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Fisheries biology and interaction in the northern Australian small mackerel fishery

Final report to the Fisheries Research and Development Corporation

Projects 92/144 & 92/144.02

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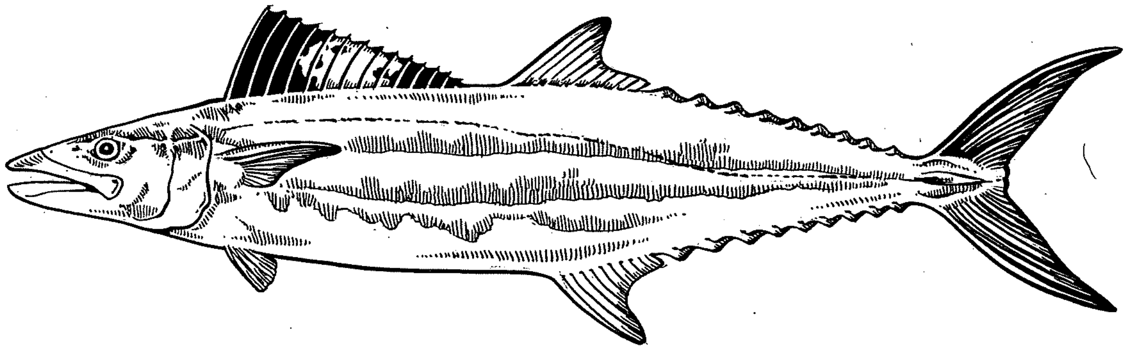
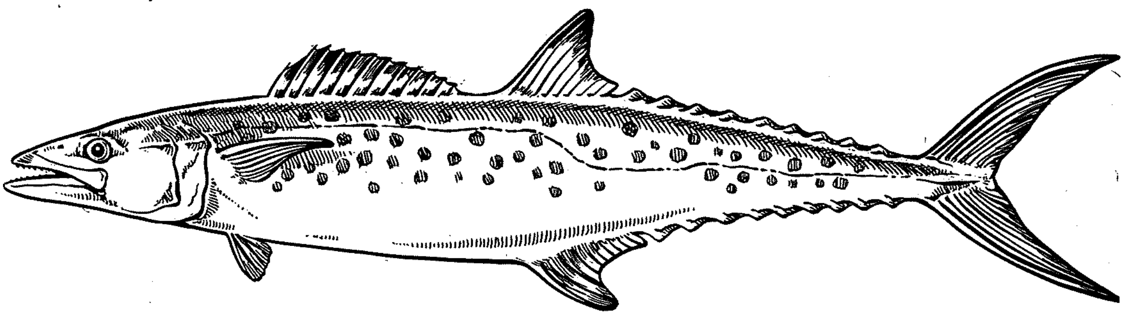
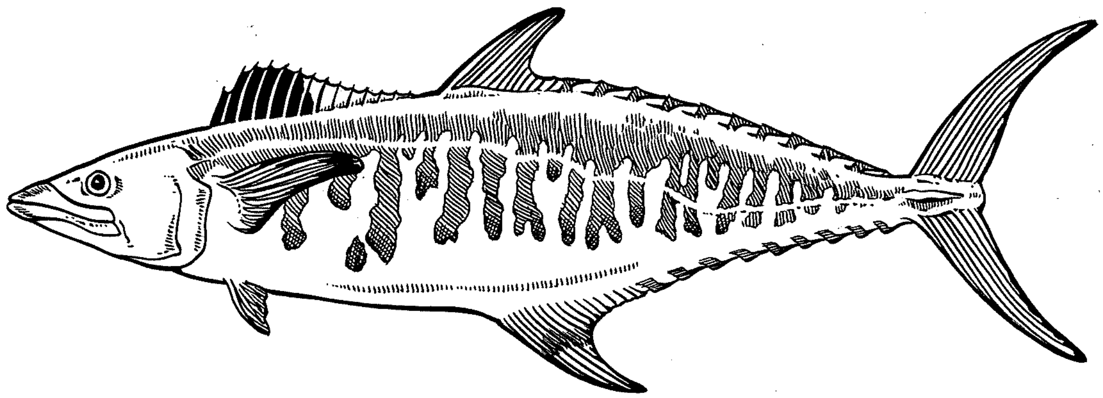
Northern Australian Small Mackerel Species



School Mackerel (*Scomberomorus queenslandicus*)

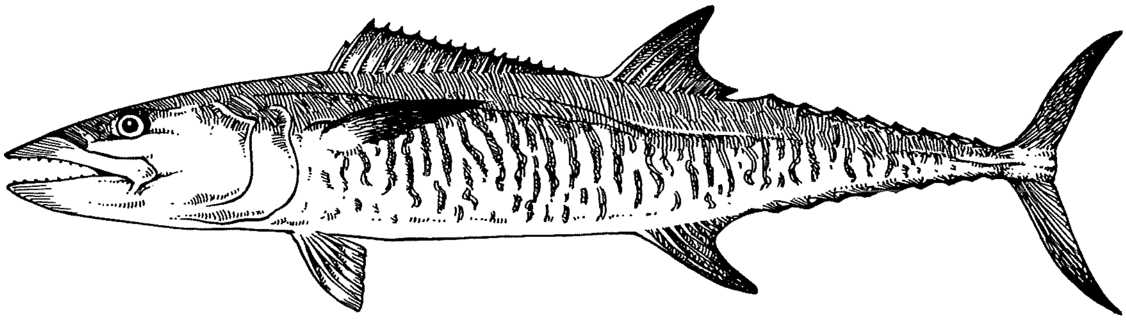


Spotted Mackerel (*Scomberomorus munroi*)

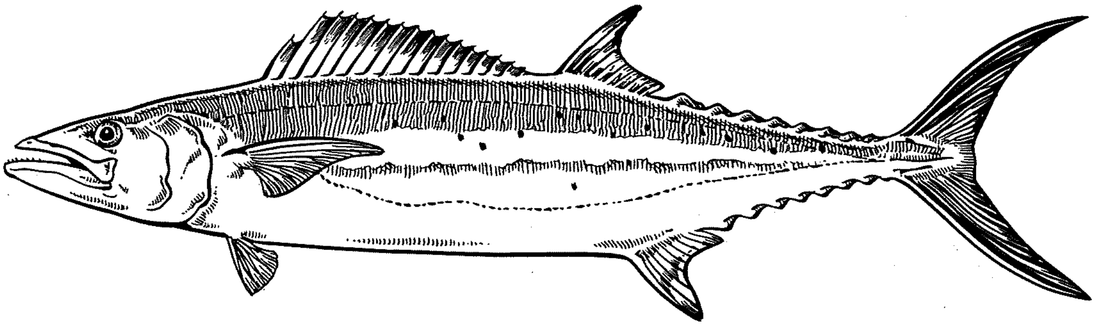


Grey or Broad-barred Mackerel (*Scomberomorus semifasciatus*)

Additional Northern Australian Mackerel Species



Narrow-barred Spanish Mackerel (*Scomberomorus commerson)*



Shark or Salmon Mackerel (*Grammatorcynus bicarinatus*)

(Drawings courtesy of Department of Primary Industries Queensland Fisheries Service and Food and Agricultural Organisation of the United Nations FAO Species Catalogue Vol. 2 Scombrids of the World)

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OBJECTIVES:

The original project tested the following hypotheses:

1. That the Australian Spanish mackerel resource, comprising four main species of the genus *Scomberomorus*, is exploited recreationally and commercially in three distinct areas of tropical Australia, in each of which the population of each species is an autonomous unit stock.
2. That the species composition of the resource is the same in the three areas.
3. That the three unit stocks of each of the three smaller species (school mackerel, *S. queenslandicus* spotted mackerel, *S. munroi* and grey mackerel, *S. semifasciatus*), do not differ as to growth rate, reproductive potential or survival rate under average environmental conditions, nor, in consequence, in composition as to sex, age and size.
4. That results obtained from "Deuel" surveys will be a sufficient basis for allocation of fishery access between commercial and recreational fishers.
5. That the "Deuel" special survey method can yield a reliable estimate of the amount of fishing for the small mackerels by commercial and recreational fishers in remote regions of northern Australia.

An extension to the project aimed to determine:

1. The rate of gill net drop out in the commercial spotted mackerel ring net fishery.
2. If the rate of gill net drop out varied with respect to fish length, mesh size or location fished.

1. NON-TECHNICAL SUMMARY

The small mackerels comprising school mackerel (*Scomberomorus queenslandicus)*, spotted mackerel (*S. munroi)* and grey mackerel (*S. semifasciatus*) are important and valued species to recreational and commercial fishers in northern Australia. Prior to this project very little was known about the basic biology of, or fisheries for, small mackerels. Each species was found to exhibit distinct life history patterns with differing stock structures. Though there is some overlap between fisheries, there was much spatial and temporal separation of the fisheries, with gill net specialisation for each species targeted by the commercial fishery. Recreational hook and line fisheries for school mackerel and spotted mackerel were important with most of the grey mackerel harvest taken by the commercial sector.

Age and growth of school mackerel and spotted mackerel in Queensland east-coast waters, and grey mackerel throughout northern Australian waters were determined to provide population parameters for future stock assessment. Each species grows quickly for the first three years of life and recruits to the respective fisheries by one or two years of age. Considerable variation in length was observed for any given age and sex of each species. Female school mackerel grow to a greater asymptotic length, but at a slower rate, than males. The growth of school mackerel differed between geographic regions and suggested the existence of separate stocks throughout the east-coast distribution. In contrast, female spotted mackerel reached a greater asymptotic length at a faster rate than males. There is no difference in growth between spotted mackerel from different regions, suggesting that there is a single stock along the Queensland east coast. The growth of grey mackerel is consistent between regions with males growing faster and attaining a smaller asymptotic length than females. Of the three species of small mackerel, grey mackerel grow to the largest size, followed by spotted mackerel; school mackerel are the smallest.

Spatial and temporal spawning patterns of school mackerel and spotted mackerel in Queensland east-coast waters and grey mackerel throughout northern Australian waters were varied. School mackerel spawned along the Queensland coastline from October to January. Female school mackerel were sexually mature between 401 and 450 mm, and males between 351 and 400 mm LCF (length to caudal fork). In contrast, spotted mackerel spawned in northern Queensland waters from August to October. Females of this species attain sexual maturity between 451 and 500 mm and males between 401 and 450 mm LCF. Grey mackerel spawned throughout their entire northern Australian range between September and January. Grey mackerel attain sexual maturity between 651 and 700 mm and males between 551 and 600 mm LCF. Each species is dioecious with no evidence of any sex changes.

In tagging studies of school and spotted mackerel on the east coast of Australia, recapture rates of 2.1% and 1.8% respectively were achieved. School mackerel moved small distances from their release sites (26 ± 55 km, mean ± s.d.; maximum distance, 270 km), with these restricted movements supporting the hypothesis for existence of a number of stocks. In contrast, spotted mackerel moved large distances from their release sites (202 ± 290 km; maximum distance, 1110 km). Temporal and spatial movement patterns of spotted mackerel are characteristic of fish from a single stock undertaking a seasonal migration. Commercial harvest information in combination with tagging effort reflected the different movements of school and spotted mackerel and strengthened the suggested stock structure of these species.

Insufficient numbers of grey mackerel were tagged or recaptured to provide any useful information on movement.

Age-related differences in trace element concentrations indicated that spatial differences between individual mackerel may be the result of environmental influences throughout their life history. Variation in the chemical composition of trace elements deposited in whole otoliths supports the hypothesis of stock structure developed from ageing and movement studies. These analyses identified groupings of at least two stocks of school mackerel and a single stock of spotted mackerel on the eastern Australian coast, although our results showed that the most informative comparisons were made among fish of the same year class. Analysis of pooled grey mackerel otolith elemental composition did not allow discrimination of fish between Queensland east coast, Gulf of Carpentaria or Northern Territory waters. Interpretation of the progressive overlap in trace element samples from the east coast of Queensland was also inconclusive. The importance of incorporating year classes into analyses of otolith trace element work was clearly demonstrated by work on east coast grey mackerel. Although there was some overlap, fish of different ages from Mackay exhibited different otolith elemental compositions. Otolith trace element analyses offered no indication of differences between grey mackerel from the Gulf of Carpentaria and Northern Territory waters. These analyses corroborated the evidence for school mackerel and spotted mackerel stock structure derived from ageing, reproductive and tagging studies.

