ASSESSMENT OF THE FISHERY FOR SNAPPER (*Pagrus auratus*) IN QUEENSLAND AND NEW SOUTH WALES

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93/074 Assessment of the fishery for snapper (*Pagrus auratus*) in Queensland and NSW.

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OBJECTIVES

To estimate the recreational snapper catch in the Moreton Region and evaluate methodologies for estimating offshore recreational effort.

To provide fisheries managers with models for assessing the impact on yield of proposed changes to the legislated minimum legal size of snapper.

To provide fisheries managers with information on the genetic relationship between snapper populations in south Queensland, Northern New South Wales and east of the Swains Reefs (Southern Great Barrier Reef).

To develop methods of estimating relative abundance and year class strength of juvenile snapper.

NON TECHNICAL SUMMARY

Previous work to validate snapper age estimates was supported but this validation is still suspect in northern NSW and Queensland. The reason the validation is called into question is that the clarity of interpretation of otolith edges changed with latitude. More than half of otolith edges could not be interpreted in northern NSW and interpretation of edges in fish from Queensland was abandoned. The problem with determining otolith edges may mean that the time of sampling should be adjusted to account for this difficulty. The precision of multiple age assignments from snapper otoliths was high by published standards and there was little bias between Queensland and NSW age readers meaning that the age compositions estimated by the two labs were comparable.

The fishery for snapper in NSW and Queensland is dominated by the harvest of individuals very close to the minimum sizes set in each state. Consequently, most of the snapper caught are either two or three years old. The age distribution of fish in the catch remained similar amongst the three winter/spring seasons where this was estimated. Estimates of total mortality from catch at age suggest mortality from fishing is high. There are differences among locations along the NSW and Queensland coast in the average size of snapper of a given age, particularly in older age groups. The largest fish of a given age were from the middle of the study area, near the NSW-Queensland border.

A logbook program run between 1994 and 1995 documented the number of undersize snapper returned by trappers in NSW. During that period, the catch of undersize snapper from over 12,000 trap-lifts was described. These data have provided an insight into the number of fish returned by professional trappers and into the distribution of those fish by season, depth, fisher and location on the NSW coast. We could not detect any relationship between the catch of undersize snapper and subsequent landings of fully recruited snapper.

Baited traps were tested as a means of estimating relative abundance of young of the year snapper. When compared with a demersal trawl in estuaries, a more standard survey method, baited traps and trawls had similar ability to detect spatial variation in juvenile snapper abundance. The cost of deploying traps in estuaries was similar to trawling for the same detection sensitivity. Baited traps are an appropriate tool for surveys of juvenile snapper in estuaries, and are particularly suitable where trawling is not applicable. This was not the case with large, professional-style traps used to survey juvenile snapper in nearshore coastal habitats to 50 m. Compared with trawl-based survey data over the same spatial scale, trawl surveys were a far more sensitive and efficient estimator of the relative abundance of juvenile snapper.

An analysis of allozyme frequencies for 8 snapper populations from the central coast of NSW to the northern limit of the species distribution in Mackay found no evidence of more than one genetic stock. Despite this, data related to growth, movement, otolith readability and other factors indicated

that most of the members of local populations did not migrate large distances as adults. Larval transport by the East Australian current, as well as large scale movements of a small proportion of the stock is believed to be responsible for the uniformity of stock identity.

Yield per recruit analysis showed that significant gains in yield in terms of both weight and value were likely to be achieved by increasing the minimum legal size of snapper in both Queensland and NSW. The model indicated that there was only a small likelihood of long term reductions in yield for increases of minimum legal size of up to 30% above present legal minimum sizes.

Access point creel surveys at 6 locations in southern Queensland were used to estimate recreational snapper catch rates. These estimates were used in conjunction with effort estimates derived from aerial surveys of offshore reefs to estimate recreational harvest. The recreational snapper catch in South-East Queensland between April 1994 and March 1995 was estimated at 148 tonnes (representing 163,125 fish) compared to a commercial catch of approximately 50 tonnes. In only 4 of 4400 interviews conducted had the snapper bag limit of 30 per angler been reached and over 65 % of offshore fishing trips failed to catch any snapper at all.

The size structure of the legal sized recreational catch of snapper in offshore waters was similar to that of the commercial fishery. However, a significant undersized component was found in the recreational fishery from inshore waters. Seventy five percent of snapper caught and landed in inshore waters were undersized while this percentage reduced to 10% for offshore recreational anglers. Compared to offshore anglers, inshore recreational anglers also reported catching and releasing a high proportion of undersized snapper.

Snapper populations at the northern end of the species range spawned during the winter, which is approximately 3 months earlier than populations from the more temperate waters of southern Australia and New Zealand. A consequence of this discrepancy in timing allows an extended early growing season for northern populations of snapper. Fecundities of snapper at the northern end of the species distribution were significantly lower than New Zealand snapper.

1. PROJECT BACKGROUND

1.1 Queensland

Historical Trends

The earliest reports which provide information on snapper fishing in Queensland come from an early Queensland naturalist named Thomas Wellsby who reported numerous large catches of snapper taken from offshore reefs of southern Queensland in the late 1800's. Perhaps the most notable of these was a catch of 567 "school snapper" weighing an average of 4.78 lb (2.2 kg) taken by 9 lines, whilst fishing 9 miles off Point Danger in 36 fathoms of water.

Reports of the Queensland Fish Board during the 1950's refer to snapper as " universally acknowledged as the premier game fish of the southern division of the State, referring to snapper weighing as much as 43 lb (19.5 kg) being relatively rare with "the ordinary market rate averaging no more than 5 or 6 lbs" (approximately 2.5 kg). In the 1950's officers of the Harbours and Marine Department were concerned about the "denudation of our home snapper grounds caused by the catching of undersized snapper by week-end boating parties." The "home grounds" they were referring to were the waters of Moreton Bay. Apart from these reports by early naturalists, information on the magnitude of the recreational catch for this species is almost non existent. There is, however, virtually universal acceptance that the magnitude of the recreational catch must have increased significantly over the years given the continuing increase in boat registrations and advances in GPS and sounder technology.

Records maintained by the Queensland Fish Board between 1937 and 1975 (Figure 1.1) showed a relatively dramatic increase in the commercial catch during the late 1940's. Prior to this time the larger categories (snapper) made up the majority of the catch, however by the 1950's the catch of larger fish had declined, being replaced by the smaller sized "squire". Unfortunately, during this time no records of fishing effort were maintained and there may also be some doubt over the criterion used to discriminate between snapper and squire. However, the pattern of a large increase in the catch of both snapper and squire and the subsequent decline and stabilisation of the catch of the larger snapper is consistent with the "fish down" of larger and older individuals from a previously lightly exploited stock.

What most of the pre 1960 historical reports of recreational and commercial catches have in common is an average size of snapper in the catch at around 4 to 6 lb (1.8 - 2.7 kg).

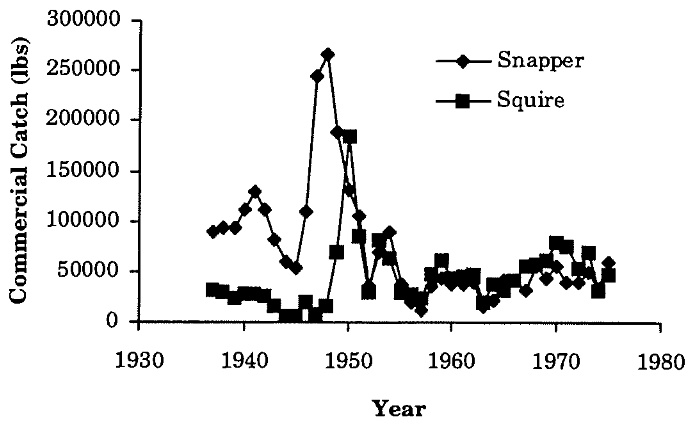


Figure 1.1 Commercial snapper catch recorded by The Queensland Fish Board between 1937 and 1975. Snapper and Squire were artificial categories used to differentiate between different size grades.

No commercial catch statistics were collected between 1975 and 1987, however, QFISH, a compulsory commercial logbook system was implemented in 1988. Cursory examination of this database shows total commercial snapper landings of around 100 tonnes during the last 8 years (Figure 1.2). Likewise, there has been little dramatic change in catch per unit effort (CPUE). The impact of a change in the management regulations in 1993, which saw a 5 cm increase in the minimum legal size for snapper, was evident in the data. Theoretically, such an increase should have produced a short term decline in the CPUE and this was evident in the log book data, however it is also interesting to note that both the CPUE and the catch recovered fairly rapidly (within 12 months).

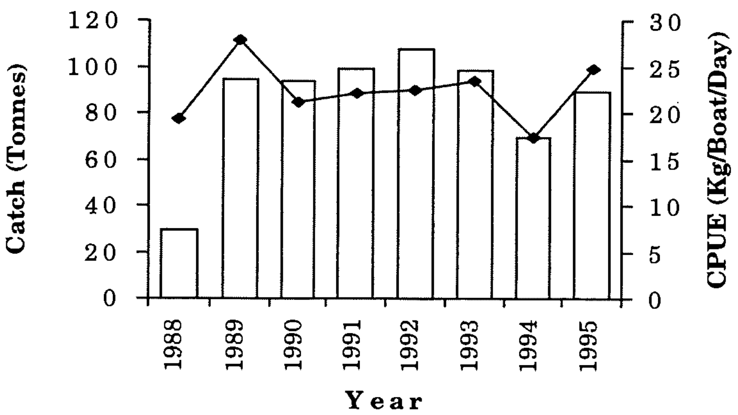


Figure 1.2 Annual trends in commercial snapper line catch (Bars) and Catch per Unit Effort (Line) Data from QFISH summary database

Seasonal trends show that the majority of the commercial catch is taken during July to September with catches displaying a steady increase from February (Figure 1.3). This is consistent with the fishing of spawning aggregations, a feature which has been demonstrated in snapper fisheries in both New Zealand and Southern Australia

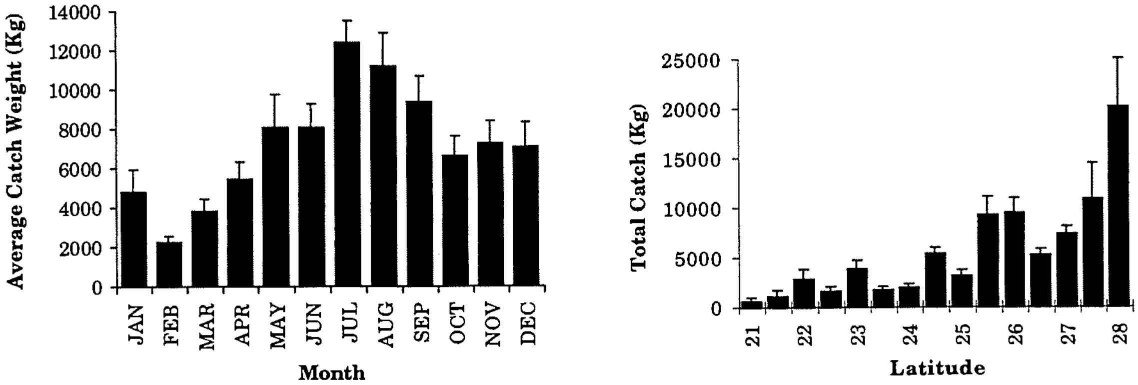


Figure 1.3 Seasonal and latitudinal trends in commercial snapper line fishery catch. Data are averages with standard errors for the years 1988 - 1995. (Data from CFISH summary database)

Due to the lack of historical fisheries data the validity of anecdotal reports of a marked decline in snapper catches over the last couple of decades could not be assessed.

Method of Fishing

The majority of fish landed by the commercial sector are line caught fish, however there are a couple of NSW licensed fishers who use traps in waters off the Gold Coast under a joint Commonwealth - State offshore arrangement. Analysis of the commercial logbook data shows that there is a small trawl by-catch component and a small proportion caught in gill and tunnel nets, largely as a by-catch in Moreton Bay and Hervey Bay. The total quantity taken by trawling and netting is less than 10 tonnes however this may well be an underestimate due to reporting irregularities of fish captures in the trawl fishery database. The recreational catch is taken almost exclusively as line caught fish. Regulations governing the line gear used by both sectors are identical, and in offshore waters the rigs commonly consist of lead sinkers of 100g to 1 kg with a variable number of 3/0 to 7/0 hooks (either individually or ganged) positioned above the sinker. Larger snapper can also be taken on these rigs, however they are usually taken using “floaters”, a rig comprising a running ball sinker (usually No 8) and ganged hooks. Variations on these rigs are enormous as is the preferred bait and line type. Sea and wind conditions as well as current speed and direction play an important role in determining the type of fishing gear and fishing strategy used.

Spatial Distribution of Fishing Grounds.

The major snapper fishing grounds are situated in offshore rocky reef areas in depths between 20 and 100 metres although larger snapper can be taken in water over 150 metres in depth. The majority of the catch is caught south of the northern tip of Fraser Island (latitude 24°30’), however significant commercial catches are also taken at times around the Capricorn Bunker group (23° - 24° latitude) and outside the southern end of the Swains reefs (22°30’). The general trend is for commercial catches to increase south from

Mackay with the largest catches recorded on the Gold Coast There are large and important recreational fisheries inside Moreton Bay and Hervey Bay as well as in the same areas as the commercial sector.

Degree of Utilisation by Commercial and Recreational Sectors.

Since the establishment of the commercial logbook system in 1988 the commercial catch has been modest, at around 100 tonnes. Snapper are also regarded as the premier offshore recreational species in Southern Queensland, however the extent of the recreational fishery is unknown but is believed to be substantial. One of the main reasons for undertaking the current research revolved around uncertainties about the magnitude of the recreational catch.

Markets and Commercial Value

Snapper caught locally by line are mainly destined for export markets as whole gut-in fish. An export market for live fish is being developed and this is an area that is likely to see considerable expansion in the future. Trap caught fish are predominantly destined for the Australian domestic market as gilled and gutted fish, because their condition is inferior to line caught fish. The domestic market also takes line caught snapper as whole fish (gut in), gilled and gutted fish and as fillets. The price per kilogram varies seasonally however assuming an average price of $6.50 per kilogram (whole weight) to the fisher would value the Queensland commercial catch at $585,000 in 1995.

1.2 New South Wales

Historical Trends

Records of NSW snapper landings are available from 1952 to 1994 and are shown in Figure 1.4 Average annual landings are around 650 tonnes but landings have not been above that level since the mid 1980's. Year-to-year variation in landings has often been high, and annual differences of 150 tonnes or more have been relatively common (Figure 1.4).

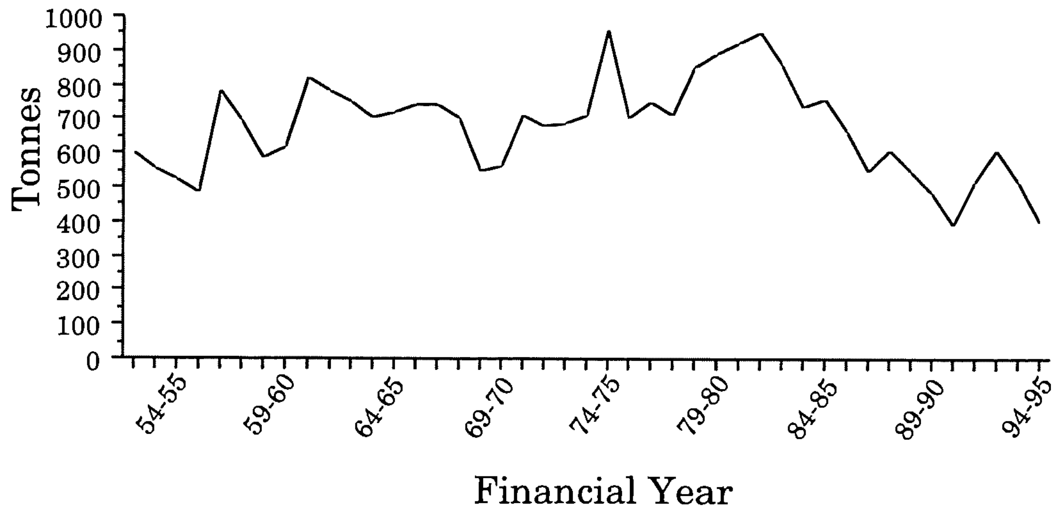


Figure 1.4 Annual commercial landings of snapper reported on catch returns in NSW between 1952-53 and 1994-95 financial years.

Season and Location of Catch

About 60% of the commercial snapper catch comes from the northern third of NSW. The one-degree reporting area from 30°S to 31°S, surrounding the port of Coffs Harbour traditionally has the highest landings of snapper of any comparable area in the state (Figure 1.5 a). In the far north of NSW, the largest landings are in winter-spring and there is little snapper fishing in summer. The difference between the quantity of snapper landed in summer and winter diminishes and the pattern becomes somewhat reversed in southern latitudes (Figure 1.5 b).

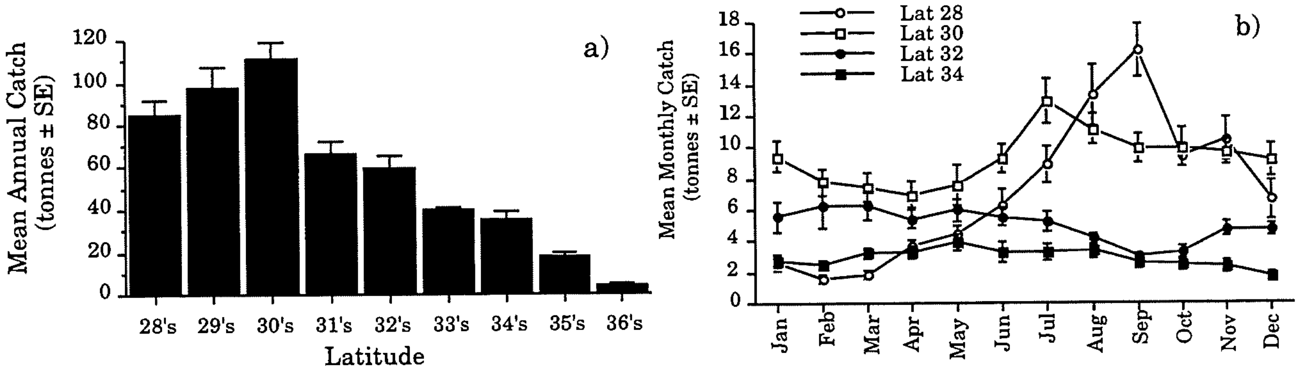


Figure 1.5 a) The distribution of average annual commercial landings of snapper in NSW by one-degree bands of latitude. b) Average monthly commercial landings of snapper for selected one-degree bands of latitude (Data are means for the period 1984 to 1995).

Method of Fishing

Demersal fish traps are the main method of capture in NSW but records do not allow a precise estimate the distribution of catch by method. At least 30% of all landings were caught in traps and 23% of all landings were caught using other methods. A large proportion of the remaining 47% of the total catch is likely to have been caught in traps because trapping was listed among several methods and because most trapping targets snapper.

Recreational Sector

The recreational fishery for snapper is active along the entire NSW coast. In a recent two year survey of offshore trailer boat anglers, snapper was the second most caught species by weight in both years of the study (Steffe *et al.* 1996). The estimated catch by the recreational trailer boat fleet was in excess of 180 tonnes per year in both years. The distribution of the recreational snapper catch along the NSW coast mirrors the commercial catch, with the largest landings coming from the northern third of the state. However, the proportional division between recreational and commercial landings changes from north to south. In the north of the state, recreational catches of snapper are between 25% and 36% of the commercial landings in the same area. However, commercial catches are much less in the southern part of NSW and the quantity of snapper caught by recreational and commercial fishers is very similar (Steffe *et al.* 1996).

Value of Commercial Landings

The value of commercial snapper landings in NSW varies with supply and according to variation in price and supply of other, competing species. In the three financial years from 1990-91, estimated value at point of first sale has varied from 3.1 million dollars in 1990-91 to 4.8 million dollars in 1992-93 (Pease and Scribner 1993, 1994, Scribner and Kathuria 1996). Prices in 1995 averaged about $11.00/kg at the Sydney Fish Market, but were much higher in the same market for fishers with an established reputation for high quality (see Section 11, below).

2. NEED

The snapper, (*Pagrus auratus*) is one of the most common and most sought after species by commercial and recreational fishers across the coastal waters of southern and eastern Australia. Over recent years evidence of a long term decline in commercial catches in NSW has emerged (See previous sections) and there is anecdotal evidence from commercial snapper fishers in Queensland. As a result of declining commercial catches and apparent increase in recreational effort, there is a clear need to review existing management arrangements for snapper. In Queensland, commercial fishers are under identical restraints on gear and other regulations as recreational anglers. The commercial catches since 1988 are known from the C-Fish database, but little is known about the catch and effort of the recreational sector. This lack of information is a serious impediment to an assessment of the fishery because recreational effort is likely to be many times greater than commercial effort. In contrast, NSW has a much larger commercial fleet that target snapper (predominantly using traps) and in the face of declining catches, there is pressure on managers to reduce commercial fishing effort. The potential harm to snapper recruitment from prawn trawling has been highlighted by the FRDC funded project (No. 88/108) to quantify by-catch of prawn trawlers in NSW and this is an area of intense public interest in both states

While the structure of the fishery for snapper is very different in the two states there is common information needed by managers in both NSW and Queensland. In addition, there are several areas where further development of research methods is needed in both Queensland and NSW (and other states) before the traditional tools of fisheries stock assessment can be applied. Our approach in this research was to undertake a series of sub-projects which address problems with methodology, as well as providing management information which can be applied across the snapper fisheries in both states.

Since the drafting of the original proposal there has been an increased need identified by Management Advisory Committees in Queensland for monitoring of important fish stocks such as the snapper. Being mindful of this need we have extended the size and age structured sampling program of the original proposal to enable a longer time series of data to be collected. As research priorities are set in future, the long term commitment to this monitoring by each state may be ongoing. If this is the case, then the extra data collected will provide a longer, and more continuous time series than was originally proposed.

3. OBJECTIVES

1. To estimate the recreational snapper catch in the Moreton Region and evaluate methodologies for estimating offshore recreational effort.

2. To provide fisheries managers with models for assessing the impact on yield of proposed changes to the legislated minimum legal size of snapper.

3. To provide fisheries managers with information on the genetic relationship between snapper populations in south Queensland, Northern New South Wales and east of the Swains Reefs (Southern Great Barrier Reef).

4. To develop methods of estimating relative abundance and year class strength of juvenile snapper.

3.1 Achievement of Objectives

The original proposal for the assessment of offshore recreational catches in south-east Queensland involved the use of research and enforcement staff to intercept vessels as they were re-entering each of three coastal bars on their return from fishing trips. After an initial 3 month pilot program, which established the most frequently used access points and the extent of recreational involvement in offshore fishing at various locations it was decided to alter the methodology in favour of an access point boat ramp survey at 6 locations. This was because there were more than 3 important access points for offshore fishers in the Moreton region and the interception of vessels proved difficult due to weather conditions and the loss of interviews due to fishers returning across coastal bars in groups. The change in methods allowed for a greater coverage of the survey area (covering 6 locations instead of 3). The estimates derived from the survey whilst probably being underestimates still provide the first estimates of the magnitude of the offshore snapper catch in southern Queensland. In addition, data have also been collected on a number of other offshore species including Pearl Perch, Teraglin, Jobfish and various mackerel species. Information on inshore species has also been collected, and recreational harvest estimates and other statistics for these and other species are currently being derived and will be reported separately to management agencies in NSW and Queensland.

Yield per recruit models are presented which allow managers to see the impacts of proposed changes to snapper minimum legal sizes. Lack of precision in estimates of natural mortality used in these models is perhaps their greatest weakness, however we have attempted to minimise this by using monte carlo simulation to test the sensitivity of the models to variation in natural mortality. Likewise we have used conservative growth parameter estimates which if anything will understate the increase in yield with increasing size at capture.

Although not explicitly stated in the objectives, perhaps the most important part of the research was to collect size and age structured catch information on the commercial fishery along the east coast. These data have been used to derive total mortality estimates which have helped us choose more accurate ranges of fishing and natural mortalities used in the yield models. They are also a prerequisite for the construction of age structured models. These data will be most useful in the future if age structured data continue to be collected since such models require a reasonable time series of catch-at-age data. The original proposal only allowed for the collection of two years of age structured information, however our established links with commercial snapper fishers allowed the collection of 3 years data which has been presented in this report. In addition, a further year's data (1996) has been collected, and, along with data presented in this report, will form the basis for the long term monitoring of this resource. Prior to this study there was no age based catch information for the east coast snapper fishery. Limited size based information existed for the NSW fishery, collected as part of a study by Henry (1990).

The genetics component of this proposal was only a minor component, initially involving sampling at 4 locations along the east coast. However, we were able to expand the spatial scale of this component of the work to include areas in central and southern NSW, making up a total of 8 sampled populations. The results provide some evidence for stock structure although the populations were not considered to be genetically isolated

Prior to this project, surveys of juvenile snapper in Australia had only ever been done with demersal trawl gear. We have demonstrated that baited traps can be as efficient, and provide robust and sensitive estimates of snapper abundance as the standard method. Baited traps have been confirmed to provide a useful alternate survey tool in situations where a trawl cannot be used. As a result of our developmental work on trapping, we can now provide estimates of the relative cost and efficiency of baited traps compared to demersal trawls.

We successfully tested a logbook to estimate catches of snapper in commercial traps. The logbook collected data from more than 14,000 trap sets across central and northern NSW over 2 years. Although keeping the interest of the voluntary participants was time consuming, the logbooks provided insights into the distribution of juvenile snapper at spatial and temporal scales that could not be gathered any other way. The logbook also provided an excellent description of commercial trapping activity.

4 AGEING TECHNIQUES

4.1 Introduction

The ability to estimate the ages of fish using bony structures has become a key technique in fisheries science. Age estimates provide insight into population structure, growth, stock identification and the effects of fishing (see Secor *et al.* 1995). Age-structured estimates of population status can be amongst the most powerful tools for monitoring and assessing fish populations (reviewed in Megrey 1989).

There are a wide variety of methods used to estimate the ages of fish and these vary in cost, precision and accuracy (e.g. Libby 1984, Lai *et al.* 1987, Richards *et al.* 1992). Accurate estimates of age are much more difficult, and therefore less common, than precise estimates of unknown accuracy (Beamish and McFarlane 1987). Accuracy of age estimates must be determined using one or more of the commonly used methods of validating the periodicity of increment formation (Beamish and McFarlane 1983) The accuracy of snapper age estimates has been established in New Zealand (Francis *et al.* 1992) and for young fish only in central NSW (Ferrell *et al.* 1992).

Assuming age estimates are accurate, the precision of age estimates from different methods can be measured relatively easily (e.g. Kimura and Lyons 1991). The precision and cost of age estimates both have important impacts on the size of samples needed to estimate the age composition of a population (Worthington *et al.* 1995), and how such age compositions can be used in age structured analyses (Bradford 1991).

In this section we document the precision with which age estimates of snapper can be made using a variety of methods. We also present further evidence regarding the accuracy of age estimation in snapper. The description of sources of ageing error will allow us to make decisions about age estimation methods that may be less costly, providing either lower cost or more precise estimates of age composition from larger samples for the same cost (Worthington *et al.* 1995).

4.2 Methods

The sampling for material used in this section is described in Chapter 5.

Otolith preparation and reading

Otoliths were examined whole, sectioned and by breaking the otolith transversely across the focus and burning the exposed material. Sections of otoliths were prepared by mounting clean, dry otoliths in clear epoxy resin. A section through the focus of the otolith was made using a low speed saw with two diamond blades spaced to leave a gap of about 0.25 mm. The resulting section was lightly polished on an abrasive sheet (9 µm Imperial Lapping Film, 3M LTD) and mounted on a standard microscope slide. Thin sections were viewed with reflected light at a magnification of 20 X on a compound microscope. For broken and burnt viewing, otoliths were broken through the focus and baked in an oven at 28° C for five minutes. The broken surface of the otolith was polished on 1200 grit abrasive paper and the polished surface coated with glycerine for viewing. Whole otoliths were immersed in glycerine against a black background to enhance viewing of the distal surface. Whole and broken, burnt otoliths were read under reflected light at magnifications between 6 X and 25 X using a dissecting microscope.

All otolith reading was done without knowledge of the size of fish or the month or location of capture. Where multiple readings of the same material were done, the readings were separated by minimum of several weeks so that the individual readings could be considered independent. Where samples were chosen to represent a particular location or size category, otoliths were chosen at random from the appropriate strata.

Ages estimated from thin sections were counts of completed opaque rings. The first ring was assigned as the ring where the zone of sagitta-subcupular mesh work fibres (SMF) first deflected (M. Francis *et al.* 1992). The position of the distal ring with respect to the margin of the otolith was estimated from sections of otoliths on slides. Newly formed increments are usually first visible in the dorsal margin of the otolith (L. Paul, pers. comm.) and the status of otolith margins was only made on that arm of the otolith. Otolith margins were classified into three groups: (1). opaque margins, (2). margins where the distance between the terminal ring and the edge was less than 25% of the distance of the previously completed ring and (3). margins where the distance between the terminal ring and the edge was greater than 25% of the previously completed ring.

For many age estimates, a subjective index of confidence or readability was assigned. Initially, this index was simply for reference in order to check outliers. However, it became clear that this subjective index related closely to precision of multiple readings (see below) and thus it was used to segregate data and to repeat analyses with subsets of data in which we had a high level of confidence. The index was comprised of 4 readability classes. Class 1 was assigned to otoliths that were perfectly clear and unambiguous. Class 2 was assigned to otoliths where the interpretation was still unambiguous but not perfectly clear. Class 3 otoliths had an alternate, plausible interpretation leading to a different age than the one assigned, which almost always involved a single difficult ring that made the next most plausible age within one of the age assigned. Class 4 otoliths had multiple plausible interpretations, making it difficult to assign an age estimate.

The precision and bias of age estimates, both between age readers in NSW and Queensland and within the single reader for each state, was estimated by multiple readings of sectioned otoliths from 194 fish. In order for the readings to be considered independent, both readers read each sectioned otolith twice, with an intervening period of several weeks. Sections were identified only by sample number and no knowledge of the size of the fish was made available to the readers. Just over half (100) of the samples came from Sydney and the remainder were from Fraser Island. Both sets of samples were a random selection of the material available from those locations (Figure 4.1). Precision was estimated using the mean coefficient of variation (CV) and the percentage agreement of multiple readings (Kimura and Lyons 1991). Within-reader bias was estimated between pairs of readings by age group. Age group was defined by the first reading and the bias was the deviation in years of the mean age of each group from the second reading (Kimura and Lyons 1991). For example, if there were 10 fish assigned to the age class 2^+ in the first reading, but 5 of these were scored as 3^+ in the second reading then the bias between readings would be -0.5 years. Bias between readers or labs was treated the same way as that for within readers except that the age used was the mean age of paired readings. Where the mean age was not an integer, one of the two age estimates was chosen at random.

Precision of reading using different methods of ageing

A trial was conducted to examine differences between ages estimated from sections of otoliths, whole otoliths and broken and burnt otoliths. Age estimates from scales were not included in this trial because our initial examination of scales suggested that they were extremely difficult to interpret, particularly from northern NSW and Queensland. We also examined the precision of multiple readings based on fish size rather than age, in order to provide advice on which sizes of fish might be aged using less expensive methods.

We used two relatively inexperienced readers for this trial because both principal investigators had extensive experience with otolith sections but relatively little experience with the other methods. We wanted to assess the different methods from the basis of readers having equivalent experience among each of the methods. Otoliths from five size classes were compared from two locations in NSW (Sydney and Ballina). Five contiguous 2 cm size groups were chosen, starting from 24 cm (i.e., the five groups were 24-25 cm, 26-27 cm, 28-29 cm, 30-31 cm and 32-33 cm). From each location in each size class we selected 25 fish and for each of those 250 fish, each reader made two independent estimates of age from whole otoliths, broken and burnt otoliths and from otolith sections (i.e. a total of 3000 age estimates for both readers combined). Because of their widespread acceptance as an age estimation method (but see Milton *et al.* 1995), sectioned otoliths were used as the standard with which the other two less costly methods were compared.

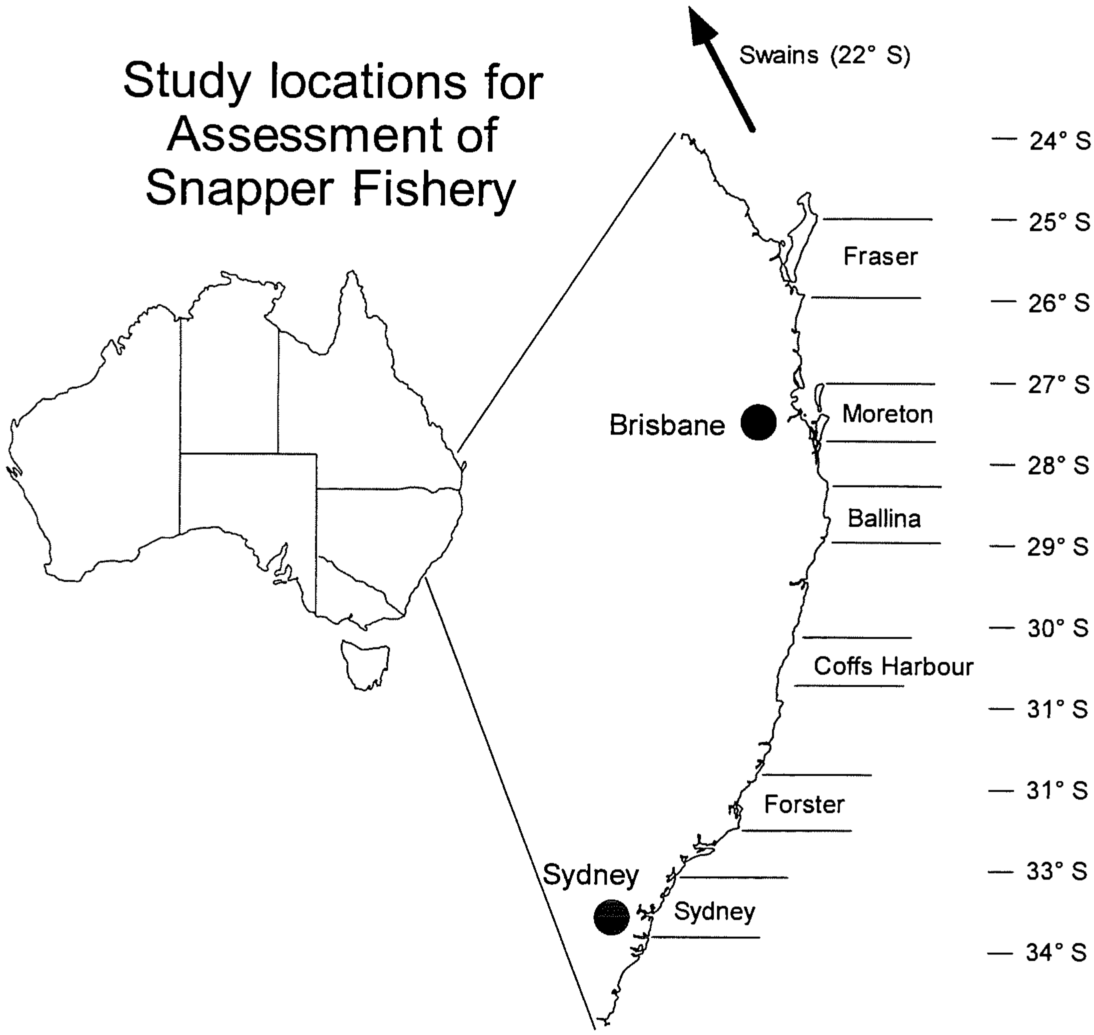


Figure 4.1 Map of the locations used for sampling commercial landings of snapper in this study.

4.3 Results

Validation

In fish with two or three rings, the position of the distal ring with respect to the edge of the otolith section throughout the year provided strong support for the hypothesis that rings are formed annually in late winter and spring (Figure 4.2a). The greatest proportion of otoliths with opaque edges were found in November and in the adjacent months. The peak occurrence of otolith margins where the terminal ring was distant from the edge of the otolith was in late autumn and early winter, although sample sizes for June and July were relatively small (Figure 4.2a).

The ability to interpret the margins of otoliths decreased progressively north of Sydney (Figure 4.2a). In Ballina, nearly 45% of otolith margins could not be interpreted, compared with 21% in Sydney. While this interpretation difficulty did not change with season, it was the reason that scoring of margins was abandoned in samples from Queensland. We were unable to determine whether there was any effect of location on the timing of the formation of rings because sample sizes in some months from some locations very low.

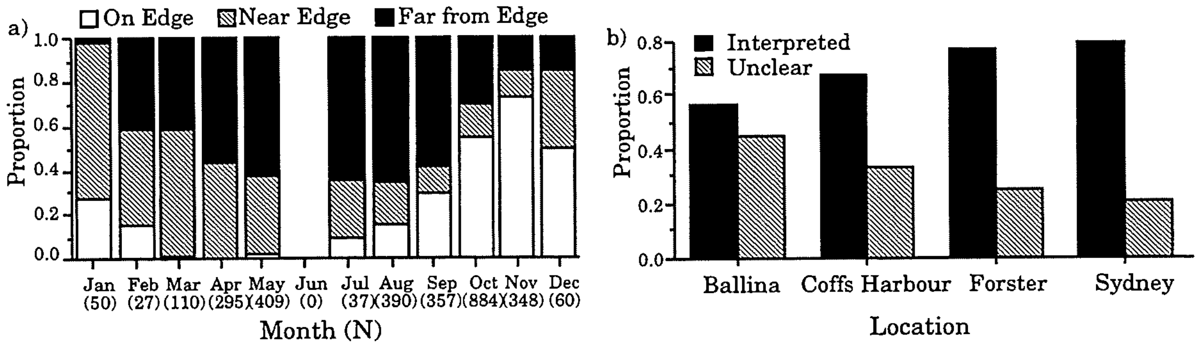


Figure 4.2 a) Proportion of otoliths with margins in different conditions in different months of the year. Sample sizes for each month are shown below that month and only two and three year old fish are included. b) The proportion of otolith margins from thin sections that could be interpreted by sampling location in NSW.

Precision and bias between NSW and Queensland reading

The precision of age estimates was poorer for fish from Fraser than for fish from Sydney. The mean CV of paired readings by WDS was 4.9% on fish from Fraser and 1.3% on fish from Sydney. Similarly, readings by DJF had a mean CV of 5.6% on fish from Fraser and 2.3% on fish from Sydney. The percent agreement among all four readings gave a similar result. All four readings agreed in 71% of fish from Sydney and 44% from Fraser. Over 13% of fish from Fraser had differences among the four readings of two years or greater, with no more than two agreed readings. The maximum difference among the four readings from any NSW fish was one year.

Overall mean bias between the readers from NSW and Queensland was negligible (0.04 years), however there were differences in age assignments for some year groups (Figure 4.3). The two readers assigned ages differently in one group of young fish from NSW (Figure 4.3). DJF assigned age estimates of 1^+ to 11 fish from Sydney and WS scored half of these as 2^+, leading to a bias of about 0.5 of a year (Figure 4.3). These age assignments were the only consistent difference between readers that were geographically based (there was only one fish from Fraser assigned as 1^+). DJF's second reading of all fish was biased upward relative to that of the first reading by 0.11 of a year. With the exception of 1^+ fish, biases between the two readers were small and within the range of differences found within consecutive readings by the same reader. Apart from the 1^+ fish that were mostly from NSW, there were no differences in between-reader bias in the collections from the two locations. The between-reader differences seen in older fish were not in a consistent direction and may have been affected by relatively small samples (Figure 4.3).

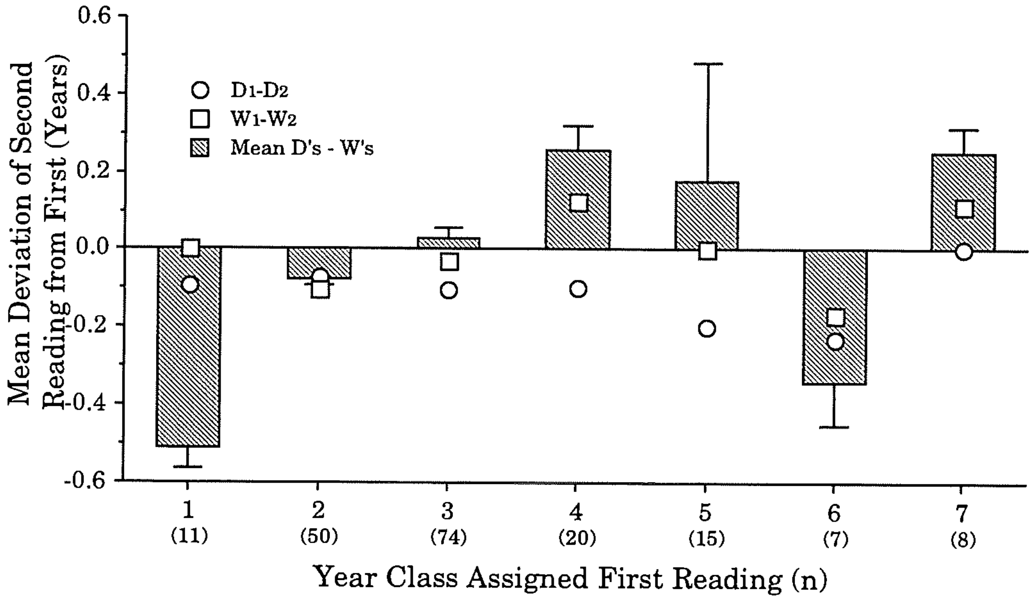


Figure 4.3. Bias between sets of readings by readers from NSW and Queensland. D_1-D_2 refers to differences between first and second readings by DJF. W_1-W_2 similarly refers to readings by WDS. Bars show the mean (± SE) of the four possible combinations between DJF and WDS.

