting strategy. This strategy is a constant exploitation rate strategy set at 10% (0.1) of the initial exploitation rate on the virgin stock, F_0 (Deriso, 1987) and is more economically efficient than maximum sustainable yield strategies, F_{msy} (Hilborn and Walters, 1992). This strategy has been applied extensively to fish stocks in the Canadian Atlantic region (Doubleday et al., 1984) to provide a conservative harvest strategy which achieves close to the maximum yield per recruit. The $F_{0.1}$ exploitation levels for the stout whiting fishery are tabulated to show the sensitivity of the analysis to the value of estimated natural mortality.

Results

Commercial Catch; 1991 - 1994

The commercial catch, effort, CPUE and average length are given below in Table 4.1, along with the area fished and a modified CPUE. The modified CPUE is based on the catch and effort data from an area within the designated fishery that was fished in all 4 years.

Table 4.1: Catch, Effort and CPUE of *S. robusta* fishery in south-east Queensland

	1991	1992	1993	1994
Catch (tonnes)	526.072	925.951	1002.266	2414.015
Effort (hours)	3744	5217	5346	12458
CPUE (kg/hrs)	140.5	177.5	187.5	194
average Fork Length (cm)	17.32	16.70	16.28	16.70
No. Sites Fished ($6nm^2$)	54	63	81	105
Area Swept (nm^2)	1086	1513	1550	3613
modified CPUE (kg/hr)	142	189	202	173

The growth parameters were calculated from the von Bertalanffy growth curve as per section II. The seeded parameters were; $L\infty = 22.29$ cm, $k = 0.459 \pm 0.64$ (CI) year^{-1} and $t_0 = -1.03$ year^{-1}. For the estimation of total population biomass, the minimum and maximum k values seeded were 0.395 and 0.523 respectively.

The Length-Weight relationship was expressed as: $W (gr) = 0.01382\ L(cm)^{2.879}$

The natural mortality estimates ranged from 0.48 (Rikhter and Efanov, 1976) to 0.87 (Pauly, 1980). The estimates of Z provided by Beverton and Holt's Z-equation based on length at first capture are given below in Table 4.2. The estimated value of M from the regression was 0.65. For modelling purposes the seeded values of M ranged from 0.5 to 0.8. The seeded terminal fishing mortality was adjusted for each parameter and year combination until the pattern approached a sigmoid curve. F_t values for the "best estimates" of K and M can be seen in Tables 4.3, 4.5, 4.7 and 4.9.

Table 4.2: Annual estimates of Z derived from Beverton-Holt's length based Z-equation

Year	No. Sites Fished	effort (hrs)	effort/Area	Lc	$Lc_{50\%}$	Z
1991	54	2480	459.31	17.36	16.0	1.67
1992	63	5339	847.52	16.71	14.0	0.95
1993	81	5346	663.60	16.28	14.5	1.55
1994	105	12458	1186.48	16.70	15.5	2.14

Best estimate of M (regression of Z estimates over effort/area) = 0.65

1991 SEASON

Catch Description

Total landing length-frequency for the 1991 fishing season was obtained from 6 commercial samples. Total catch for the season was 526.072 tonnes. The size frequency of the catch, is given below in Figure 4.1 and the commercial catch by weight is presented in Figure 4.2. The VPA derived average age of the 1991 catch was 2.35 years and the average fork length was 17.32 cm.

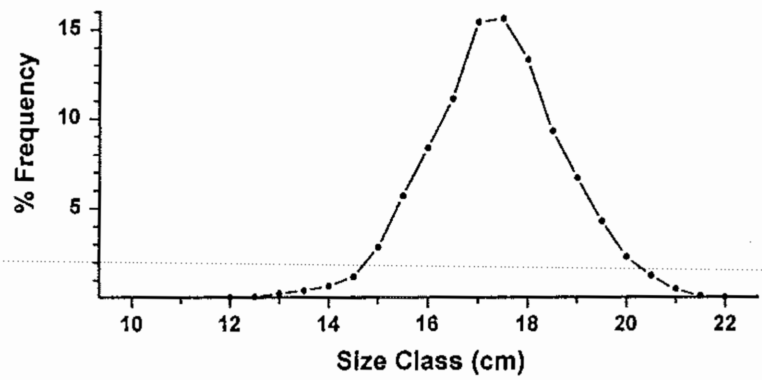


Figure 4.1: % frequency of individual size classes in the 1991 commercial catch of *S. robusta* from south-east Queensland

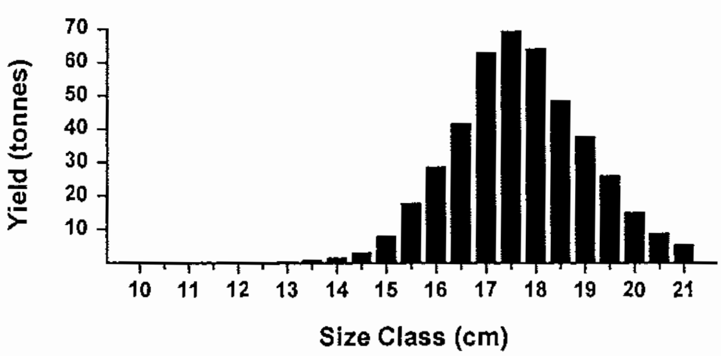


Figure 4.2: Estimated yield (tonnes) of each size class in 1991 commercial catch of *S. robusta* from south-east Queensland.

Length-cohort Analysis

Final estimates of the population total numbers, weights and mortalities for *S. robusta* in the south-east Queensland stout whiting fishery for 1991 appear in Table 4.3 using an averaged natural mortality value and k growth parameter estimates of 0.65 year^{-1} and 0.459 year $^{-1}$ respectively. Optimal seeded F_t was 1.

Table 4.3: LCA estimates of total numbers, mortalities and weights (g) of *S. robusta* in the south-east Queensland fishery in 1991 for best estimates of M = 0.65 and K = 0.459.

Class	Numbers		Mortalities		Weights (g)	
FL (mm)	Initial no.	Mean no.	Z	F(total)	Initial	Mean
95	4607835	396926.2	0.65	0	44899270	4161735
100	4349825	390121	0.65	0	48951210	4707224
105	4096181	383140.6	0.65	0	52873780	5285524
110	3847033	375974.5	0.65	0	56604120	5894783
115	3602533	368582	0.652	0.002	60078350	6532171
120	3362276	360934	0.653	0.003	63221460	7194389
125	3126751	352928.3	0.658	0.008	65972060	7875737
130	2894483	344459.1	0.663	0.013	68225780	8569012
135	2666176	335435.1	0.671	0.021	69918930	9265563
140	2441056	325553.1	0.688	0.038	70950790	9948441
145	2217137	313711.7	0.742	0.092	71171260	10568810
150	1984375	297865.6	0.844	0.194	70118170	11027040
155	1732945	276726.7	0.956	0.306	67195650	11223270
160	1468433	249695.5	1.1	0.45	62301540	11062660
165	1193764	214156	1.378	0.728	55267090	10335060
170	898617.1	171981.3	1.57	0.92	45280540	9018668
175	628543.4	129910.5	1.689	1.039	34388220	7385581
180	409175.5	93639.7	1.659	1.009	24250940	5759667
185	253788.3	64221.49	1.713	1.063	16259080	4263860
190	143757.5	40939.67	1.722	1.072	9935060	2928027
195	73253.87	24289.42	1.634	0.984	5450574	1867991
200	33571.42	12851.11	1.677	1.027	2684425	1060136
205	12015.12	7281.89	1.65	1	1030663	654958

Exploited Population

Mean F: 0.182

Mean Length: 13.68

Mean Age: 1.16

Y/R: 9.5136

Biomass estimates (in tonnes): Table 4.4 provides the best estimates of biomass from the range of natural mortality (0.5 - 0.8) and k values (0.395 - 0.523).