Genetic variation in specific enzymes enabled the discrimination of school, spotted and grey mackerel stocks throughout northern Australian waters. School mackerel appeared to comprise a number of geographically isolated breeding populations, each being associated with a distinct portion of coastline or possible water circulation pattern. In contrast, spotted mackerel south of Cairns, form a single eastern Australian stock that is genetically discrete from a Northern Territory stock. There was little genetic variation found in specific enzymes of grey mackerel although it must be stressed that only four polymorphic loci were able to be used. In each species the largest genetic differences were found between the Queensland east coast and Arafura Sea/Gulf of Carpentaria populations. The genetic data provide additional support for stock structure hypotheses resulting from ageing, reproductive, tagging and otolith elemental chemistry work.

Commercial fisheries for small mackerel species are seasonal and generally use gill or mesh nets. The mesh size, length and configuration of net, and manner in which nets are used varies considerably depending on the location of the fishery and the species of mackerel targeted. The relative magnitude and species composition of the commercial small mackerel harvest also varies considerably between states and the Northern Territory. In the five years since 1996 there have been dramatic increases and decreases in commercial effort and harvest for small mackerel species.

Prior to this study, gill net drop out in the commercial spotted mackerel ring net fishery on the east coast of Queensland was perceived by opponents of mackerel netting to be a major problem. Gill net drop out is the non-capture mortality of fish owing to the effects of gill netting. Investigations using a underwater video camera, diver observations, and trawling of the seabed at three fishing locations provided no evidence that gill net drop out in this fishery occurred. Selectivity curves and length measurements of spotted mackerel captured in 9.5, 10.2, and 12.7 cm mesh nets commonly used in Queensland fisheries demonstrated it was unlikely that many fish less than the current minimum total legal length of 500 mm (422 mm fork length) would be retained in these sized mesh nets. The optimum selection length for each mesh size was also greater than the length at first maturity for either gender of spotted mackerel. However, it is likely some female spotted mackerel smaller than the length at first maturity will be captured in the 9.5 cm mesh. The use of 9.5 cm mesh to target spotted mackerel should be reviewed in consultation with commercial fishers. At Bowen, the 12.7 cm mesh is greater than the optimum for the efficient capture of spotted mackerel. Most fishers in this region choose to harvest spotted mackerel with this larger mesh as they rightly believe that it avoids the capture of substantial quantities of small mackerel that would otherwise be captured in smaller meshes.

In Queensland, small mackerel are essentially targeted or captured by recreational anglers using boats. In the 12 months prior to the 1994 telephone and mail survey, it was estimated that in excess of 70 000 recreational boats were used for fishing in Queensland and of these, 20 500 captured small mackerel. Most fishers who captured small mackerel actually targeted them, however an estimated 5000 recreational boat owners captured small mackerel but did not target them. The importance of small mackerel to recreational fishers is clearly demonstrated where 8.4% of the annual estimated 1.4 million recreational boat days of fishing effort are targeted towards small mackerel. A recreational fishing diary exercise estimated the annual recreational harvest of resident fishers in Queensland in 1995 to be about 70t of spotted mackerel, 43t of school mackerel and 12t of grey mackerel. The quantity of small mackerel captured and released by recreational fishers was also large and if mortality of such fish was significant recreational harvest estimates would be increased. A survey of interstate visitors to northern Queensland caravan parks also indicated that small mackerel, particularly spotted mackerel, comprise a large part of interstate visitors' fish harvest. Monitoring and analyses of the activities of charter fishing vessels and on-site surveys of interstate visitors are required to provide more precise estimates of recreational small mackerel effort and harvest.

Comparison of the Queensland state-wide recreational harvest estimates with the Queensland commercial harvest for each small mackerel species during the same year-long period demonstrated the different utilisation of each species by the different sectors. School mackerel appeared to be harvested in a similar amount by each sector while the recreational sector harvested only about 50% of the spotted mackerel that the commercial fishery did. The grey mackerel fishery is essentially a commercial fishery with the recreational sector harvesting less than 5% of the overall estimated harvest of the species.

In northern Australian waters since the mid 1990s, there has been a dramatic increase in commercial fishing effort targeting small mackerel species to satisfy expanding export markets. This expansion is particularly noticeable for commercial fisheries targeting spotted mackerel in east coast waters of Australia and grey mackerel in the Gulf of Carpentaria. In Queensland, under existing management arrangements, there is also the enormous potential (particularly in east coast waters) for additional licenced commercial fishers who have not previously harvested small mackerel, to target small mackerel species in the future.

Recommendations

- **Small mackerel species should be managed with utmost caution until detailed stock assessments are undertaken.**
- School, spotted and grey mackerel are considered as separate species for management purposes;
- The respective stock structures of school, spotted and grey mackerel should be integral in considering management arrangements for each species;
- The current minimum legal length of 50 cm for school, spotted and grey mackerel in Queensland should be maintained (biological information supports an increase in the minimum legal length of both spotted and grey mackerel if problems in species identification, release mortality and gear selectivity are discounted);
- The use of gill nets with a stretch mesh of 95.2 mm (3.75 inches) or smaller by the commercial fishery to target spotted mackerel should be prohibited as some fish smaller than the length at first maturity will be captured in such nets.
- Consideration be given to the prohibition of the use of gill nets with a stretch mesh smaller than 127 mm (5 inches) to target spotted mackerel in the Bowen region. Setting this mesh size as the minimum used to target spotted mackerel at other locations should also be considered.
- Consideration be given to the usefulness of the current recreational bag limit of 30 small mackerel per person in Queensland as it is inadequate to have any effect on the harvest in the recreational fishery and does not reflect the social and economic importance of the species to the recreational fishing sector.
- Implement suggested improvements to the Queensland Commercial Logbook (QFISH) Program as data is inadequate to monitor status of mackerel stocks and dependent fisheries;
- Access point and on-site surveys investigating recreational harvest and effort for small mackerel species should be designed and undertaken to validate and compare recreational harvest estimates obtained in this study and RFISH surveys; and
- Develop a reliable estimator of stock abundance for each small mackerel species after the recommendations pertaining to commercial and recreational fisheries harvest data are adopted.

2. ORIGINAL APPLICATION

2.1. Background and Need

School mackerel (*Scomberomorus queenslandicus)*, spotted mackerel (*S. munroi)* and grey mackerel (*S. semifasciatus*) (Munro 1943; Collette and Russo 1980, 1984; Collette and Nauen 1983), collectively known as small mackerel, together with narrow-barred Spanish mackerel (*S. commerson*), form important commercial and recreational fisheries in Queensland, the Northern Territory, Western Australia, and to a lesser extent northern New South Wales. Information is available for the commercial mackerel fisheries in Queensland (QFISH Commercial Fisheries Database) and the Northern Territory (Commercial Fisheries Logbook System). Although, this data is probably accurate for narrow-barred Spanish mackerel which are easily distinguished, it is less so for the small mackerels. Commercial catch composition by species is thus limited, while the extent and magnitude of the recreational fisheries are unknown.

Narrow-barred Spanish mackerel are the predominant target species in Queensland's northern commercial mackerel fisheries. Log books from recreational angling clubs indicate that narrow-barred Spanish mackerel are also the main pelagic species taken by these club fishers north of Innisfail. South of Innisfail the small mackerels make a significant contribution to both commercial and recreational fisheries. Given the perceived heavy fishing pressure which is currently directed at many near-reef species in north Queensland, it is not difficult to anticipate that there will be increasing use of the small mackerel resources. Likewise, at the time of writing this application in the early 1990s, in the Northern Territory and Western Australia, the small mackerels are not heavily fished at present, but increased fishing pressure is anticipated.

Developing conflict between the fishing sectors over access to the small mackerel resource in Queensland waters initiated this study. Commercial fishing operations, particularly those targeting spotted mackerel, were traditionally based upon rudimentary trolling and seine netting techniques. These operations have been transformed through the use of monofilament ring nets. Most recreational fishers and some commercial fishers assert that this technique is wasteful, leading to a high non-capture mortality, disruption of migration patterns, and has resulted in the depletion of spawning aggregations and recruitment of spotted mackerel. Set netting for school and grey mackerel species has been subject to similar criticism. Recreational fishers who take small mackerel from headlands, coastal bays and inshore reefs have been reported to take a substantial catch of juvenile fish. A major concern is the overlap in activities of the two sectors, with commercial fishers encircling aggregations of spotted mackerel concurrently targeted by recreational anglers.

In the Northern Territory, the principal commercial fishing technique is by trolling from small dories, where at present there appears to be little conflict with recreational anglers. However, the high-speed monofilament ring-net technique or multiple fishing vessel methods used in Queensland are under active consideration by commercial fishers in the Northern Territory. It is also likely that numbers of recreational fishers will continue to increase, particularly in Queensland, and that technological advances will improve the efficiency of commercial fishing techniques. Management of the fishery devolves to questions of conservation and those of allocation. This proposal, thus, addresses the need for biological knowledge that is sufficient for effective management and seeks to provide data which will be used to allocate the small mackerel resource between competing user groups.

The biology and fishery for narrow barred Spanish mackerel is well known (McPherson 1978, 1981, 1982, 1985a, 1985b, 1986, 1987, 1992, 1993), but published studies which include comparable data for the small mackerel species were not available. There are no data describing species composition; seasonal occurrence and distribution of spawning activity; size and sex composition; stock structure; extent, seasonal occurrence and duration of migrations; and other biological information for small mackerel species. Landings information needs to be collated and trends in these data examined. Estimates of gill net dropout and subsequent mortality have been perceived to be high and need to be substantiated if estimates of fishing mortality are to be considered in any management policies.

Resource allocation issues are significant in the small mackerel fishery which supports a significant component of Queensland's domestic "fresh fish" sales. Restriction of commercial fisheries would have a major impact on this market. Recreational fishing is a major activity in Queensland and in the Northern Territory with mackerel being a popular target species. Recent management measures for both sectors have included minimum size limits and recreational bag limits, together with restriction on commercial activities, which have been based on limited research. Much of the debate between user groups has arisen because of the lack of biological information and disagreement over the comparative harvest of the two sectors. Unsubstantiated claim and counter-claim have fuelled the debate in Queensland and the Northern Territory. Any management measures are unlikely to be successful without basic biological information, since fishers in both sectors will have little commitment to measures seen purely in terms of political expediency. The thrust of this proposal, therefore, is to examine the recreational-commercial interface of a highly mobile pelagic resource in an area of Australia, that is logistically difficult to investigate.

2.2. Objectives

This project tested the following hypotheses:

1. That the Australian Spanish mackerel resource, comprising four main species of the genus *Scomberomorus*, is exploited recreationally and commercially in three distinct areas of tropical Australia, in each of which the population of each species is an autonomous unit stock.

2. That the species composition of the resource is the same in the three areas.

3. That the three unit stocks of each of the three smaller species (school mackerel, *S. queenslandicus* spotted mackerel, *S. munroi* and grey mackerel, *Scomberomorus semifasciatus*), do not differ as to growth rate, reproductive potential or survival rate under average environmental conditions, nor, in consequence, in composition as to sex, age and size.

4. That results obtained from "Deuel" surveys (Deuel 1980) will be a sufficient basis for allocation of fishery access between commercial and recreational fishers.

5. That the "Deuel" special survey method can yield a reliable estimate of the amount of fishing for the small mackerels by commercial and recreational fishers in remote regions of northern Australia.

The importance of small mackerel species to indigenous fishers and Traditional Owners is unknown and was not investigated during this study.

2.3. Alterations to Original Application

Changes in Queensland Government policy, increased personal liaison with fisheries personnel in other states, the development of new stock identification tools, concerns over non-capture mortality by gill nets and difficulties in interpretation of the original research project objectives which were not written by the principle investigators, neccessitated the alteration and addition of several new components to the original project.

The first objective of the original research project focused on investigations of the stock structure of four main species of Australian Spanish mackerel, including the narrow-barred Spanish mackerel (*Scomberomorus commerson*). The project did not have adequate resources to investigate the stock structure of narrow-barred Spanish mackerel and stock structure work focused on the three smaller species of mackerel only.

In the original methods it was intended that research results be presented to "panels of expertise" formed upon completion of a major telephone survey of recreational fishers in Queensland. In 1995 the Queensland Fisheries Management Authority (QFMA) formed Management Advisory Committees (MACs) and Zonal Advisory Committees (ZACs). The committees were formed on the recommendation of the 1992 State Government Inquiry into Recreational Fishing and comprised recreational and commercial fishers, government and industry representatives and other stakeholders with fisheries interests. The principal investigators believed the formation of "panels of expertise" to discuss fisheries issues in addition to MACs and ZACs would only confuse the general public and be a duplication of organisational structure. After support was obtained from the QFMA, Queensland Commercial Fishermen's Organisation (QCFO) (now Queensland Seafood Industry Associations) and the Queensland peak recreational fishing industry representative body (SUNFISH, permission to substitute the proposed " panels of expertise" with the MACs and ZACs was obtained from the Fisheries Research and Development Corporation (FRDC). Details of the MAC and ZAC meetings addressed by the principal investigators are in Section 6.4. of this report.