Cost and precision of different methods

Otolith sections took the most time to process and read (Table 4.1). However, this could be attributed to the large differences in processing time among methods. Both broken and burnt and whole otoliths took more time to interpret than did sectioned otoliths.

Table 4.1 Cost of different methods of preparing otoliths for age estimation. The methods are assumed to have equal cost until otoliths are prepared for viewing. All costs are given in hours per 100 otoliths processed

Process	Otolith thin sections	Broken and burn otoliths	Whole otoliths
Preparation	5	2	0.5
Reading	2.5	3	4
Total	7.5	5	4.5

As in the comparison of precision using readers from NSW and Queensland, readers in this trial found much more difficulty interpreting otoliths from northern NSW than from Sydney (Figure 4.4). Geographic differences in precision of age estimates were found and age estimates of fish from Sydney were more precise than estimates from Ballina (Figure 4.4). This geographic variation in ageing precision was found across all methods of ageing. For all ageing methods there was a trend towards higher precision of age estimates in larger fish compared with smaller fish.

The results from the two novice readers were similar overall, but differed from each other in a complicated way that prevented pooling of the two readings by each reader of each fish using each method. For example, Reader 1 was less precise than Reader 2 when reading the broken and burnt otoliths from Ballina (Figure 4.4). Even though there were differences in ageing precision estimated by the two different readers, their results were broadly similar between Sydney and Ballina and among the three methods. The precision of age estimates from broken and burnt otoliths and from sections did not differ and the precision from whole otolith age estimates was usually similar to the other methods (Figure 4.4). Age estimates from some groups of whole otoliths were of lower precision than estimates from other methods, but no trends were evident with respect to location or fish size.

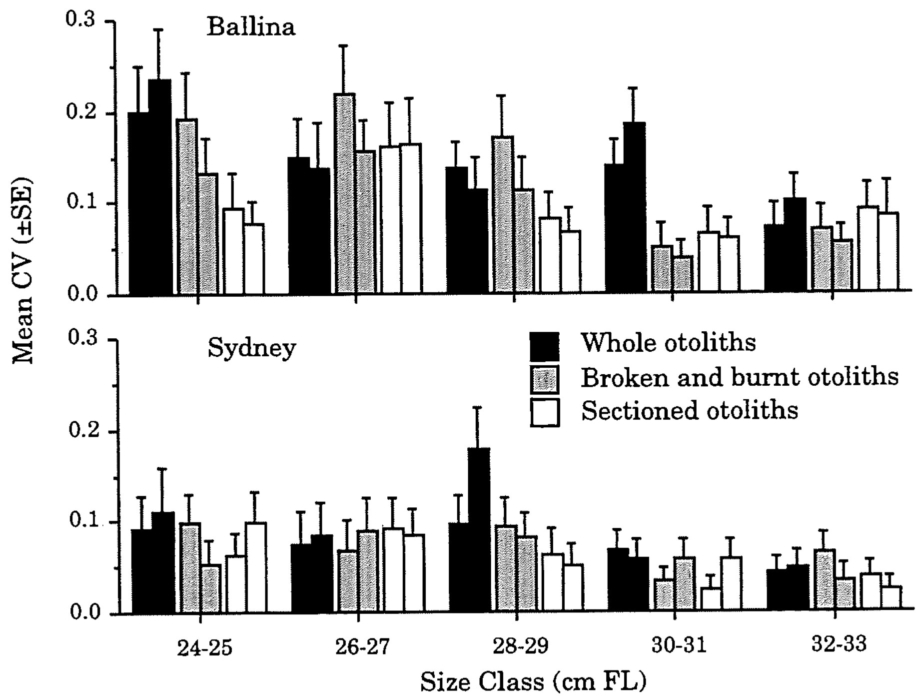


Figure 4.4 Mean CV for repeated age estimates from whole, broken and burnt and sections for Ballina and Sydney. Paired estimates are from two different readers. Estimates from Reader 1 are always the left of the paired histograms.

Age estimates from both whole otoliths and from broken, burnt otoliths were biased relative to ages from sections. Readers underestimated the ages of fish using whole and burnt otoliths relative to sections and the degree of the underestimation was greater for fish from Ballina than for fish from Sydney (Figure 4.5). The bias in some size classes from either location ranged from 0 up to 0.5 years. For most size classes, the bias in age estimates using whole otoliths was greater than that for ages derived from broken, burnt otoliths (Figure 4.5).

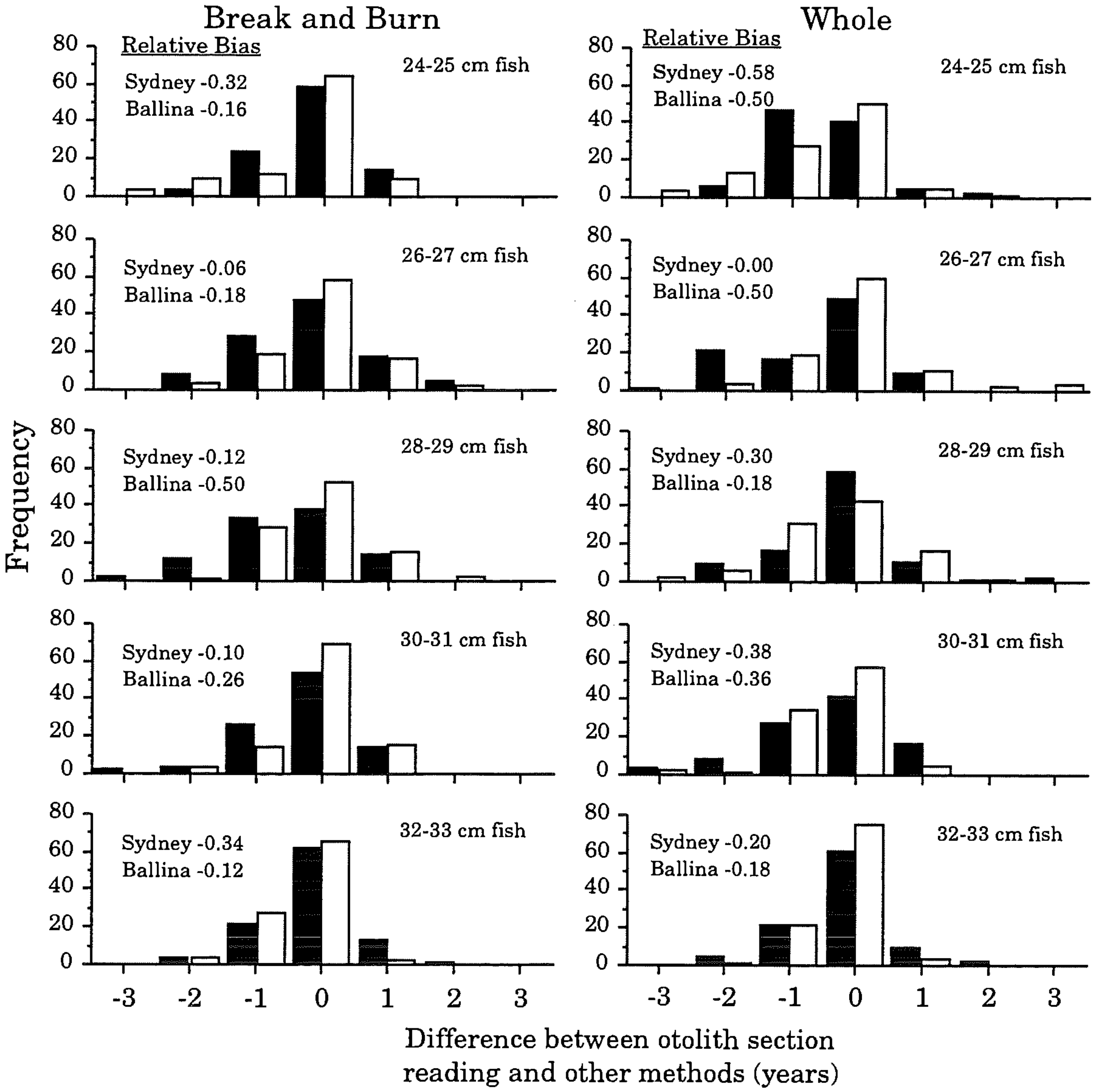


Figure 4.5 Frequency distribution of all possible paired comparisons between independent age estimates from otolith sections and other methods. Fish were from Ballina (solid histograms) and from Sydney (open histograms). All readings are from Reader 2 only and estimates of relative bias are in years.

We reviewed examples of this underestimation after the reading and analyses were complete to determine the reason for the bias. In particular, we were interested in material where the within-method precision was high, but with lower age estimates from the non-section methods. There were two common sources of underestimation for whole or broken and burnt otoliths. The most common source was due to the terminal ring being identified more clearly in the otolith sections than by other methods. When the most recently formed ring was close to the edge of the otolith, that ring was often visible in otolith sections but it was difficult to see in whole or broken and burnt otoliths from the same fish. Some of the bias of whole otolith readings relative to thin sections also came from rings that were clearly separate in sections but had been lumped into a single ring when reading whole otoliths.

Geographic variation in precision

The subjective assignment of readability or confidence was a good indicator of the expected precision of multiple readings. The four subjective readability categories were associated with a significant trend in mean CV (Figure 4.7, $F_{3,190} = 3.10$, $P<0.05$). The distribution of the subjective scores varied among the four NSW locations (Figure 4.8) and there was a consistent trend in the distribution of the index from south to north. Each location north of Sydney had increased proportions of fish that were difficult to interpret compared with fish from the nearest location to the south (Figure 4.8, Chi-square = 481.6 with 9 df $P < 0.05$).

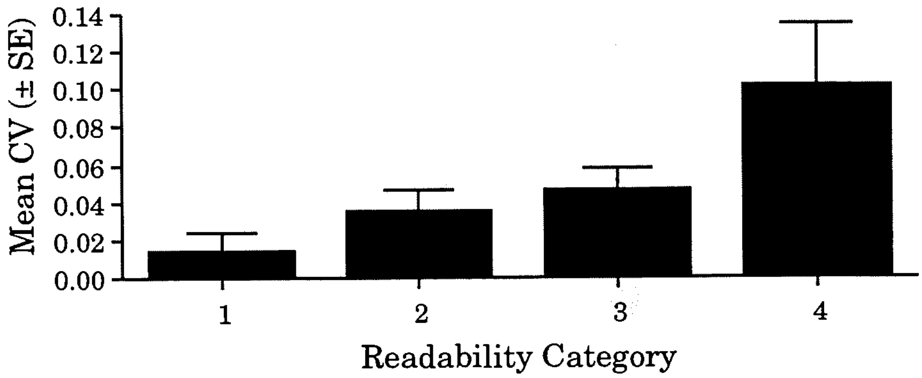


Figure 4.7 The relationship between the 4 subjective readability categories and the CV of repeated readings of otolith sections from those categories

4.4 Discussion

Validation and the accuracy of age estimates

The marginal increment validation presented here for 2 and 3 year old fish is consistent with other published ageing validation studies on snapper (Ferrell *et al.* 1992, Francis *et al.* 1992). We found that fish collected in November had the highest frequency of otolith edges that were scored as opaque and that fish collected in July and August had the highest proportion of otolith edges where the terminal ring was distant from the otolith edge. This is consistent with the formation of the opaque zone in winter or spring, which has also been reported for snapper by Ferrell *et al.* (1992) and Francis *et al.* (1992) and is also consistent with the studies reviewed by Beckman and Wilson (1995). Francis *et al.* (1992) suggested that there is a lag between the time when the opaque zone is formed and when that feature can be seen and counted. They suggested that the opaque ring is formed in winter and becomes visible in October or November in fish younger than 4 years. Our study of increment margins in fish with 2 and 3 opaque increments supports this conclusion.

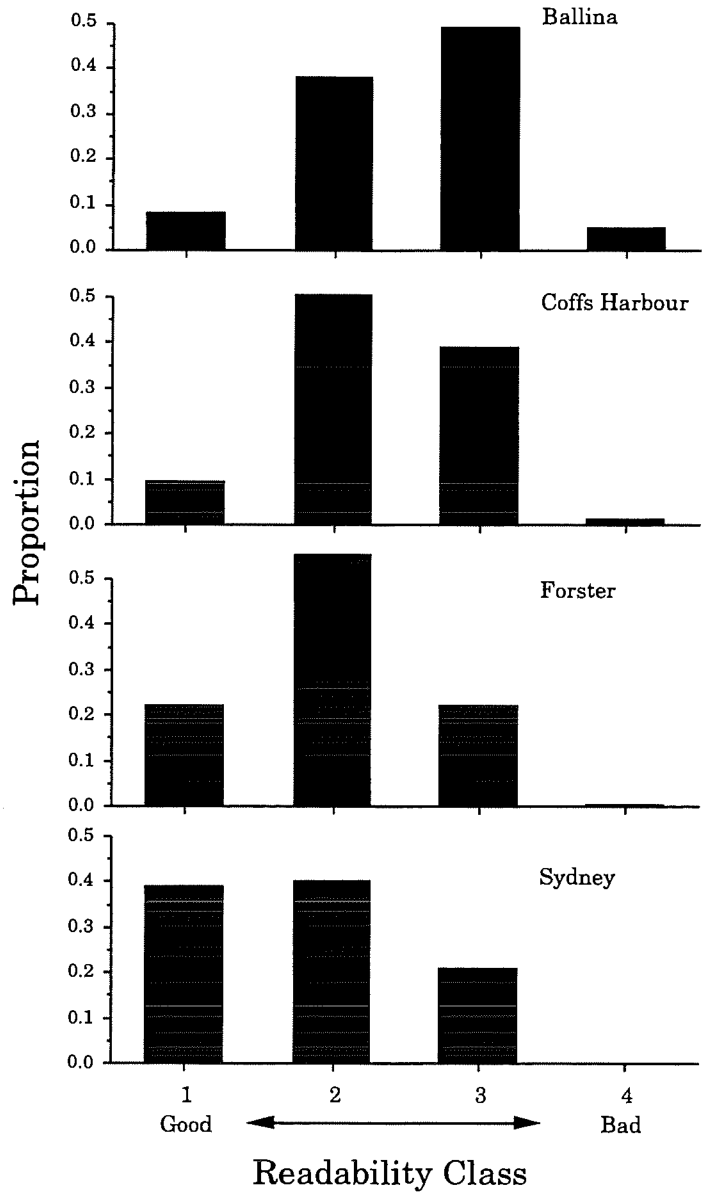


Figure 4.8 Frequency distribution of readability scores from each of the 4 sampling locations in NSW.

It has commonly been assumed that when sectioned otoliths provide age estimates higher than the estimates from whole otoliths, that estimates from whole otoliths are likely to be below the true age (Beamish and McFarlane 1987). This difference is thought to reflect changes in growth of the otolith with age and that, after a point, otolith growth is only on the interior surface and can only be seen in a section. This is probably not the reason for the bias we noted in age estimates from whole otoliths relative to otolith sections. We must consider the possibility that age estimates from whole otoliths may be correct. For example, Milton *et al.* (1995) found that age estimates from otolith sections in tropical lutjanids were greater than the ages they considered to be most accurate. We did not study increment margins in whole otoliths and we cannot say for certain that that the section ages are likely to be more accurate. Ages estimated from sectioned snapper otoliths have been validated (Ferrell *et al.* 1992, Francis *et al.* 1992) but no such work has been applied to whole snapper otoliths.

Our confidence in the periodicity and time of formation of opaque marks is limited by two features of our data. The first is that we restricted our analyses to fish aged 2+ and 3+ years because of the scarcity of older material in many months. In all study locations, at least 60% of the total catch was comprised of these two age classes (see Chapter 5) and so we feel that our age estimates are likely to be correct for the bulk of the fish in the fishery, if not all of them. The second feature is the decline in our ability to interpret the margins of otoliths in each successive location north of Sydney. This means that the certainty of our marginal increment validation must also decrease with decreasing latitude. Validation studies are often assumed to apply to a species throughout its range and we know of no study that has demonstrated an effect of geographic variation on the process of ageing validation. However, we suggest that the geographic variation in interpretability of snapper otoliths from this study demonstrates that further validation work on snapper would be useful.

Precision, bias and cost

Relative bias between NSW and Queensland readers was negligible, providing confidence in the relativity of the age estimates generated in the two laboratories. Age estimates from 2+ and 3+ age groups, which dominate the fishery in both NSW and Queensland, had bias between the two primary readers that was of the same order as bias found between readings by the same person. The only bias between the two readers that was of any importance was in a relatively uncommon age class, 1+ fish. Such young fish are rare in the fishery in Queensland and it is possible the Queensland reader simply did not expect fish of that age. Readers did not know any details of the samples they were reading but expectations can be a powerful influence on interpretation of otoliths (see Kimura *et al.* 1992, Fletcher and Blight 1996).

Both within and between-reader precision of age estimates for the experienced NSW and Queensland readers was high compared with many published estimates (Kimura and Lyons, 1991, Campana *et al.* 1995). This was particularly true with fish from Sydney (see below). This high precision is seemingly at odds with our finding of a large proportion of difficult otolith edge assignments, discussed above. Our scoring for this test of precision excluded interpretation of the otolith edge. This extra source of potential errors clearly demonstrates the point of Francis *et al.* (1992) that counting rings and assigning year classes are different parts of the same process, and that both are subject to separate sources of imprecision. Francis *et al.* (1992) used an algorithm which ignored the state of the otolith edge but used the month of capture and age of the fish to turn a count of opaque rings into an age assignment. Alternately, Horn (1993) uses edge condition in some months when assigning ages to jack mackerel. This latter approach is probably not appropriate for snapper from northern NSW and Queensland because of the high number of fish from those locations with otolith edges that cannot be easily interpreted.

The two less costly methods had somewhat poorer precision and some bias when compared with otolith sections and under-ageing relative to otolith sections occurred. The difference in precision was associated with extra time needed to interpret whole and broken and burnt otoliths but even with this extra time both methods were still substantially cheaper than processing sections. The trend toward higher precision in larger fish was probably due to the CVs in the first couple of size classes being inflated by 1+ fish, where any imprecision contributed to high mean CVs. This has been discussed by Hoenig *et al.* (1995) who argued that mean CV may not be an appropriate measure of age-independent ageing precision. We disagree that mean CV is inappropriate and concur with Campana *et al* (1995), who found that CV, in combination with bias plots, was a good way of describing differences among readers or methods.

We view the break-and-burn technique as an appropriate method for ageing the majority of fish from the commercial fishery (i.e., two and three year old fish). The loss of precision relative to thin sections can be compensated by the larger samples that could be processed because of the lower cost. We think that the relative bias between age estimates from broken and burnt otoliths and the estimates from thin sections can be overcome by sampling at appropriate times of the year (see Francis *et al.* 1992). The most obvious source of relative bias in broken and burnt otoliths compared with thin sections was the inability to see a newly-formed opaque ring on the otolith edge in the burnt otolith. Sampling only at times of the year when new opaque rings are not expected on the otolith edge should reduce the bias between the two methods to very low levels. A marginal increment study using broken and burnt otoliths would confirm this.

Age estimates from whole otoliths offer some further cost savings compared to other methods. However, we propose that before whole otoliths are used for routine age estimation in snapper, further examination of the reasons for the bias we detected between whole and sectioned otoliths should be investigated. Readings from whole otoliths were often less that readings from the same otolith sectioned and the reason for this difference was not always due to a difference in the way in which the edge of the otolith was interpreted. Readings of whole otoliths often amalgamated features that were counted as separate rings in otolith sections. Until further validation work shows which interpretation is correct, we suggest that because both the broken and burnt and section techniques for snapper have been validated in more locations for a wide range of ages, they should be used in preference to whole otolith techniques

Geographic variation in precision

Other authors have mentioned latitudinal or geographic variation in the ease of interpretation of otoliths (Fowler and Doherty 1992, Fowler 1995, Horn 1993) but have not described this variation in terms of precision of age estimation. Our view is that ease of interpretation is very likely to influence ageing precision and cost. Unclear otoliths are difficult to age, are lingered over, and are less likely to be interpreted the same way twice. If this knowledge is available *a priori*, it should be incorporated in designs for age-based sampling. Geographic variation in precision of age estimation was not related to method. The differences in ageing precision between fish from Ballina and Sydney were similar for all methods, suggesting that the cause of the interpretation difficulty was not due to preparation methods. The geographic variation in the interpretability of the otolith margins will complicate age estimation in several ways. Validation studies, such as our marginal increment study will remain inconclusive wherever the proportion of edges that cannot be determined is high. Mark-recapture studies incorporating tetracycline may be more important at lower latitudes to provide solid estimates of ageing error (Francis *et al.* 1992) as opposed to the precision estimates that we have described.

The geographic variation in precision has two effects on the costs of estimating ages along the NSW coast. Age estimates from southern NSW are more precise than those from the north of the state, so fewer fish are needed to describe the age composition of commercial landings to the same standard. The cost of time needed to interpret otoliths is an additional liability that we have not estimated well here. We found that whole otoliths and broken and burnt otoliths took more time to interpret than did sections of otoliths and that even with this extra time, the estimated ages from the two methods were less precise than those from sections. Therefore, to describe ages with the same precision in Queensland or northern NSW as in Sydney, more fish will need to be aged, at a higher cost per fish due to the extra time to make age estimates.

Future approach to age estimation in snapper

The relative bias between age estimates from broken and burnt otoliths compared with otolith sections may not be a problem for estimating the age of snapper. We have identified the principal source of that bias as the inability of the reader to identify the terminal ring of broken and burnt otoliths when it is very close to the edge. Francis *et al.* (1992) also identified this problem as an important source of ageing error in their validation study on this species. They suggested that the problem could be largely overcome by sampling at times when there is little chance of misinterpreting the otolith edge. Our examination of the margins of otoliths suggest that the possibility of misinterpretation is probably highest in the period from September to November. Unfortunately, this falls within the peak period for the fishery in northern NSW and Queensland (July to November). However we think that for sampling age composition, the best strategy will be to sample ages in the early part of the peak northern season to reduce errors due to edge determination, while sampling length composition throughout the peak season.

Broken and burnt otoliths provide a cost savings of about 30% compared with thin sections, theoretically allowing a similar increase in the sample size for the same cost. A 30% larger sample size will provide an overall benefit in increased precision of, for example, an estimated age composition, even with the slight decrease in precision due to the change of method (Worthington *et al.* 1995). This is likely to be the case across the range of sample sizes the are currently affordable (300 to 500 fish per estimate of age composition). The further small increase in sample size possible if whole otoliths were used is probably not warranted against the potential bias (see above, Worthington *et al.* 1995).

The influence of geographic range on the precision of estimated age compositions should also be estimated if equal precision among sampling locations is desired. The overall precision of an estimated age structure depends on the range of ages and variation in the strength of year classes (Kimura 1977). The simulation studies of Worthington *et al.* (1995) provide a useful guide for examining the effects of sampling error and imprecision on age compositions. Snapper in NSW and Queensland have age compositions that are similar to those modelled for *P. molluccensis* at Lady Musgrave Reef by Worthington *et al.* (1995). Worthington *et al*'s simulations, if applied to snapper, would suggest that despite a large change in CV (from about 2% in Sydney to about 5% at Fraser) there would be relatively little gain in overall precision by redirecting sampling effort from Sydney to northern areas.

5. VARIATION IN SIZE AND AGE STRUCTURE

5.1 Introduction

The collection of size and age structured catch data is fundamental to many methods of fishery assessment. Prior to this study the only catch size or age information available for the snapper fishery on the east coast of Australia was from Coffs Harbour during 1986 and 1987 when extensive size structured information was collected as part of a FIRTA project (Henry 1990).

In New Zealand the growth of snapper from a number of areas has been extensively studied using scales and otoliths as well as by length frequency analysis (Cassie 1956a, Paul 1976, Vooren and Coombs 1977, Paul and Tarring 1980, Sullivan 1985, Horn 1986, Francis *et al.* 1992, and Francis 1994a). These studies have shown considerable variation in growth rates which generally became apparent after fish had reached about 3 years old. In Australia, however, published accounts of snapper growth rates are limited to those derived from tagging experiments (Sanders and Powell 1979, and Francis and Winstanley 1989). Nonetheless, these studies have likewise documented significant differences in growth rates of fish from different areas. The latter authors noted that growth rates of 20 - 30 cm snapper caught in Port Phillip Bay were 17 - 20% higher than those in the open ocean.

The large geographic range of the fishery on the East Coast (20 - 38°) as well as variation in fishing method suggested that there may be regional differences in the size and age composition of the catch. For this reason we have attempted to monitor the fishery over a wide spatial range, concentrating our sampling on the time of the year when most snapper are caught.

New Zealand is located south of 34° latitude with summer water temperatures in Hauraki Gulf (the most important snapper recruitment area) averaging around 20° C. In Queensland snapper are caught as far north as 20° with the bulk of the commercial catch being taken between 25° and 28°. In NSW, the bulk of the catch also comes from the north of the state (see Figures 1.3 and 1.5).

The snapper spawning season in New Zealand begins around September/October although there is considerable annual variation (Crossland 1977, Scott and Pankhurst 1992). By comparison, snapper in Queensland waters begin spawning as early as May with peak spawning occurring during August (See Chapter 7). This earlier spawning period for snapper at the northern limit of their range enables a more extended juvenile growing season a fact which may influence the timing of recruitment to the fishery.

The original proposal was to collect size and age structured information for two years (1993 and 1994), however we have also collected and analysed size and age data for the 1995 spawning season as well as collecting data for the 1996 spawning period at some locations. This information will be subsequently used in future regular monitoring of the fisheries in both

Queensland and NSW and forms part of the routine monitoring which should be in place for this fishery in the future.

Here we examine the temporal and spatial variation in the size and age structure of snapper in the east coast commercial fishery and use these data to estimate total mortalities. Spatial differences in other characteristics are also described.

5.2 Materials and Methods

Commercial catches of snapper from 7 areas along the east coast of Australia were sampled between July 1993 and December 1995 (see Figure 4.1). Sampling took place throughout the year at some locations but was most intense between July and November (the main spawning season). On days when commercial sampling took place fork lengths ($\pm$ 0.5 cm) from complete catches were measured either on board commercial vessels or at marketing / processing plants. We aimed to measure at least 5% of the commercial landings at each location over the sampling period. Fish from the Swains, Moreton and Fraser were exclusively line caught whilst those sampled from Ballina, Coffs Harbour, Forster and Sydney were mostly caught in baited fish traps The exception to this was Coffs Harbour where approximately 15% of the commercial catch was line caught.

Sagittal otoliths for age estimation were randomly taken from a sub-sample of the catch at each location. In this report we use otolith terminology as described by M. Francis *et al.* (1992). We estimate the age class of a fish as the number of completed rings in its otolith and thus a snapper with 2 rings is considered to be 2^+. Otolith sections were prepared as described in Section 4.2.

The winter/spring sampling window (July to November) was assumed to be a point sample and was the period used to produce age structures. For data collected in Queensland, age structures were calculated by applying age length keys to the size frequency data. Numbers of fish aged in each length class were proportional to the numbers of fish in each size class. Where sample sizes were too small to allow for this, size classes were grouped. A different age length key was used for each location and sampling period. In NSW, age structures were calculated using a random sample of otoliths drawn by length from a length frequency distribution that matched our estimate of length frequency of landings at a given location.

Total mortality estimates were derived by calculating the slope of the regression of the natural logarithm of number-at-age against age. To reduce the problem of sampling error in rare, older age classes, the regressions excluded the oldest 1% of fish in each estimated age composition. We have calculated Z for different ages at recruitment (2^+ and 3^+).

5.3 Results

Morphometrics

Where ever possible, the fork length of fish was measured. However, fisheries regulations in Queensland and NSW specify minimum legal length in terms of total length. Total length is defined as the distance from the snout to the tip of the caudal fin extended to its maximum length. Fishermen (both commercial and recreational) are more familiar with total lengths therefore morphometric relationships were established by measuring weight, standard length, fork length and total length. These relationships were used to estimate various morphometric parameters when they could not be not measured directly. Analysis of covariance failed to yield any significant sexual difference in any of the related measures. The following relationships were established and have been used throughout the report. The convention has been to use Fork Length or its abbreviation (FL) as the standard unit of measure throughout the report except where stated otherwise.

Fork Length = 1.152 x Standard Length + 0.412 $r^2 = 0.994$

Fork Length = 0.877 x Total Length - 0.222 $r^2 = 0.996$

Standard Length = 0.748 x Total Length - 0.650 $r^2 = 0.998$

Log Weight = 2.790 x Log Fork Length - 1.350 $r^2 = 0.996$

Size distributions

The estimated proportion of the commercial catch that was used to estimate length composition of landings varied from 4.6% to about 26% of total landings within our sampling periods (Table 5.1).

Table 5.1 Sampling fractions of landings used to estimate length frequency of landings at 6 locations in NSW and Queensland.

	Location					
	Fraser	Moreton	Ballina	Coffs Harbour	Forster	Sydney
Winter 1993	4.6%	7.0%	5.1%	14.4%	9.7%	16.7%
Winter 1994	8.8%	18.0%	12.0%	13.0%	8.6%	16.5%
Winter 1995	24.0%	26.0%	9.2%	11.7%	12.0%	8.2%

Length frequency of commercial snapper landings varied, both among locations and among years at the same location. In general, the northern locations had higher numbers of larger fish in the catch and in the Forster and Sydney locations there were very few fish over 45 cm (Figure 5.1). Conversely, the landings from the Swains were almost exclusively large fish. Very large fish (greater than 60 cm) were far more common in Queensland landings than in those from NSW. Among all locations, landings from Forster were consistently made up of the smallest fish and the first 2 or 3 cm above the legal minimum (about 23.5 cm FL) were often a large proportion of the catch (Figure 5.1). Year to year variation in size composition was greatest in the samples from Moreton and Fraser locations. At both Moreton and Fraser, the proportion of smaller fish (around 30 cm) changed dramatically from year to year. In general, because they were often a large portion of landings, changes in the relative abundance of fish under 30 cm were often responsible for the largest changes in the frequency distributions form year to year.

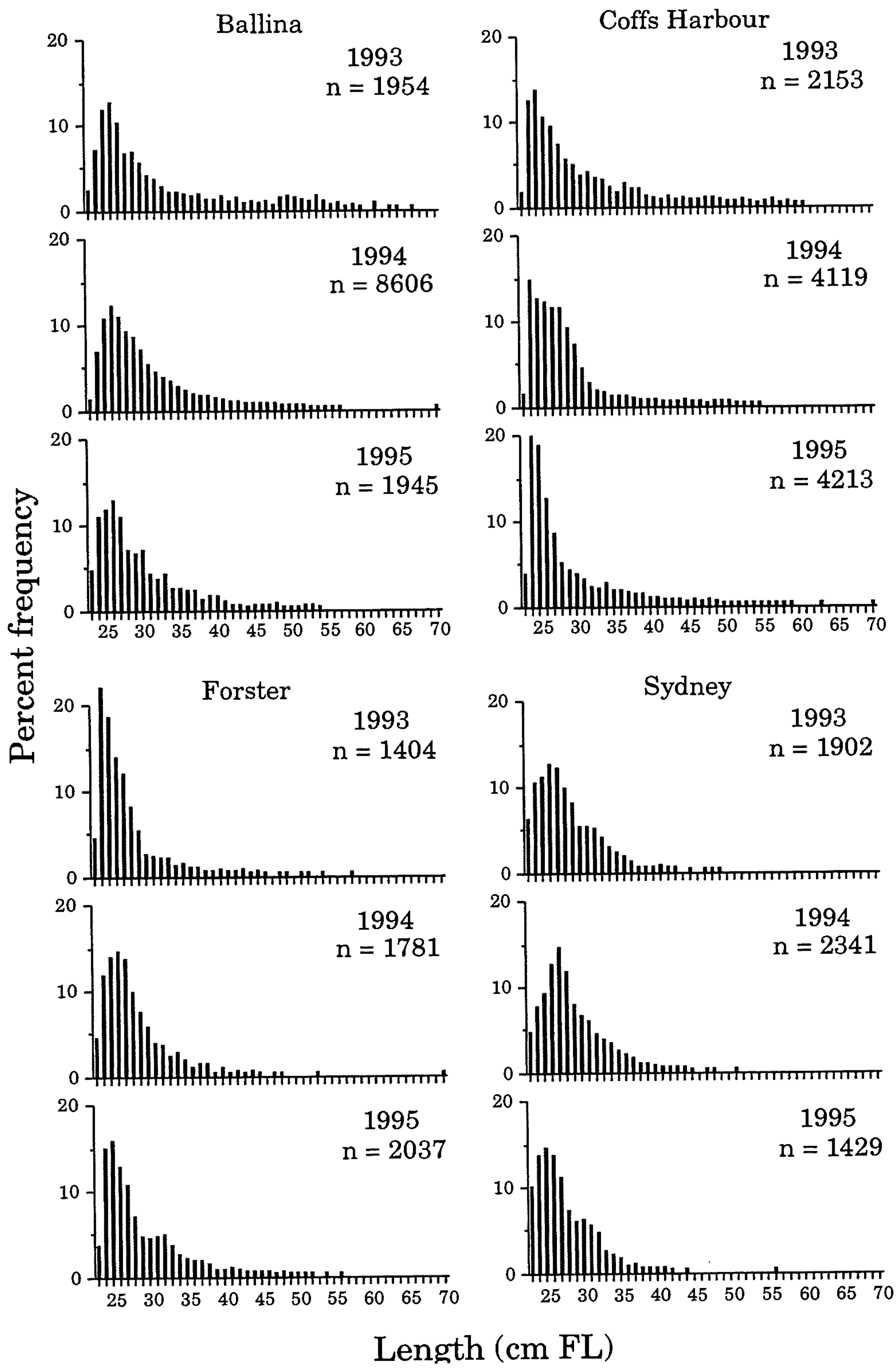
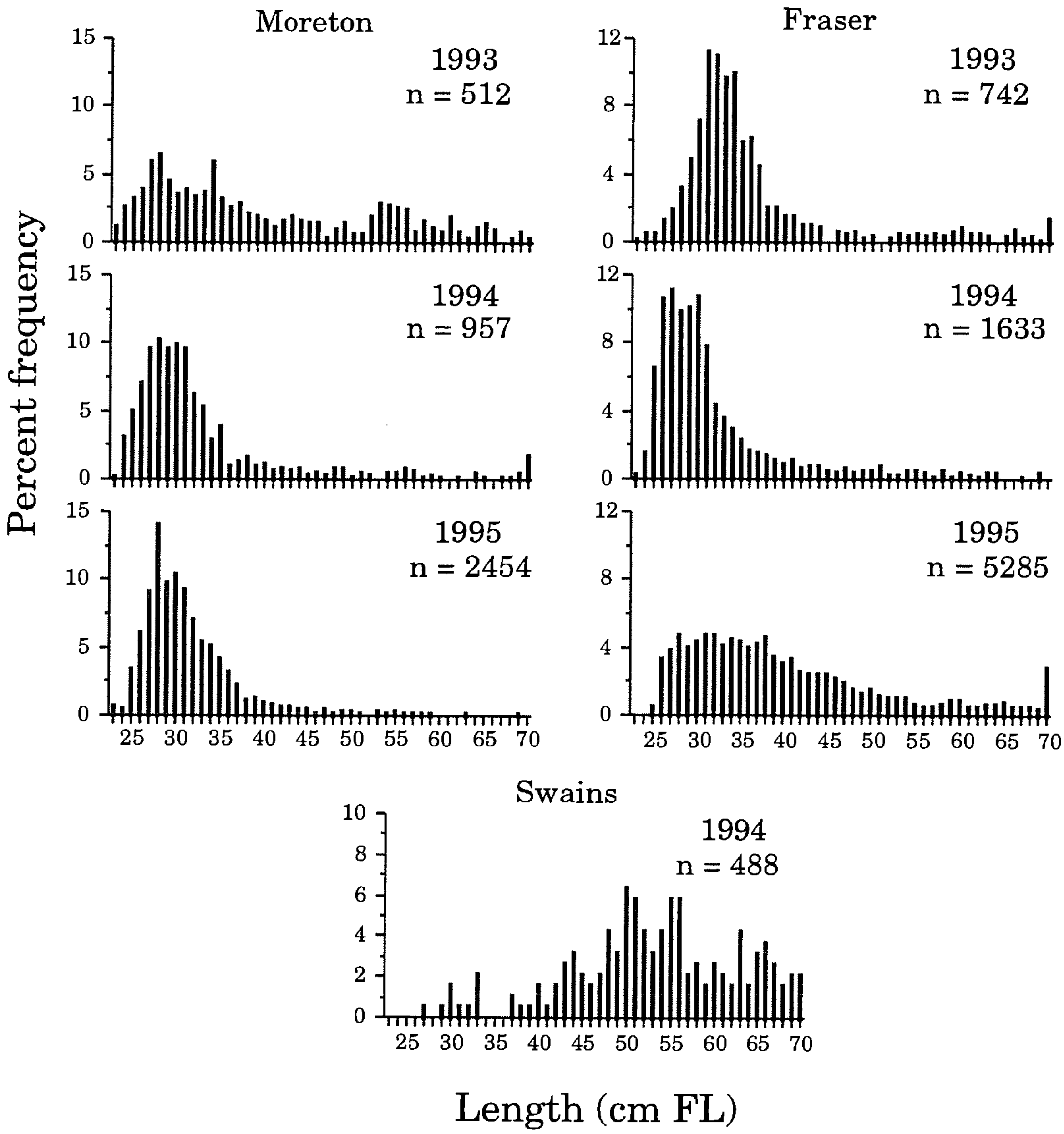


Figure 5.1 Length frequency of commercial snapper landings from 6 locations sampled in three successive years. Also shown is an estimate of the length composition of snapper landings from the Swains location for 1994. (Figure is continued on following page.)

Figure 5.1 Continued.



Size and age at recruitment to the fishery

There was great variation in size-at-age of fish recruiting to the fishery. For example, the fishery in NSW occasionally lands a small number of 1^+ fish. These fish were all very close to the legal minimum size (28 cm TL or 23 to 24 cm FL, Figure 5.2). Many fish from the 2^+ year class were also just above the legal size and some 3^+ fish were also close to the legal minimum size, suggesting that they had not been available to the fishery for long. The same pattern is repeated in Queensland landings, except that the larger size limit means very few 1^+ fish are landed and that many of the 2^+ fish are very close to the legal minimum size (Figure 5.2). The size distributions of 3^+ and 4^+ snapper from Queensland still contain some fish that are very close to the minimum size.