Table 4.4: Biomass estimates of *S. robusta* from south-east Queensland in 1991 from various seeded natural mortality (M) and growth (k) values

M =	0.5	0.6	0.7	0.8
k = 0.523	1025	1149	1302	1484
k = 0.459	1262	1452	1689	1992
k = 0.395	1642	1995	2371	2941

Best estimate of mean biomass for the 1991 season is 1452 tonnes but ranges from 1025 to 2941 tonnes.

Inputs;	Recruitment	29 %	Outputs;	Natural Death	65.8 %
	Growth	71 %		Biomass caught	34.2 %

Turnover (outputs/mean biomass estimate); 98.8 %

1992 SEASON

Catch Description

Total landing length-frequency for the 1992 fishing season was obtained from 6 commercial samples. The total catch for 1992 was 925.951 tonnes taken within the fishery during the season and a further 124 tonnes taken in prawn trawl nets as bycatch outside the season. The size frequency of the total catch, is given below in Figure 4.3 and the commercial catch by weight is presented in Figure 4.4. The VPA derived average age for the 1992 catch was 2.18 years and the average length was 16.70 cm.

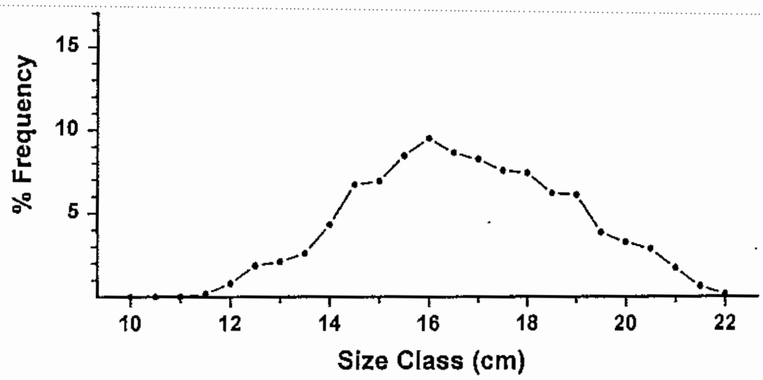


Fig. 4.3: % frequency of individual size classes in the 1992 commercial catch of *S. robusta* from south-east Queensland

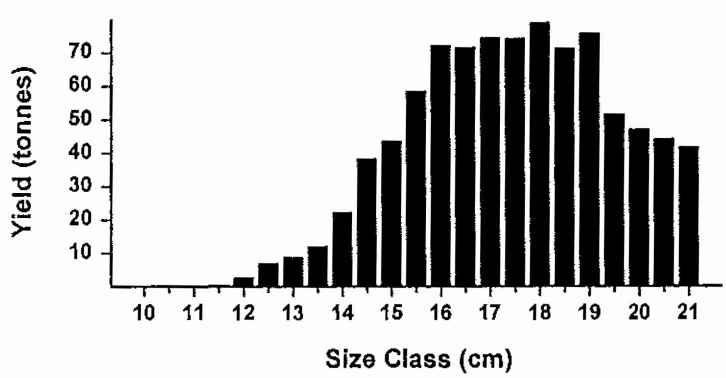


Fig. 4.4: Estimated yield (tonnes) of each size class in 1992 commercial catch of *S. robusta* from south-east Queensland.

Length-cohort Analysis of 1992 data
Final estimates of the population total numbers, weights and mortalities for the *S. robusta* in the south-east Queensland stout whiting fishery for 1992 appear in Table 4.5 using an averaged natural mortality value and k growth parameter estimates of 0.65 $year^{-1}$ and 0.459 $year^{-1}$ respectively. Optimal seeded F_t was 0.4.

Table 4.5: LCA estimates of total numbers, mortalities and weights (g) of *S. robusta* in the south-east Queensland fishery in 1992 for best estimates of M = 0.65 and k = 0.459.

Class	Numbers		Mortalities		Weights (g)	
FL (mm)	Initial	Mean	Z	F(total)	Initial	Mean
105	90493810	8464405	0.65	0	1168100000	116768600
110	84988960	8304427	0.654	0.004	1250503000	130201900
115	79555800	8132103	0.669	0.019	1326728000	144118000
120	74113570	7937171	0.696	0.046	1393570000	158202000
125	68592820	7722298	0.703	0.053	1447256000	172317900
130	63164860	7492028	0.717	0.067	1488857000	186365900
135	57791770	7226646	0.765	0.115	1515556000	199597000
140	52260360	6898122	0.838	0.188	1518979000	210760200
145	46478660	6522136	0.855	0.205	1491989000	219698100
150	40901080	6104218	0.918	0.268	1445245000	225958600
155	35299840	5627136	0.976	0.326	1368765000	228215100
160	29805460	5125976	0.976	0.326	1264563000	227143100
165	24805030	4621867	0.995	0.345	1148387000	223173100
170	20208060	4111220	1.006	0.356	1018267000	215781200
175	16072640	3585908	1.05	0.4	879349800	204083200
180	12306880	3060699	1.042	0.392	729401800	188476100
185	9118959	2527694	1.118	0.468	584210900	168029200
190	6294139	2032567	1.017	0.367	434987100	145614800
195	4226510	1587037	1.051	0.401	314480400	122252800
200	2558471	1124811	1.15	0.5	204579400	92960500
205	1264681	1204458	1.05	0.4	108484900	110291300

Exploited Population
Mean F: 0.177
Mean Length: 14.57
Mean Age: 1.46
Y/R: 9.2537
Biomass estimates (in tonnes): Table 4.6 provides the best estimates of biomass from the range of natural mortality (0.5 - 0.8) and K values (0.395 - 0.523).
Natural Mortality: 0.65

Table 4.6: Biomass estimates of *S. robusta* from south-east Queensland in 1992 from various seeded natural mortality (M) and growth (k) values

M =	0.5	0.6	0.7	0.8
k = 0.523	2044	2422	2951	3744
k = 0.459	2655	3334	4250	6035
k = 0.395	3623	5187	7481	11800

Best estimate of mean biomass for the 1992 season is 3334 tonnes but ranges from 2044 to 11800 tonnes.

Inputs;	Recruitment	36.7 %	Outputs;	Natural Death	73.7 %
	Growth	63.3 %		Biomass caught	26.3 %

Turnover (outputs/mean biomass estimate); 98.5 %

1993 SEASON

Catch Description

Total landing length-frequency for the 1993 fishing season was obtained from 7 commercial samples. The total catch for 1993 was 1002.266 tonnes taken within the fishery during the season and a further 198 tonnes taken in prawn trawl nets as bycatch outside the season. The size-frequency of the total catch, is given below in Figure 4.5 and the commercial catch by weight is presented in Figure 4.6. The VPA derived average age for the 1993 catch was 1.92 years and the average length was 16.28 cm.

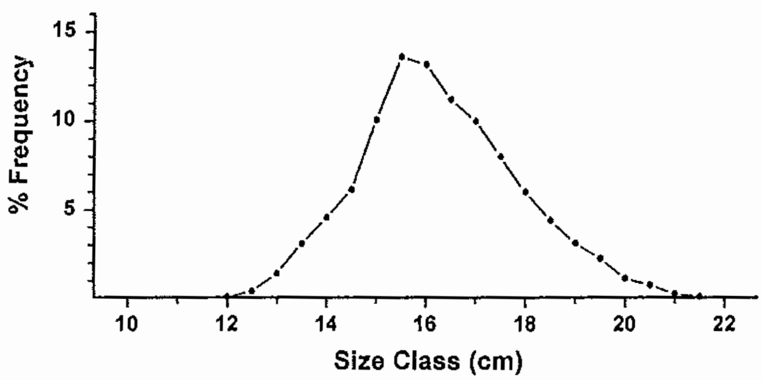


Fig. 4.5: % frequency of individual size classes in the 1993 commercial catch of *S. robusta* from south-east Queensland

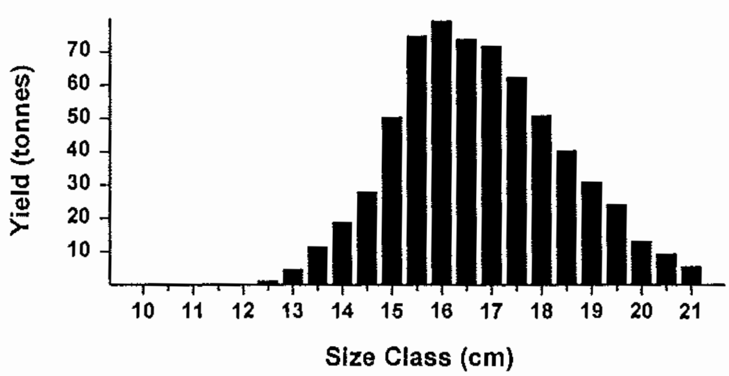


Fig. 4.6: Estimated yield (tonnes) of each size class in 1993 commercial catch of *S. robusta* from south-east Queensland.