After completion of the major telephone survey of recreational fishers in Queensland, alternative, additional methods to estimate recreational harvest were required to satisfy industry representative bodies. There was also a need to investigate the fisheries for small mackerel by interstate visitors who were not contacted in the initial telephone survey. The FRDC agreed that funds saved from the cancellation of "panels of expertise" could be used to conduct a recreational fishing diary exercise and an investigation of the fishing activities of interstate fishers.

The fourth and fifth objectives of the the original research project focused on the "Deuel" survey technique that essentially stressed the use of the most suitable and appropriate sample frame was necessary to conduct robust surveys. The various surveys conducted as part of this project have assisted in obtaining recreational harvest and effort estimates for mackerel species. The results have assisted in discussions about allocation of fishery access between recreational and commercial fishers but will not form the sole basis for such allocation.

In the early stages of the project, the discrimination of stocks of small mackerel species in northern Australia was reiterated as a high research priority by fisheries managers, scientists, and commercial and recreational fishers. Published literature and liaison with fellow scientists at the Australian Institute of Marine Science (AIMS) indicated otolith chemistry techniques may provide an additional inexpensive tool for discrimination of small mackerel stocks. In conjunction with AIMS, otolith chemistry techniques were used to supplement genetic and tagging procedures as discriminators of stock structure.

Commercial mackerel harvest information was made available by fisheries agencies in Western Australia, Northern Territory, and New South Wales. A comparison of the commercial *Scomberomorus* catches throughout each state was included. During the initial stages of the research project there were varied reports on the magnitude and descriptions of operations of commercial ring net fishers targeting spotted mackerel. A small survey of fishers participating in this fishery in Queensland was subsequently undertaken.

Some recreational fishers expressed concern throughout the research project that gill net drop out of small mackerel, particularly spotted mackerel, was a major problem. In the original project there was inadequate funds to investigate this phenomenon. The principal investigators were concerned the project would be perceived to be incomplete if an investigation of gill net drop out was not undertaken. Consequently, in 1995, additional funds to investigate gill net drop out and gill-net selectivity were approved by the FRDC.

2.4. Study Areas

Small mackerel samples were collected from commercial net fishers and recreational anglers throughout northern Australia, with particular emphasis on the Queensland east coast. Ageing, reproductive, and movement data were collected from the Queensland east coast south of Innisfail, and northern New South Wales waters. The east coast was subdivided into northern, central and southern regions for most analyses (Figure 2.4.1.). Otolith chemistry, electrophoretic and commercial catch data was collected from the Queensland east coast, the Gulf of Carpentaria, the Northern Territory and Western Australian waters. Recreational fisheries data were collected for all regions on the east coast of Queensland.

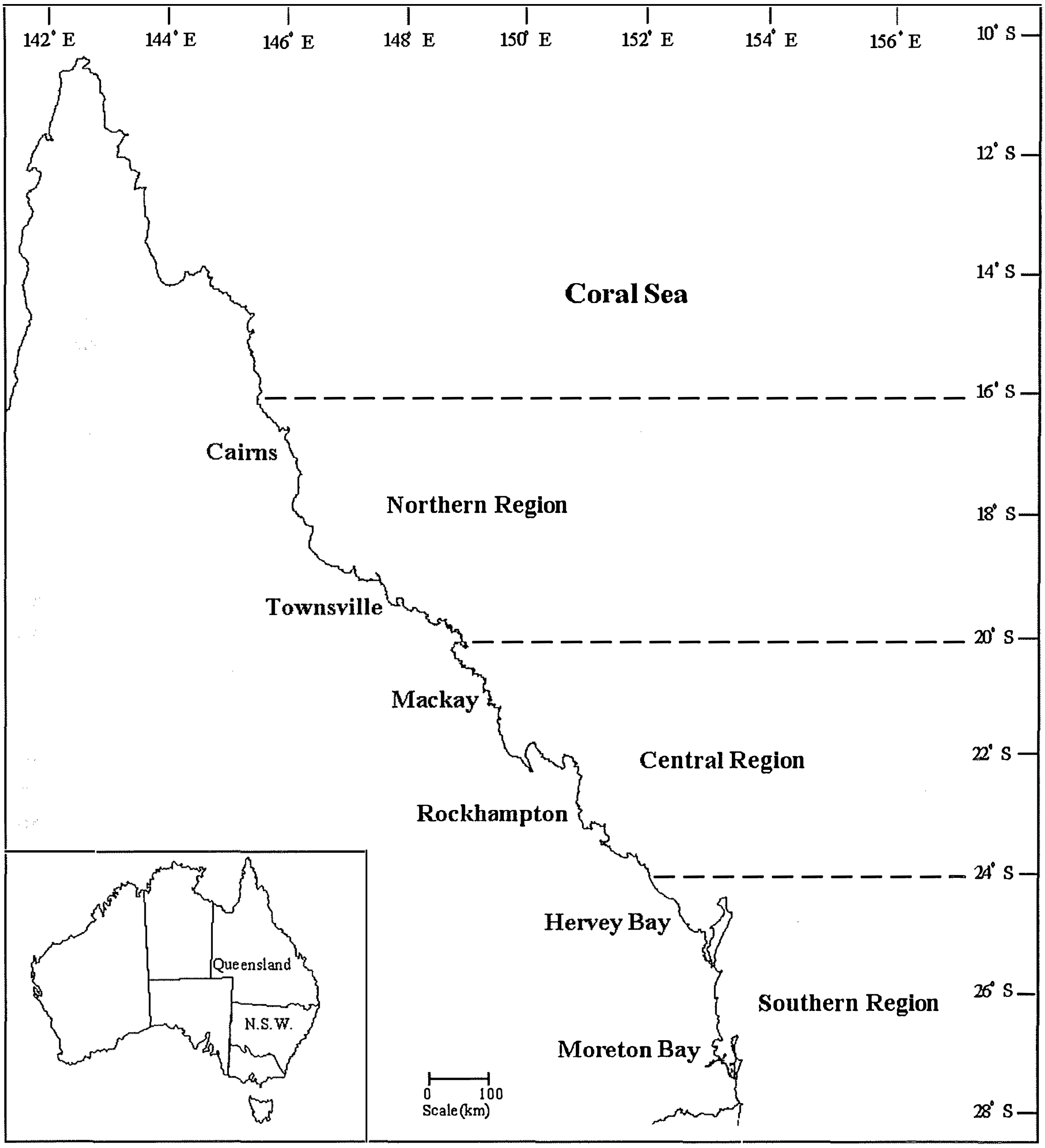


Figure 2.4.1. Mackerel sampling areas along the Australian east coast.

3. BIOLOGY AND STOCK DISCRIMINATION

3.1. Materials and Methods

3.1.1. Age, Growth and Mortality

3.1.1.1. Introduction

Scomberomorus species have almost exclusively been aged using otoliths (Beaumariage 1973; Sturm 1978; Johnson *et al.* 1983; Fable *et al.* 1987b; Manooch *et al.* 1987; Collins *et al.* 1989; De Vries *et al.* 1990; Sturm and Salter 1990; McPherson 1992; Hamasaki 1993). Whole and sectioned otoliths were also used as the ageing structures for this study owing to their permanency, continual growth pattern, and availability. In Australia ageing studies of *Scomberomorus* species have been limited to narrow-barred Spanish mackerel, where McPherson (1992) examined the age and growth rates of east coast and northern Australian stocks using whole otoliths. No attempts have been made to determine the age or growth characteristics of other *Scomberomorus* species in Australia. This component of the study aimed to examine the age structure, growth characteristics and survival rates of school, spotted and grey mackerel in northern Australian waters. Spatial patterns in growth rates within each species were assessed to investigate evidence of stock structure.

3.1.1.2. Ageing

Mackerel samples were collected from commercial and recreational fishers between 1992 and 1995 (Appendix 1.). Specimens were placed on ice as soon as practical after capture and then frozen until needed for laboratory analyses. Fish were measured (fork length, mm), weighed (wet weight, g) and sex determined by macroscopic examination of the gonads. Sagittal otolith pairs were accessed by a horizontal incision that exposed the brain cavity. The otoliths were removed, washed, dried and weighed.

Whole otoliths were examined in vegetable oil on a blackened background and illuminated by reflected light. A dissecting microscope (12.5x magnification) was used to observe the banding pattern in whole individual otoliths. Otoliths were classified into age groups based on the number of opaque nonmarginal bands. A band was considered complete when a translucent zone was visible outside its distal edge. Up to 20 otoliths from each age class were sectioned transversely. Whole otoliths were mounted in resin and a thin section (0.3 mm) was cut through the focus using a diamond edged circular saw. The section was then mounted on a glass slide for microscopic examination. Two readers independently aged the whole otoliths to maintain objectivity. Any otoliths that varied between readers were excluded from the analyses.

Otolith radii and annuli were measured on the concave posterior surface from the focus to the distal edge. Relationships between fish length and otolith radii enabled back-calculated lengths at age to be established. Distances from the focus to the otolith edge, from the focus to the distal edge of each band, and from the distal edge of the last band to the otolith edge were measured using a computer optical imagery system (OPTIMAS^{TM}). Only one otolith from each fish was used for annulus measurements. Annulus measurements for back-calculation purposes were restricted to age class five for school and spotted mackerel and age class seven for grey mackerel.

3.1.1.3. Data Analysis

Ageing agreement between readers was calculated for whole otoliths. There was a high degree of conformity in assigned ages between whole and sectioned otoliths and it was determined whole otoliths would be used for ageing work. Assumptions concerning annulus formation were validated by marginal increment analysis. Monthly marginal increments were plotted for the first four age classes for school mackerel, the first age class for spotted mackerel and the first four age classes for grey mackerel. The ability for assessment of age classes for marginal increment analyses for each species of small mackerel varied depending on whether the final annulus extended to the edge of the otolith. One-way fixed effects analysis of variance (ANOVA) were used to compare monthly means for each age class to discern any pattern in annulus formation. Tukey's studentized range (HSD) test was used for *a posteriori* comparisons.

Tag-recapture methods in association with oxytetraycline injections were also attempted as a means of age validation for school and spotted mackerel. These methods were unsuccessful owing to the low recapture rates for both species and the insufficient time at liberty for recaptured fish to observe any substantial growth.

Otolith radii were related to fish length by regression analysis. Raw otolith radii data was $\log_e$ transformed to standardise residuals and linearise power relationships. Linear regressions were used to determine the relationships between $\log_e$ transformed otolith radius and fork length. Sex (within species) otolith radius and fork length relationships were compared using analysis of covariance (ANCOVA). Mean lengths at earlier ages were back-calculated from otolith measurements using the relevant sex specific regression relationship.

Fork length-total length, and fork length-weight relationships were estimated for individual species and sexes by regression analysis. Linear, quadratic and cubic polynomial regressions were performed to determine the appropriate model. Raw weight data was $\log_e$ transformed to standardise the residuals. Each sex (within species) was compared by ANCOVA. Data was pooled across regions for all these analyses.

Growth estimates were calculated for the von Bertalanffy growth curve, $L_t=L_\infty(1-e^{-K(t-t0)})$, using length-at-age data and mean back-calculated lengths for each age class. Von Bertalanffy growth curve parameters (L_∞, K, t_0) were determined by Marquardt nonlinear iterative least squares regression analyses (SAS 1988). Initial growth parameter estimates needed for the models were calculated by Ford-Walford (1933, 1946) and von Bertalanffy (1938) linear regressions. Growth parameters were calculated for individual sexes and regions. Direct length-at-age growth curves were compared between sexes (within species) using likelihood ratio tests following Kimura (1980).

Individual otoliths were weighed and radii measured to assess the usefulness of otolith weight and length for determining age. Paired *t*-tests compared left and right otoliths from individual fish. There were no significant differences in weight observed between otoliths in school (t=-0.106, d.f.=915, N.S.) or spotted (t=-1.491, d.f.=1083, N.S.) mackerel; but there were differences in weight between otoliths in grey mackerel (t=-2.572, d.f.=915, P<.0103). Although statistically different, plots of the left and right otoliths of grey mackerel indicated they were not markedly different. An individual otolith, was randomly chosen from each pair for regression investigations of each species. Linear, quadratic and cubic regression analyses examined otolith weight and radius-age relationships for each sex (regions pooled). Otolith weight and radius were chosen as the independent variables as they were being examined for their suitability in predicting age. Sexes (within species) were compared by ANCOVA.