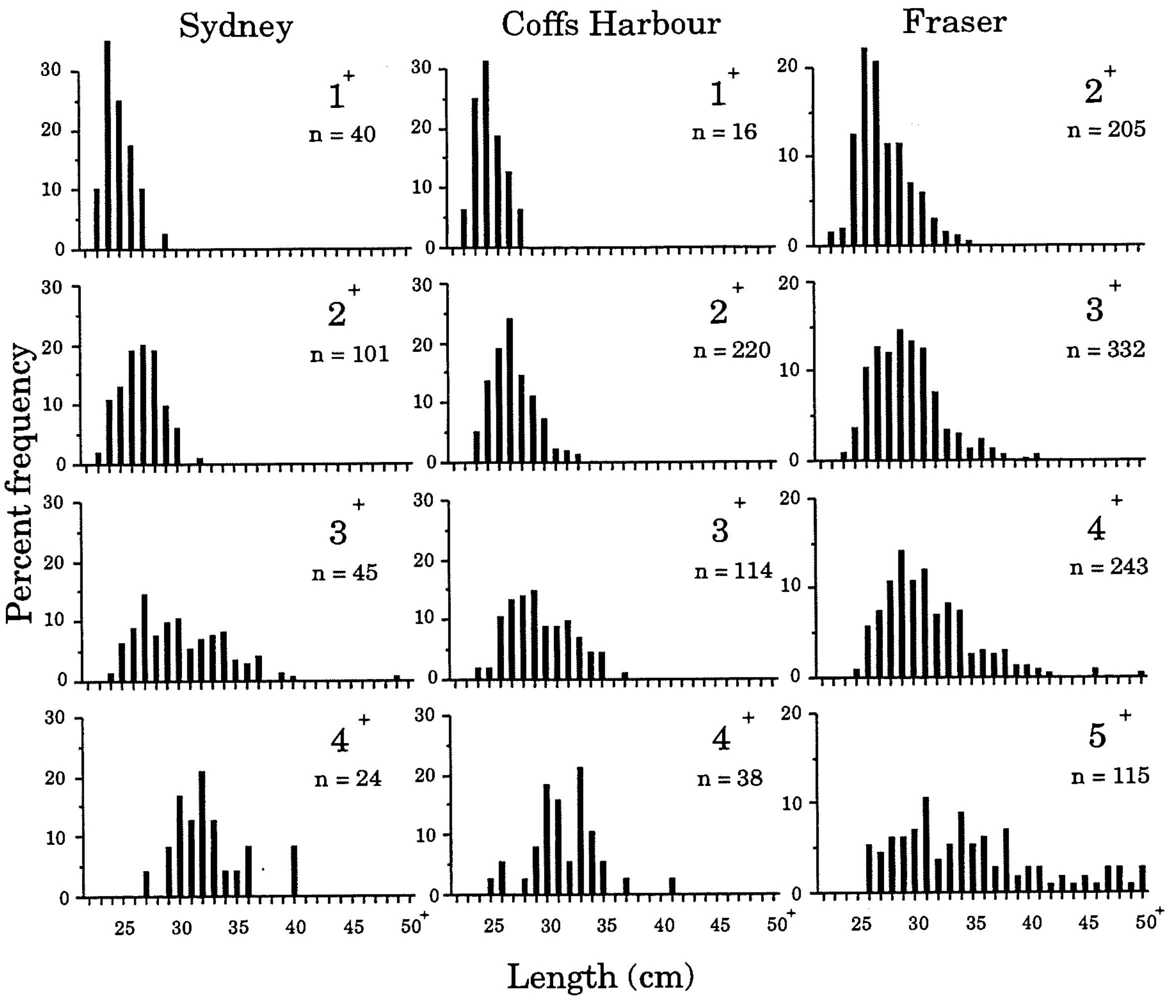


Figure 5.2 Length frequency of snapper landings from selected locations arranged by age class. Collections are all from 1993 sampling period.

Age distributions

In all locations except the Swains, fish 3+ and younger combine to be at least half the landed catch (Figure 5.3). In all NSW collections the numbers of 3+ and younger snapper in the catch ranged from 72% to 86%. In Queensland collections, these young fish comprised between 52% and 75% of landings, except at the Swains, where they were less than 12% of the catch.

There are very few fish landed that are at least 10 years old, and in NSW, average age was close to or below 3 years (Figure 5.3). Mean age in most collections was slightly higher in Queensland than NSW and the collection from the Swains had an average age of 5.2 years. The highest proportion (4%) of fish ten and older in any sample was from Coffs Harbour in 1994. In most collections those older fish were less than 2% of the catch (Figure 5.3).

There was little evidence of strong year classes progressing through the fishery in the consecutive age distributions. One possible exception to this was the cohort aged 3+ in Sydney in 1993 (Figure 5.3). The 4+ year group was more common than in other years and likewise for 5+ fish in 1995.

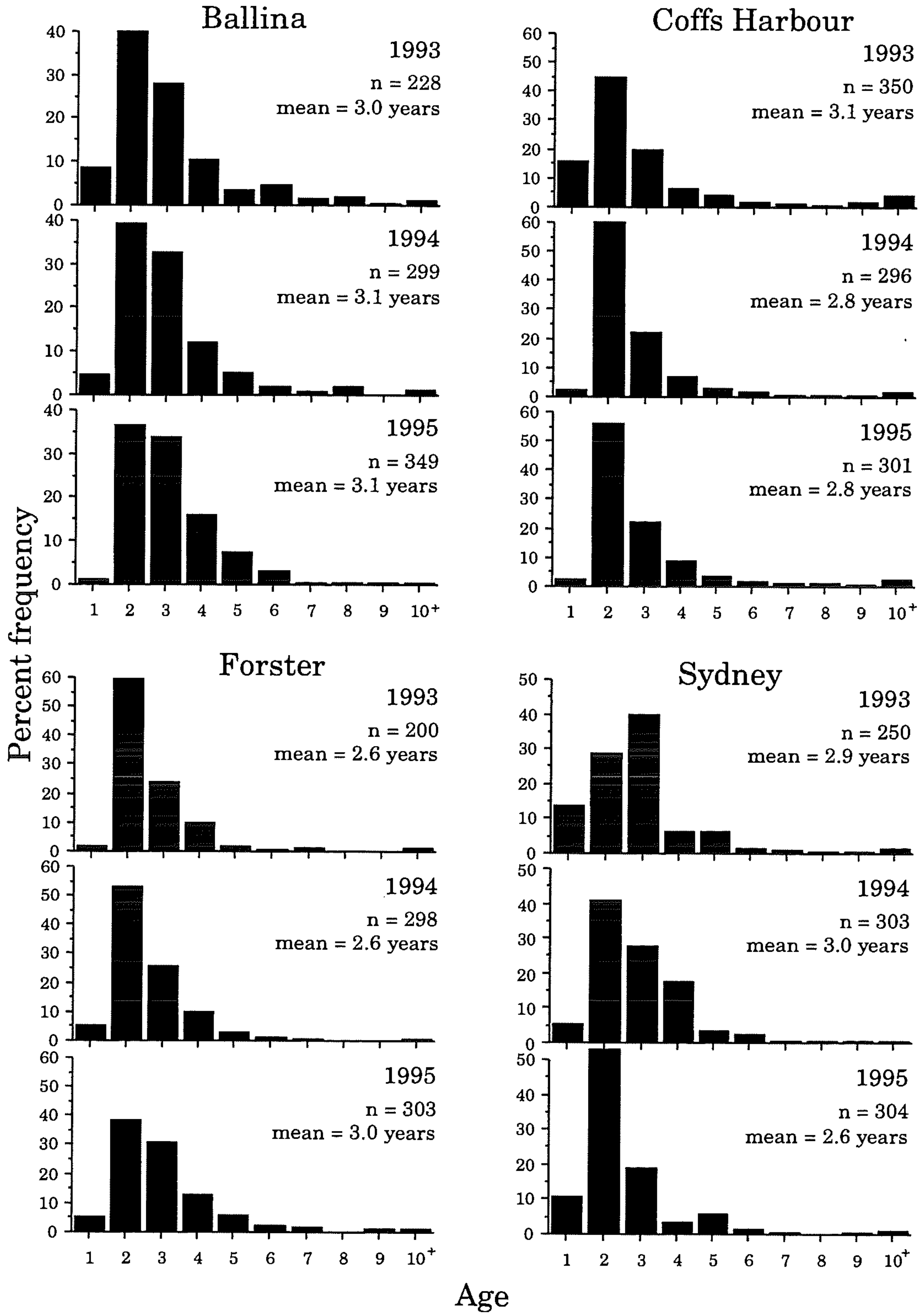
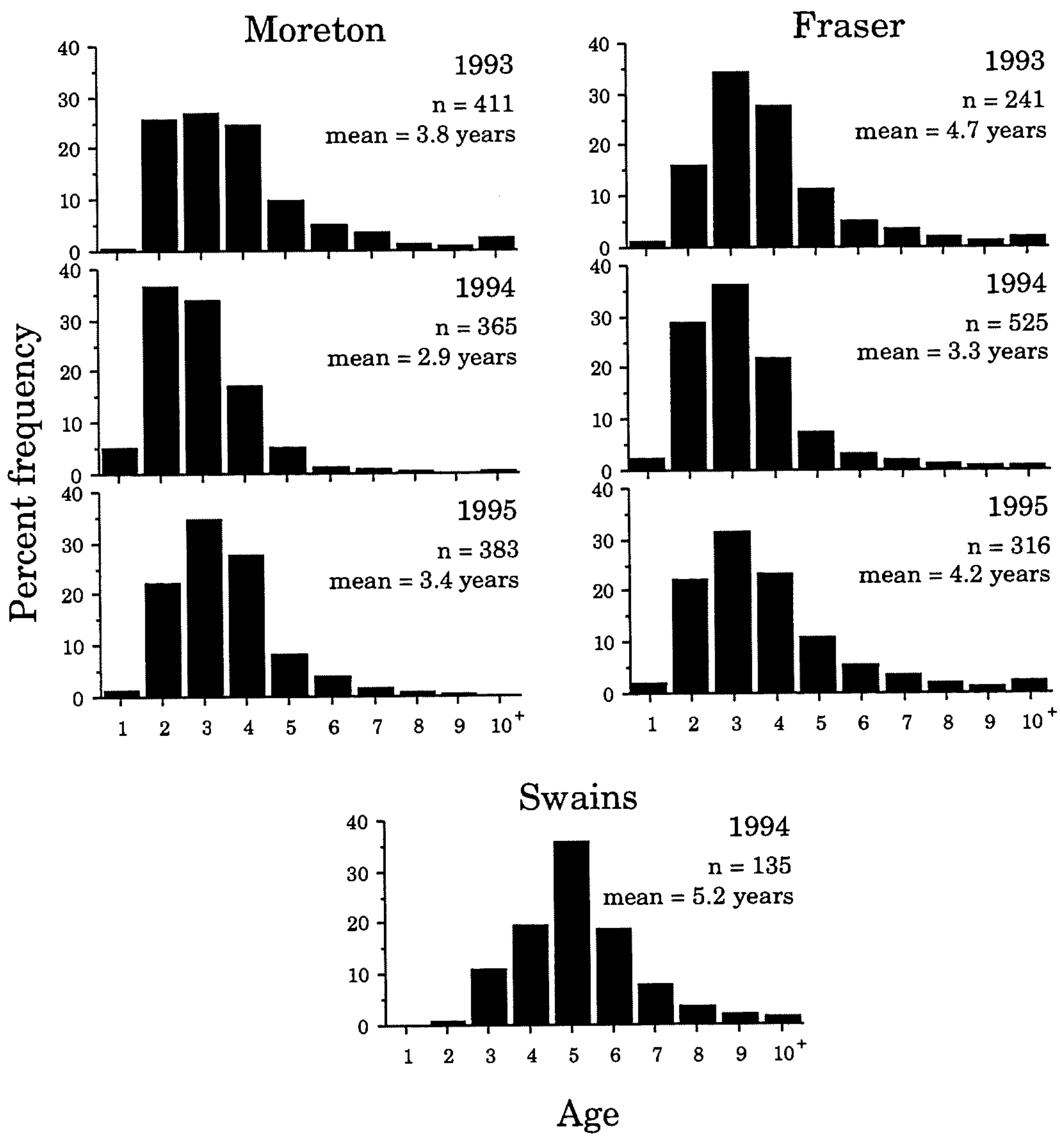


Figure 5.3 Age frequency of commercial snapper landings from 6 locations sampled in three successive years. Also shown is an estimate of the age composition of snapper landings from the Swains for 1994. Note axis scale changes amongst locations. (Figure continues on following page.)

Figure 5.3 Continued.



Estimates of total mortality

The different age compositions from collections in different years provide a range of total mortality estimates from each location (Table 5.2). The age distribution at each location in 1993 will influence the results in subsequent years so the estimates of total mortality (Z) among years at a location should not be viewed as replicates. The estimates of Z will also vary depending on the age class that is determined to be "fully recruited" and hence the youngest age in the regression. We have used both the 2^+ and 3^+ year groups as the starting point for calculations because, despite being only partially recruited, they are a huge proportion of the catch.

The lowest estimates of Z were from Fraser in 1993 (Table 5.2, Figure 5.3) and the highest were based on the age compositions from, at various times, Moreton and Forster. The assumed age at full recruitment influenced the estimates of Z. Those estimates using only fish 3 years and older tended to be slightly lower. This probably reflects low sample sizes fish that age and older, particularly in NSW.

Table 5.2 Estimates of total mortality (Z) based on regression of lognormal transformed abundances in fully recruited age classes. The age compositions are shown in Figure 5.3 and estimates of Z are calculated on an age of recruitment of both age 2^+ and age 3^+.

Year	Age 2^+	Age 3^+
	FRASER	
1993	0.28±0.03	0.28±0.03
1994	0.61±0.06	0.66±0.08
1995	0.37±0.12	0.55±0.07
	MORETON	
1993	0.56±0.08	0.54±0.10
1994	0.72±0.09	0.73±0.11
1995	0.59±0.13	0.80±0.08
	BALLINA	
1993	0.51±0.06	0.49±0.07
1994	0.65±0.07	0.67±0.11
1995	0.68±0.06	0.72±0.07
	COFFS HARBOUR	
1993	0.37±0.05	0.32±0.05
1994	0.37±0.07	0.30±0.06
1995	0.39±0.05	0.33±0.05
	FORSTER	
1993	0.71±0.08	0.65±0.10
1994	0.79±0.05	0.76±0.07
1995	0.63±0.09	0.64±0.13
	SYDNEY	
1993	0.60±0.07	0.62±0.09
1994	0.69±0.07	0.70±0.10
1995	0.68±0.09	0.61±0.11

Mean size-at-age

The 2^+ fish from all locations and the 3^+ fish from Queensland are probably not fully recruited to the fishery and we will not consider the variation in their sizes here for that reason. In general, mean length-at-age did not vary significantly among sampling periods. For 4^+ fish and 5^+ fish, the two way ANOVA to examine fish size by location and sampling year was only significant for location (see below). The differences among locations at different sampling occasions were not significant for either 4^+ or 5^+ fish ($P>0.25$), nor was the main effect of sampling occasion significant in either analysis ($P>0.25$). These terms were dropped from the model and a one-way ANOVA was used to examine differences among locations for all 4^+ and 5^+ fish (see below). The single exception to this was the 3^+ fish from NSW in 1995 - in all locations this cohort was significantly smaller than the 3^+ fish from either 1993 or 1994 (ANOVA P<0.001).

Mean size-at-age varied significantly among locations for fish from ages 4^+ to 7^+. Sample sizes from older fish were inadequate to analyse for all locations. Fish from Ballina were often significantly larger than fish from most other locations in the age groups 4^+ to 7^+. Fish from both Coffs Harbour and Moreton were often not significantly smaller than those from Ballina. Fish from these three locations were usually significantly larger than fish from other three locations (Figure 5.4).

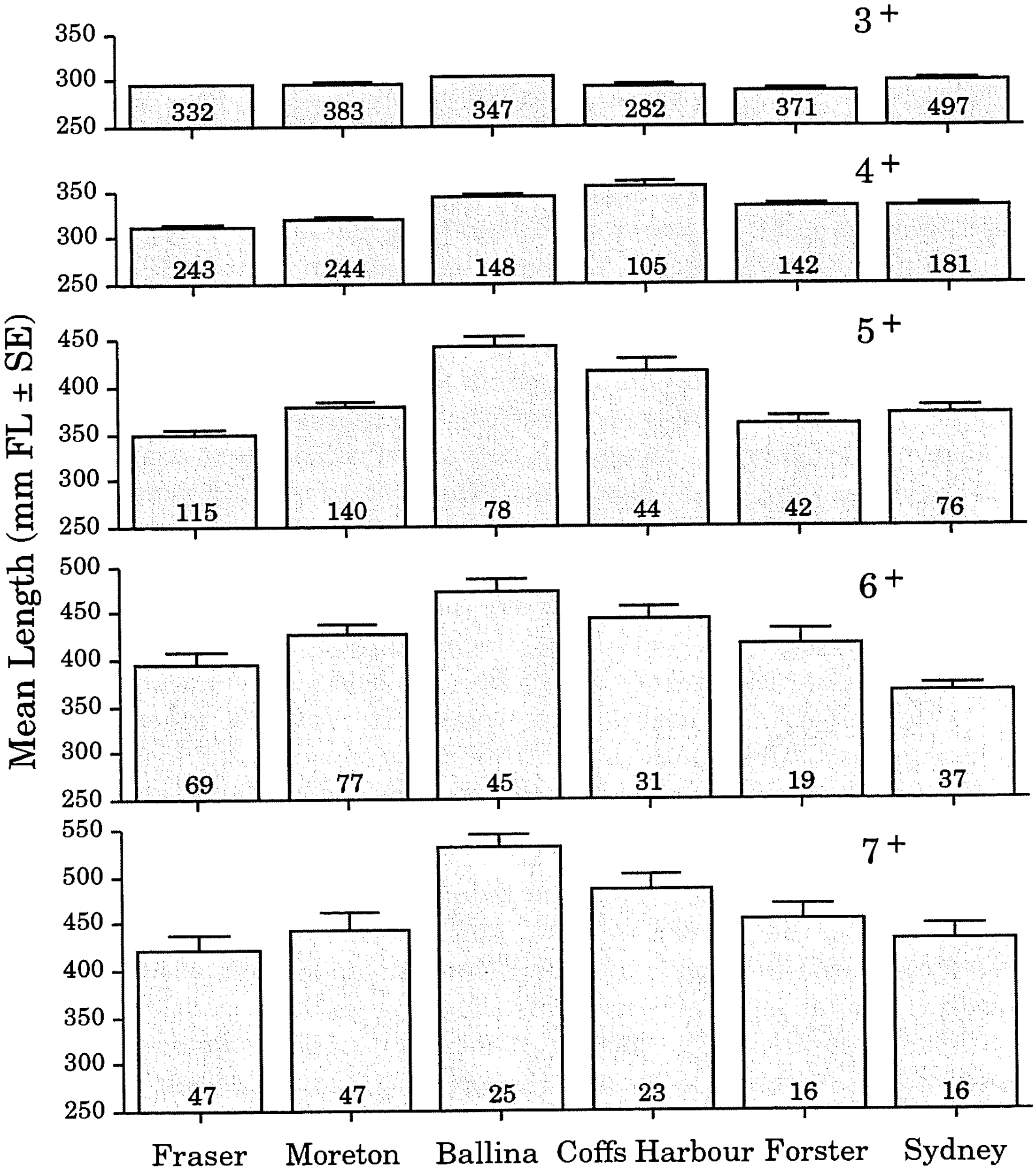


Figure 5.4 Mean size at ages 3^+ to 7^+ for snapper from 6 locations. Results pooled from collections in 1993, 1994 and 1995. Sample sizes for each mean shown.

5.4 Discussion

Age composition

Our estimates of age compositions of snapper cover a large part of the coast of eastern Australia and span the core of the commercial and recreational fishery in that area. While we have concentrated on differences in the age structures across the range of locations in our study, there are many similarities among locations. In all areas except the Swains, there are two recruiting year groups that comprise the bulk of the fishery and very few fish over 10 years of age.

Age at recruitment and mean age of snapper in NSW and Queensland is considerably different than found in fisheries elsewhere in Australia and New Zealand. All other snapper fisheries except the Shark Bay fishery in WA, are also based on many more age classes than in eastern Australia. Snapper fisheries in New Zealand are based on an older age at recruitment (about 4^{+}), but also have many more age classes making a substantial contribution to the fishery. For example, Davies and Walsh (1995) show the snapper fishery in the Hauraki Gulf of New Zealand to be comprised of more than 10 year classes with an average age of between 8 and 9 years (our average ages were mostly under 4 years, except at the Swains, Figure 5.3). The minimum size in New Zealand is similar to the minimum size in Queensland (Table 11.1), however both South Australia and Western Australia have much higher minimum sizes for their snapper fisheries. As a result, the age of recruitment is much older in both those states than on the east coast. The fishery in South Australia is also comprised of many more year groups and has much higher mean ages than fisheries in NSW or Queensland (Jones *et al.* 1990). The age composition of snapper in the fishery in Shark Bay, WA is similar in one respect to those we have studied. Despite a much larger legal minimum size (see Table 11.1), most of the fish harvested from Shark Bay are between five and seven years old (M. Moran, WA Fisheries, pers. com). In Victoria, where the legal minimum size is similar to that in NSW and Queensland, fish aged between 5 and 20 years are common in the fishery and comprise an important part of the total landings (Coutin 1996).

The most obvious conclusion from the truncated age compositions in eastern Australia is that the fishery in NSW and Queensland is relatively heavily exploited compared to other states and New Zealand. This assumes natural mortality is similar amongst areas, but there are no data to either support or reject this assumption. The lack of change in length frequency of landings between 1986-87 (Henry 1990) and the present study suggests that the age composition of the snapper stock has not changed dramatically in that time (Figure 5.5). However, the truncated nature of the age composition should increase the vulnerability of the fishery to recruitment failure.

Technical issues affecting results

Collection of samples around the time of increment formation/visualisation will blur the age compositions (see Chapter 4). A 2^{+} fish collected in September is unlikely to show the recently-formed winter ring but that ring in the same fish may be visible by November (see Figure 4.2). That same fish would then be scored as a 3+ just a few months later, lessening differences between year groups. This blurring of the age composition data will have the effect of disguising changes in levels of recruitment (see Kimura 1989) but is unlikely to have a large effect on the age composition because the imprecision is not more than 1 year.

The fishery for snapper in each of our study areas is conducted by relatively few professional fishers. For example, the 4 most productive snapper fishers in Sydney account for about 75% of snapper landings in that location. Because of this, the catch composition we measured may have been influenced by changes in the activities of one or two fishers. In Queensland the average size of snapper caught by fishers whose catch was sampled during this study ranged from 30 cm to over 45 cm. The fact that fishers switch to other fisheries (particularly crab fisheries) on a seasonal basis confounds sampling. The absence of 2 fishers (who regularly caught a high proportion of larger fish) from the Fraser fishery in 1994 was largely responsible for the comparative lack of fish over 35 cm in catches that year. Furthermore, our sampling at the time of peak productivity could also be biased if there are large changes in catch composition at other times of year.

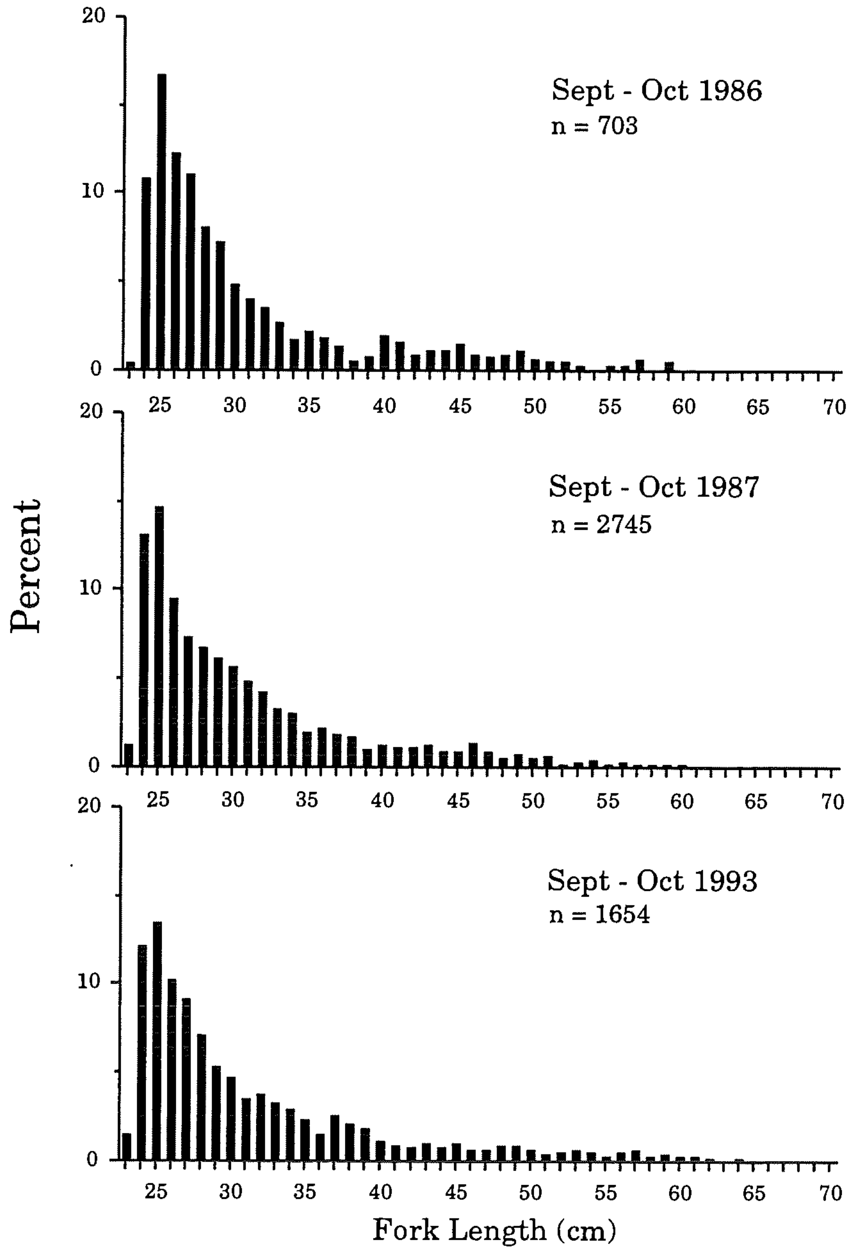


Figure 5.5 Length frequency of snapper from Coffs Harbour. Shown are distributions from 1986 and 1987 done by Henry (1990) and, for reference, the length frequency estimated in this study in 1993 (see also Figure 5.1).

Geographic variation in size-at-age

The geographic trend in differences in mean size-at-age was unusual in that there was a peak in average size in the middle of our study range, rather than at one end of the range. The differences among locations changed with fish age, and we suspect that this was largely due to our estimates of mean size in young fish being influenced by size selectivity (see below). Large variation in growth rates of snapper from different locations are known from New Zealand (Horn 1986) and from Australia (Francis and Winstanley 1989). Within New Zealand, differences in growth rate are largest between the east and west coasts of the North Island, rather than having an association with latitude.

In three locations in the middle of our study area there were disproportionate increases in the mean sizes of 5+ fish compared 4+ fish compared to other locations. There are a range of possible explanations for these differences. The estimates of size-at-age of any adjacent age classes are not independent, because they have been pooled from 3 collections. So the 5+ age class from the 1993 collection is the same as the 6+ age class from the 1994 collection, etc. If, for instance, the fish that were 5+ in 1993 had been larger than average in some locations, that pattern may have persisted throughout the entire study. However, the ANOVA of mean size-at-age did not show significant effects of sampling occasion for 4+ or 5+ fish. Another explanation of the pattern in size-at-age is systematic under-ageing of older fish from Moreton to Coffs Harbour. However, such under-ageing would have had to happen at both ageing labs independently, which we believe is unlikely.

Migration of large fish into northern NSW and southern Queensland may also be an explanation of the pattern in size-at-age. Our collections in these areas correspond with the peak of the fishery and the peak in spawning activity (see Chapters 2 & 7). Tagging studies of snapper have generally been unable to comment on migration associated with spawning (Sanders 1974, Francis and Winstanley 1989, Moran 1987, Tong 1978 but see Crossland 1976) but snapper are thought to move into shallow water to spawn (Cassie 1956b). If migration to our middle study locations was exclusive to fish older than 4+, these fish would have to be migrating from areas where their growth is enhanced relative to the fish we were sampling at younger ages. Our samples of fish older than 4 are sparse from all areas, particularly NSW and therefore a migration small numbers of older fish with significantly faster growth rates could cause the pattern we have described.

Selectivity from fishery influences results

Our collections from both commercial and recreational fishers are heavily influenced by the size limits in either state. Many of the fish caught are very close to the respective legal sizes of each state. The combination of fish being captured close to the size limit and the variation in size-at-age means that our estimates of size-at-age for age groups close to recruitment are probably overestimates. We suggest that this affects both the 2+ and 3+ age groups in all our collections and may even raise the estimate of 4+ mean size in Queensland.

6.0 INDICIES OF SNAPPER RECRUITMENT

6.1 Introduction

Understanding the distribution and early life history of fish and the processes that lead to recruitment to a fishery are important tools for managing harvest fisheries (throughout we use the term recruitment to refer to recruitment to a fishery). Estimates of relative strength of recruiting year classes are amongst the most sought after information in fisheries science (Megrey 1989, Hilborn and Walters 1992). Estimates of recruitment are integral to and enhance many types of widely used fisheries models. For example, the fishery for snapper in the Hauraki gulf provides a very large proportion of the total snapper catch and is the most important inshore finfish fishery in New Zealand. The scientific advice to managers of that fishery, who must set an annual Total Allowable Commercial Catch, comes primarily from models that use forward estimates of snapper recruitment to assess present and expected biomass of the stock (Gilbert *et al.* 1996).

Our pre-recruitment studies of snapper have the main objective of developing methods of estimating relative abundance and year class strength of juvenile snapper. Within that objective, we sought to describe the distribution of young-of-the-year (0^+) snapper among shallow habitats. Such a survey requires a method that will work on foul ground and traps were an obvious choice because of their widespread approval with industry in NSW. We also sought to examine means of estimating inter-annual and spatial variation in young snapper. Such variation may translate into variation in recruitment to the fishery and so have predictive value to industry.

Estimation of relative abundance of 0^+ snapper in trawled and non-trawled habitats is an essential first step in determining the magnitude of the problem of mortality of snapper by-catch in prawn trawlers. There are estimates of the by-catch of snapper by prawn trawlers in NSW (Kennelly *et al.* 1992) but those estimates need to be viewed in the context of total abundance and mortality of juvenile snapper. The importance of incidental mortality of snapper in prawn trawls cannot be assessed without knowledge of the distribution of snapper among the habitats in which they occur. Juvenile snapper are known to also occur in rocky nearshore areas that can not be trawled (Kingett and Choat 1981, Horn 1986).

Our interest in using baited traps as an assessment tool stems from a need to estimate abundance of fish, particularly juvenile snapper, in areas that cannot be surveyed by more conventional methods. For example both visual and trawl surveys are common means of estimating abundance of small fish. However, visibility and depth in near shore and estuarine waters can severely limit visual inspections. Likewise, trawl surveys can be hampered by foul ground or by reluctance to use a destructive sampling technique in sensitive areas.

6.2 Methods

Logbook of undersize catch

Commercial trap fishers were asked to fill out a log on the first six days they fished every month. This was a compromise between a census, where every day fished was logged, and a true random selection of days, which would have been impractical and awkward for fishers. On each of the six days the fisher agreed to record the number of under-sized fish that were returned to the water from each trap lifted that day. The depth at which each trap was set was also recorded.

Efficacy of fish traps compared to an otter trawl

Prior to the commencement of the FRDC funded project, we compared soak duration and trap types. We decided to use a collapsible "opera house" trap design (Figure 6.1), baited with pilchards with a soak time of 40 minutes. Our experiments on soak time suggested that there were no increases in catch beyond 30 minutes and that a 40 minute soak time was logistically optimal for the pilot study. The unit of replication was a "set" of 5 traps. The design for the pilot study is shown in Figure 6.2. The three estuaries selected (mainly for logistic reasons) were Port Stephens, Pittwater and Port Jackson, all in central NSW. Locations within each of the three estuaries were not selected on a random basis, but were chosen on the basis of local knowledge of snapper being present. This was to avoid comparisons where snapper were not caught by either method.

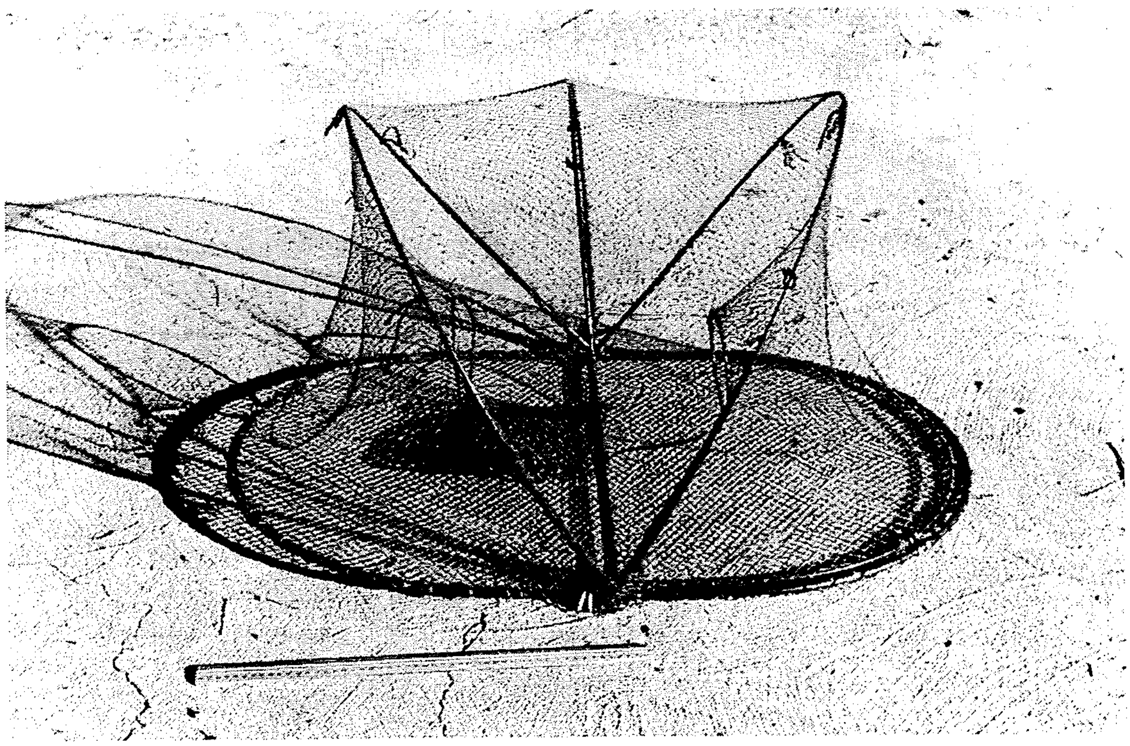


Figure 6.1 Photo of "Opera House" style collapsible trap used in estuarine surveys. Scale is 50 cm.

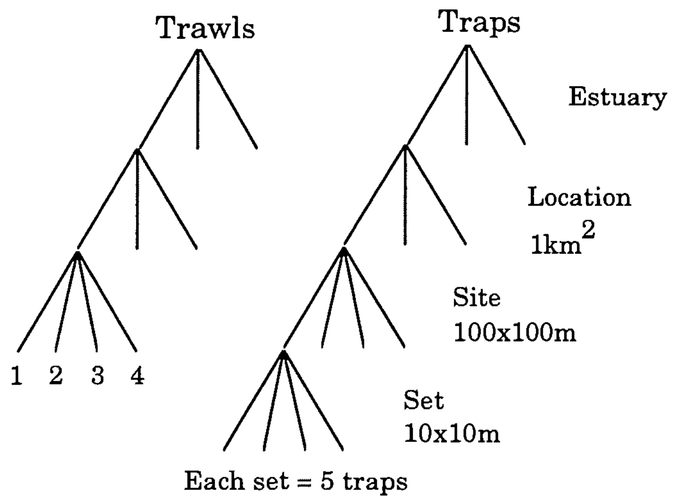


Figure 6.2 Sampling design for comparison of demersal trawls and fish traps a the same spatial scales.

Sets of 5 traps were deployed at each site about ten minutes apart. This allowed the 4 sites to be fished simultaneously and the 4 replicate sites to be completed in about 3 hours. All fish were measured and returned to the water within one minute of the trap being lifted. A single 200 m trawl was done at each site. The 8 m otter trawl had 25 mm mesh throughout and has been previously shown to be suitable for small demersal fish (Gibbs and Matthews 1982).

Trapping surveys of juvenile snapper in inshore waters

In estuarine waters, estimates of year class strength were made in the Moreton region in Queensland and in the Sydney and Forster regions of NSW. The two northern study regions of NSW (Coffs Harbour and Ballina) do not contain sufficient marine-dominated estuarine habitats to warrant inclusion in the estuarine survey. In the Sydney region we surveyed Port Jackson and Pittwater and in the Forster region we surveyed Wallis Lake and the mouth of the Manning River.

In estuarine waters, traps were deployed in 16 locations within each study region. In the Sydney region, Port Jackson and Pittwater each had 8 locations but in the Forster region, space was limited and only 4 locations in the Manning River were used with the remaining 12 in Wallis Lake. The traps were of the same design as described above. Our work comparing traps and trawls suggested that a more efficient deployment of fishing effort using traps was to reduce the number of sites within locations to two, but to increase the number of locations within a study region. Locations ranged in area between 0.25 and 1 km^2. Locations were chosen at random within estuaries. Within each location, two sites were haphazardly chosen. Sites were about 1 hectare in size and at each site there were two replicate sets of five traps.

Trawled and untrawled habitats were sampled in Moreton Bay only. Other estuarine study areas either had no trawling, no trawling coincident with snapper or too little area to provide an adequate numbers of locations for comparison. Trawled habitats were defined using local knowledge, the locations of closures and foul ground. In the 1995 survey of Moreton Bay, we surveyed 11 locations in trawled and 13 locations in untrawled habitat. In 1996 we further divided the untrawled locations to distinguish between locations that could have been trawled but were not (closures) and locations that could not be trawled due to foul ground. The 1996 survey was repeated 3 times between December 1995 and February 1996 at 8 locations in each of the three habitat types.

Offshore survey of juvenile snapper using traps

During the second year of the project a survey in near-shore habitats out to 50 m depth was done. After the successful completion of the comparison between small traps and trawling, we modified the traps used in the estuarine survey to withstand the more exposed offshore environment. The modifications included extra ballast, steel mesh bases on the traps to minimise damage from hookups on rough ground and deployment of the traps on a "longline" of 5 traps to facilitate retrieval. Traps in this configuration were successfully tested off Sydney in May 1994.

When the offshore survey commenced in January 1995 off Ballina, the small traps were not successful in rough seas or when the current was strong. It soon became clear that we required a trap similar to those used professionally, but capable of retaining smaller fish. Advice was sought from commercial fishers and various designs and mesh configurations were examined.

The offshore trapping survey was carried out between February and May 1996 with traps measuring 1.8 by 1.2 by 0.9 m, covered in 38 mm galvanised mesh (Figure 6.3). An experience commercial fisher was chartered in each of the 4 NSW locations. The surveyed area within each of the 4 locations was a reasonable working distance from the home port of the chartered fisher and usually covered between 40 and 60 km of coast. At each location we randomly chose 9 sites of 12 km^2. The seaward edge of each of the 9 sites was the 50 m contour and therefore the shape of the 12 km^2 varied depending on the width of the shelf. Sites were chosen this way so as to have roughly the same area at depth. The site from 2m to 50 m depth was stratified into 5 equal depth strata. At each site, in each depth stratum, four sampling stations were chosen at random. Depth and bottom type were ascertained at each station using depth sounding equipment. Bottom type was classified into three types based on soundings; sand, gravel and solid or broken rock. Traps were deployed at two of the stations in each of the depth strata.

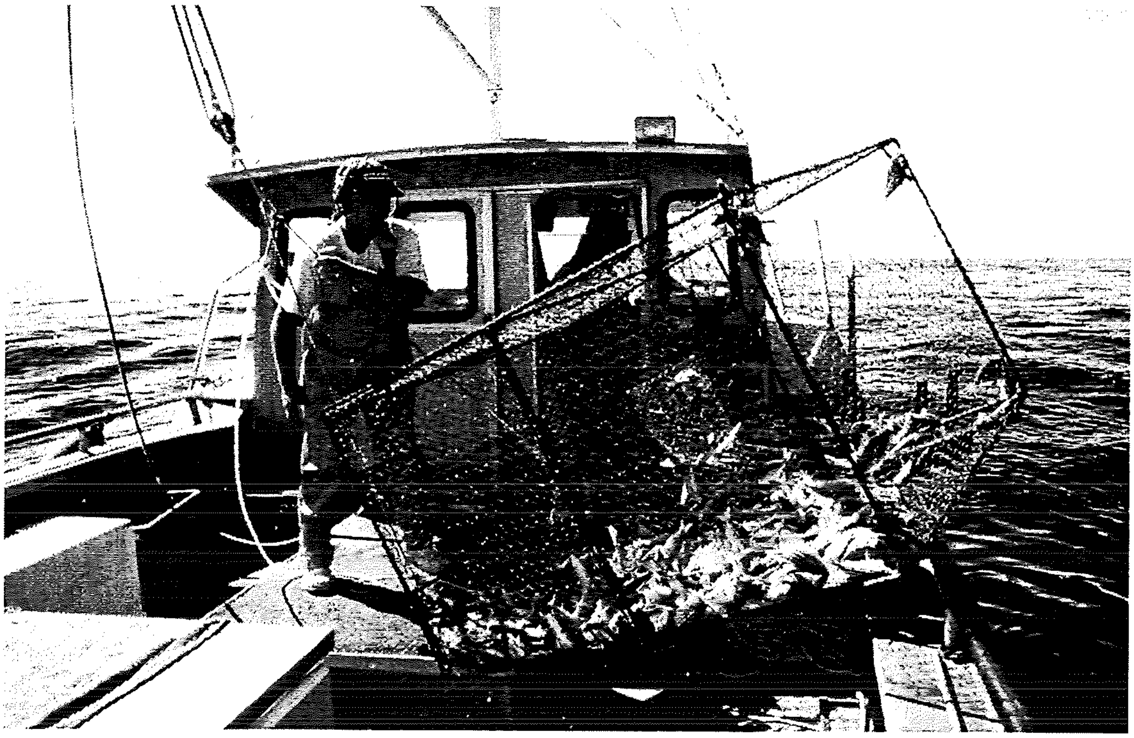


Figure 6.3 Photo of the trap design used in the offshore survey of juvenile snapper. Shown here working on the LFB Sea Queen off Coffs Harbour.