Length-cohort Analysis of 1993 data

Final estimates of the population total numbers, weights and mortalities for *S. robusta* in the south-east Queensland stout whiting fishery in 1993 appear in Table 4.7 using an averaged natural mortality value and k growth parameter estimate of 0.65 year^{-1} and 0.459 year $^{-1}$ respectively. Optimal seeded F_t was 0.95.

Table 4.7: LCA estimates of total numbers, mortalities and weights (g) of *S. robusta* in the south-east Queensland fishery in 1993 for best estimates of M = 0.65 and k = 0.459.

Class	Numbers		Mortalities		Weights (g)	
FL (mm)	initial	Mean	Z	F(total)	Initial	Mean
110	66258040	6475461	0.65	0	974901500	101526600
115	62046850	6347587	0.653	0.003	1034737000	112494500
120	57898830	6210996	0.665	0.015	1088682000	123800200
125	53767050	6053040	0.703	0.053	1134444000	135069400
130	49509840	5852988	0.771	0.121	1166995000	145585700
135	44994720	5600536	0.837	0.187	1179961000	154672000
140	40307970	5291987	0.916	0.266	1171576000	161672800
145	35457950	4879459	1.123	0.473	1138219000	164311900
150	29978500	4318774	1.372	0.722	1059295000	159777000
155	24054120	3679342	1.47	0.82	932708000	149124300
160	18643690	3060419	1.49	0.84	791000200	135518400
165	14082690	2477977	1.576	0.926	651979500	119551600
170	10177590	1942347	1.597	0.947	512839800	101852200
175	7076202	1480488	1.586	0.936	387145800	84182260
180	4728821	1094045	1.577	0.927	280266900	67303620
185	3003117	775317.6	1.581	0.931	192396200	51489850
190	1777714	510384.2	1.676	1.026	122857600	36506960
195	922519.8	315168.5	1.491	0.841	68641590	24247910
200	452610.4	173032.9	1.683	1.033	36191450	14273870
205	161480.3	100925.2	1.6	0.95	13851850	9087434

Mean F: 0.343
Mean Length: 14.26
Mean Age: 1.27
Y/R: 13.2323

Biomass estimates (in tonnes): Table 4.8 provides the best estimates of biomass from the range of natural mortality (0.5 - 0.8) and k values (0.395 - 0.523).

Table 4.8: Biomass estimates of *S. robusta* from south-east Queensland in 1993 from various seeded natural mortality (M) and growth (k) values

M =	0.5	0.6	0.7	0.8
k = 0.523	1405	1558	1722	1931
k = 0.459	1712	1927	2192	2528
k = 0.395	2190	2542	3006	3613

Best estimate of mean biomass for the 1993 season is 1927 tonnes but ranges from 1405 - 3613 tonnes.

Inputs;	Recruitment	41.7 %	Outputs;	Natural Death	57 %
	Growth	58.3 %		Biomass caught	43 %

Turnover (outputs/mean biomass estimate); 114 %

1994 SEASON

Catch Description

Total landing length-frequency for the 1994 fishing season was obtained from 6 commercial samples. The total catch for 1994 was 2414.015 tonnes taken within the fishery during the season and a further 120 tonnes taken in prawn trawl nets as bycatch outside the season. The size-frequency the total catch, is given below in Figure 4.7 and the commercial catch by weight is presented in Figure 4.8. The VPA derived average age for the 1994 catch was 2.12 years and the average length was 16.70 cm.

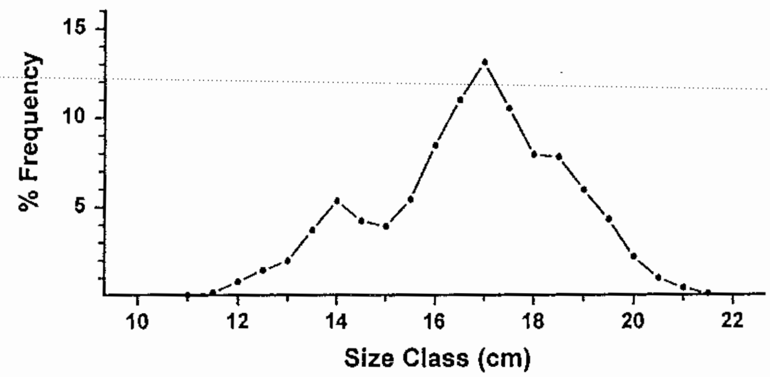


Fig. 4.7: % frequency of individual size classes in the 1994 commercial catch of *S. robusta* from south-east Queensland

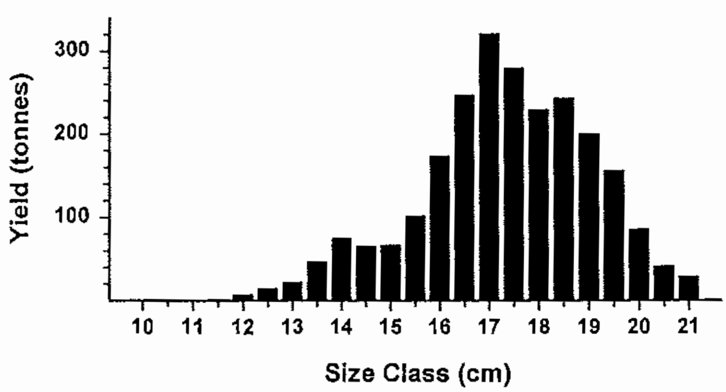


Fig. 4.8: Estimated yield (tonnes) of each size class in 1993 commercial catch of *S. robusta* from south-east Queensland.

Length-cohort Analysis of 1994 data

Final estimates of the population total numbers, weights and mortalities of *S. robusta* in the south-east Queensland stout whiting fishery for 1994 appear in Table 4.9 using an averaged natural mortality value and k growth parameter estimate of 0.65 $year^{-1}$ and 0.459 $year^{-1}$ respectively. Optimal seeded F_t was 0.95.

Table 4.9: LCA estimates of total numbers, mortalities and weights (g) of *S. robusta* in the south-east Queensland fishery in 1994 for best estimates of M = 0.65 and k = 0.459.