Instantaneous total mortality (Z = fishing and natural mortality) and recruitment estimates were obtained from linearised catch curve data (Ricker 1975). Plots of $\log_e$ (frequency) against age were examined using linear regression analyses to determine instantaneous mortality estimates (Z). Mortality estimates were calculated for different sexes, regions and gear types. All fishing gear types were selective and produced sample catch curves with inherent biases. The slope of the descending right limb of the catch curve was used to estimate mean instantaneous annual mortality rates, assuming constant recruitment and survival. Mortality estimates were based on completely recruited age fish and older. Recruitment was considered to occur for fish at the age class following those ages that comprised the ascending left limb and dome of the catch curve (Ricker 1975).

3.1.2. Reproduction

3.1.2.1. Introduction

Because *Scomberomorus* species are economically and socially important to commercial and recreational fishers their reproductive characteristics have been extensively documented. Spawning has been inferred from hatching experiments (Munro 1942), egg and larval surveys (Jenkins *et al.* 1985; Collins and Stender 1987; Grimes *et al.* 1990), gonad condition (Beaumariage 1973; Sturm 1978; Devaraj 1986; Finucane *et al.* 1986; Sturm and Salter 1990; McPherson 1991) and hormonal changes (MacGregor *et al.* 1981). Reproductive behaviour of narrow-barred Spanish mackerel in Australian waters has been researched (Munro 1942; Jenkins *et al.* 1985; McPherson 1993), but little is known about the reproductive characteristics of the small mackerel species. Okera (1982) observed maturing gonads in school mackerel from the Arafura Sea and the Gulf of Carpentaria during November and December. Tentative inferences could only be made from this study owing to the scarcity of samples and sampling periodicity. On the basis of occurrence of larvae, Jenkins *et al.* (1985) suggested school and grey mackerel spawn between October and February around Townsville and inferred repeated spawning patterns from the presence of small larvae and a wide range of larval sizes throughout the reproductive season of each species. This component of the study aimed to determine the reproductive characteristics of school, spotted and grey mackerel in Queensland east coast waters south of the Cairns region. Spatial and temporal reproductive profiles were examined to determine spawning patterns.

3.1.2.2. Reproductive Assessment

Mackerel samples were collected from commercial and recreational fishers between 1992 and 1995 (Appendix 1.). Specimens were kept on ice, then frozen until needed for laboratory analyses. All samples were obtained from the Queensland east coast, south of 16°S (Figure 2.4.1.). Fish were measured (fork length, mm), weighed (wet weight, g) and gonads extracted. Fish were sexed and maturity state assessed macroscopically. Reproductive staging schemes were developed from Yamamoto (1956), Moe (1969), Pollard (1972), Macer (1974), Coetzee (1983) and West (1990) (Tables 3.1.1. and 3.1.2.).

Table 3.1.1. Criteria used for assessing female macroscopic and histological reproductive development stages.

Reproductive Stage		**Macroscopic Characteristics**	**Histological Characteristics**
I	Immature	-ovary small -less 1/4 length of body cavity -translucent pink -no oocytes visible	-no evidence of prior spawning -ovary small in diameter -tunica tightly encases ovarian lamellae -small undeveloped oocytes embedded in ovigerous tissue, usually found along periphery of lamellae -oocytes with large nucleus and single nucleolus surrounded by thin layer of cytoplasm -cytoplasm densely staining basophilic with no vacuoles -no atresia evident
II	Recovering	-ovary more rounded -1/3 length of body cavity -opaque pink/red -no oocytes visible	-ovary that has undergone vitellogenesis and recovered into resting state -tunica thickened and distended -oocytes more rounded and larger -several nucleoli around nuclear periphery -cytoplasm more lightly stained -atretic bodies common in centre of lamellae
III	Developing	-ovary enlarged -opaque, orange appearance -oocytes visible as small dots	-ovary in active vitellogenesis -oocytes expand and become rotund -nucleus and cytoplasm become increasingly eosinophilic -appearance of cortical alveoli (appear empty with H&E stains), forming several peripheral rows in cytoplasm -chorion (zona radiata, vitelline membrane and zona granulosa) become evident -few atretic bodies present
IV	Mature	-ovaries fill most of body cavity -opaque, yellow -individual oocytes large and clearly visible	-cortical alveoli dominate, coalescing towards centre when nucleus migrates -acidophilic yolk globules replace cytoplasm -yolk globules fuse into acidophilic granular yolk mass -zona radiata present as thickened band
V	Ripe	-ovaries distend body cavity -translucent, pale orange -individual oocytes large and hydrated	-spawning imminent, leading to release of oocytes into ovarian lumen -oocyte nucleus migrates from centre to periphery and loses its integrity -rapid increase in size due to hydration of oocytes -follicle layer ruptured, zona radiata present as thin band
VI	Postspawning (spent)	-thin and flaccid -dark red, bloodshot -residual oocytes visible	-tunica stretched and flaccid -spaces in disorganised septa -ruptured empty follicles present in lumen -residual oocytes in various stages of atresia

Table 3.1.2. Criteria used for assessing male macroscopic and histological reproductive development stages.

Reproductive Stage		Macroscopic Characteristics	Histological Characteristics
I	Immature	-testes very small, thin and flattened -translucent grey	-testes appears as compact mass of dense connective tissue -spermatogonia are the dominant cells present, embedded in and along thickened lobule walls -spermatogonia are large, polyhedral cells with dark staining nuclei and prominent lightly staining cytoplasm -sperm duct not well formed and empty
II	Developing	-testes enlarged -creamy	-lobules become looser in structure lined with crypts of spermatogonia -spermatocytes proliferate throughout the testes, towards centre of lobule lumen after spermatogonia division -spermatocytes
III	Ripe	-testes fill most of body cavity -opaque and 'pure' white	-tunica stretched and thin -lobule walls distended -spermatozoa predominates, packing lobules and sperm ducts -crypts with all stages of cell development present around testes periphery
IV	Postspawning (spent)	-thin and flaccid -grey, brown with some white areas (residual sperm)	-tunica distended and flaccid -lobule walls loosely contracted and individual lobules well separated -crypts empty -testes dominated by stromal tissue portraying a 'weblike' appearance -residual spermatozoa present in lobules and sperm ducts -spermatogonia crypts beginning to form

Gonads were weighed and preserved in 10% buffered formalin. Gonadosomatic indices (G.S.I.) were determined for both sexes and calculated as follows (Cayré and Laloë 1986):

$$G.S.I.=(W_g/L^3) \times 10^8$$

where, W_g=total gonad weight (g), and L=fork length (mm).

Sections were taken from the anterior, middle and posterior regions of several randomly selected gonads for each species. Preserved tissue samples were dehydrated in an ethanol series, embedded in Paraplast (paraffin and plastic polymer media) and sectioned at 0.006 mm, or 0.010 mm for ripe staged fish. Samples were stained with Mayer's haematoxylin and eosin yellowish (Routine H&E). Specimens were examined microscopically and assigned a maturity stage. Maturation occurred simultaneously in the anterior, middle and posterior regions of the gonads. Remaining gonads therefore, were sectioned once, examined microscopically, and the maturity state was determined.

A subsample of ovaries from each length class was examined for 'total potential fecundity'. Fecundity estimates were calculated from mature gonads (stages IV and V) sampled throughout the peak spawning season of each species. These estimates did not consider the frequency of spawning that may occur. The diameters of 20 of the most advanced staged oocytes from each 'fecundity estimated ovary' were measured using OPTIMAS^{TM}, and mean oocyte diameters calculated for each gonad. Only the most advanced staged oocytes were measured as they were assumed to account for the majority of the gonad weight. Ovaries were removed from fixative, excess moisture removed and the gonad weighed. Three subsamples of oocytes were extracted and weighed. The total number of oocytes in each subsample was counted, means estimated and total potential fecundity (T.P.F.) calculated as follows (Morse 1980):

$$\text{T.P.F.} = (W/S) \times O$$

where, W=total weight of ovary, S=mean weight of subsamples from ovary, and O=mean number of oocytes counted in subsamples.

3.1.2.3. Data Analysis

Mean gonadosomatic indices (GSIs) were plotted for each state of maturity for both the macroscopic and histological staging schemes. A *6* x *6* and *4* x *4* *G*-test of independence examined the similarity of the staging schemes for females and males respectively. Cramer's coefficient (V) was calculated to measure the strength of each association between the individual staging schemes. This coefficient ranges from -1 to 1 (complete association) (Zar 1984).

School, spotted and grey mackerel from different coastal regions that were sampled in the same month and year were compared for gonadosomatic development. Where there was no significant difference between samples from different regions, samples were pooled within species, across regions for each month. Monthly samples were also compared for any year to year variation. ANOVA or unpaired *t*-tests were used depending on the number of samples to be compared. HSD was used for *a posteriori* comparisons. Monthly mean GSI's (regions and years pooled) for each sex were analysed to determine seasonal reproductive profiles. ANOVA compared monthly samples for each species. Unpaired *t*-tests compared sex (within species) for each month. HSD was used for *a posteriori* comparisons. Only fish that had attained sexual maturity (female histological stages II-VI and male II-IV) were used in the analyses. Spawning seasonality was also assessed by the monthly proportion of each histological development stage. In the parts of the southern hemisphere where this study was undertaken the months of December, January and February are considered as summer; March, April, May comprise autumn; June, July, August comprise winter; and September, October and November comprise spring.

Length at first maturity was estimated by two methods. Mean GSIs were calculated in each 50 mm length class for the species peak spawning months. Attainment of sexual maturity was assumed to occur when gonadosomatic increase was greatest between consecutive size classes. First maturity was also estimated by the smallest length category in which at least 50% of individuals were considered mature (female histological stages II-VI and male II-IV) throughout each species respective spawning season.

Sex ratios were calculated from samples of each length class and month. Individual length classes and months were analysed for variation from the expected 1:1 sex ratio using one dimensional Pearson's χ^2 goodness of fit tests, corrected for type I errors by Yate's correction factor.

The reproductive capacities of each species were examined to determine if peak GSIs during their respective spawning months were due to oocyte size or actual oocyte numbers. Relationships between mean oocyte diameters (obtained from mature female histological stages IV and V throughout the peak spawning months) and fork lengths were determined by linear regression. Regression analyses tested fecundity and length relationships. Fecundity was $\log_e$ transformed when the residual pattern suggested multiplicative errors.

3.1.3. Movements

3.1.3.1. Introduction

Evidence of stock differentiation can be indirectly obtained from tagging studies (Brown *et al.* 1987; Ihssen *et al.* 1981; Sutter *et al.* 1991). Recoveries through time give point locations of organisms from which their range and movements infer the degree of mixing between stocks (Ihssen *et al.* 1981). Collaborative tagging programs in which recreational anglers use tags and equipment supplied by government fisheries agencies have proven to be a cost effective method for studying fish populations that would otherwise be difficult or very expensive to study by conventional means (Saul and Holdsworth 1992). The infrastructure for a cooperative tagging program existed in the Australian National Sportfishing Association (ANSA) Queensland Sportfish Tagging Program (now SUNTAG) (Sawynok 1996). Subsequently, a collaborative tagging exercise with ANSA Queensland members targeting school, spotted and grey mackerel was initiated because of the existing infrastructure, economic and logistic constraints of undertaking research over a broad geographic area, and the enthusiasm and availability of experienced tagging anglers. Although the tag and release of several mackerel species is well documented (Moores *et al.* 1975; McPherson 1981; Fable *et al.* 1987a; Sutter *et al.* 1991), no information exists on the movements of school, spotted and grey mackerel. This component of the study, therefore, aimed to determine spatial and temporal movement patterns of small mackerel in Australian east coast waters by a collaborative tagging exercise. Movement patterns were used to discriminate stocks.

3.1.3.2. Tagging

Mackerel were tagged in Queensland and northern New South Wales waters (16°S to 30°S) in a collaborative exercise involving scientific researchers and ANSA members between 1992 and 1995. A total of 796 school and 229 spotted mackerel had been tagged by ANSA members from 1985 to 1991. These data were incorporated into the present study. Tagging efforts were concentrated in Moreton Bay and Hervey Bay, and in waters off Rockhampton, Mackay, Townsville and Cairns (Figure 2.4.1.). Mackerel were captured by anglers using hook and line. Captured fish were usually subdued by placing a moist cloth over their head and hooks removed. Fish were examined for any injuries that could affect their survival. Uninjured fish were measured (fork length), tagged and released. Tagged fish were usually returned to the water within 20 seconds. Date and location of each released fish were recorded. Fish were randomly selected for injection of oxytetracycline as a means of age validation. One or two yellow, nylon headed Hallprint^{TM} dart tags (102 mm long, 2 mm diameter) were inserted at an angle of approximately 45° into either side of the musculature, just below the second dorsal fin. Tags were usually locked behind the vertebral or basal fin spines. Individual tags were uniquely numbered and labelled with a 24-hour toll-free telephone number, details to be recorded by fisher and the word "Reward" to encourage the reporting of recapture information. The tagging program was publicised through posters, newspaper and magazine advertisements, television and radio, and verbal communications with fishers and processors. Rewards included certificates, hats and drink coolers.