In addition to the random trap survey stratified by depth, we instructed the commercial fishers to choose a further ten sampling stations within each of the 9 random sites. Fishers were instructed to select stations where they considered it would be most likely to catch small snapper. There was no stratification by depth and fishers were only constrained to work within each of the 9 randomly selected sites. The reason for including the targeted fishing was to provide an estimate of what we hoped would be the best possible catch of juvenile snapper at a given location. The targeted fishing provided a valuable comparison to the randomised fishing, particularly where the targeted bottom type was uncommon and therefore rare in our random survey. The combined information will be used to design future surveys that are stratified by bottom type or depth.

Traps were set for two hours any time between sunrise and 1500 hours. Bait was always at least 50% Western Australian pilchards, supplemented with either poultry or beef offal. The 12 km^2 sites were generally elongated in the east-west direction because the 50 m contour was usually at least 8 km offshore. The 20 random soundings and 20 trap sets at each site were almost always completed within one day. Efficiency of steaming among traps precluded random starting points within a location. Fishing commenced alternately inshore and offshore to avoid confounding time of day with depth.

To examine the sensitivity of our offshore trapping survey to detect differences in relative abundance we used the catch rates of snapper from the survey done by the Kapala as part of the prawn trawl by-catch project (FRDC No. 88/108). The survey by Kapala was done quarterly over two years using standard prawn gear (see Kennelly *et al.* 1992). This survey was done at four locations between Newcastle and Iluka on the NSW coast, effectively the same spatial scale as our offshore trap survey. We have used the data from the quarterly trawl samples from quarters when there were significant catches of snapper to compare the sensitivity of the Kapala survey and our trap survey. We examined changes in power associated with detecting differences in mean snapper abundance at the spatial scale of locations that was common to both surveys. These changes in power were compared for various hypothetical differences in mean abundance of juvenile snapper. The power formulae used were those from Zar (1974).

6.3 Results

Logbook of undersize catch

For the first two years of the survey, participation in the logbook study was good and the snapper by-catch was recorded on average from over 400 traps per month (Figure 6.4). Participation in the 4 study areas varied due to seasonal fishing in some locations (e.g. Ballina) and also suffered when active trappers dropped out of the program. The logbooks recorded undersize snapper from more than 12,000 traps, with an average of 2.5 snapper returned from each trap.

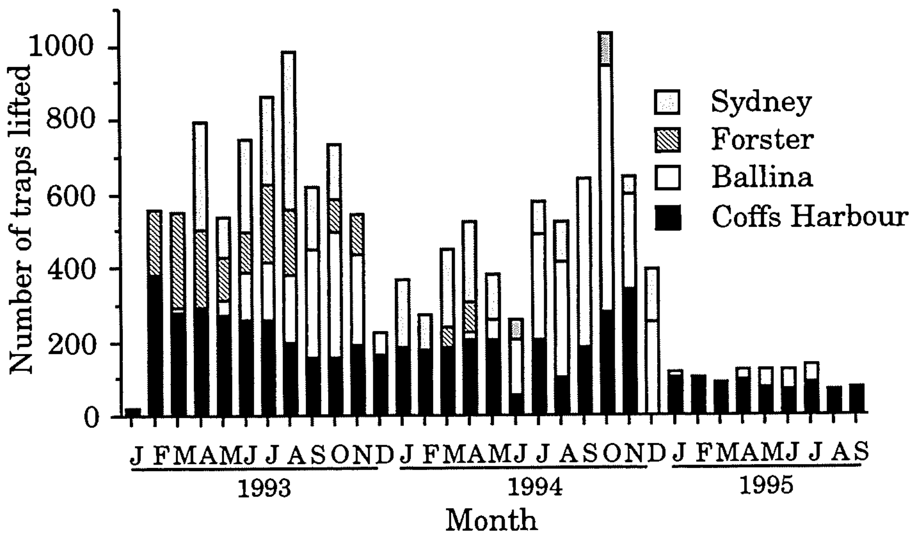


Figure 6.4 The number of traps per month included in logbook survey of juvenile snapper by-catch in the NSW commercial trap fishery, reported for four study locations.

Undersize snapper were more common in traps set in the shallower part of the depth range used by commercial trappers (Figure 6.5). In most areas there was very little trapping effort beyond 60 fathoms and the average catch rate of snapper was below one returned fish per trap in all depths greater than 50 fathoms. Catches of undersize snapper were always greatest in depths less than 25 fathoms and often in the shallowest depth stratum (Figure 6.5) Catch of juvenile snapper varied among locations and among years. For example the mean catch rate across all depths in Coffs Harbour and Forster were greater than other locations in 1993. In 1994, catches were higher than for the previous year at both Ballina and Sydney, while the opposite was true at Coffs Harbour (Figure 6.5).

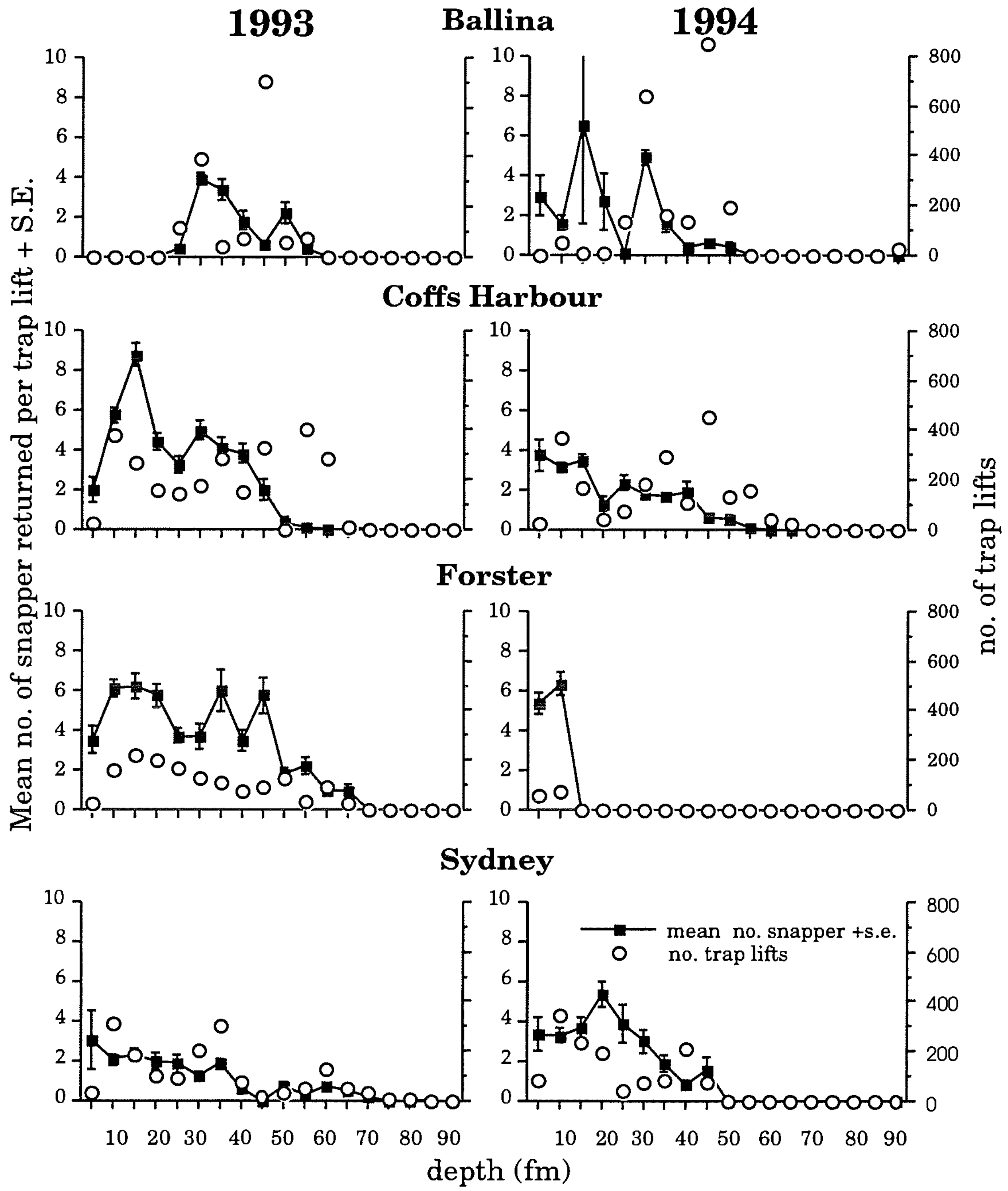


Figure 6.5 The average (± SE) number of snapper returned by commercial trap fishers in the four study locations. The open circles refer to the number of traps used to estimate the mean number of returned snapper for each depth at each location.

The distribution of trapping effort across depths was not uniform, and varied amongst locations. There were two influences on the distribution of trapping effort by depth - the season and the available reef. The reef areas suitable for fish trapping in the northern study locations, particularly off Ballina tend to be bands of reef running along a limited depth range. For example, the 45 fathom band is an active trapping area off Ballina and the 55 fathom band was popular off Coffs Harbour (Figure 6.5)

There were changes in the catch rate of undersize snapper by season at some locations, but this was always confounded with changes in the distribution of the trapping effort by depth. The seasonal change in catch of undersize fish is clearest at Coffs Harbour (Figure 6.6), with the largest catches of juveniles from shallow water between July and December. However, at both Coffs Harbour and Ballina, trappers tend to move their fishing effort deeper during the same period, confusing any effect of depth.

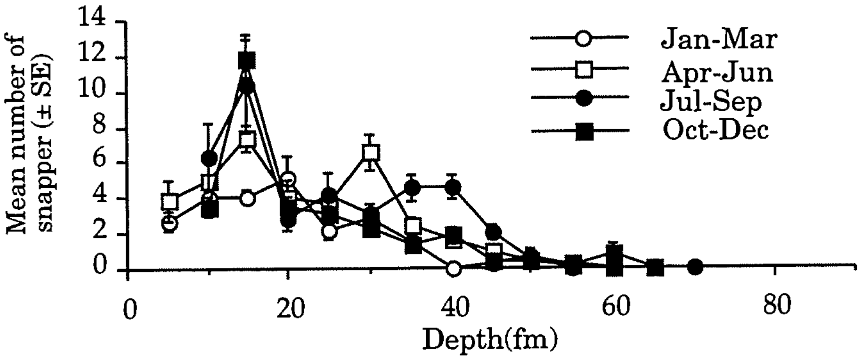


Figure 6.6 Distribution of catch of undersize snapper at Coffs Harbour plotted by depth and quarter.

It was not possible to collect information on the size of fish that were returned as part of the normal log book. However, some fishers did keep informal records for us and we did make some observations while working on industry vessels. Commercial traps retained fish as small as 17 cm but these fish were rare and most returned snapper were within 2 cm of the NSW legal size (approximately 23.5 cm).

We sought to address the question of whether there was any relationship between the catches of undersize snapper as described in our logbook and subsequent landings of legal-size snapper. We found that very little of the variation in commercial snapper catch was explained by variation in the number of undersize snapper caught in traps and recorded in our log (Table 6.1). We examined the correlation between mean monthly catch of undersize snapper and all commercial landings for each port. We also compared the logged catch of undersize snapper with the monthly landings of only those fishers keeping a log (not shown). For both these comparisons, we examined the relationships time lags varying from no lag to a lag of 10 months. The number of significant relationships between catch of undersize fish and landed catch was about what would be expected by chance. There were as many negative as positive relationships and the different lag periods made no consistent difference amongst locations.

Table 6.1 Correlation coefficients of relationship between mean number of juvenile snapper returned per trap and total catch by sampling area. The lag intervals are months after the catch of juveniles. Significant relationships ($P<0.05$, no adjustments for multiple correlation) are denoted with either "+" or "-" to indicate the direction of the effect.

Lag	Ballina	Coffs Harbour	Forster	Sydney
0	0.00	0.00	0.07	0.05
1	0.33^{-}	0.04	0.10	0.02
2	0.13	0.05	0.01	0.02
3	0.02	0.03	0.15	0.01
4	0.03	0.07	0.11	0.07
5	0.06	0.13^{+}	0.24^{-}	0.06
6	0.18^{+}	0.03	0.43^{-}	0.02
7	0.29^{+}	0.00	0.13	0.02
8	0.13	0.22^{+}	0.05	0.06
9	0.00	0.03	0.09	0.03
10	0.01	0.05	0.11	0.06

Comparison of traps with trawls for juvenile surveys

Snapper were the most abundant species in both the survey trawls and traps. The trapping took more time than four replicate trawls per location (3 hours. opposed to 2) but only required two people instead of three. This meant that the unit cost per location in this study was very similar between traps and trawls. No snapper were caught by either method from one location in Port Jackson, despite evidence to the contrary several days prior to sampling. This location was excluded from the analysis and is not reported on further.

At the largest spatial scale, both traps and trawls showed the same relative differences in abundance among estuaries (Figure 6.7). The analysis of the abundances from traps was slightly more sensitive to differences among estuaries. The two data sets also showed similar proportions of variation between the two common spatial scales (Table 6.1). That is, the ratio of variances for Estuaries:Locations:Sites is about 2:1:3 for both analyses.

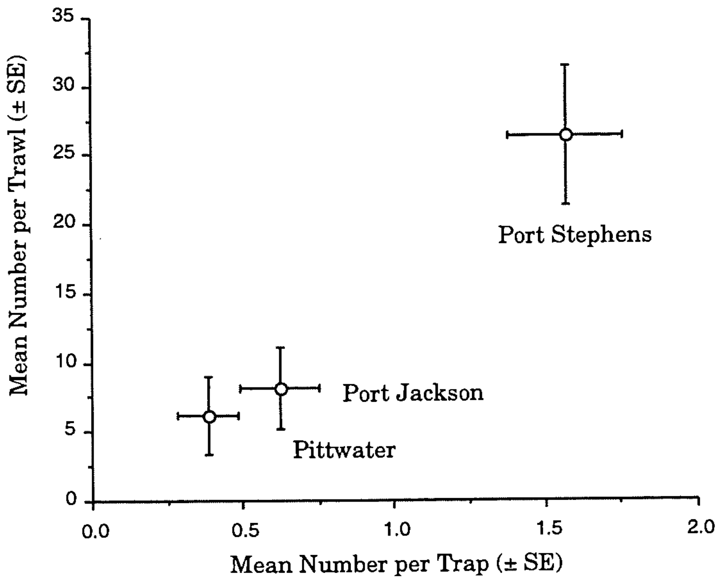


Figure 6.7 Comparison of mean number of snapper caught by fish traps and otter trawls at the largest spatial scale, among estuaries.

Table 6.1a. Analysis of variance table for differences in abundance of snapper caught in baited traps. Data are transformed ln(x+1) but left untransformed for calculation of variance.

Source	df	MS	F-ratio	Prob.	% variation
Estuaries	2	18.17	6.44	0.04	13.2
Locations (Ests)	5	2.821	1.83	0.14	6.8
Sites (Locs (Ests))	24	1.534	2.28	0.00	20.0
Error	96	0.670			60.0

Table 6.1b. Analysis of variance table for differences in abundance of snapper caught in trawls. Data are transformed ln(x+1) but left untransformed for calculation of variance.

Source	df	MS	F-ratio	Prob	% variation
Estuaries	2	9.09	2.91	0.14	33.5
Locations (Ests)	5	3.12	3.82	0.01	15.9
Error	24	0.815			50.6

At the spatial scale of locations within estuaries, the two sampling methods gave comparable estimates of relative abundance of snapper (Figure 6.8). It was clear that neither method consistently provided superior results. There were locations where one of the survey methods did not detect any snapper, but the other method did, and this applied to both methods. The traps did not detect differences among locations within estuaries but the trawls did (Table 6.1). The trawls could not sample with replication at the level of sites within locations, and the traps found significant variation at that scale (Table 6.1a).

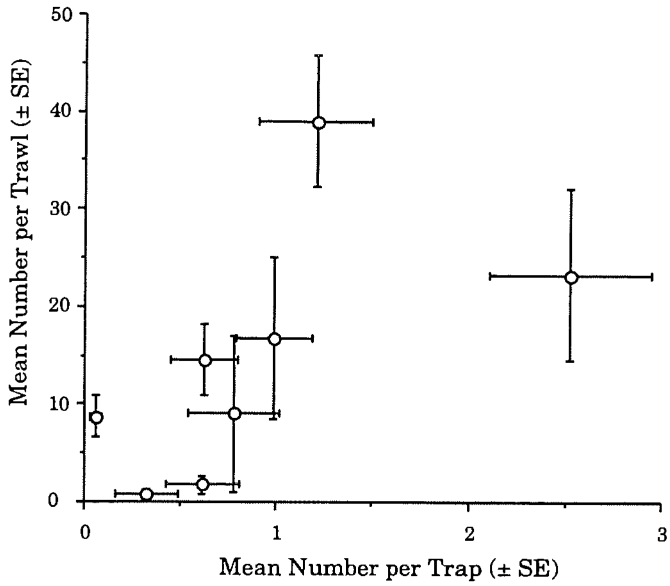


Figure 6.8 Comparison of mean numbers of snapper caught by trapping and trawling at eight locations in three estuaries. Sample size is n = 4 for trawls and n = 80 for traps.

The size distributions of snapper caught with the two methods were different (Figure 6.9). The greatest difference between the two size distributions was in the number of larger fish. The trawl caught few fish over 14 cm compared to the traps. There was no suggestion, from either size composition, of "cohorts" of fish of different ages (Figure 6.9). We had expected to find both 0^+ and 1^+ fish in these samples, separated in to two size classes. The uni-modal size distribution led us to age a subsample of small fish from Port Jackson. Ages were estimated for about 50 fish that were between 7 and 13 cm. This sample contained fish from both the 0^+ and 1^+ year groups with a 1 cm overlap at about 11-12 cm in this particular sample (i.e. there were 11 cm fish that were 1^+ and 12 cm fish that were 0^+.

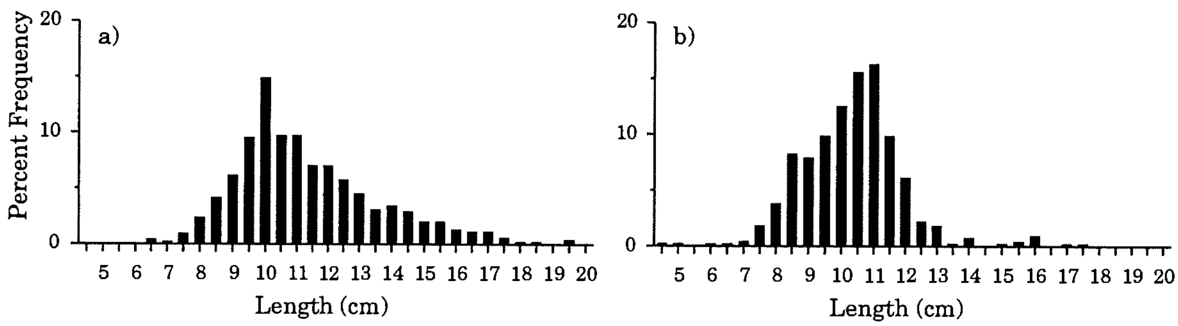


Figure 6.9 Length frequency of snapper caught in a) traps, N = 569 and b) trawls, N = 455. Frequency pooled across all estuaries.

Power to detect differences in relative abundance among locations (estuaries in this case) using traps was high for most hypothetical scenarios when we used the variance estimated from the survey comparing traps with trawls (Figure 6.10a). However, in that survey we selected locations within estuaries where we expected to find snapper and therefore we also estimated sensitivity with the estimated among estuary variance doubled (Figure 6.10b). The scenario where means among locations each differed from the other by 1 SD of our mean survey value had high power even under double our survey variance. This is approximately the same magnitude as the largest differences found in among-year variation in snapper recruitment in New Zealand (Francis 1993).

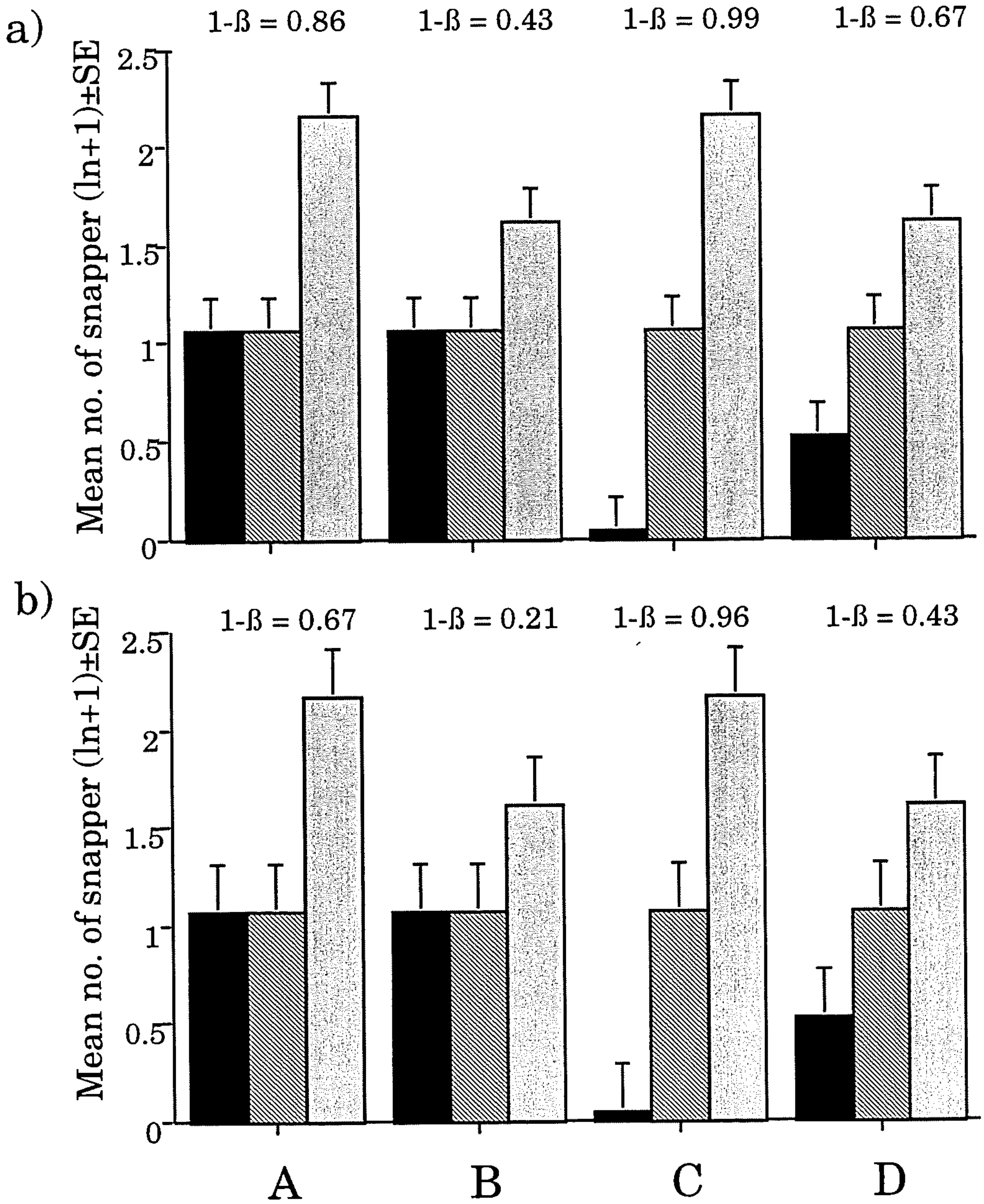


Figure 6.10 Power estimates for four hypothetical combinations of means: a) using the variance from the pilot survey ; b) using two times the variance from the pilot survey. Means of A and C vary up to 1 s.d. from the estuary grand mean of the pilot survey, and means of B and D vary up to 0.5 s.d. All estimates assume $\alpha = 0.05$.

Inshore surveys

The survey of estuaries in central NSW found large inter-year differences (Figure 6.11), with average catches approximately 4 times higher in 1996 than in 1995. These data were analysed with a nested analysis of variance where survey year and location (Sydney, Forster) were fixed factors and estuaries (e.g. Wallis, Pittwater) were nested within locations and random 1 km^2 plots were nested within estuaries. There was a significant interaction between the year of the survey and the estuaries ($F_{2,1272}$ 3.70, P 0.02) and was evident from the fact the Manning river had no snapper in 1996 (Figure 6.11).

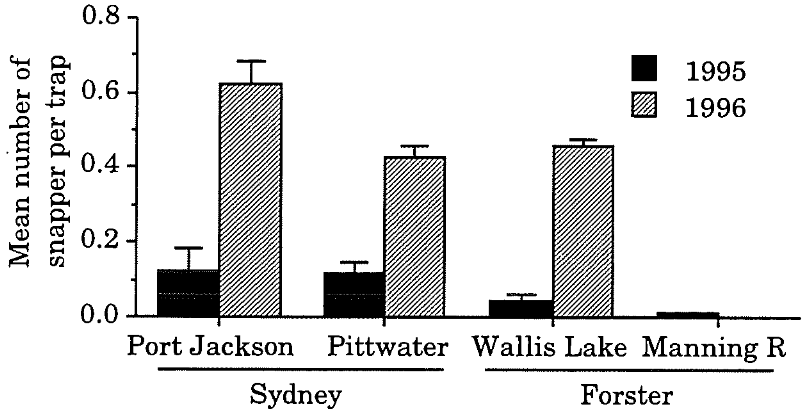


Figure 6.11 Mean number of snapper per trap (± SE) in survey in estuaries near Sydney and Forster in summers of 1995 and 1996.

There were large differences in the abundance of snapper on trawled and untrawled (closed or foul ground) bottom types in Moreton Bay in February 1995. The mean abundance on trawled bottoms was about 10% of the abundance elsewhere in Moreton Bay (Figure 6.12). However, this difference was not the same the following year when Moreton Bay was surveyed in mid November 1995, late December and early February 1996. There was no pattern that persisted throughout the summer. In November, there were no differences among the three types of grounds (SNK test on 3 way ANOVA, P > 0.25, Figure 6.13). In the following December there were significantly more snapper in the trawled grounds and in the last survey, there were again no differences among the three types of grounds Throughout this period the overall catch rate for juvenile snapper was low compared to the previous summer (cf. Figures 6.12 and 6.13).

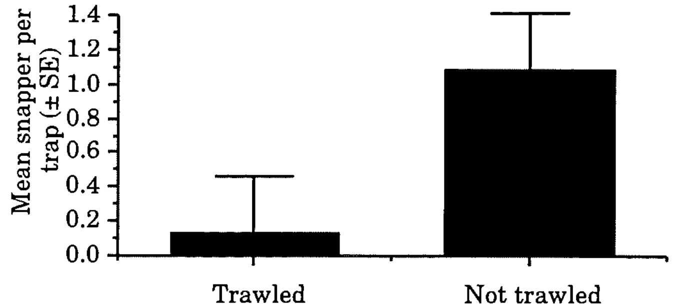


Figure 6.12 Mean catch of snapper (± SE) using baited traps in Moreton Bay in February 1995. Untrawled substrata include foul ground and closures.

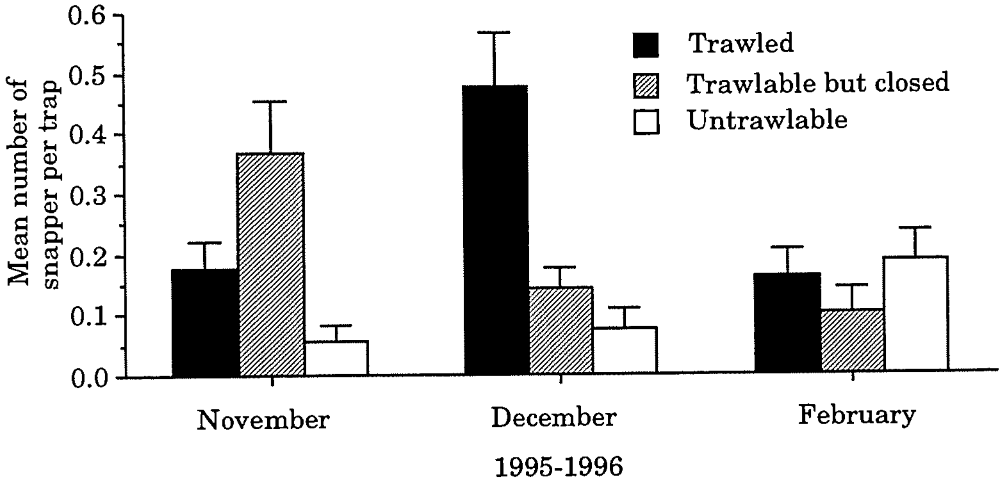


Figure 6.13 Mean catch of snapper in Moreton Bay in the summer of 1995-96. Errors shown are standard errors of data pooled across locations within bottom types.

Offshore survey

Catch rates of snapper in the random survey, across all bottom types, varied among locations by a factor of 9, but overall catch rates were very low. The lowest catch rate was from Ballina (0.07 ± 0.04 SE) and the highest was from Coffs Harbour (0.62 ± 0.24 SE) and the differences among the locations was not significant (one way ANOVA, $F_{3,356} = 2.16$, $P < 0.05$).

Catch rate differences when fishing was targeted, irrespective of bottom type, were significantly different among locations and ranged from (0.33 ± 0.14 SE) at Sydney and (02.75 ± 0.48 SE) at Forster (nested ANOVA, $F_{3,32} = 7.7$, $P < 0.05$). This analysis also detected significant variation among sites within locations.

Snapper occurred only rarely on sand in our random survey and the commercial trap fishers in the north of the state did not target fish on sand. Catches of juvenile snapper on sand were found near Sydney and on a small proportion of occasions off Foster (Figure 6.14a). At most locations, there were no differences between the catch rate of targeted fishing and random fishing within the same habitat. However, the fishing at Forster was an exception and the commercial fisher chartered there had a targeted catch rate more than 5 times his random fishing catch rate, when fishing rock substrates (Figure 6.14a).

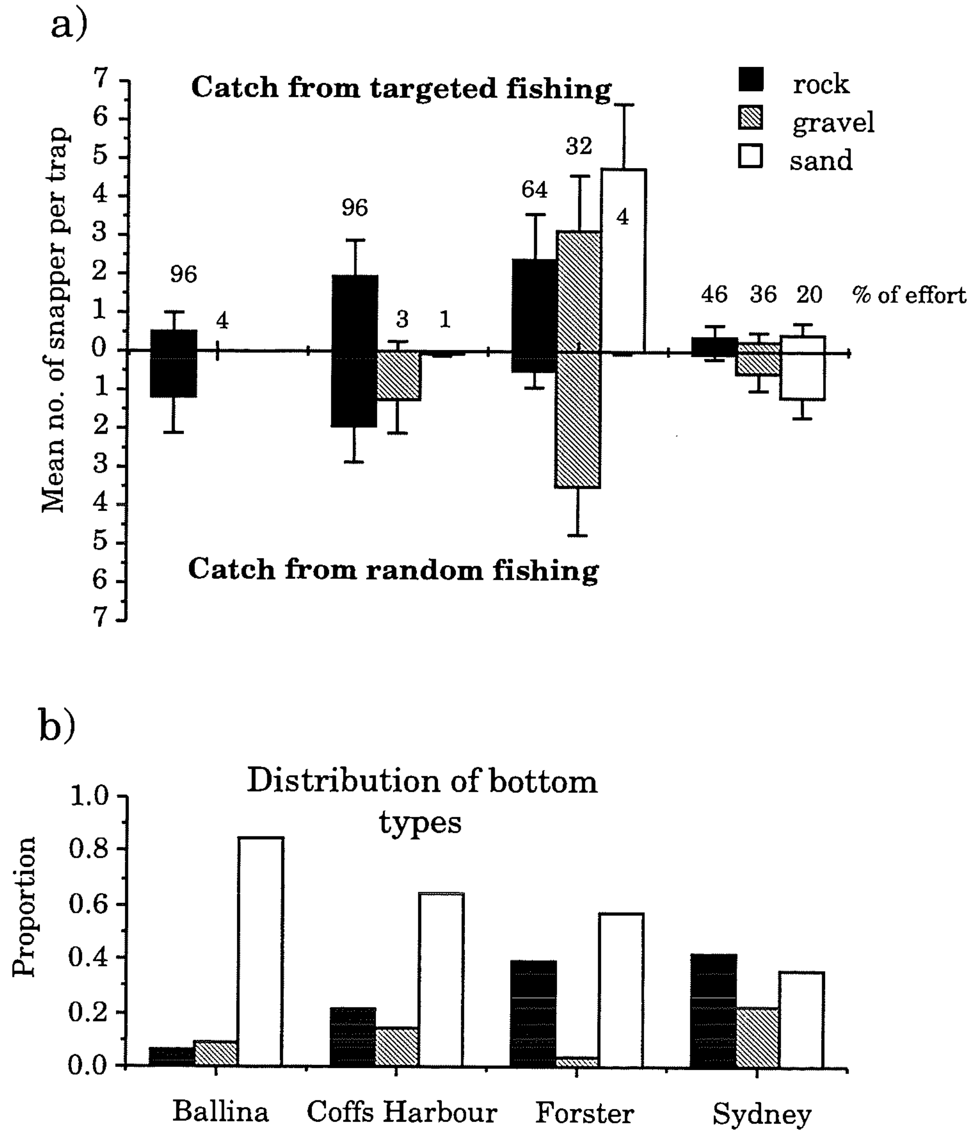


Figure 6.14 a) Catch of juvenile snapper in survey of coastal waters conducted using both random and targeted fishing effort. Sample size for each type of fishing at each location is 90. The distribution of fishing effort from targeted fishing is shown as percentages above each histogram. Sampling locations as in b), following b) The distributions of habitat types at each location are from 180 soundings taken at randomly selected coordinates.

The distribution of bottom types varied significantly among sampling locations (Figure 6.14b, Chi-square = 54.2, 6df, $P<0.05$). The proportion of total made up by sand increased at every successive location north of Sydney. There was more rock than gravel at all locations except Ballina. The distribution of targeted fishing changed among locations but not in a clear way associated with the changes in bottom type. The fisher from Forster targeted snapper on gravel in excess of the proportional distribution of habitat and this strategy was successful. Our random catches on gravel were higher than on other bottom types in Forster (Figure 6.14a & b). Likewise, the chartered fisher from Sydney chose to target snapper on sand, something that was unusual at other locations. This was also relatively successful and the strategy was supported by the results of our random sets in that habitat.

Our offshore survey of small snapper collected a size range of fish that was very different than the size range found in the estuarine surveys. The size range of fish from the survey off Forster was typical of the sizes of fish caught in all locations (Figure 6.15). Fish smaller than 16 cm were rare in samples from all locations and the mean size in all catches was 21.1 cm; if fish over the legal size are excluded, the mean size was 20.2 cm. The estuarine surveys commonly catch snapper averaging between 9 and 13 cm with some fish as small as 5 cm and fish larger than 20 cm being rare (e.g. Figure 6.9).

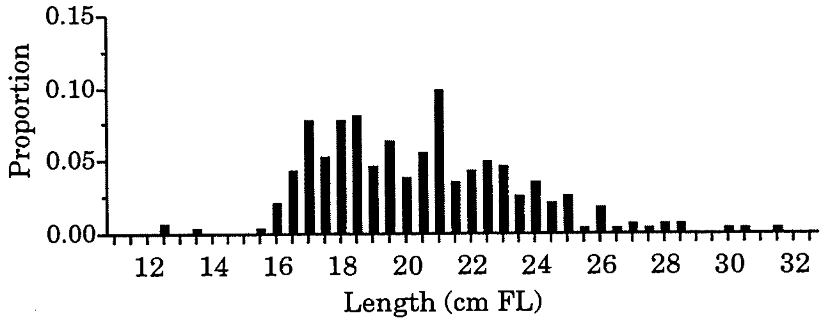


Figure 6.15 Length frequency of snapper caught near Forster in the summer 1996 survey in offshore waters. Pooled from all trapping, N= 286.

In order to determine what sizes of snapper could be retained by our offshore traps, we fished them in Wallis Lake about one month after the 1996 estuarine survey had found abundant small snapper there. The large traps designed to be used offshore retained snapper and other sparids as small as 10.5 cm and reasonable numbers of snapper smaller than 15 cm (Figure 6.16).

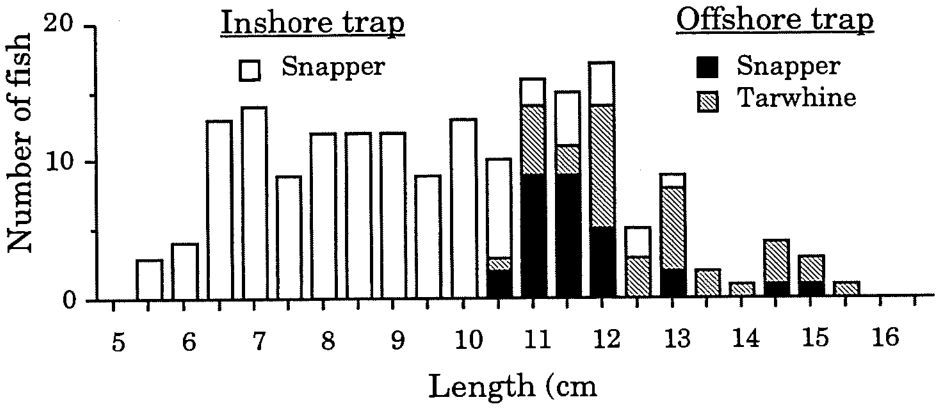


Figure 6.16 Length frequency of snapper caught in surveys of Wallis Lake in summer 1996 using the standard estuarine trap (white histograms) and using the large trap designed for the offshore survey (black histograms). Also shown from the large traps is the length frequency of tarwhine (*Rhabdosargus sarba*), another sparid very similar in shape to snapper (shaded histograms).

The relative cost and sensitivity of our offshore traps and the demersal trawl suggests that the offshore trapping may not be as effective per cost as a trawl set up such as the Kapala. We estimated the number of days of trawling or trapping that would be required to detect a difference equal to the mean (i.e. 2X difference) in the respective surveys, given the survey data and alpha = 0.05 and 1- beta = 0.80. Variances were less in the targetted trapping, where we estimate it would take 23 days trapping at each of the locations to detect the stated difference among locations. Using a random survey, this would take 33 days in each location. The Kapala or a similar trawler could sample for only two days at each location to have an 80% chance of detecting a factor of two difference amongst locations. Even given the greater cost of a trawler (about 2-5 times in charter costs), the trawl survey is much less expensive.

6.4 Discussion

Logbook of undersize catch

For a logbook such as the one kept by professional trappers in this study to be an effective indicator of upcoming recruitment to the fishery, it must be able to provide information about the relative abundance of fish through time, prior to their recruitment to the fishery. This information must be gathered at a spatial scale that is appropriate to the activities of the fishery and appropriate to the monitoring of the fishery. Our log provided data that clearly demonstrated differences in mean catch rates in juvenile snapper among locations, depths and among years. In that sense, it would appear to be an appropriate means of monitoring pre-recruit fish. However, it is not clear whether the spatial scale monitored with the log was appropriate. For example, in most port areas logs were kept by a relatively small number of fishers. We simply accepted all who volunteered to keep a log and did not examine their fishing patterns relative to the entire fleet. Any mismatch between the range of areas worked by the fishers who kept logs and the rest of the fleet could possibly add variation to the relationship between the number of fish returned and the subsequent catch. This potential problem could be rectified by increasing or adjusting the coverage of the log to ensure that it is representative. The cost of our log was relatively low and extending the log to more fishers could easily be accomplished

Our offshore survey and the limited information on the size range of undersize fish returned suggest that most fish would be 1 or 2 cm smaller than the legal length. It is likely that these fish are very close to being recruited to the fishery. The usefulness of such information on pre-recruits would depend largely on the type of management regime (Walters and Collie 1988). If feedback for management was required at an annual or shorter time scale, then such a log might be appropriate. Certainly, there was little evidence for a link between the logged catches of undersize fish and the subsequent landings of recruited fish. As an index of future recruitment to the fishery, such a technique could not be viewed as a measure that was independent of the fishery.

The logbook for undersize fish may have benefited from a longer time series. All fishers changed their fishing activities seasonally and there were differences amongst individuals as well. These sorts of changes within the year may make the month-wise comparison we made inappropriate. The seasonal changes in snapper catch were confounded with seasonal changes in fishing effort and we did not attempt to test whether catches at some times of the year were more indicative of recruitment to the fishery. We think this is unlikely as Henry (1990) found few seasonal changes in length composition of landings.

The group of fishers who were participating in the log did change from time to time and some effort by research staff was required to maintain interest and participation. Most fishers did not differentiate among the functional divisions within NSW Fisheries and therefore sometimes unfavourable interactions with the Department caused participants to drop out of the program. Once a fisher stopped the log, it was often difficult to get them to recommence.