Class	Numbers		Mortalities		Weights (g)	
FL (mm)	Initial	Mean	Z	F(total)	Initial	Mean
100	1.96E+08	17619510	0.65	0	2210849000	212598000
105	1.85E+08	17302950	0.652	0.002	2387996000	238698200
110	1.74E+08	16973510	0.656	0.006	2556101000	266120600
115	1.63E+08	16615180	0.675	0.025	2711513000	294454300
120	1.51E+08	16211880	0.696	0.046	2846429000	323131600
125	1.4E+08	15762970	0.714	0.064	2956034000	351736000
130	1.29E+08	15230300	0.774	0.124	3037139000	378833600
135	1.17E+08	14570980	0.837	0.187	3069952000	402412000
140	1.05E+08	13873580	0.805	0.155	3048067000	423899500
145	93699010	13200480	0.801	0.151	3007787000	444686800
150	83123850	12450580	0.871	0.221	2937193000	460906800
155	72273240	11474480	1.025	0.375	2802424000	465331900
160	60517030	10199120	1.198	0.548	2567569000	451807400
165	48295820	8625446	1.424	0.774	2235928000	416232000
170	36015550	7009142	1.415	0.765	1814793000	367647200
175	26101040	5600894	1.373	0.723	1428013000	318587400
180	18410540	4254143	1.587	0.937	1091153000	261702500
185	11660690	2966210	1.679	1.029	747048400	196949900
190	6681708	1864864	1.839	1.189	461772000	133339300
195	3253112	1057908	1.728	1.078	242053100	81337640
200	1425570	560038	1.576	0.926	113990900	46215740
205	542825.8	339266.1	1.6	0.95	46563850	30547970

Exploited Population

Mean F: 0.227

Mean Length: 13.91

Mean Age: 1.21

Y/R: 10.4466

Biomass estimates (in tonnes): Table 4.10 provides the best estimates of biomass from the range of natural mortality (0.5 - 0.8) and k values (0.395 - 0.523).

Table 4.10: Biomass estimates of *S. robusta* from south-east Queensland in 1994 from various seeded natural mortality (M) and growth (k) values

M =	0.5	0.6	0.7	0.8
k = 0.523	4314	4838	5472	6248
k = 0.459	5318	6103	7090	8355
k = 0.395	6899	8193	9917	12290

Best estimate of mean biomass for the 1994 season is 6103 tonnes but ranges from 4314 - 12290 tonnes.

Inputs;	Recruitment	33 %	Outputs;	Natural Death	63.8 %
	Growth	67 %		Biomass caught	36.2 %

Turnover (outputs/mean biomass estimate); 101.9 %

Yield-per-recruit Analysis

The seeded natural mortality (M) used in this analysis was 0.65. The results are based on the 1994 data set and parameters because this is the last year of data available and it represents the largest exploitation area within the fishery and as such, is most representative of actual stock levels within the total fishery area. Yield-per-recruit analysis was carried out for a possible 200 different fishery effort levels beginning at no fishing effort (0) and extended to 2X the 1994 effort level (Figure 4.9). The 3 plots represent the 3 levels of natural mortality as estimated by the 3 different techniques (Beverton and Holt, Pauly and Rikhter and Efanov).

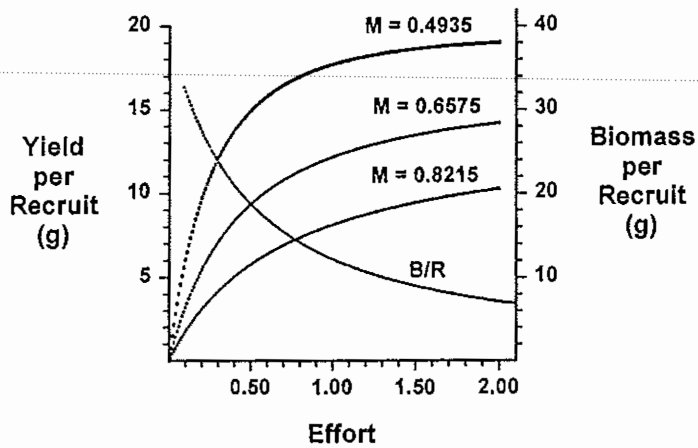


Fig. 4.9: Yield-per-Recruit and Biomass-per-recruit analysis of *S. robusta* stocks for various levels of estimated natural mortality and calculated from the 1994 commercial catch data.

None of the above mortality estimates provide a yield-per-recruit plot which has reached an asymptote, ie. F_{max}, thus implying that to obtain the maximum yield-per-recruit from the fishery, effort should be increased more than 100% above the 1994 level. However, from a comparison of the biomass-per-recruit (the biomass remaining after the Yield has been removed from the stock) for the average estimate of mortality (Figure 4.9), it is apparent that the corresponding biomass for F_{max} is less than 7% of the original virgin biomass, a situation which potentially could lead to severe recruitment overfishing.

Using the more conservative $F_{0.1}$ harvesting strategy and applying the full range of possible values for estimated natural mortality, varied by a factor of 0.05, the yield per recruit analysis gave a variety of possible $F_{0.1}$ strategy exploitation levels as presented below in Table 4.10.

Table 4.10: $F_{0.1}$ harvesting strategy from the 1994 *S. robusta* commercial catch data and a variety of seeded natural mortality (M) estimates.

Estimated M	$F_{0.1}$ harvesting strategy estimate of future Effort	Y/R
0.8 (max)	**1.42**	**9.7594**
0.75	1.23	10.466
0.7	1.06	11.239
0.65 (av)	**0.92**	**12.134**
0.6	0.79	13.106
0.55	0.69	14.289
0.5 (min)	**0.59**	**15.559**

Table 4.10 shows just how sensitive the $F_{0.1}$ harvesting strategy is to estimates of natural mortality. Assuming that natural mortality estimates and thus biomass estimates are accurate, the model shows that fishing mortality post 1994 should be reduced slightly. However, if natural mortality and thus biomass are overestimated, fishing effort should be reduced by up to 46%. Likewise, if natural mortality and thus biomass are underestimated, fishing effort could be increased by up to 51%.

Discussion

Commercial Catch

The stout whiting fishery in south-east Queensland has undergone a rapid development between 1991 and 1994 both in terms of effort and catch. In 1991 the market was severely depressed and fishers were only able to sell catch at levels considered to be below the economic threshold. As a consequence, the effort put into the fishery, and subsequent catch, were relatively small with most fishers opting out of the whiting trawl fishery in favour of more viable alternative trawl fisheries. The distribution of size classes in the 1991 commercial catch (Figure 4.1) is strongly unimodal around the 17.0-17.5 cm size classes, a result which is strongly reflected in the size class yield of the 1991 commercial catch (Figure 4.2). The stock had been lightly exploited during the previous 5 years and although it can not be considered to have been in a truly virgin state, 1991 represents the first year when fishing effort was directed solely at *S. robusta* as the target species by a number of specialised fishers endorsed to fish trawl in Queensland waters. The average size of catch (Table 4.1) and average age are the first measures obtained for this resource. The average size of the commercial catch is influenced by several factors such as gear selectivity of the 2" mesh and oscillating market demand for small (<45g), medium (45-55g) or large (>55g) fish.

By mid 1992 the market demand for *S. robusta* was increasing. This is reflected in the near 40% increase in effort and the subsequent 70% increase in catch. The total area fished has increased also by about 40% as fishers moved further afield to locate their catch. Both total and modified CPUE had increased in 1992 (Table 4.1) reflecting the increased effort over 1991 and indicating that the commercial activity in 1991 appeared to have had little effect on the total standing biomass, although there was a slight decline in average fork length and age in the 1992 commercial catch. Whether this was an early indication of fishing impact on the standing stock or a reflection of the market demand for a smaller sized fish was indeterminable from preliminary logbook data. However, an examination of the frequency of size classes from the commercial catch (Figure 4.3) shows a smaller peak percentage around the average (16 cm) size class and the overall distribution is spread over a much larger size range indicative of an ill defined market selectivity. The majority of the 1992 commercial yield (Figure 4.4) is obtained from size classes equal to or greater than the critical size class.

In 1993 there was a small increase in catch, effort, CPUE and total area fished (Table 4.1). The small increase in these parameters had occurred despite the absence of 20% of the fishing fleet in both 1992 and 1993. The total area fished in 1993 increased by 2.5% from 1992, however, the number of sites fished in 1993 increased by some 30%, indicating that fishers were moving further afield to locate more fish. Both CPUE and modified CPUE increased in 1993 reflecting resurging market demand. Average age of catch declined below 2 years of age for the first time in 1993 and average fork length was also marginally smaller. The peak size class of the commercial catch had declined for the second year running to 15.5 cm (Figure 4.5) and a smaller percentage of the commercial catch was taken from fish larger than the mean fork length (Figure 4.6). The distribution of the catch size class was much tighter in 1993, similar to that in 1991, possibly reflecting the exploitation of new fish stocks within the designated fishery area. In late 1993 several of the fishers began negotiating directly with south-east Asian processors and the resulting success, in the form of increased market demand, is reflected in the large bycatch of *S. robusta* taken outside the fishing season.