3.1.3.3. Data Analysis

Tagging patterns were determined from log-linear models, where the effects of season and area were analysed to examine their dependence on tagging effort. Lengths of tagged fish were compared to lengths of recaptured fish when they were initially tagged using unpaired *t*-tests to determine if recaptured fish were representative of the total tagged population. Spatial variations in the lengths of tagged fish were compared for each species using ANOVA. HSD was used for *a posteriori* comparisons.

Distances moved by individual tagged fish were measured by the direct route between the release and recapture locations. Movement patterns were examined by plotting the distance and direction recaptured fish moved in conjunction with dates of release and recapture. Distances moved and times at liberty of recaptured fish for each species were examined. The relationship between lengths of recaptured fish when they were initially tagged and their time at liberty were examined for each species using Spearman rank correlation coefficients. Linear regressions were used to examine any significant correlation.

3.1.4. Otolith Chemistry

3.1.4.1. Introduction

Stock structure has been deduced from genetic (Ihssen *et al.* 1981; Ovenden 1990; Smith 1990; Smith *et al.* 1990), parasitic (Lester 1990), morphometric (Lindholm and Maxwell 1988) and tagging studies (Fable *et al.* 1987a; Sutter *et al.* 1991). However, no single method currently used for stock identification can reliably differentiate among all populations of any marine fish species (Edmonds *et al.* 1989; Campana and Gagné 1995). Consequently, there still remains a considerable degree of uncertainty concerning the stock structure of a species owing to a lack of a widely applicable and direct means of determining how far and in what directions larvae disperse (Thresher *et al.* 1994). In recent years this has led to the development of alternative techniques involving analysis of the chemical composition of calcified body parts. Chemical analysis of calcified structures such as otoliths, scales and vertebrae have been used successfully to identify fish stocks (Calaprice 1971; Lapi and Mulligan 1981; Mulligan *et al.* 1983; Mulligan *et al.* 1987; Edmonds *et al.* 1989; Edmonds *et al.* 1991; Campana *et al.* 1994; Thresher *et al.* 1994; Campana *et al.* 1995). This type of analysis assumes that geographically distinct stocks possess a characteristic elemental composition that reflects the chemical constituents of the environment in which fish reside (Lapi and Mulligan 1981). This component of the study aimed to determine the validity of elemental analysis of whole sagittal otoliths as a means of stock identification for school, spotted and grey mackerel in northern Australian waters.

3.1.4.2. Materials and Methods

Mackerel samples were collected from commercial and recreational fishers in the years and by methods previously described in the ageing and reproduction sections. Sagittal otolith pairs were accessed by a horizontal incision that exposed the brain cavity. The otoliths were removed, washed, dried and weighed. Ageing of otoliths followed methods previously described in the ageing sections.

A subsample of fish from a number of areas had the concentration of the chemical elements in their otoliths examined as a method for stock identification (Appendix 1.). Fish of the same age (two year old school mackerel; three year old spotted mackerel; two year old grey mackerel) were selected to minimise age-related variation between samples. Different aged fish to those from the Queensland east coast were examined from the Gulf of Carpentaria (Weipa) and Northern Territory (Gove; Joseph Bonaparte Gulf) waters. Different fishing and sampling methods in these locations could not provide fish of the same age. Additional samples of younger fish from Rockhampton (one year old school mackerel), Hervey Bay (one year old spotted mackerel) and Mackay (one year old grey mackerel) were examined to investigate the effects of age on the deposition of trace elements in whole otoliths.

Otoliths used in the analysis were cleansed of oil and organic residues by submersion in an ultra sonic bath of distilled water for up to five minutes. Otoliths were washed in distilled water, tissue dried and placed in an oven (60°C) for 15 hours. Individual left and right otoliths were reweighed and stored in sterile containers. Whole otoliths to be analysed were dissolved in 0.5 ml of a Lefort aqua regia solution (75% nitric and 25% hydrochloric acid) and placed in an AIM500 block digester at 90°C for 30 minutes. After cooling, the solutions were made up to 10 ml with distilled water and transferred into scintillation vials. The solutions were analysed using a Varian Liberty 220 inductively coupled plasma atomic emission spectrometer (ICP-AES) (operating conditions, Table 3.1.3.). A total of 11 elements (Ba, Ca, Fe, K, Li, Mg, Mn, Na, P, S, Sr) were analysed for each sample. Element concentrations were standardised for individual otolith weights.

Minimum detection limits of the ICP-AES for the elements were determined by multiplying the mean standard deviation of six Lefort aqua regia acid blank solutions that were regularly interspersed throughout the samples, by three. A total of three standard solutions were measured regularly throughout the samples to calibrate the sample readings. The standards were made so as to cover the entire weight range of otolith material used in the analyses (Table 3.1.4.).

Table 3.1.3. Operating conditions of ICP-AES.

Operating Condition	Response
Elemental emission wavelength (nm)	Ba (455.403), Ca (184.006), Fe (259.940), K (769.896), Li (670.784), Mg (279.553), Mn (257.610), Na (589.592), P (213.618), S (182.034), Sr (421.552)
Photomultiplier voltage (V)	650
Power (kW)	1.20
Plasma Argon flow (L/min)	15.0
Auxiliary Argon flow (L/min)	1.50

Table 3.1.4. Concentration of elements used in the standard solutions to calibrate the ICP-AES.

Element	Standard 1 Concentration (ppm)	Standard 2 Concentration (ppm)	Standard 3 Concentration (ppm)
Ba	0.10	0.05	-
Ca	2500.00	1500.00	2500.00
Fe	0.10	0.05	-
K	-	12.50	5.00
Li	0.10	0.05	-
Mg	0.10	0.05	-
Mn	0.10	0.05	-
Na	20.00	10.00	-
P	0.50	0.25	1.00
S	25.00	12.50	5.00
Sr	10.00	5.00	20.00

3.1.4.3. Data Analysis

The chemical composition of whole otoliths from the different areas was analysed for evidence of distinct environmental regimes and subsequent stock integrity. ANOVA was used to compare samples from different areas for individual element concentrations. Only those elements detected above the ICP-AES' detection limits were used in the analyses. HSD were used for *a posteriori* comparisons of the different areas for each significant element.

ANCOVA determined the effects of fish length on the elemental concentration of each sample. Area was treated as the main factor and length the covariate in the analyses. Analyses were performed for all areas combined, then separate calculations were carried out for Queensland east coast and northern Australian samples. Element concentrations for which area-length interactions were significant, were not included in any further analyses because they could not be corrected for fish length. Their inclusion would have resulted in additional variation due to length being present in the analyses, which may in turn have biased area discrimination.

Elements whose concentrations were significantly correlated with length were corrected for variable size using the common slope for the different areas, following the calculations of Edmonds *et al.* (1989):

$$AC = C - rL$$

where, AC is the final concentration used in the subsequent analyses, adjusted for length, C is the concentration of a given element (mg/Kg) for a fish of fork length L (mm) and r is the regression coefficient or the 'common slope' for the covariate length.

Overall stock structure patterns were examined by comparing the appropriate elements (length corrected) mean concentrations of the different areas. All areas sampled for each species were classified into groups using an unweighted pair group mean arithmetic sorting strategy, based on Euclidean distances. The resultant dendrogram was used to identify stock relationships between the different sampling areas.

Forward stepwise discriminant analyses (Seal 1964) were used to determine differences in the overall chemical composition of otoliths for school, spotted and grey mackerel samples from the different areas. Analyses were performed for all areas combined, then separate calculations were done for Queensland east coast and northern Australian samples. Separate analyses were performed for Queensland east coast and northern Australian samples as more elements could be used in the individual analyses owing to reduced size related effects on the chemical concentrations from using the same aged fish, providing greater discriminatory power between samples. Wilks' lambda denoted the statistical significance of the discriminatory power of the overall model, ranging from 1.0 (no discrimination) to 0.0 (perfect discrimination) (StatSoft 1995).

The accuracy of the discriminatory functions in classifying samples to their respective groups was determined by posterior probabilities, which were based on the known values of the elements that a respective sample belonged to a particular group. These probabilities were derived from Mahalanobis distances, which are measures of distance between two points in space defined by two or more correlated variables (StatSoft 1995).

3.1.5. Genetic Variation

3.1.5.1. Introduction

Electrophoretic detection of genetic variation in scombrid species has often been used as a means for discerning the stock structure of a species (Barrett and Tsuyuki 1967; Fujino 1970, 1976; Richardson 1983; Belyaev and Ryabov 1987; Johnson *et al.* 1994). Genetic stock discrimination of *Scomberomorus* species in Australian waters has been limited to narrow-barred Spanish mackerel. Shaklee (1986) and Shaklee *et al.* (1990) determined that narrow-barred Spanish mackerel comprise three main genetic stocks, centered on Australia, Papua New Guinea and Fiji. The stock status of Torres Strait mackerel was uncertain, possibly being a mixture of Australian and Papua New Guinea fish, or a fourth stock. Preliminary results of FRDC Project 98/151 "Stock Structure of Northern and Western Australia Spanish Mackerel" indicate narrow-barred Spanish mackerel may form a mosaic of sub-stocks in northern Australia. Lewis (1981a) screened school and spotted mackerel from Australian waters for genetic polymorphism, as part of a wider study of the biochemical genetics of scombrids. Prior to our study there was no information available on stock discrimination patterns of small mackerel, based on genetic variation. This component aimed to determine whether genetic variation, from specific enzyme staining and starch gel electrophoresis, could be used to detect the existence of genetically distinct stocks of school, spotted and grey mackerel in northern Australian waters. Genetic data were examined to provide evidence of stock discrimination patterns that may confirm a genetic basis for population structuring suggested by tagging, ageing, reproduction, and trace element data.

3.1.5.2. Electrophoresis

Mackerel samples were collected from commercial and recreational fishers in the years and by methods previously described in the ageing and reproduction sections. (Appendix 1.). Muscle, liver and retina tissues were removed and stored in microcentrifuge tubes at -70°C until required for electrophoresis. Removal, preparation and ageing of otoliths followed methods previously described.

Preparation of partially thawed tissue samples for electrophoresis involved adding a few drops of homogenising buffer and centrifuging for five minutes in a microcentrifuge at 13000 rpm, in a refrigerated room (5°C). Samples were kept on ice until the completion of gel loading, and the remainder of the sample re-frozen. Initially a sample of muscle, liver and retina extracts was screened for 37 enzymes (Appendix 1.). Tissue and enzyme combinations were tested using eight different buffers (CAME, EBT, LiOH, Poulik, TC-1, TM, Tris Glycine and TVB) to determine the most suitable system for subsequent electrophoretic examination. Details of buffers and chemicals can be found in Selander *et al.* (1971), and Shaklee and Keenan (1986). All electrophoresis procedures were performed using horizontal starch gels (Connaught, Lot 497-3) following the method of Shaklee and Keenan (1986). Enzyme stains were applied to the gel as agar overlays or as solutions, following methods of Shaw and Prasard (1970), Harris and Hopkinson (1976) and Shaklee and Keenan (1986). Distances between the origin and the location of the stained alleles were measured and assigned relative mobility values, with the most common allele distance recorded as *100*. Observed patterns of enzyme variation were scored and recorded as genotypes.

3.1.5.3. Data Analysis

Samples were assigned to a particular year class according to their back-calculated birth date, month and area of collection. Specimens were assigned a year of spawning, calculated by subtracting the age of the fish from the year it was actually captured to minimise potential variation from samples of mixed ages and to formulate the most homogeneous groups (genetic cohorts) possible for each region.

Individual back-calculated birth date sample genotypes were examined for their conformity to Hardy-Weinberg equilibrium to ensure that the samples were homogeneous. The log likelihood ratio, or *G*-test, compared the observed distribution of genotypes with the expected distribution for each locus, calculated from the allele frequencies. In samples where genotypes were uncommon, they were pooled with other rare genotypes to form expected cells of five or more whenever possible.

Temporal and spatial variation in allele frequencies for each locus were examined between samples using contingency *G*-tests. Monthly collections within the same year and area were initially compared, and pooled together if there were no significant differences between samples ($p>0.05$). Yearly variation was examined between samples collected from the same area, and were similarly pooled, if they were statistically homogeneous. Subsequently, spatial heterogeneity of allele frequencies was examined, by comparing the different areas. Homogeneous samples that were pooled together were re-examined for their conformity to Hardy-Weinberg equilibrium. All analyses were calculated using the program 'Genes in Populations' (May and Krueger 1990).