Inshore Survey

The small baited traps we used in the inshore survey were an appropriate, sensitive and cost-effective sampling tool in protected shallow waters. They were shown to be equal in cost and sensitivity to a demersal otter trawl that had been specifically designed for similar sorts of survey work (Gibbs and Matthews 1982).

On the basis of our trials of small baited traps and from the surveys that followed the trials, we can suggest a number of situations where trawls are likely to be more useful than traps. Likewise, we can also nominate a range of situations where traps may prove useful or appropriate survey tool. Trawl surveys will improve in cost relative to traps as the size of the smallest spatial scale in the survey increases. We wished to document variation among 1 km^2 locations within estuaries as well as describing variation among estuaries. To do this we had to run replicate trawls within each location, but if estuaries were the smallest spatial scale where replication were required, longer trawls could have been made and this may have been more efficient than our short trawls. Alternately, it is clear that traps can provide information on small spatial scales where a trawl may not work or be very inefficient. Trawling is often deemed unacceptable to the public, particularly in estuarine waters. In that situation, a trap survey may not excite the interest or public comment that trawling would.

Offshore survey

Catch rates throughout the offshore survey were low when fishing was completely random. This was in part a result of extremely low catches on sandy bottom and the relatively high proportion of that habitat in some areas. The targeted fishing had an overall catch rate much higher than the random fishing, which we expected. However, in most locations we found the catch rates from the random survey from within the bottom types that were being targeted were not different from the targeted catch rate on that bottom type. This suggests that a random trapping survey that was stratified across bottom type could expect sensitivity similar to our targeted survey.

The large traps we used in the offshore survey were clearly capable of retaining smaller snapper than were commonly caught in our surveys. We know that small snapper between 5 and 15 cm do occur in near shore waters because they have been documented in by-catch of prawn trawls (Kennelly 1993) In that study, done quarterly over two years, small snapper were very patchy in space and time but were extremely rare in "offshore" waters (from 45 to 100 m depth) and were only caught in their "inshore" stations (from 10 to 20 m). We do not know why we caught so few very small snapper in this survey. Anecdotes from the fishing industry suggest the presence of such small fish in prawn trawl by-catch may be associated with flood events, but the work of Kennelly (1993, pers. com.) does not support this hypothesis.

Despite the offshore traps not being cost effective compared to a trawl, there may be questions that require a survey tool like our traps. More than 98% of the catch from targeted fishing was on grounds where it was not possible to trawl so for some questions, traps may be the only survey tool available. As with the small traps, the smallest spatial scale for which information is required is also a consideration and traps of either type can be used to describe variation at small spatial scale, if required.

In both the inshore and offshore trapping surveys, we have examined the sensitivity of traps relative to a more standard technique (trawling). We have also examined the ability within those surveys to detect differences at the largest spatial scale of each survey. Without a time series of surveys to analyse, we have used the ability of the survey data to distinguish differences among locations as an indication of the likely sensitivity of such surveys to differences among years. We reasoned that the analysis of variance framework we used to test for significant differences among locations would be less sensitive than some future analysis based on a time series of surveys. We have sought survey tools sufficient to describe the factor-of-ten variation in year class strength documented for snapper elsewhere (Francis 1993). Having demonstrated the ability of data from trap surveys to detect such differences, we are less concerned with the specific difference among locations.

7.0 REPRODUCTIVE BIOLOGY

7.1 Introduction

Despite an extensive literature dealing with reproductive biology of snapper in both New Zealand and Japan very little work has been published on the reproductive biology of snapper in Australia. The exception to this is the work of Battaglene and Talbot (1992), who examined the induction of spawning and larval rearing of snapper. They also noted that running ripe wild snapper were found off Port Stephens (32° 40S) in November. By comparison, New Zealand, snapper spawn from October through to February (Crossland 1977a, Scott and Pankhurst, 1992) although there is yearly variation in the timing of spawning related to water temperature (Scott and Pankhurst, 1992). The fact that the distributional range of snapper extends as far north as 20° in Australia, suggests that there may be differences (at least in terms of reproductive seasonality) between the species in its subtropical range compared to cooler temperate waters where most of the research has focussed.

The presumed environmental trigger for spawning in New Zealand is believed to be an increase in water temperature to about 18°C. Battaglene and Talbot (1992) have also presented evidence for a 18°C spawning trigger. The seasonal variation in sea surface temperature in Hauraki Gulf, (the main snapper fishing area in the north island of New Zealand) is 14° to 22° C (Crossland 1977a). By comparison, water temperatures at the northern limit of the species range in Queensland rarely fall below 20° C and can reach as high as 30° C. Even at a latitude of 27° oceanic sea surface temperatures during winter rarely fall below 18° C. These differences suggest that other environmental influences may be involved in triggering the spawning of snapper in lower latitudes.

Scott *et al* (1993) have presented evidence for a daily spawning pattern of snapper based on diurnal changes in oocyte diameter. They found that ovulation was synchronised to occur soon after midday and that most of the population was involved in spawning which occurred in the late afternoon and early evening. The same authors have also discussed some of the difficulties in deriving estimates of fecundity for snapper. Yet, estimates of fecundity, or at least size related changes in relative fecundity are important parameters in egg per recruit models which are often used when assessing an appropriate minimum legal size. In New Zealand, Crossland (1977b) has derived fecundity estimates of snapper based on the assumption that the species had a deterministic fecundity.

Here we describe the reproductive characteristics of snapper at the northern extreme of their range. We also attempt to use methods used recently in New Zealand to estimate the fecundity of snapper at the northern extreme of its range in the southern hemisphere. These data are particularly useful when producing egg per recruit models to determine appropriate minimum legal sizes (See Chapter 9).

7.2 Materials and Methods

Snapper were collected mainly from commercial and recreational line fishermen between December 1992 and October 1995. These samples were augmented by collections on research line fishing cruises carried out east of Moreton Island during the months of June - September of 1994 and 1995. Typically, gonads came from freshly killed fish or fish that had been kept on ice after capture, however, a proportion of gonads (< 20%) were from fish that had been frozen. Fish were measured (Fork Length, cm), weighed (wet weight, grams) and sagittal otoliths removed for ageing. Gonads were removed, sexed, staged macroscopically (Tables 7.1 and 7.2) and then placed in 10% neutral buffered formalin prior to histological processing or other analysis. Macroscopic and microscopic staging schemes were modified from those of Matsuyama *et al* (1987a, 1987b) and Scott and Pankhurst (1992) and was based on the most advanced oocyte stage observed in the section. Gonosomatic indices were calculated as the percentage gonad weight to the gonad free wet body weight.

Specimens selected for histological preparation were removed from the fixative and a section was taken across one lobe unless there was an obvious difference between lobes or between regions on the lobe. If this was the case multiple sections were taken. Sections were cut at 6 microns and standard Haematoxylin and Eosin staining carried out.

Batch fecundity estimation

Specimens selected for fecundity analysis all had histological samples taken for slide preparation. A sample of between 1 and 5 grams, (dependent on the size of the gonad), was cut from the middle of one lobe, usually the same lobe as that used for the histology. If the sample was removed at the same time as the histological section then the fecundity sample was removed immediately adjacent to it. If not then the sample was removed far enough away to negate the possibility of egg loss from the earlier cut. Ovary samples (from fish in Stages 4 - 5) were weighed, then sieved through a nest of Caldicott sieves (63 micron, and 2mm). Eggs were removed from connective tissue and then placed in vials of 10% neutral buffered formalin. Samples were then sorted under a stereo microscope and all eggs were counted to obtain estimates of the numbers of eggs per gram of ovary tissue. The number of eggs in each pair of ovaries was then calculated using the equation $N = C \times k_f / k_w$ where C is the count of the sub-sample, k_f is the fraction of eggs > 0.1 mm counted and and k_w is the ratio of ovary weight to sub-sample weight.

Fecundity was estimated in two ways. Firstly using the methods of Crossland (1977b) who used counts of the number of oocytes in the ovary at the beginning of the season and subtracting the number at the end of the spawning season. Secondly batch fecundity was estimated as the number of hydrated oocytes in the gonad of ripe females. Initially, the ovaries of mature snapper were investigated to determine any variation in egg counts and microscopic staging related to whether samples were taken from the proximal, medial or distal region of the gonad or whether the gonad was frozen. Five replicate 0.5 gram (approximately) samples were taken from each region of the gonads and all eggs counted. Histological preparations were also taken from each region and immediately adjacent to where the egg sample was taken.

A random sample of approximately 200 eggs from a sub-sample of these ovaries was measured using a binocular microscope interfaced to an image analysis system (OPTIMAS ™). The technique involved shaking the sample and pouring a sub-sample into a small petrie dish and then measuring all oocytes in the field of view. This procedure was repeated several times until approximately 200 oocytes had been measured. The resultant distributions were often multi modal reflecting the batches of oocytes at different stages of development. Eggs from these distributions were classified on the basis of their diameters into the following stages (Scott *et al*, 1993):- primary oocytes (0.05 to 0.19mm), Vitellogenic oocytes (0.2 to 0.49mm), early final oocytes (0.5 to 0.69mm) and hydrated oocytes (>0.7mm). Verification of these classifications was not quantified, however subjective observation of egg sizes during counting confirmed the classification.

In addition the spawning habits of snapper held at a large ocean aquarium (Underwater world, Mooloolaba) were observed on a daily basis during the 1995 spawning season. Males were identified by grey colouration around the throat, a feature observed in reproductively active snapper in New Zealand.

Table 7.1 Criteria used to classify male testis into macroscopic and microscopic histological reproductive stages.

Reproductive Stage	Macroscopic Features	Histological Features
1 Immature	Testis thin and flattened Translucent white threads	Testis composed predominantly of dense connective tissue Spermatoogonia dominate
2 Developing	Testes enlarged Creamy white in colour	Lobules lined with spermatogonia crypts Spermatocytes proliferate Few spermatozoa
3 Mature	Opaque and white Viscous milt in sperm ducts	Tunica thin and lobule walls distended Spermatozoa predominate and crowd sperm ducts and sinuses Testis periphery contains crypts with cells of all developmental stages
4 Ripe	Testis firm, creamy white Free flowing milt in spermduct	Spermatozoa predominate packing lobules and sperm ducts
5 Spent	Testis thin and flaccid Residual sperm visible as white areas in overall darker grey testes	Crypts beginning to form but empty Connective tissue dominates Residual spermatozoa present

Table 7.2 Criteria used to classify female ovaries into macroscopic and microscopic histological reproductive stages

Reproductive Stage	Macroscopic Features	Histological Features
1 Immature	Ovary thin & firm Pale or translucent pink No oocytes visible	Ovary small in diameter Tunica tightly encloses ovarian lamellae Cytoplasm without vacuoles densely staining basophilic No evidence of prior spawning
2 Resting	Ovary more rounded Pale, opaque pink or red No oocytes visible	Ovary has previously undergone vitellogenesis Tunica thick Oocytes more rounded than immature ovary
3 Developing	Ovary enlarged Usually pale orange, sometimes pink Oocytes visible but small	Oocytes undergoing vitellogenesis Nucleus and cytoplasm increasingly eosinophilic Yolk vessicles present Chorion evident Atretic bodies may be present
4 Mature	Ovary enlarged Orange but not speckled in appearance Oocytes large and easily discernible	Yolk vessicles dominant Nucleus migrates from centre and disintegrates Zona radiata evident as a thickened band
5 Ripe	Ovary greatly enlarged Translucent pale orange Hydrated, clear eggs giving a speckled appearance Eggs extruded by applying pressure to abdomen	Yolk globules appear as acidophilic and granular Zona radiata evident as a thin band Oocytes greatly enlarged and hydrated
6 Spent	Ovary dark red and bloodshot Thin and flaccid	Tunica flaccid Residual atretic oocytes Post ovulatory follicles Septa disorganised

7.3 Results

Over the range of latitudes (21° to 24°) where samples were collected seasonal variation in gonosomatic indices (GSI's) did not differ between areas and in subsequent analyses these data have been grouped. Over the two main years when samples were collected (1994/95) the peak in female GSI occurred at the same time (during the winter months) although there was evidence of spawning as late as September (Figure 7.1). The pattern for male GSI was similar to that of the females with GSI values peaking during the winter (Figure 7.2). This study was primarily concerned with delineating female reproductive patterns and males were not as extensively sampled and there were insufficient males collected to allow for a discussion of differences between years. On the other hand, female GSI"s tended to be lower during 1994.

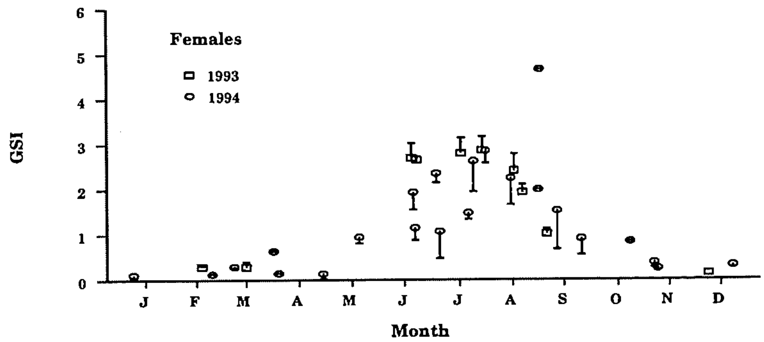


Figure 7.1 Female gonosomatic indices of mature *Pagrus auratus* sampled during 1993 and 1994 (Standard errors are shown as vertical bars. Points without errors represent a single sample).

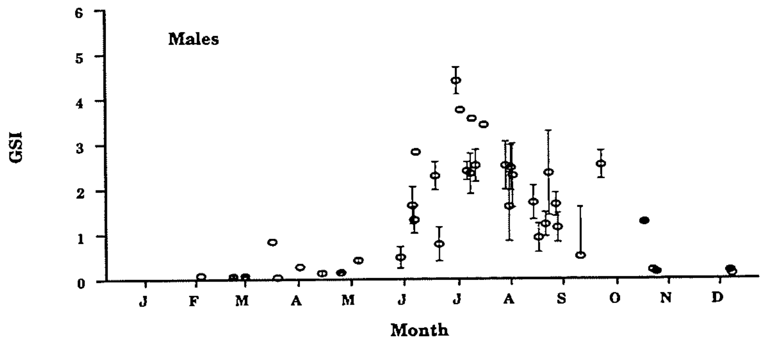


Figure 7.2. Seasonal variation in gonosomatic indices of male *Pagrus auratus* for 1993 and 1994 combined. (Standard errors are shown as vertical bars Points without errors represent a single sample).

Microscopic staging of female gonads confirmed the results of GSI studies although there were some females with mature gonads appearing as early as April. Spent females were only recorded during June, July and August and September with the latter month having the highest proportion of spent females, reflecting the end of the spawning season. Post spawning males were only present during August - November (Figure 7.3) and there was a high proportion of ripe males very early in the season(as early as April)

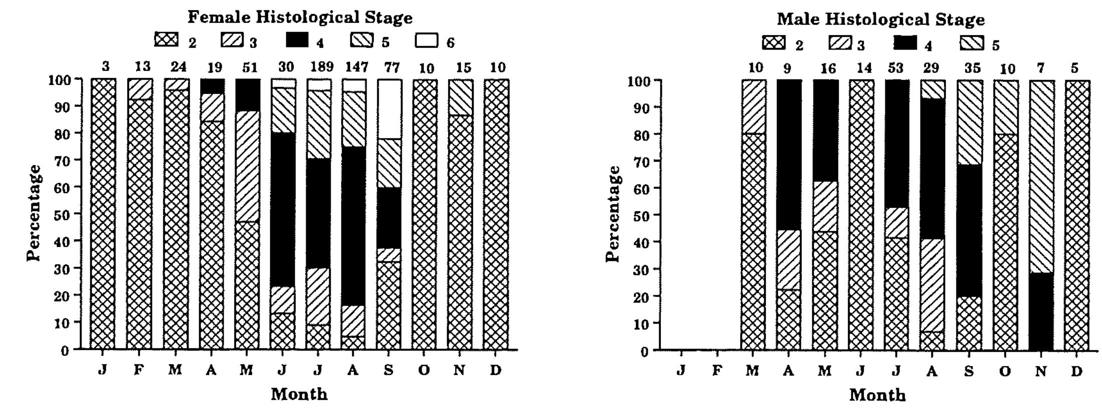


Figure 7.3 Seasonal variation in reproductive state of male and female snapper based on histological staging (Tables 7.1 and 7.2)

Figure 7.4 shows the relationships between gonad weight and age for both male and female *Pagrus auratus*. As expected, for both sexes gonad weight increased with size, however there was a group of females aged 5 and 6 which had gonad weights disproportionably large for their age. Although these could be explained as ageing errors, careful examination of the otoliths indicated that this was unlikely since repeated readings by independent readers gave the same ages. These fish were also mostly sampled from the northern extreme of the fishery (either the Swains or Mackay).

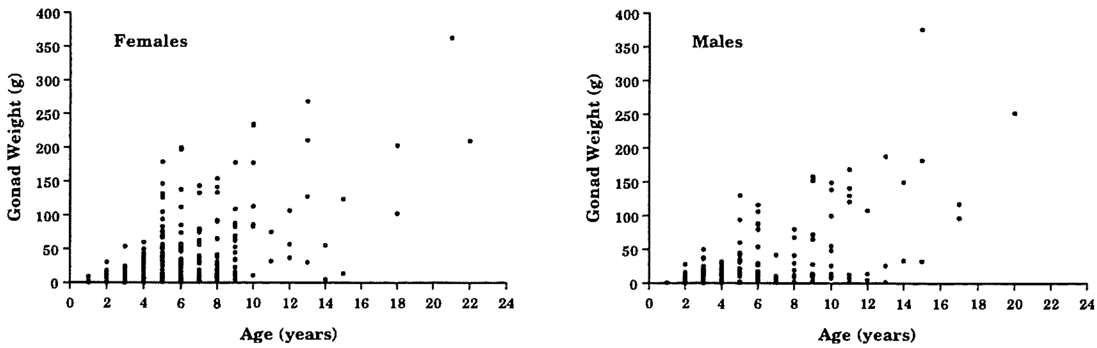


Figure 7.4 Relationship between gonad weight and age for mature male and female *Pagrus auratus*

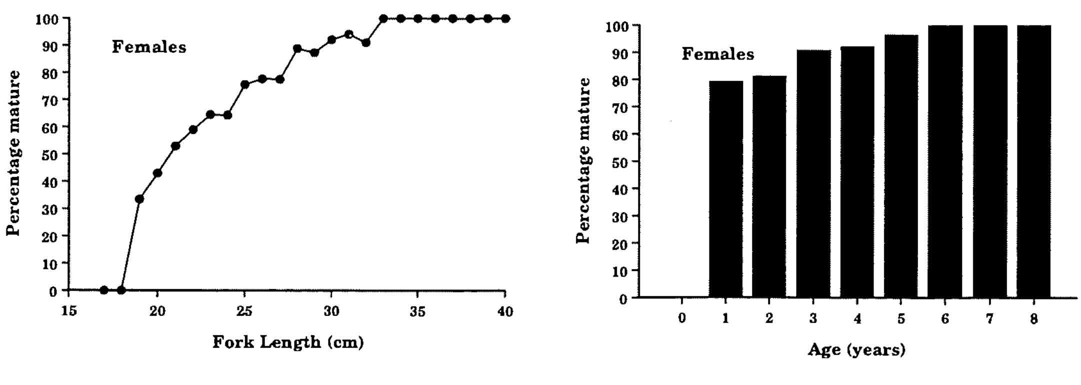


Figure 7.5 Size and age at sexual maturity of female *Pagrus auratus* from southern Queensland waters.

Snapper reached maturity over a wide range of sizes with 50% sexual maturity occurring at approximately 22 cm fork length although there were numerous fish greater than this length which had not yet spawned (Figure 7.5). There were many snapper recruited to the fishery as young as 1+ year old which were sexually mature, however this only occurred very late in their first year when they were at least 22 months old (see Chapter 4). It was interesting again to note that whilst snapper appeared to mature at close to 2 years of age there were fish as old as 5 which had apparently never spawned. However, all fish greater than 5 years of age and 33 cm in length were classified as sexually mature.

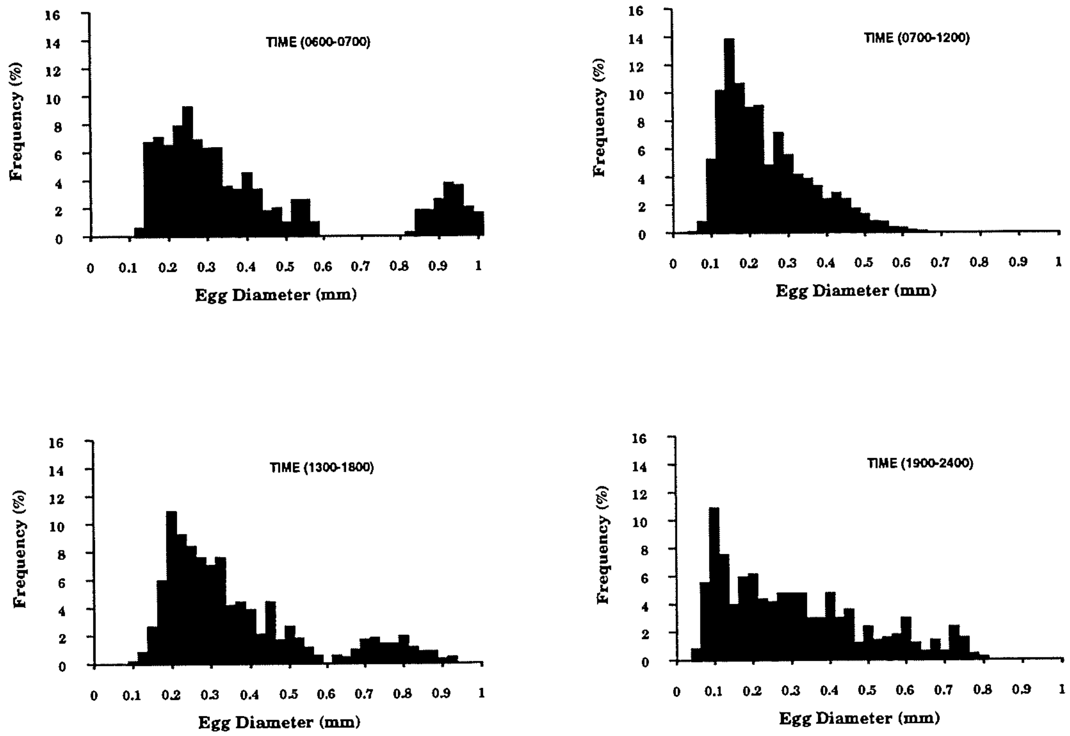


Figure 7.6 Frequency of various oocyte sizes in the ovaries of ripe (Stage 5) female snapper sampled during various times of the day

Oocyte development did not show strong small scale temporal trends although these data are limited by the fact that there was insufficient resolution in the time of capture, and the method of capture (line fishing) resulted in little control over the time of capture (Figure 7.6). The most obvious trend was for fish captured between 0700 and 1200 hr to have relatively poorly developed oocytes in comparison to other times. The strongest evidence for bimodality in oocyte size distributions can be seen in the samples collected between 0600 and 0700 hr.

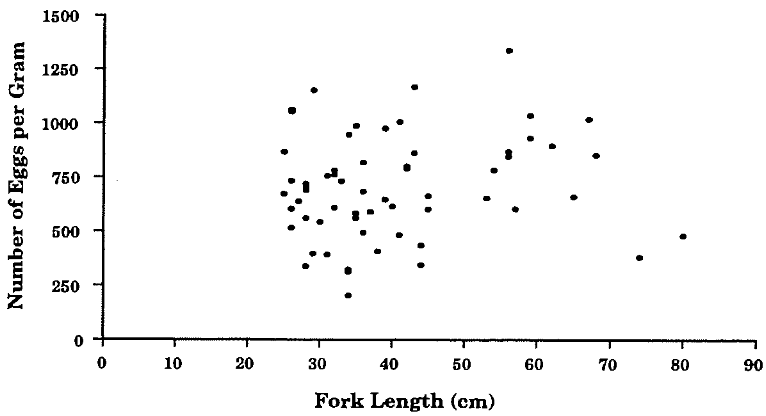


Figure 7.7 Relationship between the number of hydrated eggs per gram of ovary and length of mature female *Pagrus auratus*

Likewise examining the relationship between fork length and number of hydrated eggs per gram of ovaries in either stages 3 to 5 (Figure 7.7) showed that there was no significant relationship ($r^2 = 0.003$). This indicated that the increase in fecundity with size was due to the larger gonad size of larger fish and not to any increase in the number of eggs per unit weight of gonad. Although egg samples were collected during both the 1994 and 1995 spawning seasons there were insufficient numbers taken during 1994 to allow a meaningful comparison of yearly differences in fecundity. In order to estimate the annual fecundity an estimate of the spawning frequency needs to obtained in addition to the batch size estimates already derived. Scott *et al* (1993) as already mentioned have presented evidence for daily spawning in wild populations of New Zealand snapper, however, we were unable to determine spawning frequency even given that the spawning season extended over approximately 3 months.

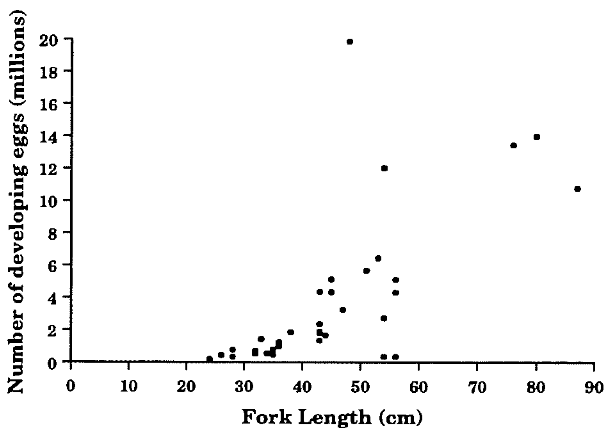


Figure 7.8 Relationship between the number of developing eggs and fork length for Pagrus auratus during the beginning of the spawning season.

Estimates of the number of developing eggs and the fork length of snapper were fitted to a log linear relationship as follows:- $\log_{10}$ (Number of Eggs) = 0.02835 x Fork length (cm) + 5.011 ($R^2 = 0.55$, $P<0.001$, Figure 7.8). Unfortunately insufficient numbers were sampled at the end of the spawning period to allow a meaningful estimate of the number of eggs spawned using Crossland's (1977b) method.

Spawning Observations

Fish living in a large tank at "Underwater World" at Mooloolaba were observed weekly over the months May to October 1994. Prior to the onset of the breeding season the snapper present in the tank were swimming as a single school consisting of all sizes of fish with the majority of activity taking place in the lower section of the water column. At the onset of the breeding season the fish segregated by size with the fish smaller than approximately 40 cm separating from the others and limiting their activities to the bottom of the tank. The larger fish moved to the upper half of the water column and started to develop their spawning colouration. The males develop a grey to dark grey colour along the ventral surface particularly in the throat area. The females lightening to a vivid white this colour easily observed from the observation tunnel. As the season progressed a further segregation took place amongst these larger fish. The females moved to within half a meter of the water surface and their swimming speed slowed down, for a lot of the time they swam slowly right on the surface with their dorsal and tail fins breaking the surface. The males swam around below the females at three times the speed, though no actual spawning was observed. This behaviour was consistent with that described by observations made on wild populations by commercial fishermen.

7.4 Discussion

The length of the spawning period of snapper did not differ markedly in duration from the spawning season of snapper in higher latitudes (approximately 3 months), however the season began up to 6 months earlier than in some New Zealand populations (Cassie, 1956b, Crossland, 1977a). The much earlier spawning period at higher latitudes allows for at least another 3 months of early rapid growth before growth slows during the first winter. In addition, juveniles produced from fish spawning earlier in the season would have an even longer growing season than snapper spawned later and may provide for earlier recruitment into the fishery. Interpretation of growth checks on otoliths may also be complicated if spawning has an influence on otolith appearance. Snapper ageing validations come from areas where spawning occurs at the opposite time of year from the formation of growth marks in otoliths (Ferrell *et al.* 1992, Francis *et al.* 1992) but growth checks and spawning are broadly concurrent in southern Queensland. The northern populations were clearly more difficult to age (See Chapter 4).

In subtropical waters snapper can reach maturity and are capable of spawning as early as the end of their second year of life although there are a small proportion of fish as old as 5 which appear to have never spawned or at least are not spawning during the particular spawning season in which they were sampled. Maturity did not appear to be closely related to either size or age since its onset occurred over a wide range of both sizes and ages. In general, snapper reached sexual maturity between 22 and 30 cm FL and at an age between 2 and 5. The lower limits of snapper size and age at sexual maturity can not be considered accurate because most of the fish which were sampled were from the commercial fishery (Minimum legal size of 25 cm) and thus not representative of the entire population. It is likely that the proportion of fish in their second year of life which are sexually mature is considerably less than that estimated here because this age class is still recruiting to the fishery. Regardless of this bias, it is clear that by the end of their third year of life a large proportion of snapper are capable of spawning.

Fecundity estimates were much lower than in New Zealand populations of snapper (Scott, 1991). Scott estimated the annual egg production of a 55 cm snapper in Hauraki gulf was 22.5 million eggs, which was almost 25% greater than even the largest fish estimated in the present study. It is difficult to say whether this variation is due to actual lower reproductive output by warmer water populations of the species or whether it merely represents normal annual variation, or perhaps differences in methods used to estimate fecundity. There are a number of studies where large annual variations in fecundity have been demonstrated (Demartini, 1991; Lenarz and Echeverria, 1986) whilst others have demonstrated a reduction in spawning frequency rather than actual batch fecundity (Fiedler *et al*, 1986) The present study coincided with an El Nino event which has been postulated to cause low levels of plankton production and therefore possibly influencing egg production (Demartini, 1991). In addition, in the present study there were insufficient data collected to correct for differences in the sizes of batches which normally occurs during the spawning season (Scott, 1991).

Crossland's (1977b) method of determining annual fecundity may not be applicable because it relies on snapper having a determinate fecundity (Wallace and Selman, 1981). This means that there is a clear division in the size frequencies of pre-vitellogenic and vitellogenic oocytes at the beginning of the spawning season. It also relies on the untested assumption that the number of eggs in the ovary at the beginning of the spawning season represented the total potential spawnable number of oocytes. However, it appears that snapper have an indeterminate fecundity due to the continuous nature of their oocyte size frequency distributions. Therefore estimates derived from this method may be grossly underestimated. Demartini and Fountain (1992) in fact estimated that previous studies of fecundity of the sardine Queenfish (*Seriphus politus*) were under estimated by at least an order of magnitude because they were derived using this method. We found it impractical because of difficulties in defining the precise timing of the beginning and end of the spawning season and collecting sufficient samples from those periods. The variation in batch size between fish collected at any one time was so great as to make this method unreliable unless large sample sizes could be analysed. Finally, we were unable to obtain sufficient samples from the end of the sampling period in order to apply this method.

Intensive sampling conducted during the presumed spawning season delineated the length of the spawning season at approximately 3 months although the height of the season appears to be around half that figure. There are important implications given that the spawning season for snapper at the northern end of the species distribution occurs during the winter. This is the time of the year when both weather and current conditions are more favourable to fishing. Winds are generally lighter in winter and tend to be more offshore breezes. Likewise currents are generally not as strong. This is also the time of peak activity in the trap fishery in NSW (See Figure 1.5a). All these features imply the focus of the fishery on the spawning population.

Spawning closures have been used as a means of protecting spawning populations (see for example barramundi in northern Queensland) but they may not be effective for this fishery given the geographic and temporal range over which the species spawns. The enforcement of either area or temporal closures could prove difficult because of the relative remoteness of many of the fishing grounds. In addition, there are a number of other demersal and pelagic species which are taken from the same fishing grounds as snapper and it would be difficult to target these species without landing a considerable by-catch of snapper. Even though these fish could be released, there are survival problems since the fishery generally operates in relatively deep water where swim bladder expansion may cause mortality.

8. STOCK STRUCTURE

8.1 Introduction

The collection of information on the structure of fish stocks is an integral component in the implementation of successful management methods to maintain fisheries at sustainable levels. With little knowledge of the stock structure, overfishing can decimate isolated breeding populations to a level where recruitment cannot sustain the harvest and the isolated populations which contribute to the total harvest can collapse, as occurred in the 1970's with the North Atlantic herring *Clupea harengus*. It is now generally agreed that allozyme electrophoresis is still the most appropriate method for looking at population structure, ".....for reasons including cost effectiveness, ease of application, and necessary sample sizes, applying (other molecular) procedures should generally follow only when protein electrophoresis cannot adequately resolve or identify differences among groups." (Utter and Ryman, 1993). In New Zealand there have been a number of studies which have looked at the stock structure of *Pagrus auratus*. The results of these studies, as well as growth rate studies, have been used to separate the New Zealand snapper into 2 stocks for management purposes. In Australia, five State fisheries authorities each have their own snapper management measures which often differ substantially amongst each other. MacDonald (1980) used allozyme techniques to examine the stock structure of snapper throughout most the species Australian range. He concluded that there was evidence of stock structure, particularly for Shark Bay in Western Australia where allellic frequencies differed significantly from other populations around Australia. More recently Johnson *et al* (1986) have used results of allozymes to postulate the existence of separate breeding populations of snapper within Shark Bay itself. Despite these studies, most of the evidence for separate stocks on the southern and east coasts of Australia comes from growth rate studies and tagging experiments which have largely been confined to South Australian and Victorian waters. Recently, Donnellan and McGlennon (1996) used allozymes and Mitochondrial DNA techniques to look at the stock structure of snapper in South Australia but failed to show evidence of separate genetic stocks.

MacDonald's (1980) work, whilst examining the Australian distribution of the species only examined a total of 203 animals from 3 populations from the east coast and recommended the sampling at a finer spatial scale in order to detect population differences.

The purpose of this study was to use allozyme techniques to study the stock structure of snapper on the east coast of Australia at a finer spatial scale than that of MacDonald (1980). In addition, the population of snapper within the large subtropical embayment of Moreton Bay was compared to offshore populations for evidence of structure similar to that found in Shark Bay, Western Australia. This is particularly relevant given that two states are involved in the management of the fishery and the nature of the fisheries differ between the states as do management arrangements.

8.2 Materials and Methods

Sample Collection and Preparation

Liver and muscle samples were collected from 1469 snapper caught at 8 locations between Mackay and Sydney during the period August 1992 and November 1995. Sampling always took place during the spawning season, and most fish were obtained from commercial fishermen, apart from samples taken inside Moreton Bay which were collected on research cruises. The fork length of each fish was recorded and sagittal otoliths were removed and subsequently used for ageing. Most tissue samples were removed from freshly caught fish and stored at -70° C prior to electrophoretic analysis. Tissue samples from fish caught at the Swains and Moreton Bay were removed from frozen whole fish.

Enzymes were extracted by adding a few drops of homogenising buffer (Selander *et al,* 1971) to the samples followed by centrifugation at 13 000 rpm for 5 minutes at 4°C. The labelled vials were then stored in an ultra-freezer at 70 °C until electrophoresis was conducted.

Horizontal starch gel and polyacrylamide electrophoretic methods followed Shaklee and Keenan (1986). Starch gel moulds were modified after Aebersold *et al.* (1987). Starch gels consisted of 10% w/v hydrolysed potato starch. The locations of the enzymes in the gels after electrophoresis were observed using the histochemical staining procedures of Shaklee and Keenan (1986) and Aebersold *et al.* (1987).

Locus nomenclature followed Allendorf and Utter (1979) where multiple loci encoding functionally similar proteins were designated numerically, starting from the cathodic end of the gel. Alleles were designated by their electrophoretic mobility's relative to the mobility of the most common allele, which was designated as "100". Those in the cathodal region were preceded by a negative sign. Enzyme abbreviations, recommended names and Enzyme Commission numbers were in accordance with guidelines set forth by the IUB Committee on --Enzyme Nomenclature (Anon. 1984).

Without precise knowledge of Mendelian inheritance through breeding studies, the genetic nature of protein variants can be assessed following the guidelines of Grant (1985) and Richardson *et al.* (1986): 1) the banding patterns should be consistent with analogous genetic variation in other teleosts; 2) banding patterns should match the predicted quaternary structure of the protein in the heterozygote condition; 3) no unexpected phenotypes should be expressed; 4) when a gene is expressed in more than one tissue, variant phenotypes should be the same among tissues; and 5) samples should conform to Hardy-Weinberg equilibrium in a majority of the samples.

Statistical Procedures

Statistical tests were conducted using log-likelihood ratio (G) tests in preference to chi-square tests, because the G statistic and the degrees of freedom for individual loci are completely additive (Sokal and Rohlf, 1981). A microcomputer program, "Genes in Populations", designed by B. May and C.C. Kreuger and written in "C" by W. Eng, (May and Krueger, 1990) was used for these tests. Each locus was tested for conformance of genotypic counts to Hardy-Weinberg equilibrium for individual collections as well as for pooled samples. In cases where one or more alleles were uncommon, they were pooled with other uncommon genotypes to yield expected cells of five or more wherever feasible.

Spatial differentiation was analysed by comparing adjacent populations for statistical differences. To account for multiple tests of the same hypothesis, differences between collections were considered significant only if the total G statistic (summed over all loci) was significant at a level α 0.05, adjusted by the method of Cooper (1968), where α 0.05 = (0.05/n) and n is the number of polymorphic loci (ie. individual tests) contributing to the total G statistic.

Individual locus heterozygosities (h) were calculated for polymorphic loci using the formula h = 1 - x_i2, where x_i is the frequency of the ith allele. Average sample heterozygosity (H) was calculated as the mean of individual locus heterozygosities for variable loci. F_{ST} statistics were calculated using unweighted means by the method of Wright (1965) and also by the method of Weir and Cockerham (1984) using BIOSYS (Swofford and Selander 1989). Nei's (1978) unbiased genetic distance (D) corrected for small sample size was calculated and a UPGMA (Sneath and Sokal 1973) cluster analysis subsequently performed. The goodness-of-fit of the input matrix to the resultant dendrogram was evaluated using the cophenetic correlation coefficient (Sneath and Sokal 1973).

8.3 Results

Table 8.1 Summary of sample sizes for each locality.

POP #	***N***	**LOCATION**
Pop 1	126	Swains Reef;
Pop 2	220	Fraser Island;
Pop 3	217	Deep Tempest;
Pop 4	125	Peel Island;
Pop 5	244	Ballina;
Pop 6	160	Coffs Harbour;
Pop 7	160	Forster;
Pop 8	155	Sydney;

The total number of samples for which genetic data was collected, from each locality, are listed in Table 8.1. Initially, genetic loci which were either found to be polymorphic, or were reported as polymorphic by other studies, were determined from a sample of 90 fish. These polymorphic loci were then used to determine allele frequencies for all individual fish, which were then summarised by location for stock structure analysis (Table 8.2).

Table 8.2 Allele frequencies at 9 polymorphic loci for 8 locations. RM= relative mobility. Rare alleles have been pooled as shown under RM.

Locus	RM	Swains	Fraser	Tempest	Peel	Ballina	Coffs	Forster	Sydney
ADA									
	100	0.813	0.834	0.797	0.847	0.838	0.812	0.830	0.720
	112,75	0.024	0.011	0.002	0	0	0	0.009	0.127
	88	0.163	0.155	0.201	0.153	0.162	0.188	0.160	0.153
N		*123*	*220*	*214*	*124*	*238*	*154*	*159*	*134*
EST-L									
	100	0.778	0.767	0.757	0.790	0.799	0.827	0.814	0.797
	190,120,82,72	0.028	0.030	0.012	0.016	0.008	0.009	0.016	0.016
	140	0.036	0.030	0.046	0.048	0.035	0.038	0.038	0.019
	114	0.105	0.105	0.112	0.056	0.088	0.057	0.060	0.116
	85	0.052	0.068	0.073	0.089	0.070	0.069	0.072	0.052
N		*124*	*219*	*206*	*124*	*244*	*159*	*159*	*155*
FDH									
	100	0.984	0.975	0.985	0.988	0.983	0.991	0.988	0.990
	130,70	0.016	0.025	0.015	0.012	0.017	0.009	0.013	0.010
N		*125*	*120*	*132*	*125*	*118*	*159*	*160*	*155*
FH									
	100	1.000	1.000	0.998	0.976	0.984	0.982	1.000	0.994
	66	0	0	0.002	0.024	0.016	0.018	0	0.006
N		*126*	*100*	*214*	*124*	*244*	*141*	*160*	*154*
GPI-M									
	100	0.972	0.973	0.965	0.960	0.971	0.984	0.987	1.000
	120,90,76	0.016	0.007	0.016	0.008	0.006	0	0	0
	88	0.012	0.020	0.019	0.032	0.023	0.016	0.013	0
N		*124*	*220*	*214*	*124*	*244*	*157*	*158*	*151*
IDH-E									
	100	0.865	0.815	0.846	0.847	0.865	-	-	-
	153,114	0.045	0.005	0.006	0.004	0.020	-	-	-
	80	0.040	0.105	0.099	0.069	0.056	-	-	-
	60	0.050	0.075	0.049	0.081	0.060	-	-	-
N		*100*	*100*	*81*	*124*	*126*	*0*	*0*	*0*
IDH-L									
	100	0.714	0.851	0.769	0.858	0.854	0.824	0.811	0.833
	135	0.246	0.104	0.167	0.068	0.085	0.110	0.104	0.104
	125,85	0.040	0.045	0.065	0.074	0.061	0.066	0.086	0.063
N		*63*	*67*	*93*	*88*	*106*	*136*	*140*	*120*
MPI									
	100	1.000	0.975	0.988	0.992	0.994	1.000	1.000	0.997
	120,88,80	0	0.025	0.012	0.008	0.006	0	0	0.003
N		*126*	*100*	*81*	*124*	*244*	*160*	*160*	*155*
PGM-1									
	100	0.984	0.984	0.981	0.984	0.986	0.988	0.987	0.977
	165,160,140,60	0.016	0.016	0.019	0.016	0.014	0.013	0.013	0.023
N		*126*	*220*	*214*	*124*	*244*	*160*	*159*	*153*
Avg Hs		0.165	0.160	0.172	0.149	0.143	0.114	0.112	0.129
std err		0.058	0.050	0.056	0.045	0.045	0.048	0.050	0.059
Avg Ho		0.133	0.147	0.169	0.149	0.142	0.114	0.108	0.129
std err		0.045	0.047	0.055	0.044	0.045	0.048	0.049	0.059

All locations had samples sizes that were adequate for the statistical tests. In addition, information on the age of individual fish was collected and the birth year calculated. The sexes of fish were not available for all populations which prevented any analysis of variation in genotype frequency between the sexes.