By 1994, the market could be considered to be fully recovered. All endorsed vessels were actively fishing during the full season and the dramatic increase in effort (133%) and catch (141%) reflects the strong market demand. Although overall CPUE has increased marginally in 1994 (Figure 4.1), the modified CPUE, based on an area fished during all 4 years, shows a 14% decline. Although some might like to interpret this as a sign of declining fishery yield, Sparre et al. (1989) emphasise that decreasing CPUE is a sign of increased fishing effort, not necessarily overfishing. Both the average age and average fork length of the 1994 catch increased. However, an examination of the 1994 % frequency distribution of each size class in the commercial catch (Figure 4.7) shows a poly-modal distribution with peaks at 17 and 14 cm size classes. This is reflected in the size class yield in the commercial catch (Figure 4.8) and is a possible indication of either an excessively heavy exploitation rate, or market driven targeting of large and small sized catch. Future catches should be closely monitored for similar trends.

Length-Cohort Analysis

Stout whiting are a short lived species (5 years maximum). An arbitrary decision was made at the start of this analysis to conduct the VPA based on a length-frequency series rather than age structured series because length based analysis would have a greater number of classes to analyse and thus give a more robust interpretation of the population dynamics (more degrees of freedom). Research into the *S. robusta* stocks off south-east Queensland has only been carried out for the last 4 years. Thus, there is a limited amount of time series data on which to base a population analysis. Any virtual population analysis on such a short time series of data will, by necessity, be based on the restrictive hypothesis of the stock being at equilibrium (Leonart and Salat, 1992). The program used for the length-cohort analysis in this research project, VIT, falls into this category, but was specifically developed to analyse fisheries with a limited amount of data for input. While the results may not explain the exact status of stocks of *S. robusta* in south-east Queensland waters, they do give a good indication.

Estimates of natural mortality were achieved using a variety of methods. At best they may be considered to be educated guesses (Sparre et al., 1989). None of the methods available account for the degree of targeting by fishers of the various size ranges. Beverton and Holt's (1956) Z based regression method assumes that effort is always proportional to fishing mortality, an assumption that does not take into account the improvements in gear technology through time, nor migration of target species. Modifying this formula by analysing the effort spent in subsections of the whole fishery does account for some of the variability in effort observed in the developing fishery. Pauly's (1980) empirical formula of natural mortality, based on the relationship between annual sea surface temperatures and growth parameters, does not really account for reproductive , ecosystem or behavioural changes such as schooling. Rikhter and Efanov's (1976) relationship between size at first maturity and natural mortality has been found to be more appropriate for species from higher latitudes. Clearly no one method stands out from the others, rather a combination of several provides a suitable starting point for modelling purposes.

In the stout whiting fishery both effort and area fished have increased during the past 4 years. The overall increase mean fishing mortality (mean F) over the past 4 years has been less than 0.05. This is a very small overall increase compared with the increase in effort over the same period. Fishing mortality should increase as the fishery progresses from "virgin" status (Hilborn and Walters 1992) and, considering the increase in effort over the past 4 years, is much smaller than expected. Given the increase in area fished over the past 4 years, the most obvious conclusion is that, essentially, the fishery was still developing.

Length cohort analysis of the past 4 years data highlight growth as the major input into *S. robusta* stocks in south-east Queensland and natural death as the major output. This is to be expected in a stock where several age cohorts are exposed to fishing pressure (Leonart and Salat. 1992). However, between 1991 - 93 there was a gradual decline in input by growth and a greater input by recruitment. A large or increasing recruitment input is a good indication of heavy exploitation of fish stocks (Leonart and Salat, 1992). The 1994 inputs and outputs are similar to that observed in 1992, supporting the theory that in 1994, the developing fishery was still in an expansionist phase. The increasing biomass estimates from 91- 94 also support this conclusion. Analysis of the 1995 commercial catch data will give a very good indication as to whether the fishery is still expanding or not.

One of the problems with the length cohort analysis used in the project, and many other VPA models, is the problem in estimating natural mortality and fishing mortality and their effect on the predicted total biomass estimates. None of the yearly LCA have taken account of the bycatch of stout whiting outside the fishing season or the mortality of juvenile stout whiting taken as trash by the prawn trawl fishery. In 1991 the commercial catch was about 30% of the estimated total biomass. In 1992 it was the same. However, if we include the bycatch of stout whiting taken outside the fishing season, but inside the fishery area, the commercial catch represents 34% of the total estimated biomass. In 1993 the commercial catch was equivalent to about 45% of the estimated biomass and including the bycatch component raises it to 53% of the estimated biomass. The 1994 results are very similar to those of 1992, reflecting the increased area fished in that season. The overall trend is that the fishery has taken out a larger percentage of the estimated biomass than is generally accepted as a conservative yield and that if we consider the bycatch, then it is higher still. Such an increase will affect our estimates of CPUE and natural mortality. There are surplus production models that can predict the optimal yield, however, given such a short time series of data as available from the stout whiting fishery, these models would be based on the assumption that the stock was at equilibrium, an assumption that Hilborn and Walters (1992) warn against because it leads to overestimation of the available surplus production. One alternative is to fish an amount considered to be a conservative representation of the surplus standing stock. This is generally in the range of 20 - 30 % of the spawning stock biomass per recruit (Goodyear, 1993). Another alternative is to use the $F_{0.1}$ strategy from yield per recruit analysis.

The Ricker (1975) yield-per-recruit analysis used in this LCA is based on the 2 parameters, fishing effort (F) and age at first capture (Tc) which are both easily controlled by fishery managers (Sparre et al., 1989). Although a range of fishing effort was examined, the analysis has failed to reach the asymptotic F_{max} for any of the estimated natural mortality values seeded. Gulland (1988) has linked the absence of an asymptotic yield-per-recruit curve in situations where stock density-dependant mortality is not linked to density-dependant growth. The implication from this is that there is little chance of growth overfishing at current levels of exploitation, assuming that natural mortality estimates are accurate. However, it would be very wrong to conclude that fishing effort could be safely increased. Sparre et al. (1989) recommend that biomass-per-recruit be examined in such cases. An analysis of biomass-per-recruit for the same data, but using only the average estimated natural mortality (0.65), shows that if effort is increased anywhere near the predicted F_{max}, the predicted stock biomass will be less than 7% of the original virgin biomass, a situation that would probably lead to recruitment overfishing.

Considering the errors in estimating the total biomass with such a short term data set, the outcome is obvious that if the biomass is underestimated, then the future stock size may be affected by current exploitation levels. One of the more acceptable conservative management techniques in such a situation is to use the widely accepted $F_{0.1}$ strategy(Doubleday et al., 1984, Andrew and Butterworth, 1987, Hilborn and Walters, 1992). This analysis, although considered to be very robust to various alternative stock-recruitment relationships (Hilborn and Walters, 1992), is still very sensitive to natural mortality estimates. The estimated natural mortality rate is the most accurate available and the $F_{0.1}$ strategy for this rate predicts that effort should be reduced to a level that is 92% of the existing 1994 rate. However, given the real potential for error in the estimate of natural mortality, and the fact that the resulting biomass estimate is a reference point rather than a target management level of fishing yield (Jakobsen, 1993), a more conservative approach should be considered.