Nei's (1973, 1977) gene diversity index was calculated to explain the observed distribution in genetic variation. Nei's total gene diversity was calculated by the following:

$$H_t = H_s + D_{st}$$

where, H_t is the heterozygosity calculated from the average allele frequencies over all populations, H_s is the sum of each population heterozygosity divided by the number of populations, and D_{st} is the amount of genetic subdivision among populations.

Wright's (1978) F statistics were used to compare the observed heterozygosities to those expected under the model of a single panmictic population in Hardy-Weinberg equilibrium (May and Krueger 1990). The following statistics were calculated:

$$F_{is}=(H_{s(\text{average})} - H_{o(\text{average})})/ H_{s(\text{average})}$$

$$F_{it}=(H_{t(\text{average})} - H_{o(\text{average})})/ H_{t(\text{average})}$$

$$F_{st}=(H_{t(\text{average})} - H_{s(\text{average})})/ H_{t(\text{average})}$$

where, F_{is} describes the deviation from H-W within populations, F_{it} the deviation across all populations, and F_{st} the measure of differentiation due to population structure. $H_{s(\text{average})}$ is the average expected heterozygosity within populations, $H_{o(\text{average})}$ the average observed heterozygosity within populations, and $H_{t(average)}$ the average expected heterozygosity in the total population (May and Krueger 1990).

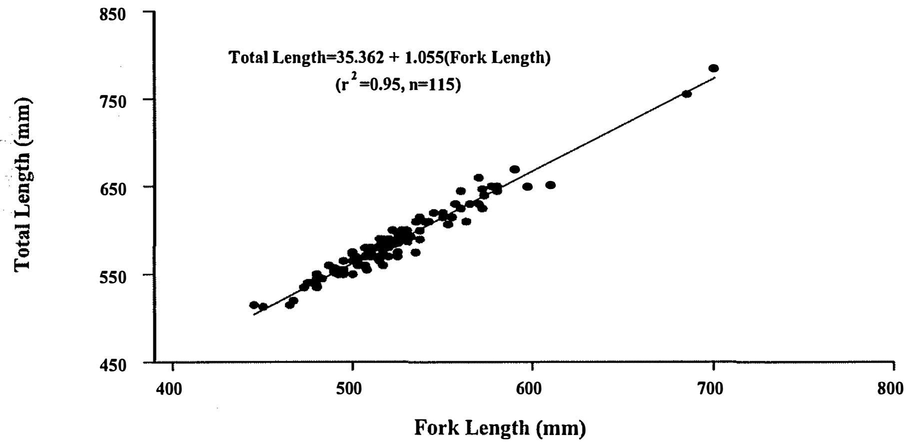
Rogers' (1972) genetic distance was used to quantify genetic differences between samples. A dendrogram of genetic distances was calculated using unweighted pair groups with arithmetic means (UPGMA) clustering. Contingency *G*-tests between adjacent areas were used to determine the significant levels of each branch of the dendrogram and to provide direct statistical tests of the species stock structure. Samples were pooled together when a non significant result was calculated for their respective pairwise comparison.

3.2. Results

3.2.1. School Mackerel

3.2.1.1. Age, Growth and Mortality

School mackerel have a significant linear relationship between total length and fork length (F=2398.25, d.f.=1, 113, $P<0.0001$). School mackerel sexes have similar length-weight regression slopes (ANCOVA, F=0.03, d.f.=1, 298, N.S.), however, males have a significantly larger intercept for their length-weight relationship (ANCOVA, F=6.65, d.f.=1, 299, $P<0.0104$) (Figure 3.2.1. and Table 3.2.1.).



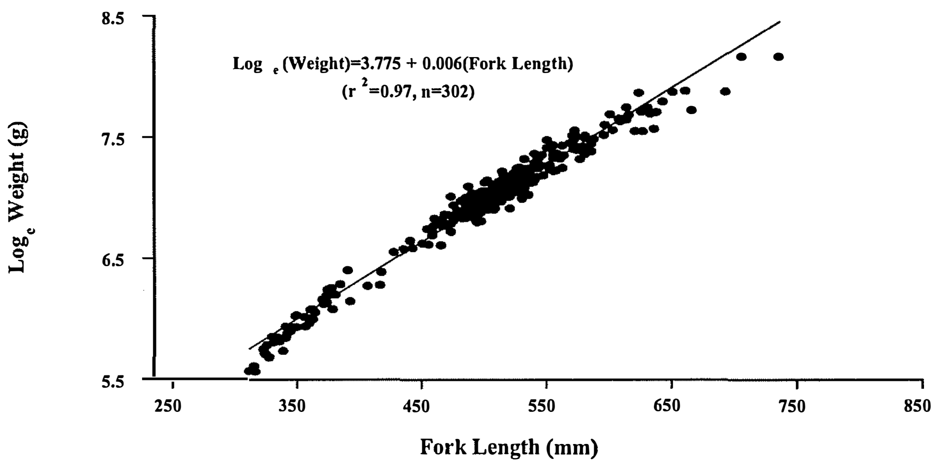


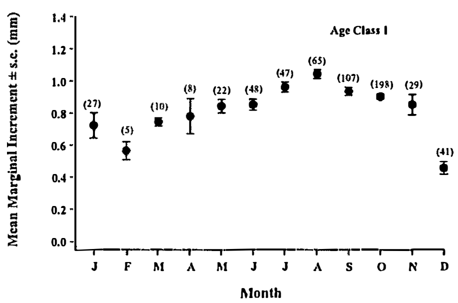
Figure 3.2.1. Total length (mm), $\log_e$ transformed weight (g)-fork length (mm) relationships of school mackerel (sexes and regions combined).

Table 3.2.1. Total length (mm), $\log_e$ (Ln) transformed weight (g)-fork length (mm) relationships of school mackerel (regions combined).

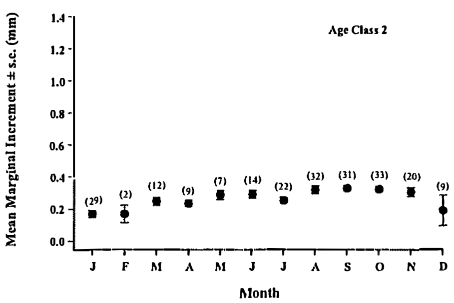
Sex	Relationship	Intercept s. e.	Slope s. e.	n	r^2
Females	Ln(weight)=3.766+0.006(fork length)	0.047	0.00009	129	0.97
Males	Ln(weight)=3.781+0.006(fork length)	0.047	0.00009	173	0.96
Combined	Ln(weight)=3.775+0.006(fork length)	0.033	0.00007	302	0.97
Combined	Total Length=35.362+1.055(fork length)	11.302	0.022	115	0.95

Whole school mackerel otoliths were more easily aged than sectioned ones owing to their greater readability and clarity. A total of 1158 (88%) whole school mackerel otoliths were aged the same by two independent readers. Whole otoliths, therefore, were used for age and growth assessments. Monthly variation in mean marginal increments was observed for one (*1*-way ANOVA, F=16.57, d.f.=11,595, P<0.0001), two (*1*-way ANOVA, F=5.29, d.f.=10,207, P<0.0001) and three (*1*-way ANOVA, F=4.21, d.f.=6,40, P<0.0023) year old fish. Age class four showed a similar increment pattern, although owing to a lack of samples variation could not be statistically compared between months. Otolith marks appeared to be formed from December to February (Figure 3.2.2.). Marginal increments were significantly lower in December, January and February for one year olds, December and January for two year olds and February for three year olds (HSD, P<0.05). Marginal increment analysis validated the interpretation of marks in the otolith as annuli for school mackerel up to two years of age. Beyond two years of age the proximity of later annuli to the edge reduced the effectiveness of marginal increments (Figure 3.2.2.).

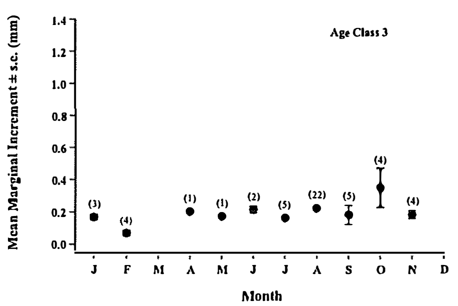
Age class 1



Age Class 2



Age class 3



Age class 4

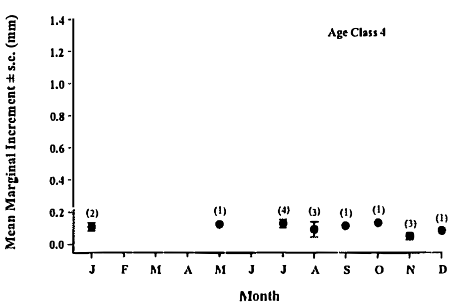


Figure 3.2.2. Monthly mean marginal increments (mm) ± standard errors of school mackerel age classes 1 to 4 (sexes and regions combined). The numbers in parentheses above each data point refer to the numbers of fish for which marginal increments were measured.

Female school mackerel successfully aged, ranged in size from 310 to 784 mm. Males were between 312 and 692 mm fork length. The oldest female school mackerel aged was seven years and the eldest male was ten years (Figure 3.2.3.). Female school mackerel attained a greater maximum length than males (Table 3.2.2.). Application of Kimura's (1980) applied likelihood ratio test to all data indicated that the sexes have different von Bertalanffy curves (χ^2=8.012, d.f.=3, P<0.05) (Figure 3.2.3.). Growth curves diverged between the sexes from six years of age onwards (ages 0 to 5, χ^2=6.139, d.f.=3, N.S.), and appeared to be different in each region for each sex (Figure 3.2.4.).

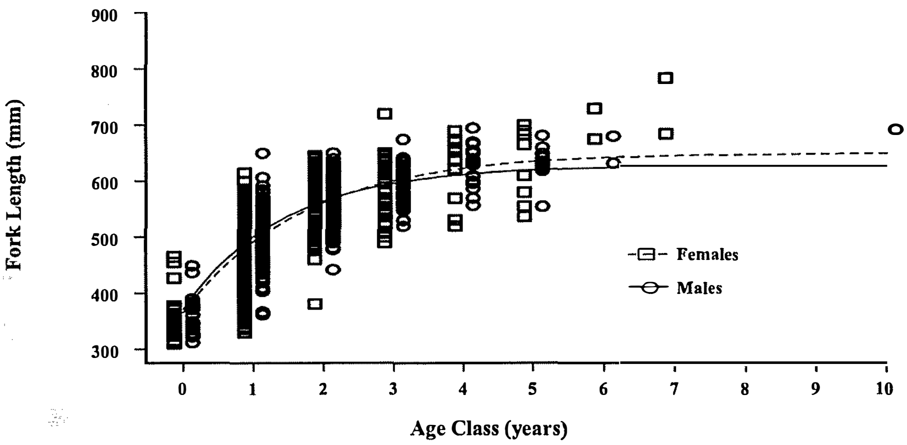


Figure 3.2.3. Von Bertalanffy growth curves fitted to observed age and fork length (mm) data of each school mackerel sex (regions combined).

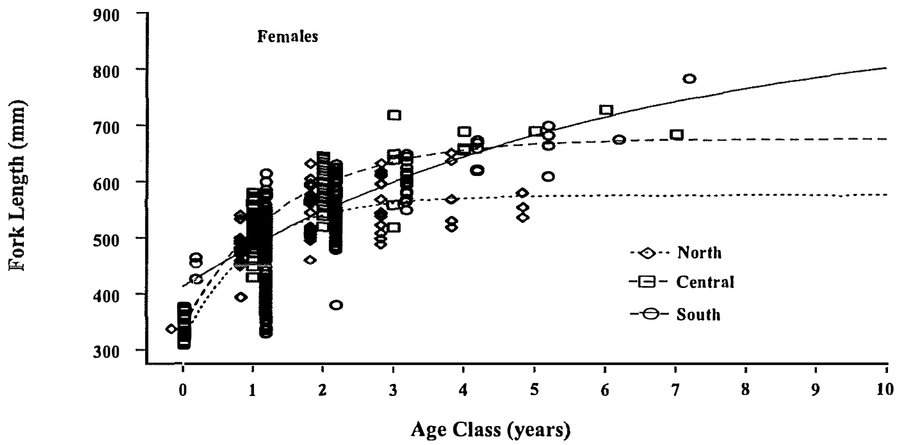
Table 3.2.2. Von Bertalanffy growth parameters (± 95% confidence intervals) calculated from observed length-at-age data of school mackerel.