Nine polymorphic loci were identified as suitable for data collection. Overall sample heterozygosity at these loci was moderate with H = 0.136. Over all populations, there was considerable observed heterogeneity (P<0.001) which was primarily based on significance at two loci (*ADA*, P<0.0001 and *FH*, P<0.001), and also at another two loci (*MPI*, P<0.01 and *GPI-M*, P<0.05). Allele frequencies, however did not show dramatic changes between populations. No valid tests, where the expected frequency was greater than five, of Hardy-Weinberg equilibrium for all combinations of populations and loci were significant.

A single pairwise test of adjacent populations of snapper displayed a significant difference. This test, between the Sydney and Forster samples, was based on the significant difference observed at the *ADA* locus alone.

Locus	**Fis**	**Fit**	**Fst**	**G**	**df**	
ADA	0.084	0.100	0.018	38.362	2	P<0.0001
EST-L	-0.011	-0.008	0.003	8.826	6	
FDH	-0.011	-0.011	0.000	0.115	1	
FH	-0.007	-0.003	0.003	2.856	1	
GPI-M	-0.013	-0.006	0.006	5.391	3	
IDH-E	0.000	0.000	0.000	0.000	-1	
IDH-L	-0.019	-0.018	0.001	1.021	3	
MPI	-0.003	-0.002	0.002	1.420	1	
PGM-1	-0.020	-0.018	0.002	0.965	1	
Average	Fis	Fit	Fst			
	0.018	0.025	0.007			
Total				G	df	
				58.956	17	P<0.001

Several other pairwise comparisons had individual loci that showed significant differences. These are tabulated below.

Fraser Island vs Swains Reef;

IDH-E	0.008	0.016	0.008	14.706	5	P<0.025
IDH-L	0.376	0.393	0.027	9.259	3	P<0.05
MPI	0.385	0.392	0.013	8.224	1	P<0.005
Average	Fis	Fit	Fst			
	0.139	0.146	0.009			
Total				G	df	
(not corrected for number of tests)				37.304	22	P<0.025

Deep Tempest vs Peel Island;

FH	-0.023	-0.013	0.009	7.282	1	P<0.01
IDH-L	0.006	0.020	0.014	8.674	3	P<0.05
Average	Fis	Fit	Fst			
	0.010	0.015	0.005			
				G	df	
Total				30.854	23	ns

Ballina vs. Deep Tempest;

FH	0.207	0.211	0.005	5.364	1	P<0.025
Average	Fis	Fit	Fst			
	0.012	0.016	0.004			
				G	df	
Total				25.742	23	ns

Coffs Harbour vs. Forster;

FH	-0.018	-0.009	0.009	7.631	1	P<0.01
Average	Fis	Fit	Fst			
	0.022	0.022	0.001			
				G	df	
Total				14.086	16	ns

Cluster analysis, using UPGMA of Roger's genetic distance, was used to display the relationships between the populations. With three populations missing data for the *IDH-E* locus, this was removed from the data prior to analysis. The resulting dendrogram is illustrated in Figure 8.1.

Figure 8.1. UPGMA dendrogram of Roger's Genetic distance.

ROGERS GENETIC DISTANCE

```
                     0.008          0.015            0.023         0.031
        ................|..............|...............|.............|
Sydney  -------------------------------------------------------------
                                                                     |
Fraser  -------------------------------------                        |
                                             |                       |
Coffs   --------------------                 |----------------       |
                            |-----------     |                |      |
Forster --------------------            |    |                |      |
                                        |----                 |      |
Peel Is ---------------------           |                     |------
                             |----------                      |
Ballina ---------------------                                 |
                                                              |
Swains  ---------------------------------------               |
                                               |--------------
Tempest ---------------------------------------
        ................|..............|...............|.............|
                     0.008          0.015            0.023         0.031
```

This phenogram shows that fish sampled from the central NSW coast (Sydney) were those which were least similar to all other populations. It was interesting to note that the population inside Moreton Bay clustered closely to offshore populations and in particular those populations in NSW. Overall, the genetic distance between populations was not extensive enough to suggest isolated populations.

8.4 Discussion

Results of this study suggest that snapper on the east coast constitute a single stock. This is essentially in agreement with the earlier findings of McDonald (1980) who examined the east coast stock under a less extensive sampling program. However, there were differences between the results in this study and those of MacDonald (1980). In the present study no heterozygotes were observed at the *Gpi* locus in the Sydney population whilst populations in Southern Queensland all had heterozygotes for *Gpi*. By comparison, McDonald (1980) found the opposite, although sample sizes in the present study were at least double those of the earlier study. Both studies however, displayed relatively low variation in allele frequencies across east coast populations.

The main differences between the east coast stock and those in Western Australia (Johnson *et al*, 1986) and South Australia (Donnellan and McGlennon, 1997) relate mainly to differences in the frequency of *MPI* and *PGM* allelles. Populations on the east coast consistently had lower heterozygosities at these loci than did other populations, however statistical comparisons were not possible.

Unlike snapper in Shark Bay there was no evidence of breeding isolation between populations of snapper within Moreton Bay and snapper caught in adjacent offshore waters. This conclusion is supported by both the present allozyme data which failed to show significant differences in allele frequency and tagging studies. Tagging studies (Sumpton *et al*, personal observations of ANSA tagging program.) have found small numbers of fish (only 2 fish of over 2000 tagged) which were tagged inside Moreton Bay had moved to adjacent offshore waters. Henry (1990) who tagged large numbers of fish in Northern NSW has also shown that the majority of snapper (at least those less than 30 cm) are captured within 100 kilometres of their release point. However he found that there were a few individuals which are caught 100's of kilometres from their release location.

Unlike Shark Bay, which has a low rate of water exchange between the inner and outer areas, there is considerable mixing of oceanic, and waters inside Moreton Bay. In addition, Moreton Bay does not possess the magnitude of salinity gradient found in Shark Bay. The actual contribution that juveniles recruited into embayments such as Moreton Bay have on the offshore population remains unresolved. Despite the fact that embayments such as Hervey Bay and Moreton Bay support large numbers of 0+ and 1+ juveniles, tagging studies have as yet failed to show extensive movements of these juveniles to the offshore populations

It appears from other evidence that we have collected that the vast majority of snapper on the east coast are locally resident at least on a broad scale, but the East Australian Current allows for considerable transport of larvae over a scale of hundreds of kilometres. In addition there is a small proportion of the population which undergo fairly extensive migrations causing considerable genetic mixing. Most studies have shown that relatively low rates of female migration are capable of producing homogenous allele frequencies, particularly when population size is large.

In conclusion, this study has confirmed the need to manage east coast snapper as a single genetic stock. Changes to fishing regulations and practises in either Queensland or NSW may have an impact on the snapper fishery in the other state. These impacts are likely to be minimal in terms of evolutionary effects however ecological effects may lead to localised over-exploitation.

9.0 YIELD PER RECRUIT ANALYSES

9.1 Introduction

Commonly applied methods of stock assessment are made difficult by the lack of historical data on the snapper fishery in both Queensland and NSW. This is particularly the case for Queensland where, until this study, nothing was known about the magnitude of the recreational catch, and commercial catch and effort data has only been available since 1988. The fact that commercial catches in Queensland have been essentially constant during the last 8 years limits the information about stock status that can be derived from these data. In addition the use of commercial CPUE data as an index of abundance is questionable given that snapper is a schooling species and depletion of localised stocks may not be detectable using catch and effort data. Whilst catch information has been collected for many years in NSW, fishing effort data for the fishery lacks precision and is of limited value for assessment purposes. Any analysis which uses CPUE data will also be complicated by the use of traps as the main fishing method (Miller, 1983). This lack of empirical data means that neither full dynamic pool nor surplus production methods of assessment can be confidently applied to the fishery at this stage.

Despite this, yield per recruit analysis can provide information on the desired level of exploitation of a resource for which data are relatively scarce. Buxton (1992) presents a number of studies where yield per recruit methods have been used to provide information on reef fishes in particular (See for example Mason and Manoch, 1985; Hughes, 1986; and Bannerot *et al*, 1987). These methods have a number of restrictive assumptions including constant recruitment and equilibrium conditions.

There has been moves within industry, particularly in Queensland for an increase in the minimum legal size of snapper. This has been prompted by concerns over the status of the stocks and large differences in snapper minimum legal sizes around Australia, particularly since both Western Australia and South Australia have minimum legal sizes over 20% larger than either Queensland or New South Wales. Currently the minimum legal size of snapper in Queensland is 30 cm total length and in NSW is 2 cm less.

In this section we present yield per recruit models which evaluate the impacts on yield (in terms of eggs, weight and value) of changing the minimum legal size of snapper using information derived from the present study. We have chosen a Monte Carlo approach that allows us to incorporate uncertainty in defined parameters. Throughout this section we use the term yield interchangeably with yield per recruit

9.2 Methods

Natural Mortality

Natural mortality (M) has usually been the parameter which is known with the least accuracy. The estimation of natural mortality is also a difficult task for any fish stock which has been exploited and where there are no long term records of the age structure of the catch as well as total catch and effort statistics. The absence of such information about the snapper fishery on the east coast precludes the estimation of M using virtual population analysis or other techniques. Where natural mortality can not be directly assessed from observations on the population being studied the usual approach has been to use a range of natural mortality estimates or use estimates derived from empirical formulae such as those of Pauly (1980) and Hoenig (1983).

In the case of the snapper fishery, natural mortality has been estimated for an unexploited (or at least lightly exploited) stock of snapper on the west coast of New Zealand using trawl catch curves The estimated natural mortality generated from that study was 0.06 yr^{-1}. This is the figure commonly used in stock assessments of the New Zealand snapper fishery (Gilbert *et al.* 1996). By comparison stock assessments of Sparid fisheries in South Africa routinely use a value of M of 0.15 yr^{-1} (Punt pers. Com.). We have attempted to calculate natural mortality for snapper on the east coast using historical data documented prior to the development of an extensive fishery along the east coast. These data (See Background Information) suggest that the average size of the snapper taken at that time was between 4 and 6 pounds (1.7 and 2.7 kg). Using this information we have simulated the age structure of a population assuming negligible fishing mortality during that time and also under the assumption that selectivity was similar to what it is now. The selectivity pattern chosen was a cumulative normal distribution with a mean size of 25 cm FL and a standard deviation of 2 assuming that all sizes had the same probability of capture. Using these criteria and assuming Von Bertalanfy growth parameters of $L\infty$ = 67, k = 0.16, To = -0.11 (from the fast growing NZ west coast stock) (Annala, 1995) estimates of natural mortality ranged from 0.08 to 0.15 depending on how selectivity was modelled.

We feel the estimates of natural mortality from lightly fished snapper populations in NZ and from South African sparid species are probably the most robust and relevant to snapper on the East Coast. However, our desire to be conservative has led us to model from a range above the estimate from New Zealand.

Model Specifications

The various forms of yield per recruit were calculated as follows

Yield per recruit $$Y/R = \sum_a W_a S_a F N_a e^{-(t1+t2)M}$$

Egg per Recruit $$E/R = \sum_a W_a S_a F E_a e^{-(t1+t2)M}$$

Value per Recruit $$V/R = \sum_a W_a S_a F U_a e^{-(t1+t2)M}$$

where W_a is the weight of a fish aged a years and weight is assumed to be known exactly according to the relationship $W = 0.0447 L^{2.79}$

Weight is calculated using a deterministic Von Bertalanfy growth equation with parameters of k = 0.16, $L_\infty = 68$, to = -0.12. This was a conservative choice given the variability in mean size at age observed throughout the range of the species on the east coast.

S_a is the selectivity (modelled as a cumulative normal distribution of mean equivalent to the minimum legal size and a standard deviation of 2 cm.

F is the rate of fishing mortality (modelled as a triangular distribution with a mean of 0.65 and a range between 0.2 and 1.1. Fishing mortality was chosen within this range to cover the levels of total mortality which we found from our catch curves (See Chapter 5) with the most conservative value being at the high end of the range.

M is the rate of natural mortality (modelled so that the logit of M was normally distributed with a mean of the logit of 0.15 and a standard deviation of 0.5). We have chosen the natural mortality rate used in South African sparid fisheries as a conservative compromise between the relatively low levels used in snapper models in new Zealand and the high levels computed using the Pauly and Hoenig relationships. The distribution chosen, however spans the range of likely values.

N_a is the proportion of fish surviving to age a .

E_a is the egg production of a female of age a (modelled according to the relationship $E = 0.02835 L^{5.011}$ where L is fork length in cm) See Chapter 7.

V_a is the Value per recruit which was based on the following price series collected as an average 12 month price series of snapper sold at the Sydney markets. 24 - 32 cm FL, \$10.54; 33 - 40 cm, \$9.23; > 41 cm, \$8.64.

t_1 and t_2 are the times at the beginning and end of the year

The model was run over 1000 iterations assuming a starting minimum legal size of 25 cm FL. For each run of the model parameter values were chosen at random from the distributions defined above.

The mean conditions of the parameters used in the model give rise to an "average" size distribution. The estimates of the effect of possible size limit changes follow from those average conditions, with the variation we incorporated in each of the parameter estimates. We showed that there were often large differences in the size composition of landings among ports in our study area (see Chapter 5). The average conditions used in the model are within the range of size compositions we found (Figure 9.1). However, the results of the yield models in this section need to be viewed with an understanding of these starting conditions and how they might vary among the locations we studied.

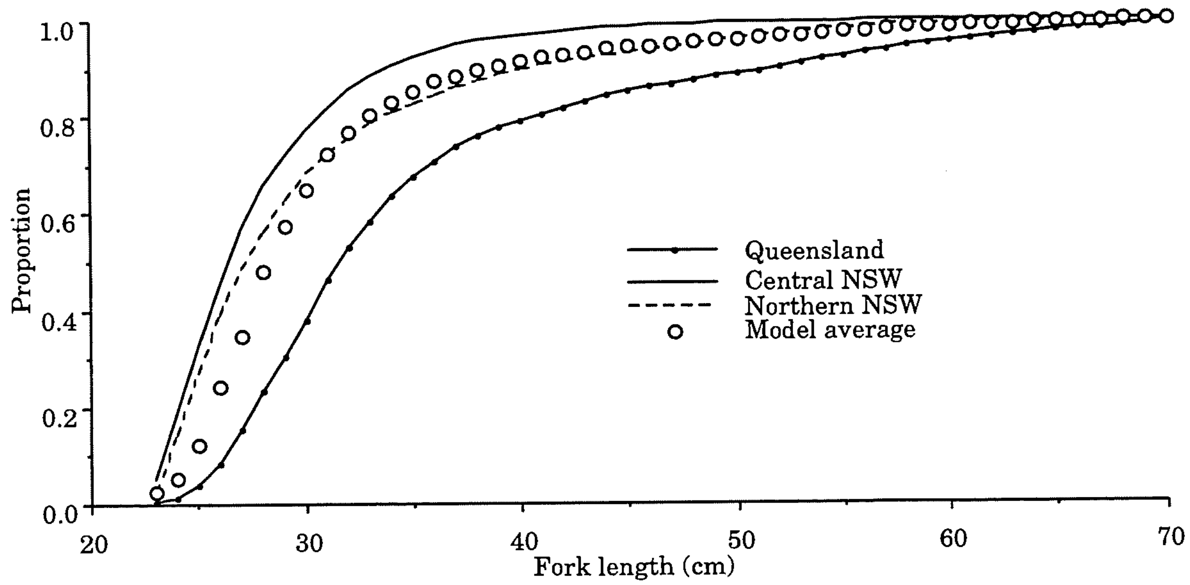


Figure 9.1 Cumulative frequency distributions of pooled length frequency samples. Each winter sample is pooled with equal weight. The six length distributions from Fraser and Moreton shown in Figure 5.1 are pooled here as "Queensland". Similarly, distributions from Ballina and Coffs Harbour are pooled as Northern NSW and Central NSW is comprised of samples from Forster and Sydney. The model average distribution was back calculated from the mean parameter estimates

9.3 Results

As minimum legal size was increased over the entire size range egg per recruit analysis showed that gains were made in egg production per recruit (Figure 9.2) Egg production per recruit is predicted to double with an increase of size from 25 to 33 cm. Within the parameter space chosen there is virtually no risk of egg production per recruit declining below existing levels for increases in minimum legal size up to at least 50 centimetres. In this, and other figures that follow the 95% confidence limits around the model predictions all increase with size (age). This is a reflection of the compounding effects of the uncertainty in natural mortality and fishing mortality which are built into the model.

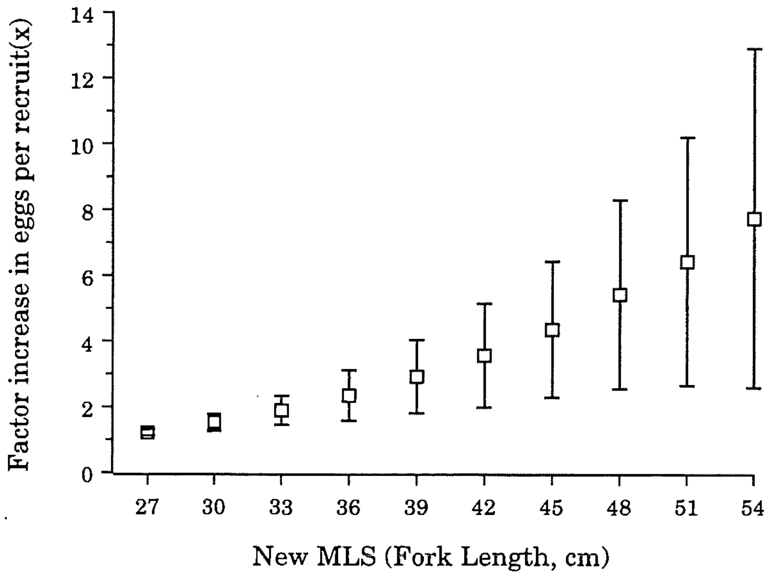


Figure 9.2 Factor increase in egg production per recruit for a range of minimum legal sizes. 95% confidence limits are shown as vertical bars.

Any increase in minimum legal size would obviously cause a reduction in the total number of fish available for capture since natural mortality would remove fish which would previously have been available to the fishery under a smaller size limit (Figure 9.3). For even moderate increases in MLS these reductions can be considerable. For example, an increase to 33 cm may result in a 19% reduction in the number of fish taken. If natural mortality is higher than predicted then the number of fish taken would decline even further.

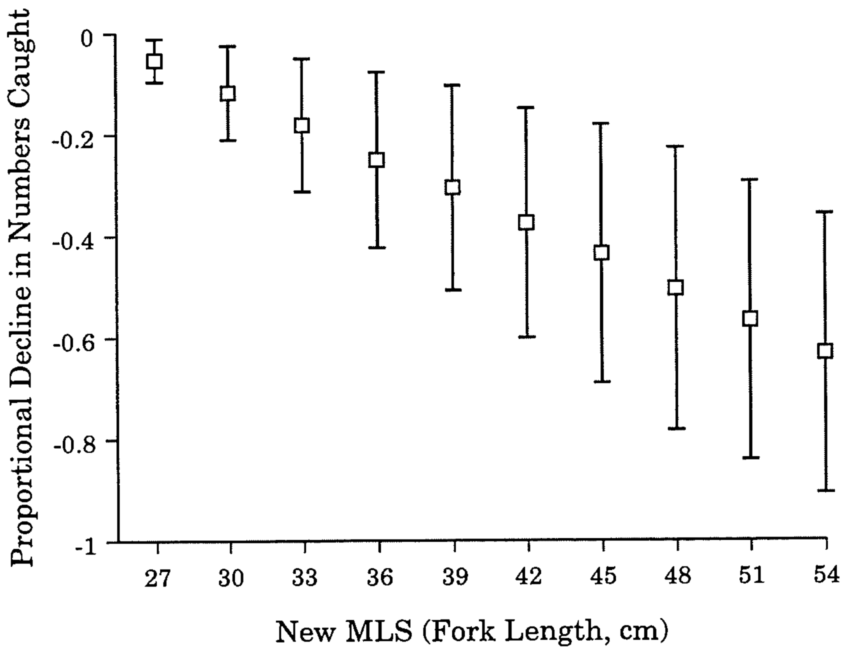


Figure 9.3 Proportional change in numbers caught per recruit for a range of minimum legal sizes. Presentation as for Figure 9.2.

Despite the fact that increases in minimum legal size cause reductions in the numbers of fish landed there are significant gains to be made in terms of yield in weight (Figure 9. 4). It is not until the size limit is increased to over 40 cm that the risk of achieving reduced yields becomes apparent as natural mortality negates gains that are made due to growth. However, increases in yield of over 50% are predicted for increases up to about 40 cm. Value per recruit analysis (Figure 9.5) suggests that financial returns may not be as great due to the price differential between small and large fish. Nevertheless, increases up to approximately 36 cm should see significant financial gains: Once the fish excluded from capture by a new size limit have reached the new minimum size, financial gains of over 25% can be obtained for an increase to 33 cm. However, in comparison to the yield in weight analysis there is a possibility of achieving financial losses if minimum legal size is increased above 33 cm.

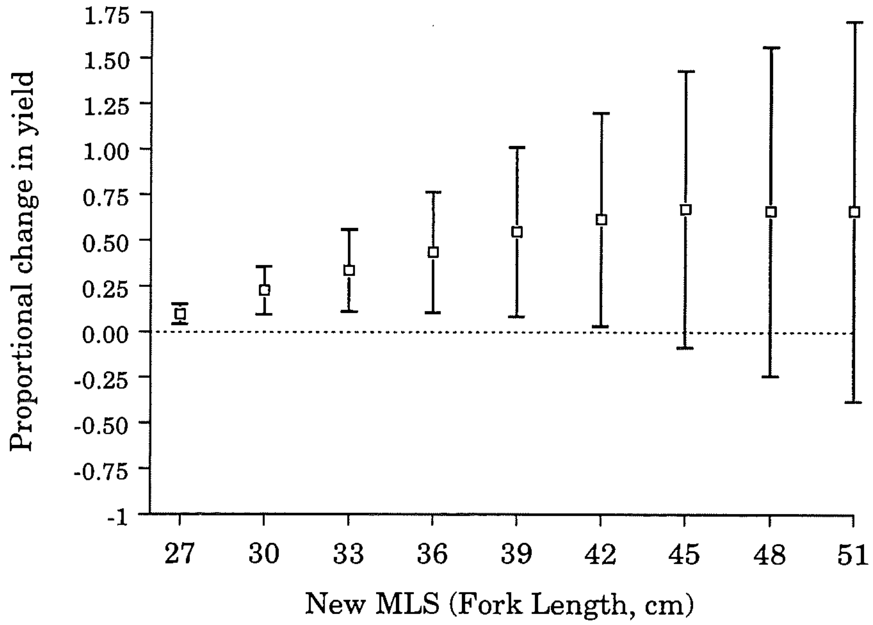


Figure 9.4 Proportional change in yield per recruit for a range of minimum legal sizes. Presentation as for Figure 9.2.

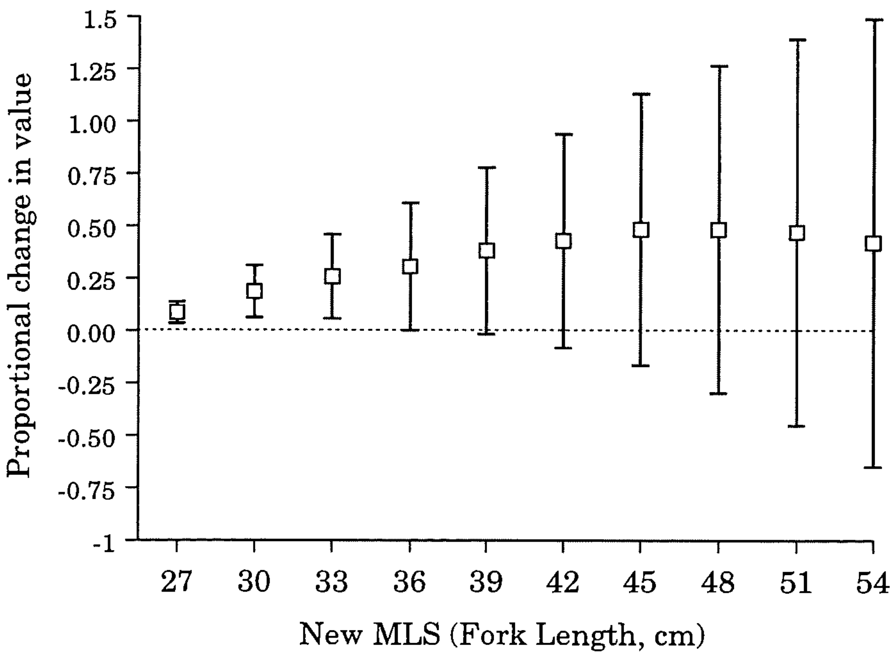


Figure 9.5 Proportional change in value per recruit over a range of minimum legal sizes (MLS) compared to the current size of 25 cm. (95% confidence limits are shown as vertical bars)

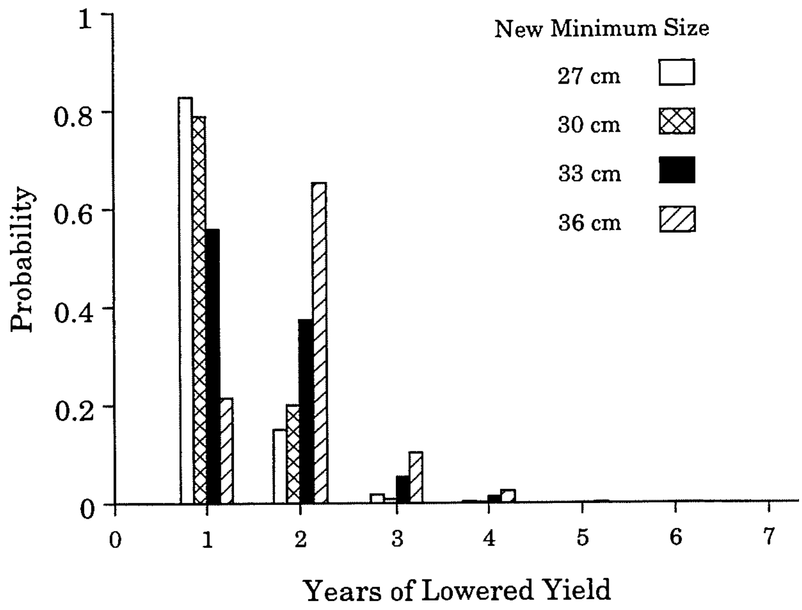


Figure 9.6 Numbers of years of reduced yield before a net increase in total yield is recorded for 4 different minimum legal sizes changes.

The previous figures have shown that significant gains in terms of both weight and value can be achieved by even modest increases in the minimum legal size of snapper. Any increase in minimum legal size would doubtless result in a short term drop in income to fishermen, the size of which would depend on the magnitude of the change in MLS and the size distribution at the location. This is because of the lag between increasing the size limit and the time it would take for fish of a length between the old and new sizes to reach the new harvestable size. The loss in numbers of fish brought about by the effects of natural mortality has to balanced against the increase in weight that is achieved by waiting until the fish grow to the new size. Figure 9.6 shows that, for a an increase of minimum legal size from 25m fork length to 27 cm, there is over an 80% probability that it will take 12 months (or less) for the yield (in terms of weight) to return to pre-change levels. Obviously, more substantive increases in MLS would take longer for yields to return to, and surpass, pre-change yields. Even for a relatively large increase to 36 cm there is over a 60% probability that present yields will return within 2 years. We estimate only a 2 % probability that yields would take 4 years to return to pre-change levels if MLS was increased from 25 to 36 cm. It should also be noted that this model assumes constant recruitment and that large variation in recruitment could alter the time it takes to match earlier yields.

The distributions in Figure 9.6 arise from the theoretical age distributions that would arise from the various runs of our yield model. However, size distributions of the harvest do vary amongst locations and starting conditions will play an important role in the availability of fish after any change in size limit (see Figure 9.1).

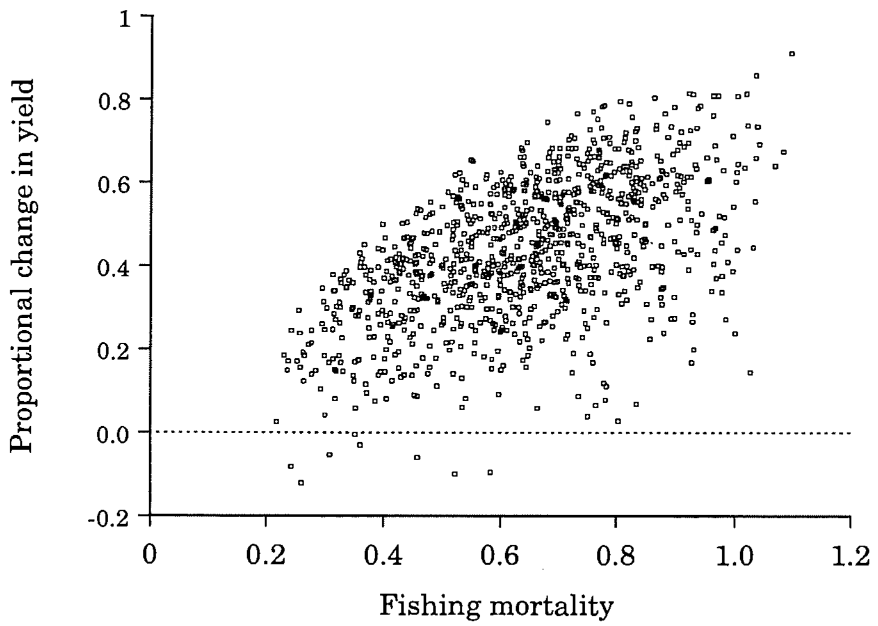


Figure 9.7 Sensitivity of yield changes to the seeded value of natural mortality at a new minimum legal size of 36 cm FL.

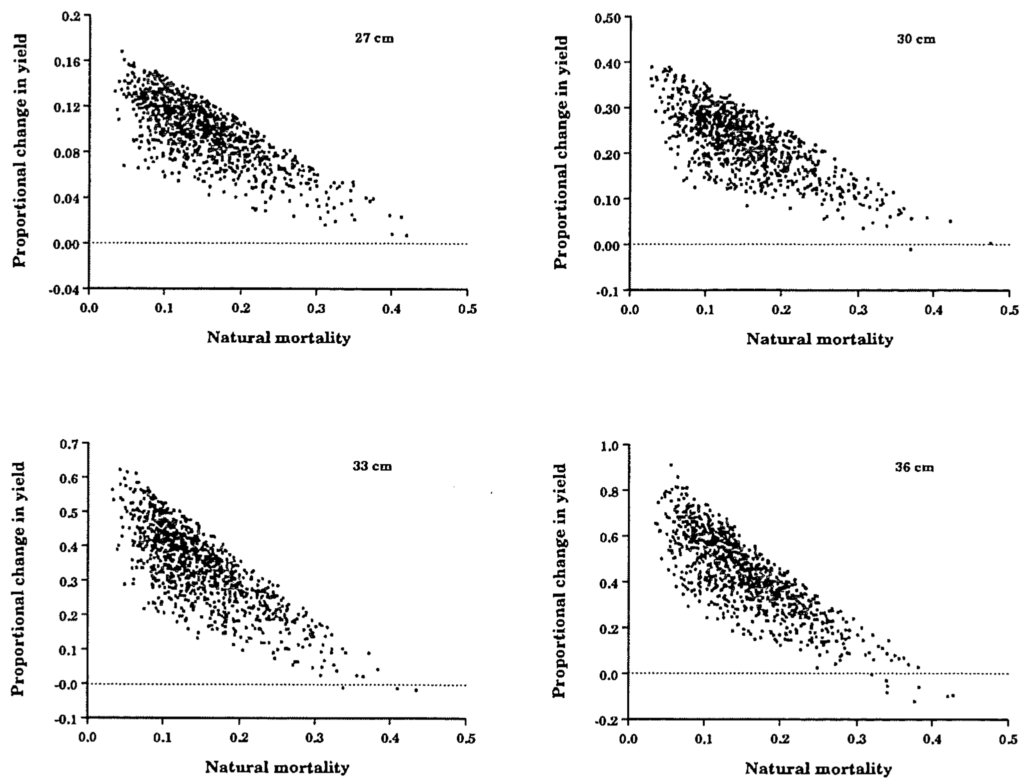


Figure 9.8 Sensitivity of yield per recruit changes to natural mortality over a range of new minimum legal sizes.

The models are obviously very sensitive to the levels of fishing and natural mortality which are used (Figures 9.7 and 9.8). Higher than predicted values of fishing mortality increase the probability of achieving higher than predicted gains in yield. Similarly, if we have under-estimated natural mortality, yields will be less than estimated. Even with large changes in MLS, these models still predict mostly positive yields in the 0.3 to 0.4 range of natural mortality (Figure 9.8). Providing fishing mortality is higher than natural mortality there will be gains in yield regardless of the particular levels of mortality.

9.4 Discussion

We have accounted for plausible levels of variation in many of the parameters used to calculate yields. It is important to note that there are other possible sources of variation that are not included in the yield models that could affect the timing of changes in yield. In other words, we believe the models correctly reflect outcomes in the medium to long term, but variation in factors not included in the models could alter the results in the short term. The most obvious source of variation we have not included is that of variation in recruitment. Francis (1993) has documented ten-fold variation in snapper recruitment in the Hauraki Gulf of New Zealand. Obviously, successive large or small year classes could completely alter the predictions of Figure 9.5.

Egg production models are often criticised because the relationship between spawning stock size and recruitment is poorly understood and therefore large increases in egg production may not translate into significant increases in total landings. Here we have used a deterministic fecundity function, however, considerable uncertainty exists about its accuracy. Whilst larger fish clearly display a disproportionate increase in egg production compared with smaller fish, the viability of their eggs and other aspects of their reproductive biology remain poorly understood. Despite these shortcomings egg per recruit analyses do suggest that moderate increases in the MLS would have positive effects.

This analysis, which is based on equilibrium conditions does not include any allowance for possible increases in the number of recruits which may follow an increase in MLS. It is possible that increases in egg production and subsequent possible increases in the number of recruits entering the fishery, may at least partially offset the predicted drop in numbers caught with an increased size limit. Recreational anglers surveyed during the course of the creel survey program favoured the catching of fewer larger fish rather than catching a large number of smaller fish. When asked whether they preferred to catch 6 fish weighing 0.5kg each, or 3 fish weighing 1 Kg each, 87% of anglers interviewed preferred to catch the latter.

The situation with respect to the commercial sector, including processors and marketeers is not as simple. Fish size may have important implications for each of these groups more so than recreational anglers. Currently the minimum legal size of snapper in New Zealand is 25 cm fork length. If the demand for fish of a size currently close to the legal size is high, an increase in the minimum legal size may provide an extra incentive to import those fish into Australia from New Zealand. The economic impact of increasing the minimum legal size is difficult to predict, however in both Western Australia and South Australia the MLS of snapper is over 38 cm total length (8 cm greater than the current MLS in either NSW or QLD) and the commercial snapper fisheries in both these states do not appear to be suffering due to market irregularities based on size.

The situation with respect to value per recruit is similar to the yield (in terms of weight) results. Obviously the value per recruit scenario may differ between different markets and between seasons, however discussions with fishermen indicated that the "small to medium sized" fish were the most valuable and this is reflected in the price series chosen in the model.

An important issue relevant to the question of raising the minimum legal size relates to the discard mortality of undersized fish. We have little information on the possible mortality from the discarding of undersized snapper caught in enclosed waters, but this could be an important factor when considering raising the minimum legal size. In NSW Talbot *et al.* (1992) suggest long-term mortality of ~10 cm snapper caught for research purposes was about 25%, and that these fish were handled with "best practice" (Talbot, pers. com). This suggests that handling mortality of fish this size from general fishing could be higher.

Our creel survey analysis has already shown a large recreational catch of fish less than the current minimum legal size, particularly in inshore waters. This has also historically been the case in NSW (e.g. Henry, 1984) where the proportion of undersized snapper in creels exceeded 90%. It is unlikely that the catch of these undersized fish would stop in Moreton Bay and elsewhere, even if the probability of catching a legal size fish was very low. An increase in the minimum legal size would simply mean the proportion of undersized fish caught, and kept, would be likely to rise. The effect of this change would remain unknown without hook mortality information. The capture of undersized fish by offshore anglers may not be as problematic as that of inshore anglers because the proportion of undersized fish in the creels of offshore fishermen is comparatively low. The assumption here is that compliance levels of offshore anglers will remain at the same level. This may not necessarily be the case given that a proportion of the now available fish population will still be present but unable to be retained. We have found that compliance levels of inshore anglers is low (See Chapter 10) but we do not know if this is a result of the size distribution of fish available to be caught, or related to some other factor.

Of further relevance to the question of increasing minimum legal size is the possibility that the catchability of larger fish is not as great as those fish which make up the bulk of the fishery (ie. fish between 30 and 40 cm). It can be argued that current low catches of fish greater than about 40 cm are at least partly due to their lower catchability. This is a common observation made by experienced recreational and commercial fishermen. Our models assume equal selectivity above a certain size and a reduction in selectivity of large fish would mean we have overestimated potential yields. We have already mentioned that it is possible to modify line fishing practises to actively select for certain sized fish. What is unknown is the selectivity of traps and whether different trap designs or fish schooling behaviours increase or reduce the probability of capture of certain sized fish. In addition, changes in behaviour of larger fish, such as offshore migrations or reduced schooling behaviour of larger fish may limit their availability to both the trap and line fisheries. There are a number of offshore areas which harbour large populations of juvenile snapper, however, we have little understanding of the scale and distribution of these areas, making area closures impractical, at least on a small scale. However, it is possible to modify fishing techniques to actually select for larger fish and professional fishers tend to avoid such locations because of the extra work generated. Many recreational anglers possess the ability to select for larger snapper and it is clear that education programs could assist in this regard. Selecting for larger fish using traps can be achieved by using escape gaps or mesh sizes in traps which allow smaller fish to escape.

The Q-fish catch data surrounding the 5 cm increase in minimum legal size which was introduced in Queensland in 1993 supports our conclusion that recovery of yields should be relatively rapid (see Figure 1.2). That change resulted in a short term decline in both catch and CPUE which was largely recovered the following year. Caution is required in interpreting these data since normal population fluctuations may be just as responsible for the variation in catch and CPUE as the management change itself. The full impact of the earlier change will be better understood when further years CPUE data are available. Nevertheless, the declines in catch and CPUE are within those predicted in Figure 9.5 which shows that there would be about a years reduction in yield before the catch returned to levels prior to the change.

10. RECREATIONAL FISHERY FOR SNAPPER IN SOUTHERN QUEENSLAND

10.1 Introduction

In Australia, there have been relatively few published surveys of recreational fishing. However, in recent years there has been renewed interest in recreational fisheries assessment as demands are being placed on management authorities to allocate a greater share of the resource to recreational users. Most of the studies that have been conducted in Australia are from either freshwater or estuarine environments and embayments, although a notable exception is a recent survey conducted to assess offshore recreational catches in NSW (Steffe *et al* 1997).