Summary of Population Analysis

The overall picture from these analyses is that in 1991 the stocks of *S. robusta* in south-east Queensland were lightly exploited within the area fished. In 1992, the fishery increased in area. The size-distribution of the catch increased and, as expected, average length and age decreased along with increasing fishing mortality. However, overall the fishery was still expanding. In 1993, there was little expansion in the fishing area and the resulting decline in average length, average age and increase in fishing mortality indicated a fishery under increasingly heavy exploitation. The 1994 results do not highlight a major decline in the quality of the above reference points, probably due to the significant increase in fishing area. However, the size-frequency of fishing catch is polymodal and very broad, indicating either the possibility of heavy exploitation of the stock or market driven targeting of different sizes of fish. A yield-per recruit analysis indicates that effort should be reduced. The biggest problem with these analyses is the short duration of data available for analysis. The monitoring of future catch and effort will be imperative to establishing an ecologically sustainable management strategy for the fishery.

5. MARKETING TRIALS

Methods

(a) International Trials

In early 1992, discussions were held between QDPI Fisheries Officers and representatives of a Japanese seafood distributor to establish a program for test marketing of *S. robusta*. It was agreed that test marketing processed *S. robusta* directly into a supermarket chain may be a way of establishing a market niche for Queensland fishers. The final proposal involved the processing of south-east Queensland caught *S. robusta* in Bangkok by a Japanese processor/distributor, Yokohama Reito, and supplying a sample directly to a supermarket chain in Japan. The samples were to processed into Kisu Hiraki which is the Japanese style of butterfly filleting whiting from the dorsal fin, leaving them joined along the belly and leaving the tailfin on the fillet. The proposal relied on direct negotiation between the Australian representative of the Japanese processor/distributor and south-east Queensland whiting trawl fishers on a commercial footing and, if the sample was successful, the pilot marketing of a more substantial quantity (a container - 14.5 tonnes) was proposed.

(b) Domestic trials

Automatic filleting
In October 1993, a commercial processor in Western Australia indicated that it was possible to mechanically fillet *S. robusta* for human consumption. This processor had filleted a small sample of Queensland sourced *S. robusta* on a modified Baedder fish filleting machine in 1992. QD Fisheries Officers negotiated to send a small shipment of whole scaled *S. robusta* to Fremantle for trial processing. Frozen samples were picked up from a fisher at Mooloolaba and taken to the Brisbane fish markets. The partially thawed fish were placed in a Fish-Quip built stainless steel drum type scaling machine for 4.5 minutes to remove all scales. The scaled fish were repacked into plastic lined 10 kg cartons and re-frozen for transport to Fremantle by road freezer (-18^0C). The Fremantle processor trialed the S. robusta in both Hiraki and Australian style butterfly fillets (Australian style butterfly fillets are cut from the ventral fin and joined along the dorsal fin), bare and crumbed, to ascertain the best method of value adding.

Manual Filleting
In December 1993, officers at the National Seafood Centre, IFIQ, discussed the possibility of obtaining samples of frozen stout whiting for a nonstructured consumer acceptance trial being conducted in Brisbane. They were conducting a domestic trial on *S. bassensis flindersi*, but were unable to obtain enough samples of the trial species. *S. robusta* was identified as an acceptable alternative. Several samples of *S. robusta* were supplied to the NSC nominated retail outlet in both frozen and fresh state. These samples were kept whole in brine slurry (-2^0C) or butterfly filleted immediately and kept in a brine slurry for periods of up to 7 days. Whole *S. robusta* were removed from the slurry every day and butterfly filleted. Both the freshly cut and stored fillets were examined every day and samples were marketed to ascertain consumer acceptance.

Results

(a) International Trials

In December 1992, a 100 kg sample of *S. robusta* was airfreighted to Bangkok for processing into Hiraki style butterfly fillets. When landed, the product was of an equivalent quality and standard to that sourced from any other country. The sample was thawed and hand filleted into Hiraki. It delivered a 45.3% recovery of Kisu Hiraki of excellent quality. The frequency distribution of product was;

12-13 gm	23%
16-17 gm	40%
23-24 gm	30%
34-35 gm	7%

The processor indicated that a continuity of supply of raw product and realistic price were likely to be the principal determinant of a successful market for Australia. This shipment was considered very successful and follow up orders were anticipated. However, due to an oversupply of Kisu Hiraki on the Japanese domestic market during 1991- early 92, such orders did not eventuate.

(b) Domestic trials

Automatic filleting

In late November, 1993, a sample of 20 kg bulk frozen and 40 kg Individual Quick Frozen (IQF) *S. robusta* were road freighted to Fremantle. After thawing, the samples had to be size graded before loading into the automatic filleting machine. This machine, which was originally set up to cut two fillets from sardines, was further modified to cut a butterfly fillet from whiting either in the Japanese style or in the Australian style. The Australian style was much quicker to process (and thus cheaper). The processor estimated that a total of 4 tonnes/day could be processed into the Australian style of butterfly fillet. These fillets would be suitable for crumbing. The processor also reported that fresh *S. robusta* was not as acceptable for the Japanese tempura market as *S. bassensis flindersii,* but both were of similar quality when frozen. However, the shelf life of processed *S. robusta* was not as long as that of *S. bassensis flindersii.*

Estimated costs would be in the vicinity of;

whiting stock -	$1.50/kg
processing and layer packing -	$4-4.50/kg
Transport -	75¢/kg
total costs -	$7.50/kg wholesale returned to Brisbane.

Contemporary retail prices for Australian butterfly filleted *S. maculata*, a similar sized fish, were in the vicinity of $10-15.00/kg.

Frozen samples of the value added products were airfreighted back to Brisbane in early December, 1993. On examination of the products it became clear that mechanical filleting was unacceptable because of the number of bones left in the fillet. With the Japanese style of filleting, the machine left in the 2 spines on the ventral fin. With the Australian style of filleting, the machine left in the spines on the 2 dorsal fins. These spines were large enough to be unaffected by cooking. Thus the samples were unable to be marketed as fillets. This was unfortunate because in all other aspects, the product was of superior quality and presentation. Further trials with mechanical filleting were abandoned.

Manual filleting

In April, 1994, approximately 100 kg of frozen and fresh whiting were supplied to a local Brisbane retail outlet. After 7 days whole fish kept in an ice slurry were beginning to soften around the stomach. Filleted samples had a shelf life of around 6-7 days and whole fish had a marketable shelf life of about 5-6 days. *S. robusta* did not keep quite as well as *S. bassensis flindersii,* but nearly so. They were best filleted fresh and stored as fillets, rather than stored whole and filleted when required. The fillets were boneless except for several very fine bones along the central ventral surface, which support the anal fins. These bones dissolved when the fillet was cooked. The retailer indicated that buyer interest was very good and expressed his desire to pursue the market further. He was given the names and contacts of all endorsed stout whiting fishers and encouraged to pursue commercial negotiations. All of the stout whiting endorsed fishers were notified of the results from this trial and given the retailers name and contact in order to follow through on a commercial footing. Unfortunately, 1994 was the best season for export markets in the past 5 years and none of the fishers expressed further interest in developing the domestic market.

Discussion

(a) International Trials

The Queensland stout whiting fishery is one of state's largest in terms of quantity caught. However, it has nothing of the economic significance one would anticipate, due to the low product price and instability of the product's market. The market is entirely export orientated with negligible domestic demand. Currently the market for stout whiting products is limited to Japan, which uses small stout whiting (Kisu) as a butterfly filleted product (Hiraki). Size appears to play a significant role in marketing, with a small fillet being preferred. All filleting is carried out manually and, due to labour costs, takes place in South East Asia, typically in Thailand.

As with northern New South Wales, the local fishery has been characterised by cyclical production trends that have been largely driven by market demand. Thus several years of increasing catch and high demand have been followed by a collapse in demand (and consequently price) and a redirection to other fisheries by the fishermen until things again pick up. Such collapses occurred in the mid 1980's, and again in 1990-91. This has been largely due to the Japanese market. Japan has one of the highest consumption rates of fishery products, both in aggregate and per capita, of any country in the world. The Japanese traditionally have had a culture which has included considerable quantities of fishery products in their diets due to the availability of productive seas and the scarcity of arable land. However the market for seafood in Japan can be extremely volatile. Japanese companies consider that price is more important to Japanese consumers than quality when purchasing frozen seafood. In general, Australian seafood represents only a minute fraction of the Japanese market (less than 5%). Japanese buyers will seek to force down prices and play exporters off against each other. Buyers that don't differentiate product, are able to switch suppliers relatively easily, have very low profit margins and have an extremely good understanding of the supply situation. They are thus in a relatively strong position.