Sex	Region	n	L_∞ (95% c. i.)	K (95% c. i.)	t_0 (95% c. i.)
Females	Northern	66	577 (551, 603)	0.980 (0.532, 1.429)	-0.834 (-1.455, -0.213)
	Central	152	678 (654, 702)	0.697 (0.594, 0.801)	-1.024 (-1.173, -0.876)
	Southern	265	900 (540, 1260)	0.163 (-0.013, 0.338)	-3.785 (-6.167, -1.403)
	Combined	483	651 (624, 677)	0.585 (0.458, 0.711)	-1.411 (-1.739, -1.083)
Males	Northern	53	614 (582, 645)	0.967 (0.307, 1.627)	-0.632 (-1.648, 0.384)
	Central	156	644 (624, 665)	0.836 (0.708, 0.964)	-0.941 (-1.085, -0.796)
	Southern	358	709 (641, 776)	0.284 (0.158, 0.410)	-3.262 (-4.429, -2.096)
	Combined	567	628 (614, 641)	0.704 (0.605, 0.804)	-1.272 (-1.484, -1.059)

School mackerel have no difference between sexes in their otolith radius-fork length regression slopes (ANCOVA, F=0.11, d.f.=1, 1041, N.S.), nor between their intercepts (ANCOVA, F=0.98, d.f.=1, 1042, N.S.). Data were therefore combined for the sexes to form a common relationship (Figure 3.2.5. and Table 3.2.3.).

Back-calculated data suggested that male and female school mackerel grew at a similar rapid rate (Figure 3.2.6.). Growth tapered off after four years for both sexes (Tables 3.2.4. and 3.2.5.). Estimated von Bertalanffy growth parameters from back-calculated data were generally larger than those derived from direct length-at-age data (Tables 3.2.2. and 3.2.6.). However, confidence in back-calculated estimates were lower than for the length at age data owing to the greater variation in back-calculated values.

Females



Males

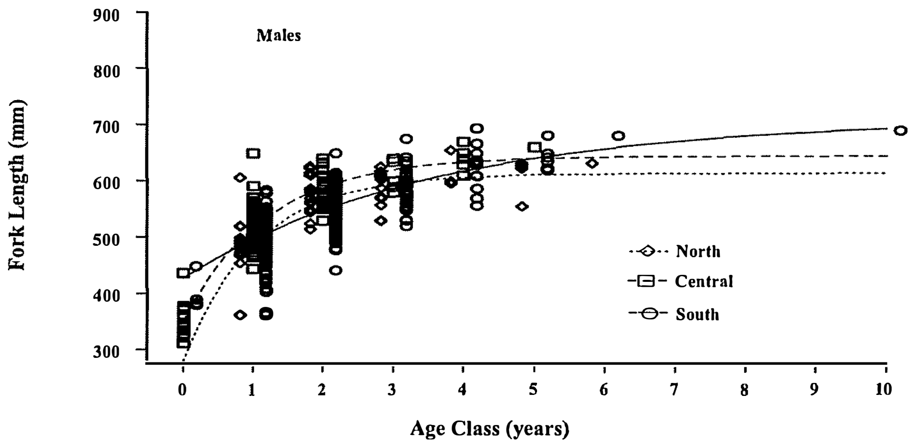
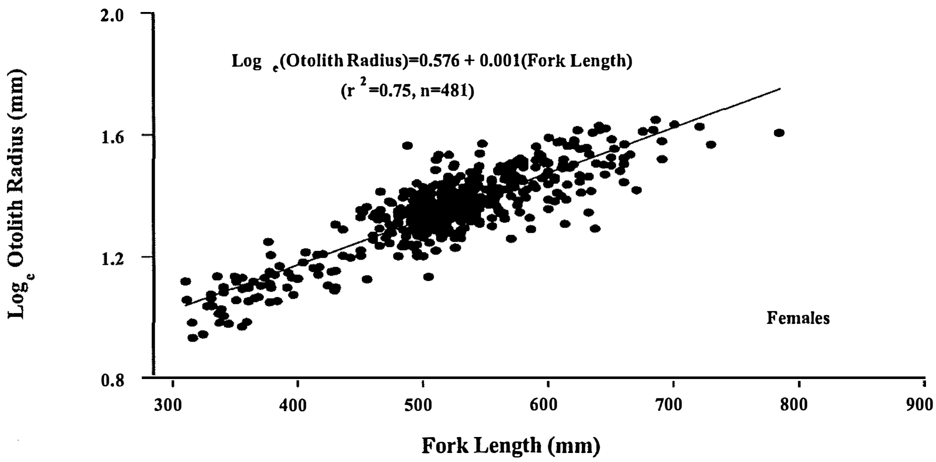


Figure 3.2.4. Von Bertalanffy growth curves fitted to observed age and fork length (mm) data of each school mackerel sex and region.

Females



Males

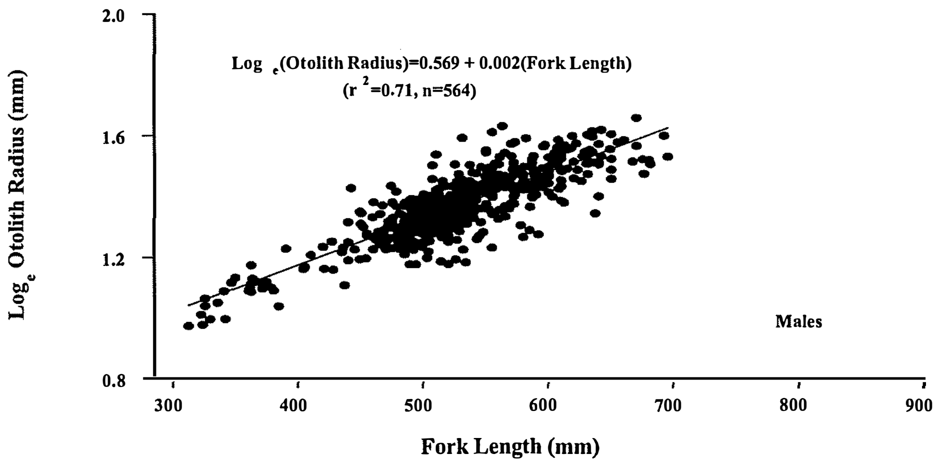


Figure 3.2.5. Log_e transformed otolith radius-fork length (mm) relationships for back-calculation purposes of school mackerel (regions combined).

Table 3.2.3. Log_e transformed otolith radius-fork length (mm) relationships for back-calculation purposes of school mackerel (regions combined).

Species	Relationship	Intercept s. e.	Slope s. e.	n	r^2
Females	Ln(ot.rad.)=0.576+0.001(fork length)	0.021	0.00004	481	0.75
Males	Ln(ot.rad.)=0.569+0.002(fork length)	0.022	0.00004	564	0.71
Combined	Ln(ot.rad.)=0.572+0.002(fork length)	0.015	0.00003	1045	0.73

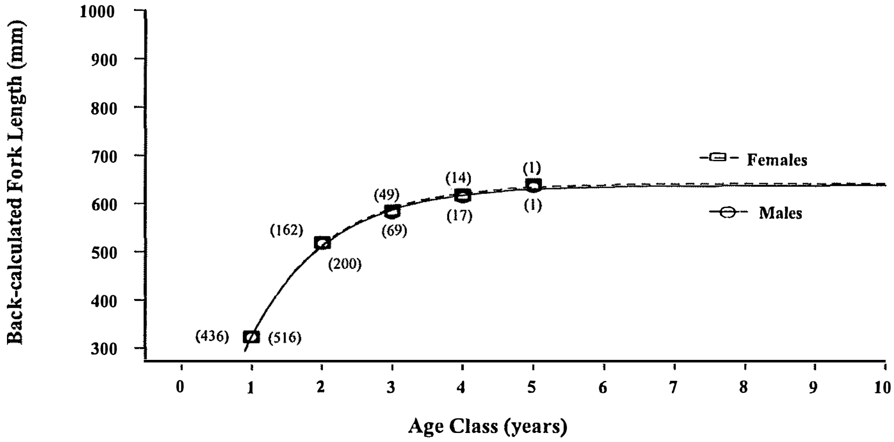


Figure 3.2.6. Von Bertalanffy growth curves fitted to mean back-calculated age and fork length (mm) data of each school mackerel sex (regions combined). The numbers in parentheses adjacent to each data point refer to the number of fish of each sex for which back-calculated lengths at each age were estimated.

Table 3.2.4. Mean back-calculated fork lengths (mm) of female school mackerel (regions combined).

Age (years)	n	Mean length at capture (mm)	Mean back-calculated length (mm) at age (years)				
			1	2	3	4	5
1	274	495	329				
2	113	558	305	525			
3	34	586	318	520	591		
4	14	640	320	523	585	625	
5	1	610	338	507	575	609	638
n			436	162	49	14	1
Mean length (mm)			322	518	584	617	638
Annual growth increment (mm)			322	196	65	33	21

Table 3.2.5. Mean back-calculated fork lengths (mm) of male school mackerel (regions combined).

Age (years)	n	Mean length at capture (mm)	Mean back-calculated length (mm) at age (years)				
			1	2	3	4	5
1	316	504	329				
2	131	557	305	522			
3	52	591	318	517	587		
4	16	629	319	520	582	621	
5	1	642	337	504	571	605	634
n			516	200	69	17	1
Mean length (mm)			322	516	580	613	634
Annual growth increment (mm)			322	194	64	33	21

Table 3.2.6. Von Bertalanffy growth parameters (± 95% confidence intervals) calculated from mean back-calculated length-at-age data of school mackerel (regions combined).

Species	L_∞ (95% c. i.)	K (95% c. i.)	t_0 (95% c. i.)
Females	642 (609,673)	0.910 (0.593, 1.228)	0.230 (-0.046,0.507)
Males	637 (603,671)	0.913 (0.570,1.255)	0.224 (-0.075,0.524)

Otolith weight was a more precise estimator of age than otolith radius for school mackerel (Table 3.2.7.). Male school mackerel grew at a significantly greater rate than females both in terms of otolith weight (ANCOVA, F=11.73, d.f.=1, 834, *P*<0.0006) and radius (ANCOVA, F=14.13, d.f.=1, 1031, *P*<0.0002) (Figures 3.2.7. and 3.2.8.).

Table 3.2.7. Otolith weight (g), radius (mm) and age (years) relationships of school mackerel (regions combined).

Sex	Relationship	n	r^2
Females	Age=-1.440+182.7(otolith weight)	384	0.65
Females	Age=-3.443+1.283(otolith radius)	481	0.35
Males	Age=-2.034+216.6(otolith weight)	452	0.67
Males	Age=-5.188+1.716(otolith radius)	552	0.43

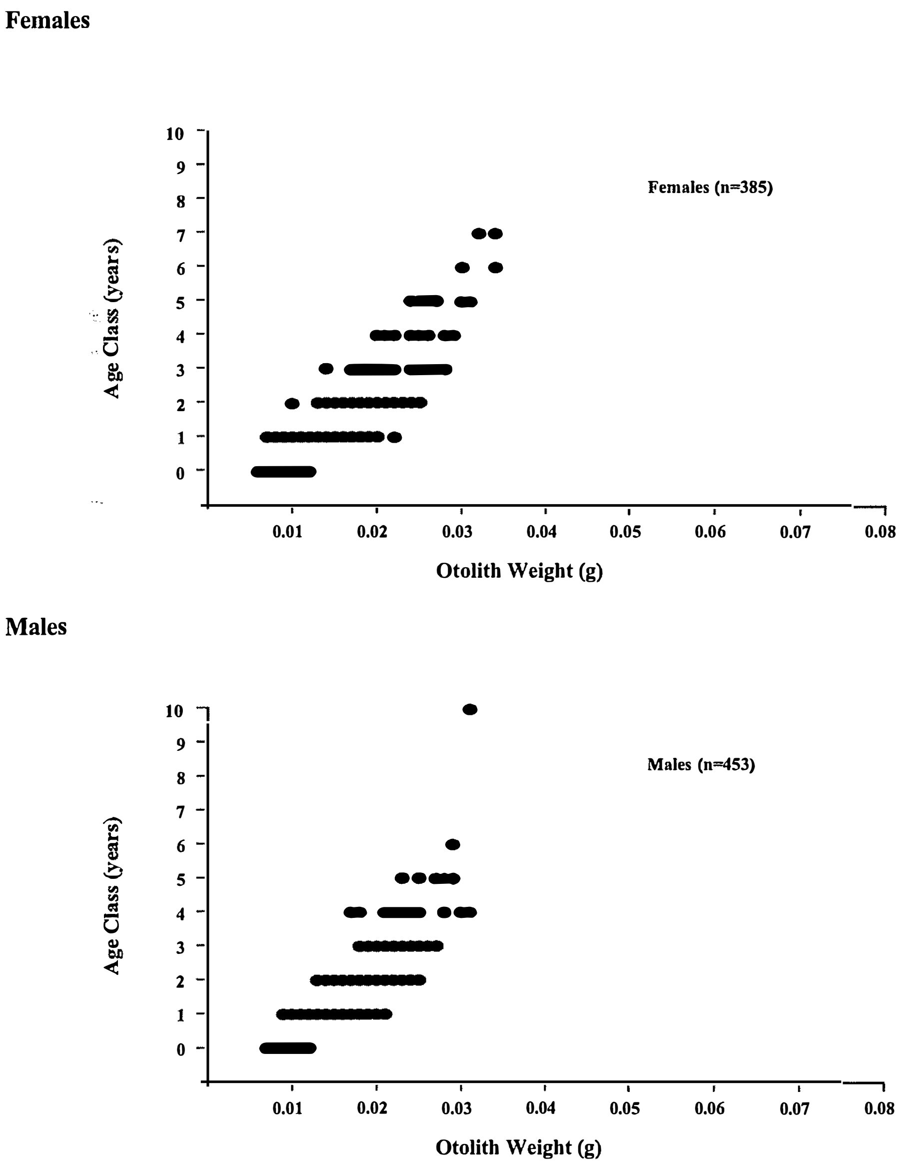


Figure 3.2.7. Relationships of otolith weight (g) and age (years) of school mackerel (regions combined).