Caputi (1976) described recreational catches in the Blackwood River Estuary in Western Australia using a roving creel survey approach. West and Gordon (1994) also used roving creel surveys to assess the recreational fisheries in two estuaries in Northern New South Wales. The latter authors compared the recreational catches with those of the commercial fisheries in the same areas and highlighted the need for a greater understanding of the magnitude of the recreational harvest, since many studies have shown that the recreational harvest of several inshore fish species exceeded that of the commercial sector. More recently, McGlennon and Kinlock (1997) examined the recreational harvest rates in Spencer Gulf and the Gulf of St Vincent in South Australia and found that the recreational snapper catch was less than 20% of the total harvest for that species. The most current estimate of recreational snapper harvest in the Hauraki Gulf of New Zealand is 2800 tonnes, compared to a 4800 tonne commercial harvest (Gilbert *et al.* 1996).

The number of commercial fishers and the commercial harvest of most fin-fish species in Queensland have remained relatively stable since a commercial logbook program was implemented in 1988 (CFISH). Despite this result, Lal *et al.* (1992) have noted that a dramatic increase in recreational fishing effort has occurred in recent years throughout Australia, largely as a result of population growth. Studies by Pepperell have shown that the proportion of people in the population who fish has remained the same, but increases in the coastal population have resulted in increases in fishing effort If both commercial and recreational sectors share the harvesting of a resource, as is the case in the snapper fishery, then a knowledge of the catches of both sectors would seem a prerequisite for the successful management of that resource. Many methods of stock assessment require estimates of the total catch of a stock (See Hilborn and Walters, 1992). Harvest estimates may be relatively easy for fisheries where the catch is taken exclusively by a commercial sector, where members are required to fill in catch and effort logbooks, it is a much more complex exercise when a considerable proportion of the catch is being taken by recreational anglers.

With the decreasing cost of advanced electronics for recreational fishers, an increasing amount of effort is being directed towards offshore fish stocks.

However, little information is available on the magnitude of the offshore recreational catch, largely because of the logistic problems involved in assessing offshore fisheries. Population increases in the southern part of Queensland and northern NSW, suggest that recreational effort has increased dramatically in recent years and this trend is likely to increase.

Aerial survey methods have been used extensively in Australia in the areas of wildlife research for estimating numbers of livestock and other terrestrial animals (Bayliss, 1985; Bayliss and Yeomans, 1989) and have also seen application overseas in the area of fishing effort assessment. Most of the studies which have used aerial methods have been developed for assessing fishing effort on North American Freshwater lakes where they have provided a cost-effective method of estimating the fishing effort of anglers for many years (Hoenig *et al*, 1989; McNeish and Trial, 1991)

Traditionally aerial methods are expensive because, as essentially an instantaneous method, they require the stratification of the primary sampling unit (sample day), into secondary sampling units (some part of the sampling day). These secondary units must then be sampled with appropriate probability. The number of flights and therefore the costs can be greatly reduced if information that provides an independent estimate of the temporal distribution of effort throughout the sampling day is available. Such data may be available by positioning observers at river mouths or coastal bars. Radio logs kept by volunteer search and rescue organisations or similar groups can also be used to describe the distribution of boating activity throughout the day. When this information is used as an alternative to within day temporal stratification of sampling effort it can reduce the costs and increase the accuracy of estimates of daily fishing effort (see Steffe *et al*. 1996). The conjunction of aerial reconnaissance with an independent estimate of effort distribution through the day may be useful where offshore fisheries are centred on discrete locations such as reefs but where as many as 50 boat ramps may service those fishing locations.

Vessels leaving from an ocean access point may travel in excess of 50 nautical miles to reach their preferred fishing grounds. If there is a significantly large distance between access points and the fishing grounds then the resolution of data will be greatly reduced if only vessel counts leaving the access points are recorded. However, this type of survey provides little detail on the fine scale distribution of fishing effort which is often required for management purposes.

The need to study recreational snapper harvest in SE Queensland has been prompted by concerns about the magnitude of the recreational catch and concerns about the impact of the current recreational bag limit of 30 snapper per person. Recreational anglers argued that a generous limit was needed because snapper made up the vast majority of their catch in southern Queensland and there was not the diversity of other species that were available to anglers fishing the tropical waters of Queensland. This bag limit has been widely criticised in Queensland as being too generous and is far higher than in other fisheries for snapper.

Here we use access point catch surveys coupled with aerial effort surveys to document the characteristics of offshore recreational snapper fisheries in southern Queensland and northern NSW and provide estimates of recreational harvest. The specific objectives of this research were to estimate the recreational catch of snapper in the Moreton region of south-east Queensland and to document essential elements of that fishery, including the catch size structure and the species composition of the offshore recreational catch.

10.2 Materials and Methods

Estimates of Fishing effort

Aerial surveys were flown between June 1994 and June 1995 using a twin engine, fixed high-winged aircraft with all flights beginning and terminating at Coolangatta (Figure 10.1). Prior to this time, 4 preliminary flights were conducted during April and May to determine the optimal flight path and altitude as well as standardising other techniques. After the preliminary period, surveys were standardised at an average altitude of 150 metres and an average speed of 185 km/hr. Two observers positioned on opposite sides of the plane counted in transects 3 kilometres wide (either side of the plane). The transect width was delineated by reference points on the wing struts and counts of both observers were pooled. Aircraft speed varied during the survey due to head-winds and tail winds.

When the flight path of the plane traversed directly over a vessel(s) the pilot assigned the count to one of the observers to avoid possible double counting. Observer bias was assessed by an independent observer who counted in tandem with the observers on a randomly chosen sub-sample of flight days. This was achieved by counting with the port side observer for part of the trip and with the starboard observer for the remainder of the trip.

Preliminary studies showed that offshore fishing effort was low on days when the wind speed exceeded 25 knots. Thus after a pilot survey which established the fishing effort on days when wind strength exceeded 25 knots, flights were only undertaken when wind strength was less than or equal to 25 knots. When wind speed was predicted to exceed 25 knots at 6:00 am on any scheduled day, the flight was rescheduled for the next available day. While weather conditions often changed across the length of a transect, a flight was cancelled and rescheduled if the predicted wind speed for any section of its flight path exceeded 25 knots.

Aerial counts at selected locations (usually reefs within 3 nautical miles of the shore) were validated by ground observers who took instantaneous counts of vessels when the aircraft flew overhead. This was carried out on a total of 20 days and was only possible for reefs adjacent to prominent headlands (Currumbin, Tweed Heads and Burleigh Heads. Flight days were scheduled at random within two day type strata (weekdays and weekends, with public holidays included as weekends). Twenty four days were assigned to weekends and public holidays and 24 days were assigned to week days. Flights within day type and seasonal strata were scheduled between the hours of 0800 and

1200 to coincide with the times when the greatest number of recreational vessels were on the fishing grounds as determined by radio logs kept by Air Sea Rescue and Coast Guard Bases. This was initially done to reduce errors when multiplying up raw counts to adjusted counts using effort distribution data collected from coast guard bases. However, the data collected from coast guard and air sea rescue bases was accurate enough to enable the estimation of the weighting factors without error (see later).

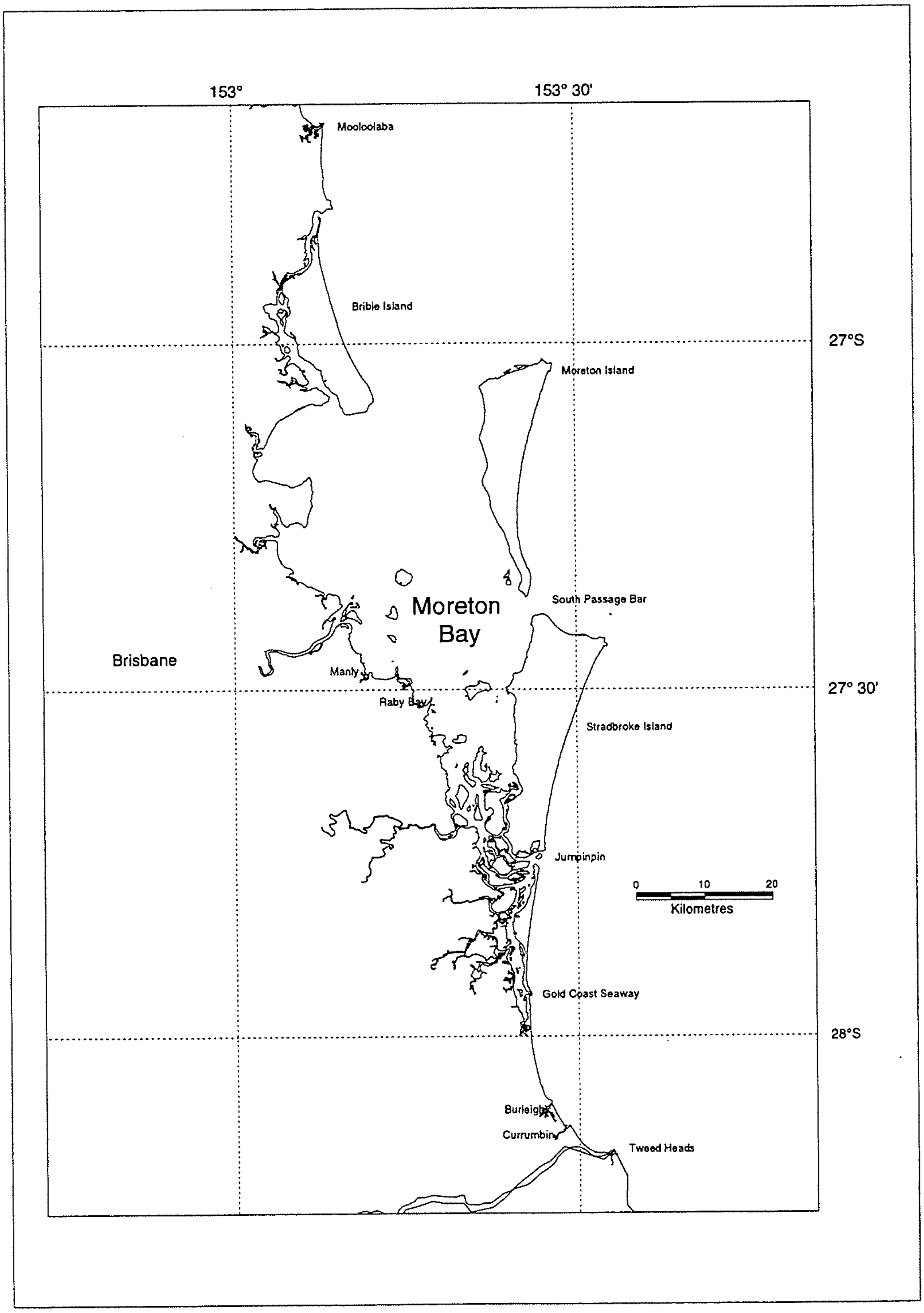


Figure 10.1. Locations mentioned in text and the extent of the area where creel surveys were undertaken.

Numbers of recreational fishing vessels and their positions in relation to the flight path were recorded on maps which detailed the positions of reefs and adjacent coastal geography.

During the period in which the aerial survey was being undertaken, counts of recreational vessels leaving coastal access points were obtained from radio logs of local volunteer air sea rescue and coast guard bases at Tweed Heads, Currumbin, Gold Coast Seaway and Manly. Most vessels radio details of their intended trip to these bases which then record details including the number of people on board, and their log in time. On return from a trip the anglers on board a vessel would generally log off, providing a further record for the base. In addition, observers were used to count vessels leaving from, and returning to 3 of the access locations for a total of 34 days because only some of the vessels that venture offshore actually radio their intentions to the bases. These observers recorded the numbers of boats leaving from and returning to these locations with the times of departure and return. Boats were individually identified by their registration number. The observer data were used to confirm the temporal distribution of fishing effort recorded in radio log sheets. Raw counts of vessels from the aerial surveillance were adjusted for time of day by dividing the interval counts at a particular location by the probability of a vessel being offshore for that particular hour and location. The probability used was that obtained from the logbook records since observer data confirmed the accuracy of logbook records (see later). The means and variances for the adjusted daily counts and the weighted mean vessel trips per day for the particular seasonal strata and their associated variances were then calculated using standard sampling theory (See Pollock *et al*, 1994). The quarterly effort was estimated as the product of the season length (number of days in the particular strata when wind speed was less than 25 knots) and the weighted mean vessel trips per day within that strata.

CATCH SURVEY

Recreational catch information was gathered using a random stratified access point survey conducted at 6 locations (Tweed Heads, Currumbin Creek, Gold Coast Seaway, Raby Bay, Manly, and Mooloolaba). These locations were chosen after a pilot survey conducted during January to March (1994) showed that these ramps were used most frequently by offshore anglers. In addition, enforcement officers and fishing club members were asked for their recommendations of the most popular ramps used by offshore anglers. These recommendations correlated closely with the results of the pilot survey. While non-random selection of ramps was considered a possible source of bias in determining catch rates, the fact that there were over 200 ramps in the survey area necessitated a compromise. During the pilot program insufficient interviews were obtained at other ramps surveyed to allow an assessment of the variability of catches among minor ramps. It was also recognised that non random selection of ramps would heavily bias any estimates of effort obtained from the survey. However, it was considered that maximising the numbers of interviews was a better strategy since recreational effort was also being assessed using an independent aerial survey and observations of coastal bars.

It was originally proposed that only 3 ramps be surveyed but results of the pilot study suggested that differences in the species composition of the catch among ramps were large enough to warrant a larger sample of ramps.

Sampling was undertaken on 54 randomly chosen days at each location (minimum of 12 days per quarter) with equal probability of sampling weekends and weekdays (public holidays were included as weekends whilst school holidays were considered weekdays). Surveys were conducted during daylight hours only between 0800 and 1800 hrs. The length of surveys was typically 8 hours with a random starting time between 0800 and 1000.

The following data were collected from the boat owner (where possible) of recreational vessels returning to the ramp on the sampling days.

Estimated time the vessel left the ramp

Number and sex of persons fishing from the vessel

Vessel size (metres)

Postcode of the boat owners residential address

Location(s) fished (up to a maximum of 3)

Number of lines and hooks used

Estimated travelling and fishing times

Target species (up to 3 species were recorded)

Estimates of the number of each species caught and released.

Number and size (Total Length in centimetres) of each fish retained (These were generally identified and measured by the creel clerk).

When the overall catch exceeded 30 individuals a sub-sample of each species was measured. There were also times when a smaller sub-sample was measured, or fish were unable to be measured due to lack of co-operation by anglers, or other circumstances. This was the case in less than 2% of interviews. Fish lengths obtained from interviews were used to estimate the weight of fish using relationships available in the published literature.

Generally an occupant from all vessels returning to boat ramps was surveyed, except at times when there were too many vessels to allow a total coverage. Since the pilot survey showed that offshore effort was negligible on days when wind strength exceeded 25 knots, survey days were rescheduled to the next available day within the particular strata when wind speed was predicted to exceed 25 knots. The overall percentage of missed interviews was less than 5% of those anglers returning, although at times it reached 10% on some weekends at the larger 4 lane ramps (e.g. Raby Bay).

Limited sampling was also undertaken during the night, but this did not form part of the structured survey process and was only undertaken by one creel clerk (Wayne Sumpton) at one ramp location over a period of 15 nights. Effective night time sampling was not undertaken because of a number of logistic problems including fear of personal safety and relatively low numbers of completed interviews (only 13 interviews in 90 hrs of survey time)

Harvest was calculated as a direct expansion of daily catch and effort counts summed across all strata ($H_j = C_j \times E_j$) to give an estimate of the recreational harvest $H_{tot} = \sum H_j$. Where H_j, C_j and E_j are the harvest, daily catch and effort estimates respectively in the jth strata. The variance was calculated using the following formula with individual stratum variances summed over all strata to obtain an estimate of the total harvest variance:-

$$var(H_j) = E_j^2 \times var(C_j) + C_j^2 \times var(E_j^2) + var(E_j) \times var(C_j)$$

Throughout this document we have used first quarter to include the months of January February and March 1995, second quarter, April to June 1995, third quarter July to September 1994 and fourth quarter, October to December 1994 so that the usual understanding of quarters is retained.

10.3 RESULTS

General Recreational Catch

The species composition of the offshore recreational catch varied from ramp to ramp and to a lesser extent seasonally (Table 10.1). A total of 194 taxa were identified in recreational catches during the survey period. The contribution of snapper to the total catch varied, but snapper was still the most common species retained by anglers, making up just over 34% of the total recreational landings by number in the area surveyed. At the most northern location (Mooloolaba) and at Currumbin, snapper did not contribute to the total catch as much as it did at other locations. Recreational catches at Currumbin were dominated by various mackerel (*Scomberomorus*) species, particularly during the summer and autumn months. The tropical wrasse *Choerodon venustus* was the second most common species in recreational catches and was caught most commonly at Mooloolaba. Other significant features of the species composition included the large contribution of tailor (*Pomatomus saltatrix*) to the total recreational catch and the fact that Pearl Perch (*Glaucosoma scapulare*) was a relatively large contributor to the total catch at all locations.

Targeting preferences also clearly showed that snapper was the dominant species targeted by offshore recreational anglers in SE Queensalnd (Table 10.2). Over 50% of the offshore anglers that indicated a specific targeting preference listed snapper as their first targeting preference. Fifteen percent of anglers also were not targeting any specific species but listed the generic term of "Reef Fish" as their targeting preference. The pelagic mackerels (*Scomberomorus*) species made up the bulk of the remainder of the targeting preferences.

Table 10.1 Percentage contribution (by number) to recreational catches of the top 20 species caught by offshore recreational anglers

Species	Mooloolaba	Manly	Raby Bay	Gold Coast	Currumbin	Tweed	Total
Pagrus auratus	24.31	56.58	64.36	45.87	11.98	32.76	34.17
Choerodon venustus	18.29	3.23	2.75	4.62	1.33	4.83	10.35
Pomatomus saltatrix	2.47	0.00	0.25	15.47	6.84	4.72	4.51
Lethrinus fraenatus	7.42	0.00	0.00	0.00	0.38	0.17	3.40
Ranina ranina	4.69	0.00	0.00	6.41	0.00	0.00	2.98
Glaucosoma scapulare	2.94	2:23	4.41	1.42	1.71	3.11	2.87
Caranx spp.	0.41	0.25	0.00	1.29	0.57	8.88	2.63
Atractoscion aequidens	0.17	0.25	3.91	8.88	3.42	1.11	2.18
Lutjanus russelli	2.47	0.99	0.67	0.55	1.33	1.33	1.78
Scomberomorus munroi	1.56	0.00	0.00	0.06	19.20	0.22	1.64
Scorpis acquipinnis	0.02	7.94	1.58	1.54	0.00	5.00	1.53
Scomberomorus queenslandicus	2.21	0.25	0.00	0.00	8.37	0.11	1.43
Scaridae	0.00	0.00	0.00	0.00	0.00	8.44	1.39
Acanthopagrus australis	0.77	0.99	0.00	0.99	1.14	3.78	1.27
Euthynnus alletteratus affinis	1.14	0.25	0.33	1.11	4.94	1.17	1.20
Scomberomorus commerson	0.92	0.25	0.08	0.00	11.98	0.17	1.09
Rachycentron canadus	1.63	0.25	0.75	0.31	2.28	0.78	1.09
Seriola lalandi	1.09	0.25	1.17	0.43	0.19	1.89	1.01
Epinepholus undulostriatus	1.84	2.48	0.00	0.00	0.00	0.11	1.00
Scorpaena cardinalis	1.61	0.50	0.08	0.25	0.00	0.83	0.94
Other	24.05	23.33	19.65	10.79	24.33	20.60	21.52

Table 10.2. Targeting preferences of surveyed offshore recreational anglers. (Percentage of anglers who listed a particular taxa as a targeted species)

Species Targeted	Percentage
Pagrus auratus	52.7
Reef Fish (General)	15.5
Scomberomorus spp (Any Mackeral)	13.2
Scomberomorus munroi	6.7
Scomberomorus commerson	3.3
Pomatomus saltatrix	1.0
Scomberomorus queenslandicus	1.0
Seriola lalandi	1.0

The average fishing time differed among ramps (Figure 10.2) with average fishing times at the Gold Coast and Currumbin being 50% less than those for other locations. It was obvious from interviews that many fishers could not recall accurately their total fishing time. In addition, several anglers demonstrated a lack of accuracy in estimating the number of people actually fishing in the boat. It was therefore decided to record catch rates as numbers of fish per boat per trip. The behaviour of fishers differed markedly among ramps. Typically fishers leaving from Raby Bay or Manly had a much greater distance to travel before they reached the fishing grounds. Trip times were long at these locations possibly because once anglers were committed to a greater fuel expenditure and travelling time they sought to maximise their fishing time.

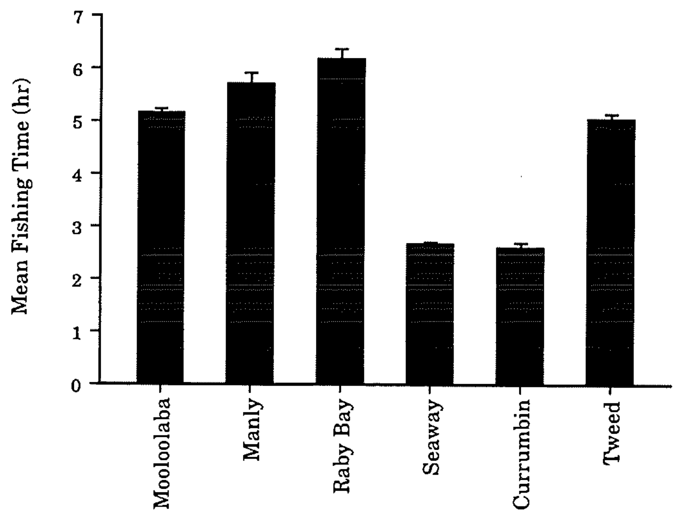


Figure 10.2 Mean fishing time for recreational anglers leaving from 6 locations in Southeast Queensland

Figure 10.3 shows the average recreational catch per boat from all ramps where surveys were undertaken. Overall there were no strong seasonal trends in the rates (when all species were included) with the average catch per trip generally ranging between 4 and 7 fish per boat. February was the only month that departed from the total average catch trend with catches for that month being significantly lower (in pair-wise comparisons) than catches for most other months. April and November were the only months when average catch rates exceeded 6 fish per boat. Overall the average number of anglers per boat was 2.2 and thus average catch rates per individual angler rarely exceeded 3 fish per trip.

This pattern of a relatively few anglers catching more than 5 fish per trip was consistent across all locations and times (Figure 10.4). In fact, occupants in over 28 % of vessels returning from a fishing trip failed to retain a single fish (or at least claimed not to have caught a fish)

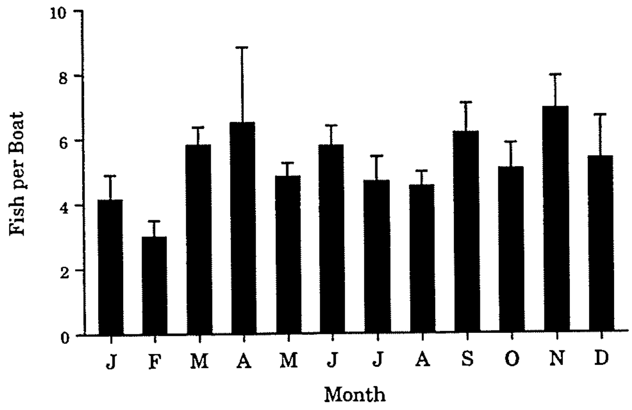


Figure 10.3 Seasonal variation in the average fish catch (all species) per vessel from Tweed Heads to Moreton Island.

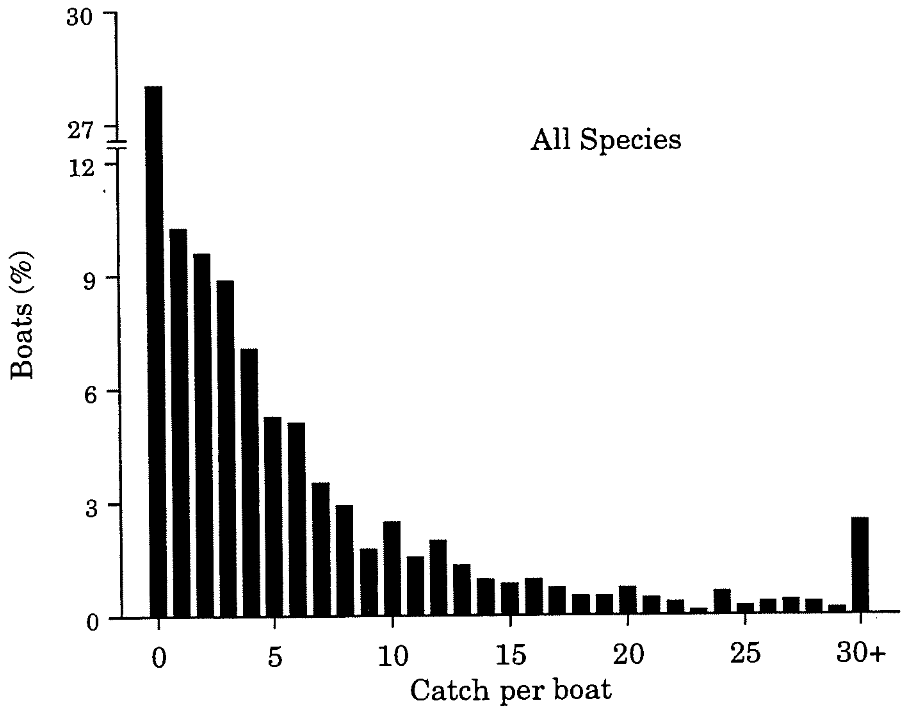


Figure 10.4. Catch per boat of all finfish species. (Data averaged over all locations and times)

Table 10.3 lists the proportion of undersized fish in the catches of recreational anglers from both inshore and offshore locations. Where a species was caught from both offshore and inshore environments, the general trend was for a greater proportion of undersized fish to be taken by inshore anglers than by offshore anglers.

Table 10.3 Percentage of under sized fish and crabs retained in the catch of offshore and inshore recreational anglers at all ramps. Asterisks are shown against species where fewer than 100 individuals were measured.

SPECIES	INSHORE	OFFSHORE
Acanthopagrus australis	35.6	18.2
Atractoscion aequidens	N/A	26.6
Choerodon spp.	61.0	20.2
Glaucosoma scapulare	N/A	10.6
Lethrinus fraenatus	59.0	26.8
Lethrinus nebulosus	90.0	67.6
Lutjanus russeli	46.2	3.2
Lutjanus sebae	N/A	82.5*
Pagrus auratus	69.6	17.8
Pomatomus saltatrix	59.0	20.8
Pristipomoides filamentosus	N/A	11.9*
Scomberomorus queenslandicus	20.5	24.5
S. munroi	12.2	5.9
S. commerson	0*	61.0*
Sillago ciliata	47.2	0*
Seriola lalandi	50.0*	31.0
Rachycentron canadus	0*	32.1
Portunus pelagicus	10.0	0*
Girella tricuspidata	1.0	0*

Other than snapper the most significant catches of undersized fish were recorded for tailor (*Pomatomus saltatrix*) with 60 % of the fish caught by inshore boat anglers being undersized. Large numbers of undersized tusk fish (*Choerodon venustus*) were also retained, particularly at Mooloolaba.

Snapper Catches

Despite a lack of seasonal variation in the total catch of all species, snapper catches showed a strong seasonal trend (cf Figures 10.5). Catch rates were significantly higher during the months of August, September, October and November than at other times of the year. During the survey there were large "unseasonable" catches of snapper during April. This was largely due to some large snapper catches being observed at one particular location (Raby Bay). Overall catches recorded during April were significantly larger than those for most other months in which snapper do not spawn, although the variation in catch was high, reflecting a heavily skewed distribution of catch rates caused by a small number of anglers who recorded large catches.

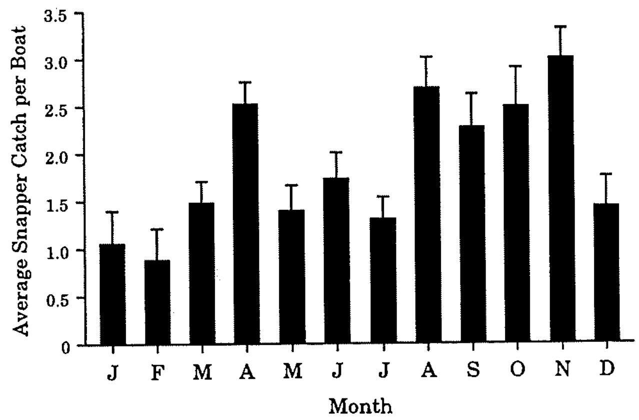


Figure 10.5 Seasonal variation in the average number of snapper caught per boat from Tweed Heads to Cape Moreton

In contrast the variance in mean snapper catches was also relatively low mainly because there were relatively few boats where the total catch exceeded 10 fish, and distributions were heavily skewed (Figure 10.6). Despite the generally larger catches of snapper during their spawning season only 4 of the 4400 daytime interviews undertaken recorded that the snapper bag limit (30 fish per angler) been reached.

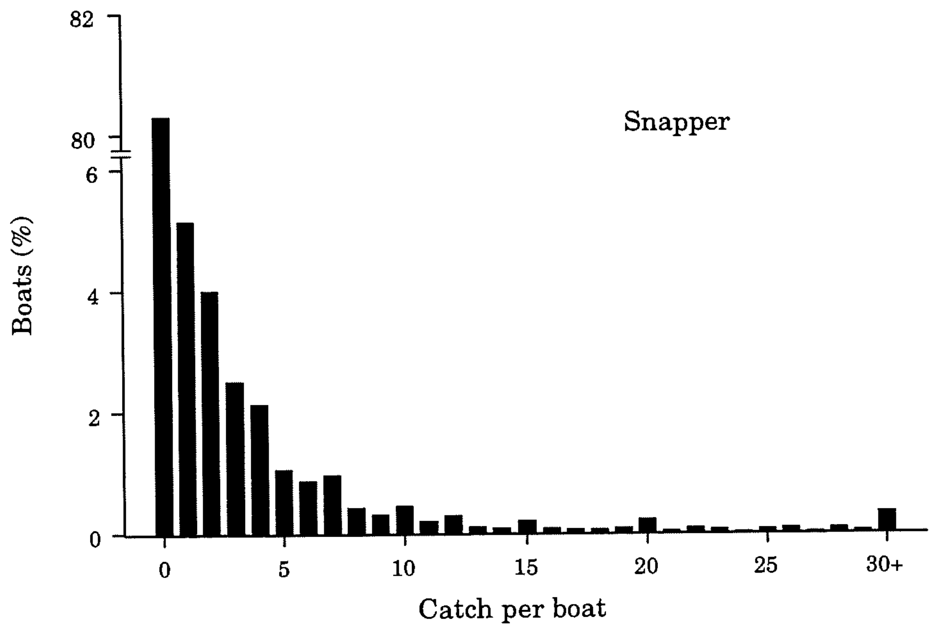


Figure 10.6. Catch of snapper per boat. (Data averaged over all locations and times)

Overall, 80% of offshore fishing trips resulting in a snapper catch of zero (which includes targeting and non targeting anglers). A major source of variance in monthly catch relates to differences in catch rates among ramp locations. When individual ramps and fishing locations were considered alone, the variance in average catches increased. Even at ramps where anglers were accessing the same fishing grounds there were significant differences in mean catch rates.

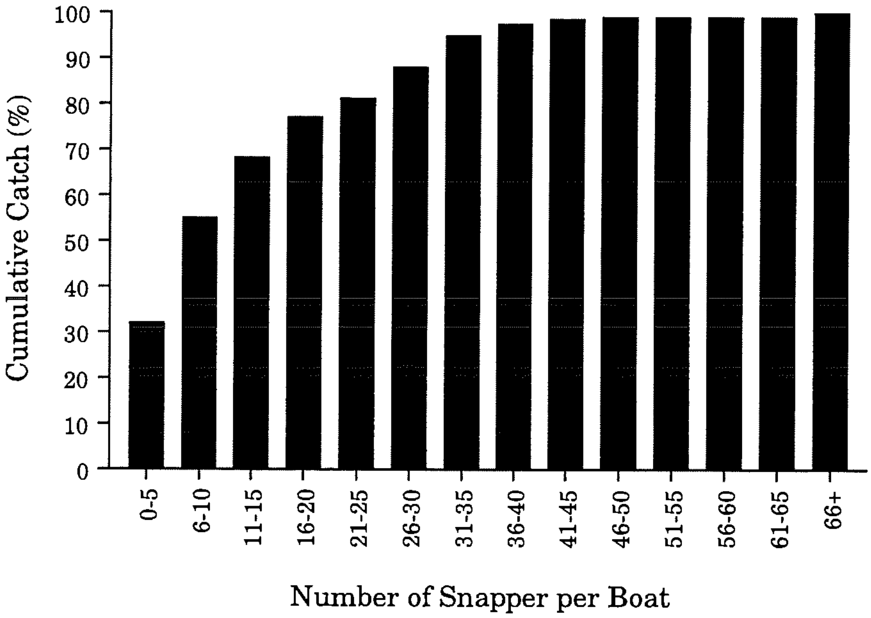


Figure 10.7 Cumulative catch of recreational fishing vessels which reported various catch rates

Over 40% of the total snapper catch was landed by recreational vessels which had greater than 10 fish on board (Figure 10.7). Approximately 18 % of the catch was landed by vessels where the catch exceeded 20 fish.

As mentioned earlier a large proportion of undersized snapper were retained by recreational anglers who fished in inshore waters (Figure 10.8).

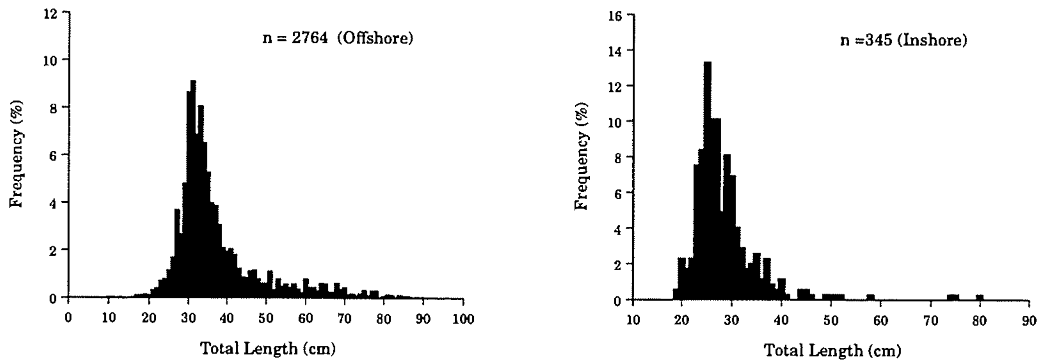


Figure 10.8 Size structure of the recreational snapper catch from anglers fishing in offshore waters and inshore waters (Moreton Bay). Minimum legal size in both areas is 30 cm total length.

Around 25% of the snapper that were measured were less than the current minimum legal length for the species in Queensland (which is 30 cm in total length). The extent of the undersized component in the catch was significantly reduced when the catches of inshore anglers were eliminated from the analysis. Discard rates decreased to less than 5% for offshore anglers, although there were very strong seasonal and location trends. The problem of retention of undersized snapper was largely restricted to anglers fishing inside Moreton Bay and the Southport Broadwater which are habitats commonly used by juvenile snapper.

Despite differences in the extent of the undersized catch between commercial and recreational fishers, the size structure of the legal component of the recreational catch from offshore waters was not significantly different from that of the commercial sector. The vast majority of the catch measuring less than 50 cm in total length (Kolmogorov Smirnov test, P>0.05, see also Figure 5.1).

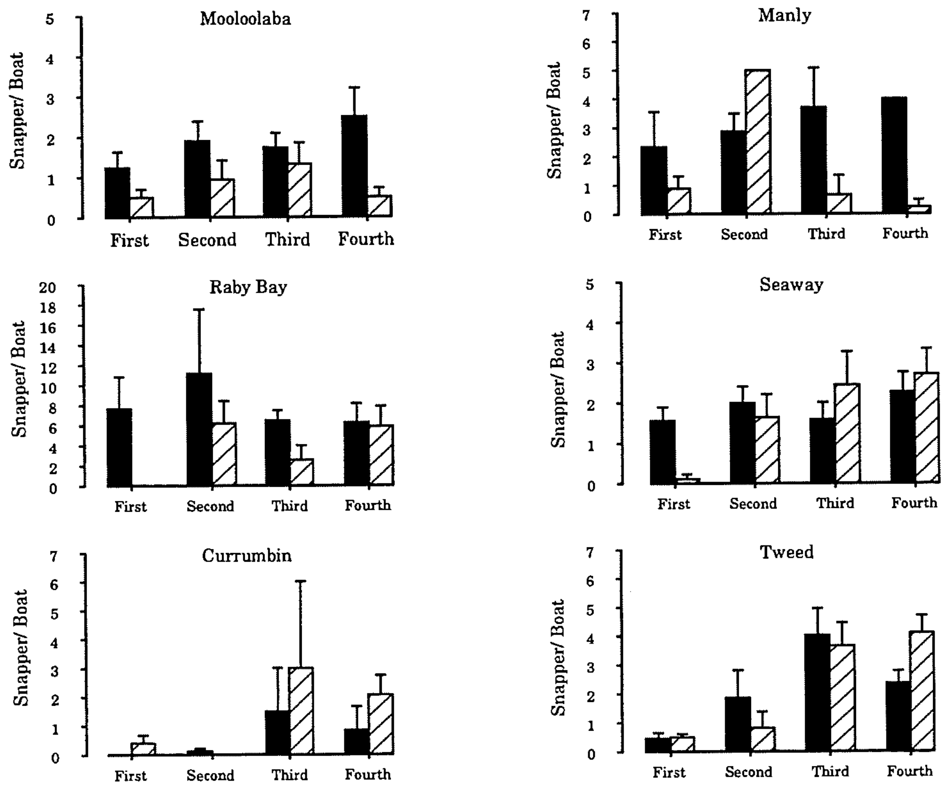


Figure 10.9 Estimates of recreational snapper catch rates (fish per boat per trip) at six locations in SE Queensland. Weekends are shown as solid bars and weekdays as hatched bars (Standard errors are shown above each bar, note scale differences among axies.).

When examined seasonally, the average snapper catch per boat was generally less than 6 per vessel at all locations except Raby Bay (Figure 10.9). The larger standard errors around these estimates reflect the wider distribution of catch numbers at this location particularly during the first and second quarters. Indeed Raby Bay was the only location where anglers reported reaching their daily bag limit of 30 fish per person. No consistent trend was noticed in catch rates between day type strata nor seasonal strata with few significant differences in pair-wise comparisons of day type strata within a quarter at any location. No snapper were recorded during first quarter surveys at Raby Bay due mainly to poor weather conditions on days when surveys were scheduled. Likewise, fewer snapper caught at Currumbin during the first and second quarters was a reflection of recreational anglers targeting mackerel which appeared over the shallow reefs offshore of Currumbin during that time.

Recreational Effort

There were no systematic biases in vessel counts between main observers and the validating observers. Discrepancies were also low, generally less than 3%. Likewise ground based validation of aerial counts indicated a 6% underestimation by aerial observers. This bias has not been adjusted for in effort estimates. A comparison of log books maintained by volunteer search and rescue organisations showed that the proportion of vessel skippers who logged in varied among locations and between day type strata. The general trend was for a greater proportion to log on during the week with fewer people logging on during weekends and public holidays. As an example the proportion of vessels who logged on at the Gold Coast Seaway averaged for the various quarters is shown in Figure 10.10.

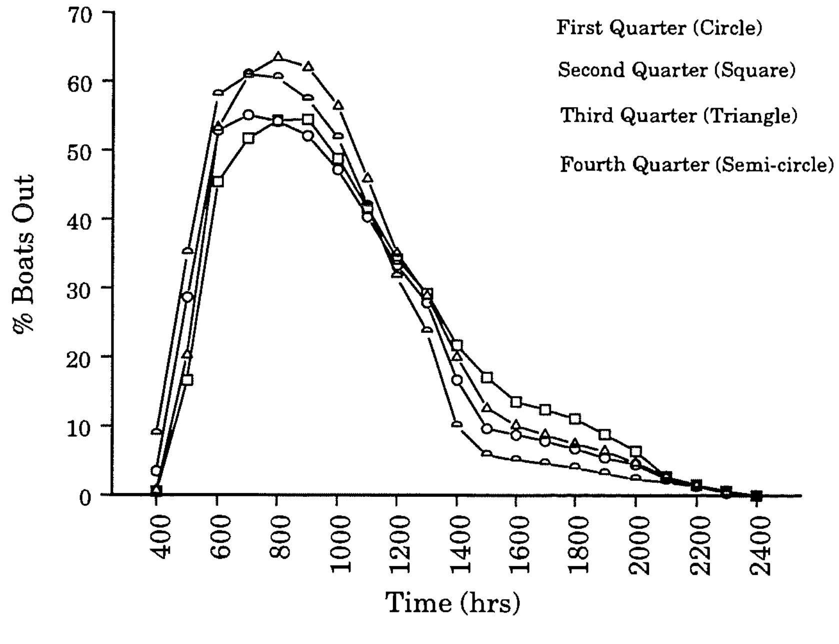


Figure 10.10. Daily distribution of fishing effort for recreational vessels leaving the Gold Coast seaway. Data are for boats which have logged on with the Gold Coast Seaway Radio Tower.