Given the complexities of processing (usually in South East Asia), on-selling (usually in Japan) and the relatively low price/volume which Australian fishermen can command for the unprocessed product, there is not much room for downward fluctuations in price before the fishery loses viability. To complicate matters, similar species are available from other sources (Thailand, Vietnam and southwest China) and are capable of over supplying the Japanese market, adding to price declines.

Without a doubt, *S. robusta* from South East Queensland are able to be processed into excellent quality products, due mainly to the quality control procedures at sea. The main products are likely to continue to be butterfly fillets (HIRAKI) and fillets. However, it is unlikely that Queensland products can be sufficiently differentiated from other similar products other than on the basis of origin. In other words, "from pollution-free seas" etc. Japan remains the premier market but, because of the number of possible suppliers, the market is likely to remain fragile. Any "hole" in this market is likely to be filled by Vietnam, China and Thailand, since those countries are more attuned to rapid market reaction than are Australian suppliers. Since buyers are reluctant to enter into commitments because of the market volatility, Australian suppliers will continue to supply on an *ad hoc* basis. This strong competition and the inability to create a recognisable and distinctive product will continue to limit Australia's growth into the Kisu Hiraki market in Japan.

(b) Domestic Trials

There is little hope for long term constant prices from overseas buyers because Australian producers are only augmenting south-east Asian supplies to keep up market continuity. One alternative is to establish a domestic market. To do this, a bulk supply of bone free fillets, preferably larger than those currently marketed in Japan, will be required. The development of a domestic market as a suitable alternative will be assisted by marketing under an "Australian" brand name using a generic "whiting" term rather than specific species name. Such a marketing strategy will to help to reduce overseas competition. The Australian product is of very high quality and trials have proven its acceptance by the Australian consumer. However, the establishment of a domestic market has been hampered by several factors.

Initial resistance to establishing a domestic market was encountered from the fishers themselves. In 1992, when the project began, the prevailing view amongst most fishers was that developing a domestic market would only result in its being swamped by cheaper south-east Asian imports, leaving domestic producers with the dual loss of overseas export markets and the holding costs associated with a domestic oriented product. Recent experiences have shown this phobia to be surmountable by various marketing strategies which emphasise the origin of the product (eg. Barramundi vs Nile Perch) and highlight the value of the Australian caught product.

A more intractable problem in establishing a domestic market has been the cost of production. Trials have proven that the Australian product has local consumer acceptance. However, manual filleting of large volumes of such a product in Australia is not an economically viable proposition. One alternative is for offshore processing and re-importation to Australia but fishers have not been prepared to undertake this because of the perceived threat from cheaper imports. A second alternative is the use of mechanical filleting machinery. These machines are well established in the Atlantic Salmon industry in Tasmania and the Sardine industry in Western Australia. However, trials with whiting have not proven successful. There is still the problem of several spines being retained in butterfly fillets. This result is born out by the experiences of a local fishing company which has also examined alternative processing techniques. They have sent samples of *S. robusta* for trial processing in Germany (Baedder) and Japan (Toyo Suisan Kikai and Nippon Fillestar). These trials have been unsuccessful, with no commercial filleting machine being able to cope with the rib cage and gut lining of stout whiting in preparation of a butterfly fillet. Should local demand increase, it is quite possible that a machine could be developed which will successfully butterfly fillet whiting. However, demand will have to grow appreciably before the filleting machine manufacturers recognise a suitable return for their technological investment. In the interim, the Australian domestic market will remain localised and small, in the shadow of the more lucrative export market.

Age structure of the fished population appears to have been stable during the past three years and catch rates have increased. Variations in catch are largely attributable to changes in effort directed at the stock and area fished. These changes in effort appear to be solely the consequence of alternative economic decisions made by fishers, with effort and catch being determined by the relative profitability between alternative target species. There does not appear to be any potential for an increased whiting catch, in terms of stock sustainability, and future increases in return to the fishers will be based on value-adding for improved marketing of the product. Such a development is currently being examined by one of the commercial fishers. If his development proves profitable, then it is expected that others will follow his lead towards higher value, lower volume production with the net effect of conserving the resource.

IMPLICATIONS FOR THE FISHING INDUSTRY

The objectives of any fishery should be to derive the maximum economic yield while maintaining the fished stock at an ecologically sustainable level. The implications of this research on industry are two-fold from a management and monitoring perspective. This fishery is based on a short-lived, rapidly growing species. The length-frequency and age structure data obtained imply a rapidly developing fishery which has reached its geographical limits. VPA data is indicative of a fishery that is potentially at or slightly beyond its maximum sustainable yield. There is a demonstrable need to curb further effort in the fishery and a arguable case to reduce it below current levels. Given the current nature of the market, any reduction in catch will require close consultation between management and industry to ensure that the long term market outlook is maintained in a favourable light. Given the short history of this fishery, the research program has established several important biological reference points from which the fishery can begin to be managed. However, it is very important to refine these reference points further via the continued close monitoring of the fishery.

While Australian suppliers remain as an adjunct of the existing Japanese Kisu Hiraki market, they will continue to be subject to the volatile economic bind of prevailing demand and supply of whiting from south-east Asia. This research has proven that the local product is superior in quality to that of the south-east Asian competitors. However, the market in its current form is not willing to pay a premium for that quality. Attempts to establish a domestic market have met with limited success, due primarily to the limited volume of demand. There is a strong need for the focusing of producers towards value-adding within Australia to establish the product in a lower-volume higher priced market. Fortunately at least some of the producers have come to this conclusion and have invested time and finances toward this goal. The success of their endeavours will have a strong bearing on the future of the industry as a whole.

The total budget for this research project over the past 4 years has been approximately $840,000, of which some $240,000 has been contributed by FR&DC and the QFMA combined. During that time the fishery has developed from a gross value of around $657,500 in 1991 to in excess of $M4 by 1994. Given the conservative recommendation for a reduction in effort within the fishery, and assuming that the estimated baseline reference points which the project has developed are truly representative of the stock, then the project has potentially prevented the possibility of overfishing of the resource by 10 - 50 % . This represents a saving of between $400,000 to nearly $M2 per annum. In the long-term, there is still the potential to increase the total value of the fishery by improved application of value adding technology, as being developed by several of the fishers.

INTELLECTUAL PROPERTY

There are no new inventions or processes associated with this project. Intellectual property relates to the raw data gathered and their subsequent analysis. The analysed results have been submitted to the Queensland Fish Management Authority. The publication of manuscripts will provide general access to the results.

REFERENCES

Andrew, P.A. and D.S. Butterworth, 1987. Is $F_{0.1}$ an appropriate harvesting strategy for the Cape Hakes? south African Journal of Marine Science 5:925-935.

Beverton, R.J.H. and S.J. Holt, 1956. A review of methods for estimating mortality rates in exploited fish populations, with specil reference to sources of bias in catch sampling. Rapp. P. - V. Réun. CIEM, 140:67-83.

Bererton, R.J.H. and S.J.Holt, 1957. On the dynamics of exploited fish populations. Fisheries Investigations by the Ministery of Agriculture, Fisheries and Food, Great Brittain (2 Sea Fisheries) 19:533p.

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

Butcher, A., 1991. The Trawl Fishery for stout whiting *Sillago robusta* in southeast Queensland. Internal DPI end of year report to QFMA.

Butcher, A., 1992. The Trawl Fishery for stout whiting *Sillago robusta* in southeast Queensland. Internal DPI end of year report to QFMA.