The Gold Coast Seaway was the access point which had the greatest proportion of vessels that logged on and concurrently had the most accurate records of vessel movements and the most extensive research validation program. The variance associated with these estimates was greatest on weekends, due largely to anglers on board large numbers of vessels fishing offshore on weekends when wind speed was less than 10 knots. At times over 500 vessels left the Southport Seaway on these days. Vessel counts made by research staff gave the same results in terms of the temporal distribution of effort with Kolmogorov Smirnov tests showing that no significant differences in the temporal distribution of fishing effort existed (Figure 10.11).

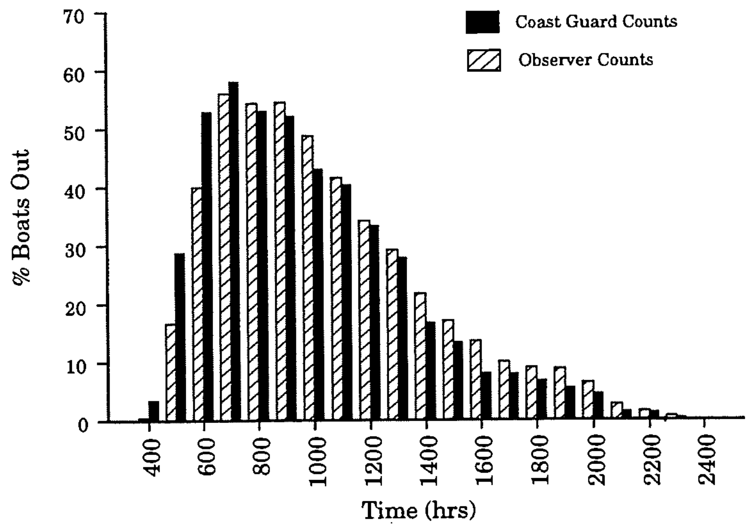


Figure 10.11 Difference in the distribution of daily fishing effort as estimated from radio logs and validated by counts from observers (n = 21 days).

From these data we then assumed that the times when fishing trips began and ended for boats that logged on were similar to those of the total offshore fishing population. The averaged distributions of fishing effort throughout the day were remarkably similar among areas where vessel logbooks were maintained. However, there was considerable daily variation related to weather conditions (See Figure 10.12) In addition, despite small temporal shifts in the distributions which were related to varying periods of daylight hours, there were few differences in the average daily pattern of offshore fishing times (Figure 10.10).

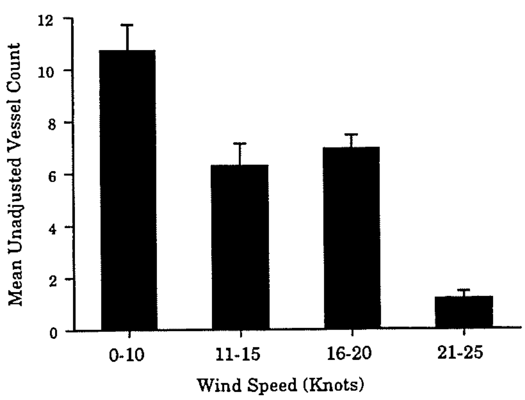


Figure 10.12 Mean unadjusted counts of recreational vessels along the flight transect during various wind conditions

The most noticeable exception to this was Currumbin where the pattern was very much truncated with most vessels leaving earlier in the morning and also returning earlier than at other locations. This was largely due to the fact that this access point serviced reefs which were within 2 kilometres of the shore and accessible to small boats, the skippers of which were reluctant to spend extended periods of time at sea. Data from creel surveys supported logbook recordings at this location because trip times were considerably shorter and very few interviews were conducted after 1200 hours.

Weighting factors to adjust for within day temporal variation in fishing effort were calculated for each surveillance day based on the times when the plane flew over the area. Where these were not available directly from radio logs they were estimated from the quarterly averages for that particular day type strata.

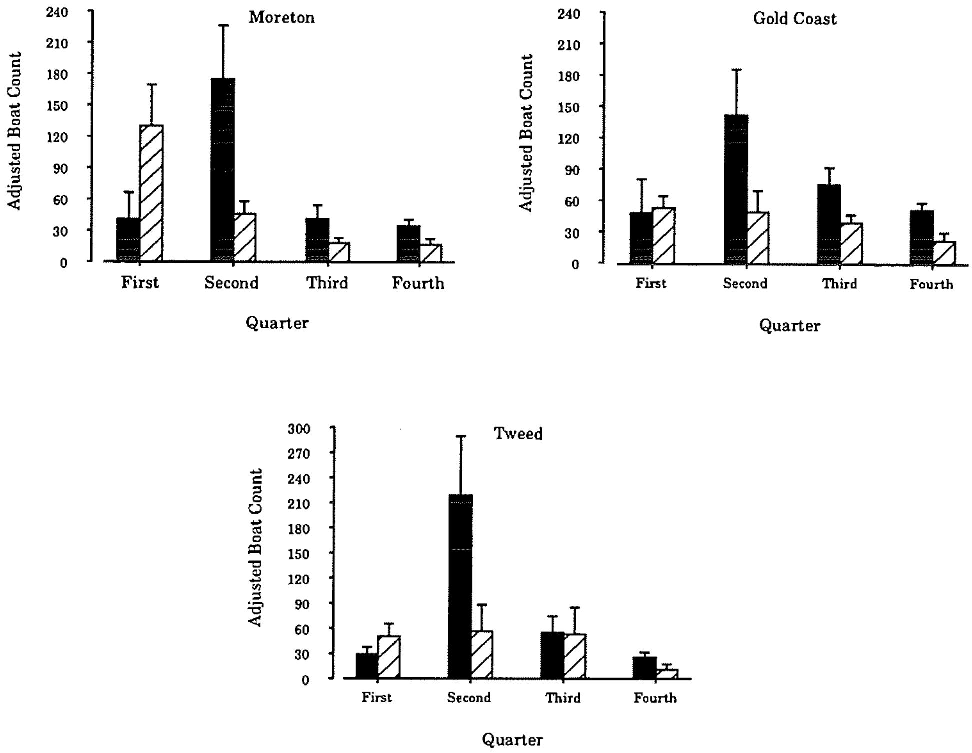


Figure 10.13 Average daily number of recreational vessels fishing offshore in 3 thirty nautical mile bands. Weekends are shown as solid bars and weekdays as hatched bars. (Standard errors are shown above each bar).

These weightings were applied to the direct observations to provide estimates of fishing effort in boat days for each area (Figure 10.13). As expected fishing effort was generally greatest on weekends (Figure 10.14) with no significant difference in effort between Saturday and Sunday. Fishing effort on Mondays also tended to be high although there was a greater variance associated with these estimates. There were 2 Mondays which were public holidays and were regarded as weekends for the overall assessment of catch rates. Heavy fishing effort on these days was largely responsible for the marked increase in overall mean fishing effort exerted on Mondays.

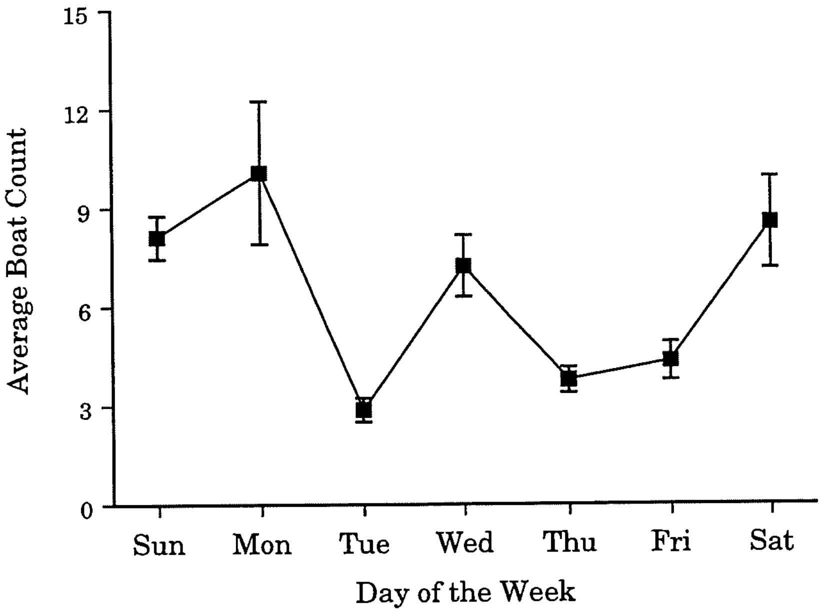


Figure 10.14 Average number of recreational vessels sighted per grid during flights to determine fishing effort.

On average fishing effort on weekend days was twice that exerted on weekdays. The exception to this was a high level of fishing effort on weekdays during the first quarter. This was due mainly to some large recorded fishing efforts on weekdays during school holiday periods which were classified at week days but which always have a considerable proportion of the population on holidays, resulting in higher fishing efforts than non-holiday periods.

Recreational Harvest

Harvest values were calculated assuming that the mean size of snapper was 0.91 kg, which was calculated using the offshore length frequency data and the snapper length weight relationship (weight = 0.0447 x Fork Length $^{2.79}$). Recreational snapper harvests were greatest at all locations during the second and third quarters which is the spawning season of this species (Table 10.4). The greatest harvests generally were recorded on weekends even though there were fewer weekend days in each quarter than weekdays. The exception to this pattern was the first quarter, when weekdays were responsible for the largest catches. As discussed earlier, this was caused by a combination of poor weather conditions on weekends during that quarter and the influence of the school holiday period in January. Weather appeared to be the major factor determining the overall recreational harvest during any given quarter.

Commercial fishers record their daily catches in logbooks with the data summarised in 30 nautical mile square grids. The harvest estimates from the recreational sector can be directly compared with those of the commercial sector in 2 of the areas described (Moreton and Gold Coast), because recreational effort estimates were based on these same grids. The commercial logbook data for the Tweed region are not complete because we only have catch records from Queensland licensed fishermen. Estimates of the NSW trap catch for this region are in the vicinity of 30 tonnes giving an overall commercial catch of about 50 tonnes for this area The data clearly demonstrate the magnitude of the recreational catch in comparison to that of the commercial sector. Despite the fact that there is considerable variation around these estimates the recreational catch is about twice that of the commercial sector and in the Moreton region it may be an order of magnitude greater.

Table 10.4 Recreational harvest estimates (numbers of fish) for 3 regions in SE Queensland (Standard Errors are shown in parentheses)

	First Quarter		Second Quarter		Third Quarter		Fourth Quarter	
Moreton	7,166	(5,201)	68,764	(11,353)	9,779	(974)	10,617	(644)
Gold Coast	2,054	(365)	12,287	(1,134)	9,068	(623)	5,969	(667)
Tweed Heads	1,841	(226)	13,539	(1,456)	18,118	(3,326)	3,973	(522)

Table 10.5 Estimated recreational harvest and commercial harvest taken from 3 areas in southern Queensland and northern NSW * Figures in parentheses are estimates of the snapper catch including that of NSW trap fishers in this region

Region	Recreational Harvest (Tonnes)	Commercial Harvest (Tonnes)
Moreton	87.66	10.30
Gold Coast	26.74	20.15
Tweed	34.10	19.87 (49.87)*
TOTAL	**148.50**	**50.32 (80.32)***

10.4 Discussion

The most noticeable finding of this study was the magnitude of the recreational snapper catch in comparison with the commercial catch in the survey area. The total commercial snapper catch for the survey area during the period of investigation was less than 50 % of the recreational catch, which does not include the charter boat catch. The Gold Coast charter boat catch has been under investigation since 1993 under a separate program (Ray Joyce, pers. comm.) and the estimates from that program rate the snapper catch of charter boats from Tweed Heads to North Stradbroke Island alone to exceed

20 tonnes per annum. The size structure of the charter boat catch is also similar to that of the recreational and commercial sectors, but tends to have fewer representatives from larger size classes. (Figure 10.15) There are also very few undersized fish retained by the charter boat fleet.

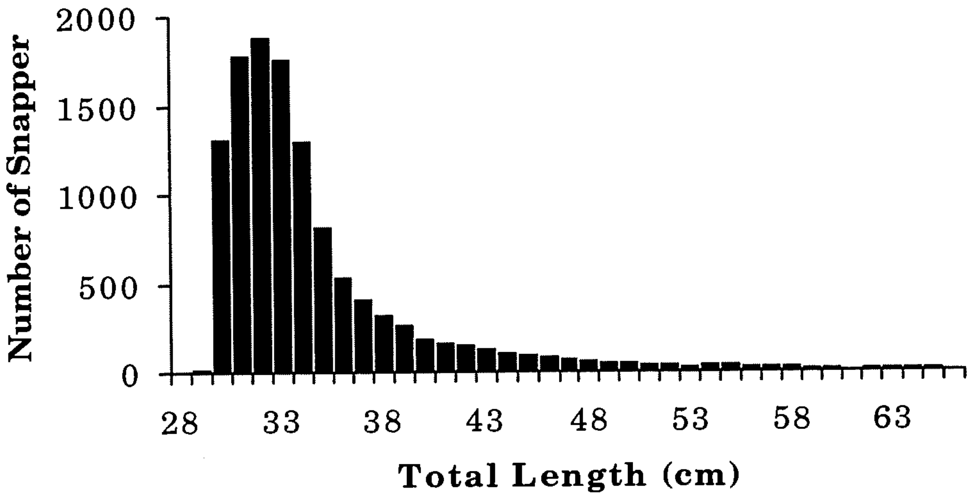


Figure 10.15 Size structure of Gold Coast Charter fishery snapper catch for 1995. (Data are total catches of 7 vessels over the 12 month period)

Steffe *et al*. (1996) examined the offshore recreational catch in NSW and found that there was a marked decline in the recreational harvest of snapper with increasing latitude. Further, they found that the northern coast of NSW produced the largest recreational harvest, but this was only between 25% and 36% of the commercial catch from that area, depending upon the year of survey. Around the larger population centres of the central NSW coast, the commercial and recreational harvests were almost identical. In southern Queensland the recreational catch exceeds that of the commercial sector. The magnitude of the allocation difference between commercial and recreational sectors in QLD and NSW is in contrast to those found in South Australia (McGlennon and Kinloch, 1997). In South Australia 48 tonnes of snapper are caught per annum by recreational anglers compared with a commercial catch of 282 tonnes per annum. The 48 tonnes was made up of an estimated 23,543 snapper (equating to an average of over 2 kg per fish). By comparison the average snapper was 0.91 kg in the present study and approximately 0.85 kg in the survey of Steffe *et al* (1996). Similarly, Bradford (1996) reports an average weight of 0.75 kg for the 2,822 tonnes caught by anglers in northern NZ (SNA 1). The differences between the fisheries on the east coast and those in SA are not surprising given that the minimum legal length of snapper in South Australia is almost 25% larger (38 cm total length) than that in either QLD or NSW. This variation in the allocation of the snapper between commercial and recreational sectors throughout Australia, and in particular, the magnitude of the recreational catch in Queensland is understandable given the nature of the fisheries. In contrast to NSW, trapping is not allowed in Queensland and there is only limited long-lining permitted. Both commercial and recreational sectors in Queensland are restricted to the same gear (line fishing). Line fishing is a far less efficient means of catching snapper compared with either longlining or trapping and thus it is not surprising that the fishery in Queensland is primarily recreational

There have been other angler surveys conducted in Australia where estimates of recreational catch and effort of other species have exceeded those of the commercial sector (MacDonald and Hall, 1987; West and Gordon 1994). In areas where population growth is extensive recreational effort is likely to increase. In the United States for example, the number of recreational anglers was predicted to increase by 30% between 1980 and 2025. (Edwards, 1989). This trend is certain to be relevant to Australia and in fact the south-east corner of Queensland is one of the 5 fastest growing urban areas in the developed world (Skinner, 1996) which will only further increase the pressure on species of fish that are targeted by recreational anglers. Relative effeciency of the commercial fleet may improve with technological change, but numbers of commercial fishers (given current management practises) are unlikely to increase.

A further interesting feature of this fishery is the very large proportion of undersized snapper that are retained by recreational anglers. In the case of inshore fisheries this is almost 70 % of the landed snapper catch. This is similar to the proportion of undersize snapper retained by anglers in Henry's (1984) survey of Sydney Harbour. In addition, it is very likely that large numbers of undersize fish are caught and released, possibly more than the actual landed recreational inshore catch. The survival of these fish is difficult to assess and would vary enormously depending on handling practises. On research cruises using "best practise" handling procedures, mortality of juveniles which were line caught exceeded 10% over a 7 day period after fish were held in the laboratory. It is likely that the overall survival rate of recreationally and commercially caught and released fish is considerably lower than this figure. The significant catch of undersized species by recreational anglers needs to be included in any assessment of the fishery and is relevant if "off site" methods of recreational catch estimation are to be employed. It is doubtful whether catch cards, diaries or other voluntary means of collecting data would provide an accurate estimate of the magnitude of the undersized catch. If, as is the case for a number of species identified in this survey, a significant proportion of the catch is undersized, then many models which fail to take this into account will give an unreliable and probably over optimistic assessments of the fishery.

For cost and logistic reasons the sample frame of this study did not include the catch or effort of night time recreational angling. However, this is likely to be a significant component of the total catch, particularly for snapper where the best catches are known to occur whilst fishing during the night at certain lunar phases. The small amount of data that was collected from anglers who were fishing at night suggested that catch rates may be twice those obtained by anglers fishing during the day. Fishing effort was considerably less at night, however effort estimates extrapolated from radio logs maintained at 24 hour Coast Guard bases show that the effort at night time can be over 10 % of the fishing effort for a particular quarter.

For logistic reasons, and for reasons of accuracy and precision, we targeted our survey at the area which had the largest commercial catch and was also the main population centre where recreational effort was likely to be large. The commercial production in this area represents approximately 50% of the statewide commercial snapper harvest. Providing the allocation between commercial and recreational fishers remains the same throughout the species distribution then the total statewide recreational catch would be in the order of 300 tonnes. Caution should be exercised in this sort of interpretation since the allocation between commercial and recreational anglers changed dramatically over the geographic range investigated by this survey.

From this survey the areas that appear to be most vulnerable to over exploitation due to the greatest concentration of fishing effort and lower catch rates are those areas adjacent to the Gold Coast. This is largely because of the easier access afforded by the Gold Coast seaway which is close to a number of well maintained and easily accessible ramps. Access to the offshore areas east of Moreton and Stradbroke Island (east of Brisbane) require a more extensive journey across Moreton Bay, and also can involve the crossing of the South Passage Bar, which is more treacherous than gaining offshore access via the Gold Coast Seaway. Fishing effort was always greatest on reefs adjacent to the seaway and other access points on the Gold Coast, particularly on weekends. By comparison this is an area of relatively limited commercial line fishing effort. Most of the commercial effort on the Gold Coast comes from dual Queensland and NSW licensed trap fishermen, although much of that effort will eventually be removed due to the fact that there are only 3 fishermen who are licensed to trap fish in Queensland waters and these licenses are subject to a "sunset clause" which will eventually eliminate trapping effort in Queensland waters

Fishing effort was greatest during the second and third quarters, particularly during the second quarter (April to June). However, the second quarter also had the greatest variance in catches because several weekends had particularly good weather. It is likely that this pattern would vary from year to year depending on the frequency of weekends when weather conditions were favourable. Analysis of search and rescue logs during previous years had shown a higher proportion of trips during the third quarter in comparison with the survey period.

Weather conditions are far more critical to offshore, open ocean fisheries than they are to estuarine and inshore fisheries. It is rare to find recreational fishing vessels crossing coastal bars and fishing offshore when wind strength exceeds 25 knots. During the pilot survey, when sampling methods were still being developed it was common to interview relatively large numbers of inshore anglers without seeing a single offshore angler when wind strength exceeded 25 knots. Likewise, on occasions flights conducted during strong wind warnings failed to detect any offshore vessels, whilst numerous vessels were seen fishing in Moreton Bay and other semi-protected waters.

There are a number of factors that would contribute to the overall inaccuracy of our recreational catch rate estimates. Firstly, the catches of anglers fishing from larger, non-trailerable vessels were not surveyed in this study. On the Gold Coast, in particular the number of mariners and private moorings is significantly large. The untested assumption of this study is that the catch rates by anglers fishing from these vessels is the same as those of anglers fishing from trailerable vessels. While there were only 4 catches recorded where the snapper bag limit had been reached there were a further 3 occasions when Creel clerks noted significant catches of snapper well above the bag limit but could not reliably estimate or measure the catch due to the anglers either refusing to be interviewed or falsely reporting their catch as zero. One group of anglers had a catch which would have been at least 100 kg of snapper but reported the catch as zero. It was not until the catch was removed from the boat away from the ramp that the magnitude of the catch became apparent. The under reporting of catch is likely to be a major problem in any survey of recreational catch. During this survey, steps were taken to ensure that under reporting of the catch was minimised. However, we believe there were occasions when significant catches were recorded as a zero catch. Incidences when further questioning revealed significant catches after an initial report of zero catch were quite common. The effect of this under-reporting is obviously to lower the overall estimates of recreational catch rates and reduce the total harvest estimates.

Management Implications

The most important management implications of this work relate to the magnitude of the recreational snapper catch which is far greater than the commercial catch and also includes a large undersized component. The magnitude of the undersized catch demonstrates the need for greater education of the general public in fisheries regulations. Catch rates of offshore recreational anglers were superior to inshore anglers. A greater degree of skill is required to fish offshore than to fish in relatively sheltered estuarine waters. Despite the fact that this level of experience was not quantified in this study it seems reasonable to assume that fishing activities which require the crossing of a coastal bar and exposure to significantly worse sea conditions would require more experience and skill than fishing in sheltered estuarine locations. This is relevant to the introduction of any measure that seeks to increase size limits

Selectivity of fishing gear and various fishing practises are relevant to this discussion. Hook size as well as fishing method will influence the size of fish caught by anglers (Otway and Craig, 1993). It is possible for offshore anglers to target large fish by utilising different fishing practises (See Chapter 1). This will be far easier to accommodate in the case of offshore anglers due to their higher level of skill and motivation. By comparison, anglers fishing inshore waters generally take significantly smaller fish than their offshore counterparts. Any increase in minimum legal size should have only a short term negative impact on inshore catch rates in particular. This is provided that the magnitude of the undersized component of the catch can be controlled and that the capture and release of large numbers of juveniles can be minimised.

Any increase in the minimum legal size would require close monitoring of recreational compliance because compliance levels of offshore recreational fishermen may not remain the same. At present compliance levels by these anglers is significantly higher than their inshore counterparts. However, there are many near shore reefs which currently support large numbers of snapper less than 35 cm in length which are now within the legal size range. However, a 5 cm increase in minimum legal size would make these fish undersized. It cannot be assumed that these areas will not continue to be fished, possibly causing compliance levels to fall.

Cost Effectiveness of Aerial Overflights

The cost effectiveness of aerial survey methods for estimating recreational fishing effort has been clearly demonstrated elsewhere (See Pollock *et al,* 1994). Aerial methods are clearly superior when an extensive area is to be surveyed or where access to boat ramps is limited. One of the major limitations of the method in offshore waters is the relative narrow width of transect that can be observed. Where the majority of the fishery is restricted to narrow areas of offshore waters then this problem is eliminated. In the case of the snapper fishery, particularly in southern Queensland, much of the effort is centred on relatively narrow bands of reef. The main exception to this is the extensive area of relatively shallow (<80 m) water north of Cape Moreton. Much of this area, known as the Barwon Banks, has reef habitat that can extend for more than 25 nautical miles out to sea. Such an area is clearly too large to survey using aerial methods unless multiple transects are used. Each situation requiring an estimate of effort warrants its own assessment of the costs and benefits. Although we have not presented the data here, aerial methods also provide a much more accurate indication of the effort exerted on individual reefs. Flights enabled counts of vessels to be obtained on specific reefs which were not visible from the shore and which would prove difficult to estimate effort based on access point interviews given that anglers fishing on the reef may return to one of dozens of ramps which serviced the area. Similar situations are likely to exist elsewhere, such as the GBR. The cost of a flight was approximately $220 per hour (including charter of plane, crew and observers). Approximately 3 hours were required to survey the reduced area from Kingscliff to Cape Moreton. In comparison, for the same cost, 2 staff and two vehicles could be employed in a bus route survey of the area. This latter alternative has the advantage of being capable of collecting catch information as well but was not considered practical due to the large number of ramps in the survey area (over 100). During a pilot survey conducted before this project was attempted, over 3 hours was required to visit only the major ramps used by anglers in the greater Brisbane metropolitan area The use of observers to count and categorise vessels crossing coastal bars is another option but a minimum of 7 people would be needed to accomplish this, and in at least one of the locations (between Bribie Island and Moreton Island it is virtually impossible to count vessels because of the large expanse of water through which vessels may gain access to offshore waters.

11. GENERAL DISCUSSION

11.1 Spatial Scale and the East Coast fishery for snapper

The genetic information provided in Chapter 8 clearly indicates snapper in eastern Australia needs to be treated as a single genetic unit. This is not surprising given the potential for mixing and transport of larval snapper in the dynamic oceanographic environment that includes the East Australian Current. However, our examination of the composition of the harvest and the distribution of juvenile snapper showed regional differences in the size and age composition of catches. The magnitude of these differences are similar to those found by Steffe *et al.* (1996) in regional comparisons of catches by recreational trailer-boat anglers.

The regional differences in catch composition mean that the impost of regulation changes will vary amongst regions. It may not be practical or desirable to vary management regionally but it will be worthwhile for managers to consider the impact of potential changes to regulations beyond the average for the fishery. A good example of this is the discussion of changes in minimum legal sizes. Within NSW, the impact of raising minimum sizes will be very different in Forster compared with Ballina. The regional variation in the catch should be acknowledged and understood by both those considering management changes and those affected by potential changes.

11.2 Bag Limits

Bag limits are usually introduced for several reasons. Firstly, they allow a more equitable spread of the catch across recreational anglers. Secondly, the illegal marketing of fish is more easily detectable and prevented if reasonable bag limit regulations are in place. Finally, recreational bag limits recognise the fact that rocky reef fish are a limited resource and that whilst fishing effort is ever increasing there are limits to how much a resource can be fished before it becomes over-exploited.

In Queensland many recreational species have bag limits, and for most species this limit is around 10 per person. One notable exception to the 10 per person limit is the snapper which has a limit of 30.

The present snapper bag limit operating in Queensland is normally reached by only a very small proportion of anglers. We have found that the 30 bag limit was reached in less than 0.1% offshore fishing trips during our survey of offshore anglers. However, we noted that a small proportion of relatively skilled anglers was still able to regularly reach the bag limit. Although these anglers were rare in interviews conducted during the structured creel survey, contacts with fishing clubs and skilled recreational anglers indicated that during some years there were anglers who regularly reached their bag limit. Often these anglers fished at night and returned at night and were therefore not interviewed during our survey.

Current bag limits in the rocky reef fishery do little to control a significant amount of latent effort. Average catch rates are around 2.5 fish per person, although this figure varies considerably both seasonally and between areas. Even so, with the current bag limit of 30 there exists a potential 12 fold over-capacity in recreational effort, notwithstanding predicted population increases in the south east corner of the state, which will further increase fishing effort. Reductions in the current snapper bag limit would affect a very small proportion of recreational anglers. The fact that a large proportion of recreational fishing trips fail to land any fish at all is evidence of this fact.

In addition the present snapper bag limit in Queensland is over double that of all the other states in Australia and New Zealand and yet evidence that we have presented has shown that the east coast stock of snapper is perhaps the most heavily exploited stock in Australia

11.3 Minimum Legal Size

Minimum legal sizes are usually introduced to provide a degree of protection to spawning stocks by allowing fish to reach spawning size before they are harvested. They are commonly set at around the size at which a fish reaches sexual maturity. In the case of snapper sexual maturity occurs over a wide range of sizes but certainly over 50% of fish at the current legal size of 30 cm are mature.

One of the main problems with minimum legal sizes is that they may be ineffective if the undersized fish which are returned to the water do not survive. A large proportion of the rocky reef fishing grounds are located in relatively deep water (greater than 30 m) and therefore fish caught and brought to the surface quickly may cause the fish's swim bladder to expand, often forcing the stomach lining through the mouth. If the swim bladder is not deflated properly then the likelihood of the fish surviving is low.

Reports by officers of the Queensland Harbours and Marine Department as early as the 1950's highlighted concerns about the capture of undersized fish by recreational anglers in Moreton Bay. Likewise Henry (1984) found over 90% of the snapper catch in Port Jackson consisted of undersized fish. We have found that about 70% of the snapper catch taken within Moreton Bay were undersized and there is also a very large proportion of fish which are landed but subsequently returned to the water because they are under sized. The fate of these fish is unknown but obviously depends on how they were handled after capture.

At present no maximum legal sizes have been placed on rocky reef species in either Queensland or New South Wales, although some maximum size restrictions are in place for snapper in other Australian states.

In 1993 the minimum legal size of snapper was increased from 25 to 30 cm in Queensland. The impact of these changes saw a decline in the total commercial catch of snapper however, this decline was only short term and after 12 months the total catch had recovered considerably. Since there are only limited records of recreational catches the impact of changes to these management arrangements is unknown for the recreational sector.

Concern has been raised by anglers fishing inshore waters, such as Moreton Bay, that the increase in the minimum legal size has seen declines in the numbers of snapper able to be taken. Our recruitment surveys have shown that these inshore areas are important juvenile habitat where there is a very high proportion of undersized fish. Moreton Bay is adjacent to one of the fastest growing urban areas in the world and will always be subject to high fishing pressure. Since the southern part of the Bay is important juvenile snapper habitat, this is an area requiring careful future management, particularly given the low level of recreational size limit compliance in this area.

11.4 Variation in Quality and Price for snapper

During the sampling for this study, a high degree of variability in the quality and care of handling of the product was evident. Quality and handling were not issues to be addressed as part of the project's objectives. However, the improvements and financial gains to be made in some sectors of the snapper fishery are so obvious that we believe they call for some comment.

Fishers who ice slurry their snapper routinely get a wholesale price between 5 and 10% higher than those who do not (Figure 11.1a). Similarly, individual producers who consistently produce a good quality product are rewarded with higher than average prices (Figure 11.1b and 11.1c). "Producer X" in Figure 11.1b and 11.1c is not handling fish in an exceptional way (the fish are caught in traps and not spiked but are ice-slurried) but does produce fish that are of a consistent standard.

This sort of variation in price is more or less known to industry but is difficult to act on for many fishers in NSW. Informal discussions with buyers of snapper at the Sydney Fish Markets suggests that buyers consider fish from large cooperatives to be of inconsistent quality compared to fish supplied by individual fishers. Buyers apparently see inconsistency of product as a risk and mark the price down accordingly. We believe it is important to point out that fishers may not be achieving the best price for the fish they catch and that improvements relating to product consistency have a very great potential in the snapper fishery.

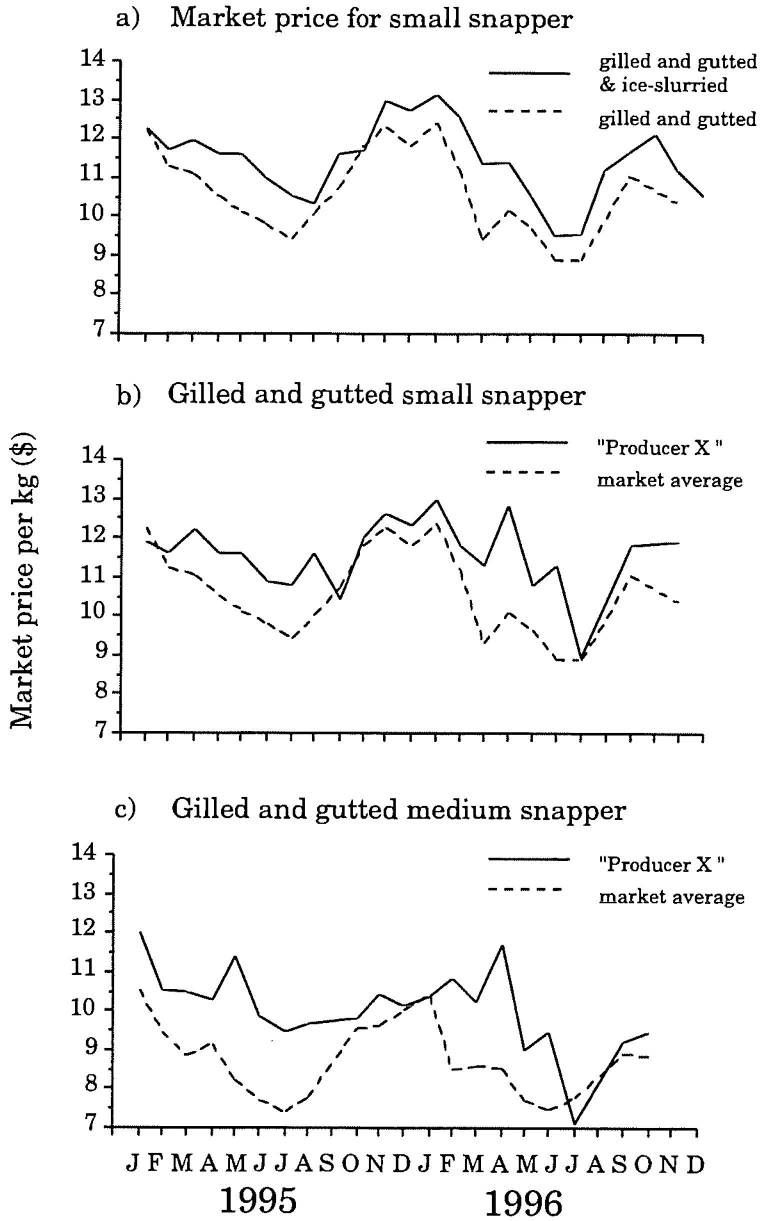


Figure 11.1 Prices of snapper sold at the Sydney Fish Markets from 1995 and 1996. a) Prices for small snapper sold as gilled and gutted only compared with fish of the same class but also ice slurried. Prices for small b) and medium c) size snapper sourced from a high-quality producer compared with market average price for the same class of fish.

11.5 Management arrangements for snapper in other jurisdictions

Table 11.1 shows considerable variation in the management measures adopted by the different states where snapper are fished with size limits ranging from 27 to 41 cm and bag limits from 5 to 30. The Northern Territory is outside the range of the species and there is only a limited fishery in Tasmania. A recent national snapper workshop organised as part of this project further highlighted the differences in the nature of the fisheries within Australia as well as New Zealand. New Zealand was the only place which had different size limits for the recreational and commercial sectors, however two Australian states had restrictions operating on the basis of a maximum size limit for the recreational sector. These maximum size limits have been introduced on the basis of disproportionate fecundity of older and larger individuals which are believed to potentially contribute more to spawning. This study has also found increasing egg per recruit for larger fish however the relative viability of eggs produced by these fish remains untested.

Table 11.1 Snapper size limits and recreational bag limits imposed by Australian state fisheries management authorities. Size limits are total lengths unless stated otherwise. In some cases these have been converted from the various measurements used by different management bodies. (*as part of a group of species)

State	Size Limit	Bag Limit
Western Australia	41 cm (28 cm Wilson Inlet)	8 per day*
South Australia	38 cm, restrictions on catch of fish > 60 cm	5 -10 per day depending on location; 15 - 40 per boat; 2 - 6 per day (>60 cm) depending on location
Victoria	27cm, restrictions on the catch of fish > 40 cm	10 per day 5 per day (> 40 cm)
New South Wales	28 cm	10 per day
Queensland	30 cm extended total length	30 per day
Northern Territory	None	None
Tasmania	None	None
New Zealand	31 cm (Recreational) 29 cm (Commercial)	9 per person

Discussions with other snapper researchers in Australia and New Zealand also highlighted a number of other structural differences between the east coast fishery and the fishery in southern Australia. The presence of strong year classes which is a feature of the snapper fishery in New Zealand, South Australia and Victoria was not evident in any of the areas surveyed along the east coast during the 3 years of data collection. Each of the southern areas has a high proportion of older fish (> 10 years) in the catch (Jones,1989) than does the east coast stock, where catches tend to be dominated by fish aged 2 to 6 years old (see Chapter 5). Most of the fishery in southern Australia operates in embayments or gulfs such as Port Phillip Bay and Spencers Gulf, with very limited fishing carried out offshore. By comparison, embayments along the east coast such as Moreton Bay produce only a very minor proportion of the total catch, with the bulk of the catch coming from offshore waters. The observed strength of some year classes in inshore catches of more southerly locations is consistent with either very strong year classes resulting from years of good recruitment (as is the case for New Zealand). Alternatively, the populations in the southern part of Australia may only be lightly exploited due to the majority of the population being relatively inaccessible to the fishery for most of the year which they may spend in offshore waters where fishing effort is limited. The composition of the fishery in Shark Bay, Western Australia, is more similar to that on the East Coast, in that there are relatively few (3-5) year classes in the fishery. There, however, the recruiting year class is age 5.

The importance of embayments such as Moreton Bay in contributing recruits to the offshore fishery is still not well established. Juveniles inhabiting Moreton Bay are not genetically isolated from the offshore populations, however their contribution to offshore populations remains poorly understood. Recent tagging studies conducted by members of the Australian National Sportsfishing Association have found a very small proportion of fish which are tagged within Moreton Bay are recaptured offshore which suggests that the contribution of inshore recruits may be low. Despite this, there are relatively few juveniles which are found in offshore waters of northern NSW in particular.

RECOMMENDATIONS

That future management arrangements for the snapper fishery recognise that the east coast snapper population as a unit stock.

This has implications for any changes to management regimes that are considered in either Queensland or New South Wales. It needs to be recognised that unilateral decisions made by either state may have an impact on the fishery in the other state.

That consideration be given to increasing the minimum legal length of snapper.

We have presented evidence which shows that, from the perspective of increasing yield in the fishery, the minimum legal size can be increased substantially, however social and other issues would also have an influence on determining the magnitude of the increase. The timing of possible changes with respect to the seasonal nature of the fishery should also be considered.

That future monitoring take into account spatial differences in the structure of the fishery, including catches by both the recreational and commercial sectors.

Whilst snapper are a single stock on the east coast we have demonstrated localised differences in size and age structure. These differences necessitate that any future monitoring is undertaken on a broad spatial scale and can account for regional differences in the fishery. It is important to note that any changes in recreational bag limits will have different implications in different regions because of the variation in the proportion of the catch taken by recreational fishers.

That programs be developed to increase public education and fisheries regulation compliance.

The high proportion of undersized fish in recreational catches needs to be addressed if changes to management arrangements are to have an impact on the resource. It is pointless to impose size limits if compliance with those limits is low.

That consideration be given to identifying inshore areas to be protected.

Our recreational surveys have shown a large proportion of small fish which are either retained or caught and released by recreational anglers from inshore waters. Any increase in the minimum legal size could further increase the proportion of undersized fish which are taken from these areas. Consideration should be given to identifying these areas with a view to restricting fishing as a means of increasing compliance with size limits.

That recreational bag limits in Queensland be reduced.

Given that the east coast stock of snapper is perhaps the most heavily exploited snapper stock in Australia and also the one where the ratio of recreational to commercial landings is the largest it is recommended that steps are taken to reduce the gap between potential and realised recreational catch. Results presented in Chapter 10 have shown that recreational bag limits could be substantially reduced without affecting the vast majority of recreational anglers.

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New South Wales

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BENEFITS

The main beneficiaries of this study will be recreational and commercial fishers in Queensland and New South Wales. The recreational effort and harvest data add to those already collected in NSW under a separate project (FRDC 94/053) and are particularly relevant to resource managers who are currently reviewing recreational bag limits as well as size limits.

INTELLECTUAL PROPERTY

No patentable inventions or processes have been developed as part of this project. All results will be published in relevant scientific articles and other public domain literature.

FURTHER DEVELOPMENT

The project has highlighted a general lack of ageing precision at the northern extremes of the species distribution. The original spatial and temporal sampling design was intended to enable the collection of representative catch size and age structures which could be used in the production of age structured models such as VPA's. The general lack of ageing precision now limits the value of these data for such purposes. The large variation in mean size at age also highlights the lack of precision that would accompany the application of age length keys to catch data at the northern extremes of the species distribution. A more precise estimate of catch age structure could be obtained by randomly sampling otoliths from the catch directly. The generally small scale, diverse nature of the commercial fishery as well as the variation in the size of fish caught by line fishers causes difficulties in utilising such an approach.

Recreational survey information has only been presented here for snapper, however, considerable information has also been collected on a range of other offshore recreational species. This information will be made available to the appropriate management agencies in the future. In addition commercial catch information has been collected on other offshore species including Pearl Perch and teraglin jew fish, since they often formed a significant part of the catch of both sectors. This information will be available once it has been analysed.

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