Butcher, A., 1993. The Trawl Fishery for stout whiting *Sillago robusta* in southeast Queensland. Internal DPI end of year report to QFMA.

Chapman,L., 1990. Sashimi quality fish from Tasmanian waters. Aust. Fish. 49:41-4.

Cleland, K.W., 1947. Studies on the economic biology of sand whiting (*Sillago ciliata*, C. and V). Proc. Linn Soc. N.S.W. 72:215-228.

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

Cockrum K.S. and G.K. Jones, 1992. Thre reproductive biology and fecundity of King George whiting (*Sillaginodes punctata*) in southAustralian waters, 1953-1988. Fisheries Research Paper No. 25. Dep. Fish. S.A.

Deriso, R.B. 1987. Optimal $F_{0.1}$ criteria and their relationship to maximum sustainable yield. Canadian Journal of fisheries and Aquatic Science 44(supplement 2):339-348

Doubleday, W.G., D. Rivard and W.D. McKone, 1984. Estimation of partial recruitment and yield per recruit for an otter trawl fishery for deepwater redfish. North American Journal of Fisheries Management. 4:15-31.

FAO 1987. Trade Year Book. 1986:40 Rome.

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

Gauldie, R.W., G. Coote, I.F. West, and R.L. Radtke, 1990. The influcence of temperature on the fluorine and calcium compostion of fish scales. Tissue and Cell 22:645-654.

Goodyear, C.P., 1993. Spawning stock biomass per recruit in fisheries management: foundation and current use. in S.J. Smith, J. Hunt and D. Rivard (ed's), Risk Evaluation and biological reference points for fisheries management. National Research Council of Canada, Canadian Special Publication of Fisheries aned Aquatic Sciences 120:67 - 82.

Gulland, J.A. (ed.), 1988. Fish Population Dynamics: the implications for management. 2nd Edn. J. Wiley & Sons. 422p.

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

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

Hobday, D.K. and J.W.J. Wankowski, 1987. School whiting *Sillago bassensis flindersi*: Reproduction and fecundity in eastern Bass Strait, Australia. Vic. Dep. Cons. For. Lan., Fish. Div., Int. rep.no. 153. 24p.

Hoque, B. and R. W.R. Patra, 1987. Fecundity of the ladyfish, Sillago domina (Cuvier) (Trachinidae:Perciformes). Bangladesh J. Zool 15(2):205-210.

Hunter, J.R., A.W. Argue, W.H. Bayliff, A.E.Dizon, A. Fonteneau, D. Goodman and G.R. Seckel, 1986. The dynamics of tuna movement: an evaluation of past and future research. FAO Fisheries Technical Paper 277.

Jakobsen, T., 1993. The behaviour of F_{low}, F_{med} and F_{high} in response to Variation Parameters used in their estimation. in S.J. Smith, J. Hunt and D. Rivard (ed's), Risk Evaluation and biological reference points for fisheries management. National Research Council of Canada, Canadian Special Publication of Fisheries aned Aquatic Sciences 120:119-125.

Jones, R., 1984. Assessing the effects of changes in exploitation pattern using length composition data (with notes on VPA and cohort analysis). FAO Fisheries Technical Paper, 256:118p.

Kashiwagi, M., H. Sakaki and T. Takahashi, 1987. A relationship between egg size and hatching rate in Jpanese whiting, *Sillago japonica*. Nippon suisan Gakkaishi 53(12):2105-2110.

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

Kingston, A.G., P. Smith and S. Beare, 1990. Japanese seafood demand. 34th Ann. Conf. Aust. Ag. Econ. Soc. Bris. Feb., 1990. 20pp.

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

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

Leonart, J. and J. Salat, 1992. VIT fisheries analysis program. Periodical Publication of the Marine Science Institute of Barcelona, Marine Science Technical Information series 168-169:116p.

McKay, R.J., 1992 Sillaginid Fishes of the World. FAO species catalogue Vol.14 87pp. FAO Rome

MacLean, J.L., 1969. A study of the biology of winter whitng, *Sillago maculata* (Quoy and gaimard), in Moreton Bay. Unpubl. M.Sc. thesis, Univ. of Qld.

Moe, M.A. Jr., 1969. Biology of the red grouper, Epinephelus morio (Valenciennes) from eastern Gulf of Mexico. Fla. Dep. Nat. Resour., Mar. Res. Lab. Prof. Pap. Ser., 10, 95p.

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

Morton, R.M., 1985. The reproductive biology of summer whiting, *Sillago ciliata* C.& V., in northern Moreton Bay. Aust. Zool. 21:491-502.

Palekar, V.C. &and D.V. Bal, 1960. Studies on the maturation and spawning on the indian whiting (*Sillago sihama* Forsskål) from Karwar waters. Proc. Ind. Acad. Sci. 54B:76-93.

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

Rikhter, W.E. and V.N. Efanov, 1976. On one of the population approaches to estimation off natural mortality of fish populations. ICNAF Research Document 76/VI/8:12p.

Sparre, P., E. Ursin and S.C. Venema, 1989. Introduction to tropical fish stock assessment. Part 1. Manual. FAO Fisheries Technical Paper 306.1:337p.

Staples, D. J., (1970). Methods of ageing red gurnard (Teleostei:Triglidae) by fin rays and otoliths. New Zealand Journal of Marine and Freshwater Research 5:70-79.

Treasurer, J.W. and F.G.T. Holliday, 1981. Some aspects of the reproductive biology of perch (*Perca fluviatilis*) L. A histological description of the reproductive cycle. J. Fish Biol. 18:359-376.

West, G., 1990. Methods of assessig ovarian development I fishes: a review. Aust. J. Mar. Freshwater Res. 41:199-122.

ACKNOWLEDGMENTS

This project owes much to the valuable cooperation of the skippers and crew of the various commercial whiting vessels for collecting samples. The time and effort of the various staff aboard the QDPI research vessel "Deep Tempest", in particular Mr. David Trama, Mr. Peter Pardoe and Mr. Brett Davidson, is much appreciated.

Kate Yeomans, John McLaughlin-Karr, Glenn Hopper, Kim Bilham and Wayne Hagedoorn, along with a number of work-experience students, provided the dedication in processing of samples in the laboratory, ageing and storing otoliths, processing gonads and entering data onto a database.

The statistical advice of David Mayer (Biometrician) and population dynamics advice of Dr. Juan-Pablo Pertierra (QDPI) and especially Dr. David Die (CSIRO) has been invaluable to the project results.

Without the help of these people, the project would not have been able to address the objectives as effectively. Our sincere thanks are extended to them all.

Appendix I

Six papers are in preparation at the present time:

Butcher, A. and K. Yeomans. Age and growth estimates in stout whiting, *Sillago robusta*, from south-east Queensland.

Butcher, A. Reproductive biology of female stout whiting, *Sillago robusta*, from south-east Queensland.

Butcher, A. Reproductive biology of male stout whiting, *Sillago robusta*, from south-east Queensland.

Butcher, A. and J. McLaughlin-Karr. the occurrence of the shark tapeworm, *Poecilancistrium caryophyllum* (Diesing, 1850) in , *Sillago robusta*, from south-east Queensland.

Butcher, A. Estimating biological reference points and biomass of stout whiting, *Sillago robusta*, from south-east Queensland.

Butcher, A. Seasonal variation in occurrence of stout whiting, *Sillago robusta*, in waters off south-east Queensland.

Appendix II

Platform Presentations:

1992 Southern Fisheries seminar series to scientists, management and industry representatives
Central Ageing Facility, Queenscliff, Victoria, seminar to scientist representatives
Queensland Finfishers Association annual pre-season meeting

1993 Queensland Finfishers Association annual pre-season meeting

1994 Queensland Finfishers Association annual pre-season meeting
Queensland Fish Management Authority board meeting

1995 Queensland Finfishers Association annual pre-season meeting
Australian Society for Fish Biology annual conference to scientist representatives
Queensland Fish Management Authority board meeting