Females

Males

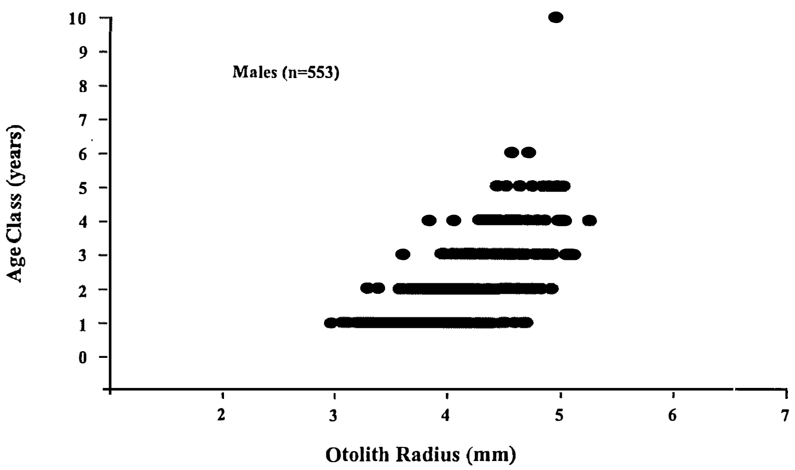


Figure 3.2.8. Relationships of otolith radius (mm) and age (years) of school mackerel (regions combined).

Mean instantaneous mortality rates ranged from 0.602 to 1.383 for school mackerel. Males appeared to have greater rates of mortality than females. Survival rates were reasonably uniform throughout the sampled regions. About 40% of the total population appear to survive each year (S=0.42 females; S=0.38 males). School mackerel appeared to be recruited to the various fisheries at one and two years of age (Table 3.2.9.).

Table 3.2.9. Instantaneous mortality and survival rates by sex, region and gear type of school mackerel (*Z*=total instantaneous mortality rate; *S*=e^{-z} survival rate; A=1-e^{-z} annual mortality rate).

Sex	Capture method and region	n	Recruitment age (years)	Mortality estimates		
				Z	S	A
Females	Line	287	1	0.869	0.419	0.581
	10 cm net	156	1	1.344	0.261	0.739
	12.2 cm net	20	2	0.602	0.548	0.452
	Northern region	50	2	0.764	0.466	0.534
	Central region	132	1	1.113	0.329	0.671
	Southern region	262	1	0.985	0.373	0.627
	Total	464	1	0.877	0.416	0.584
Males	Line	316	1	0.743	0.476	0.524
	10 cm net	205	1	1.383	0.251	0.749
	12.5 cm net	27	2	0.899	0.407	0.593
	Northern region	57	2	0.867	0.420	0.580
	Central region	138	1	0.987	0.373	0.627
	Southern region	354	1	0.916	0.400	0.600
	Total	549	1	0.961	0.383	0.617

3.2.1.2. Reproduction

Reproductive development was differentiated into six macroscopic and histological stages for females, and four stages for males (Tables 3.1.1. and 3.1.2.). A logical pattern of increasing weight change in the gonads (up to stage V for females and III for males) represented by GSIs was observed for each stage, supporting the validity of the development schemes (Figures 3.2.9. and 3.2.10.). Female (G=459.8, d.f.=20, P<0.001; Cramer's V=0.562) and male (G=381.0, d.f.=9, P<0.001; Cramer's V=0.546) macroscopic and histological staging schemes were closely related further confirming the validity of the staging schemes for school mackerel.

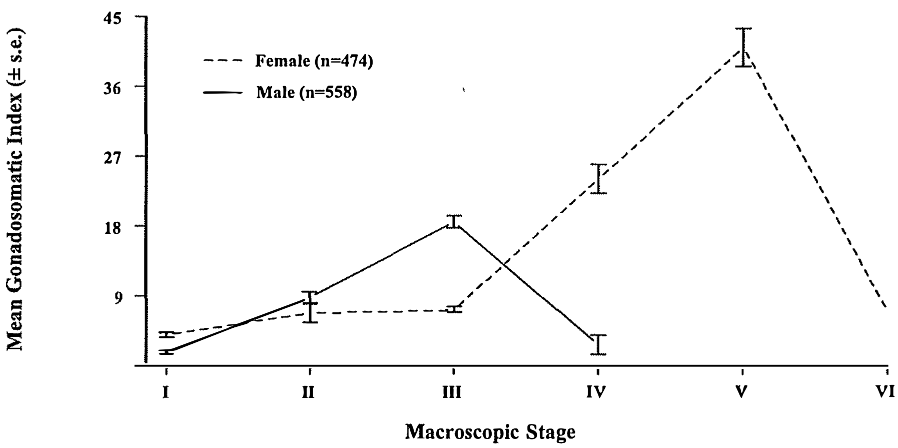


Figure 3.2.9. Pattern of mean gonadosomatic index (± standard error) with increasing macroscopic stage of school mackerel gonads.

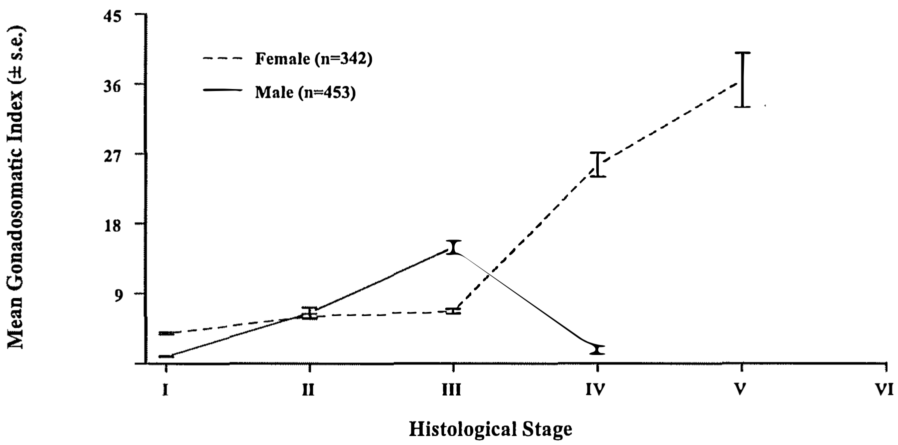


Figure 3.2.10. Pattern of mean gonadosomatic index (± standard error) with increasing histological stage of school mackerel gonads.

School mackerel monthly GSIs did not differ between regions within the same year, so monthly data were pooled across regions. However, monthly differences in GSIs were evident between years, particularly at the initial and final periods of spawning when gonad development was expected to show most variation. GSIs of female school mackerel differed significantly between years during September ($\log_e$ transformed *1*-way ANOVA, F=5.24, d.f.=2,45, $P<0.009$) and October ($\log_e$ transformed *1*-way ANOVA, F=15.07, d.f.=2,94, $P<0.0001$). Similarly, GSIs of males differed in January ($t=-4.3036$, d.f.=71, $P<0.0001$), February ($t=2.4925$, d.f.=9, $P<0.0343$) and October ($\log_e$ transformed *1*-way ANOVA, F=5.96, d.f.=2,99, $P<0.0036$).

On the basis of changes in GSIs, it appears that school mackerel spawn between October and January along the Queensland east coast (Figure 3.2.11.). Markedly greater GSIs were found for school mackerel in their peak reproductive months of October to January than the remaining months, for both females and males (HSD).

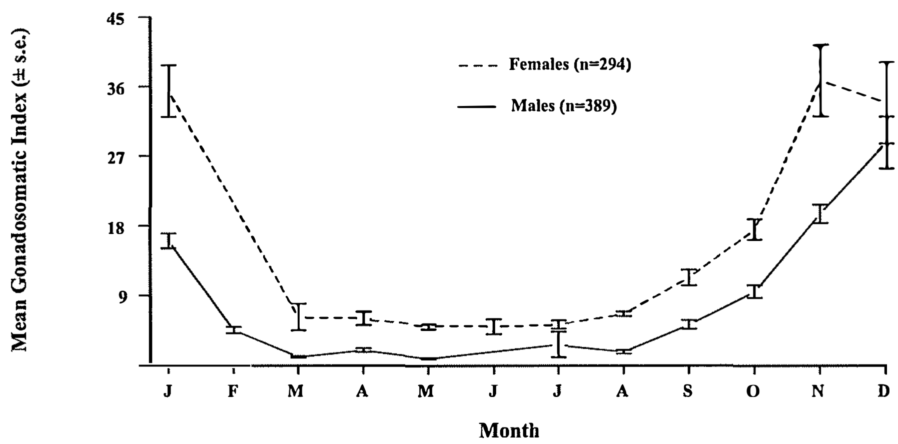
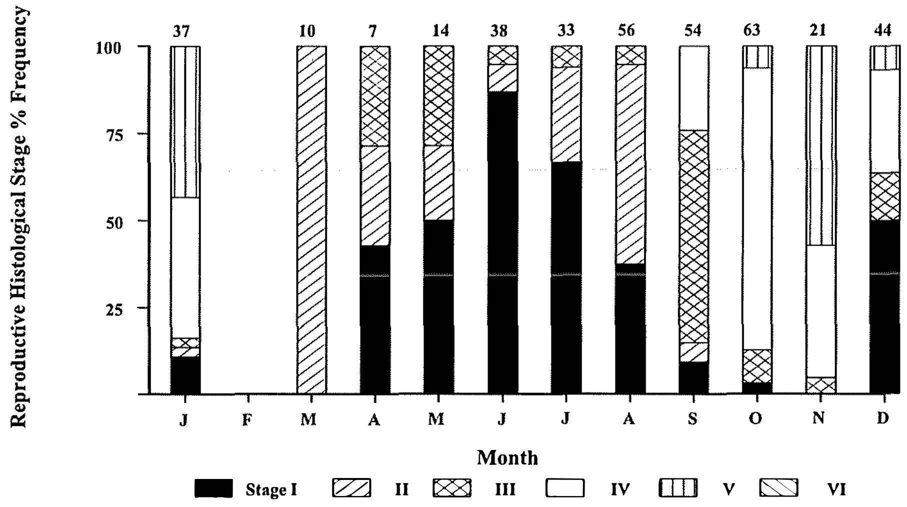


Figure 3.2.11. Monthly mean GSIs (± standard errors) of mature school mackerel (female histological stages II-VI, and male stages II-IV).

Female school mackerel were determined to be in ripe spawning condition from October to January on the basis of histology, which coincided with their peak GSI months. A significant proportion of males sampled in October to February were also ripe. Immature school mackerel dominated the late autumn, winter catches (Figure 3.2.12.). Female school mackerel were determined to be in ripe spawning condition from October to January on the basis of histology, which coincided with their peak gonadosomatic months. Significant proportions of ripe males were also observed from October to February.

The smallest ripe (stages IV-V) female school mackerel caught was 412 mm and the largest immature (stage I) female was 497 mm (see Materials and Methods Section - all lengths referred to are fork lengths in mm, unless otherwise stated). Both the smallest mature (stage III) and largest immature males measured 362 mm. At least 50% of female school mackerel between 400 and 449 mm were classified as mature (stages II-VI) during their peak spawning months of October through to January. An estimated 50% of males were considered to have first spawned (stages II-IV) at fork lengths between 350 and 399 mm. The largest size-related difference in G.S.I. occurred between 500 and 550 mm for females and 350 and 400 mm for males (Figure 3.2.13.). The current legal minimum length of 500 mm total length was greater than the initial maturity lengths.

Females



Males

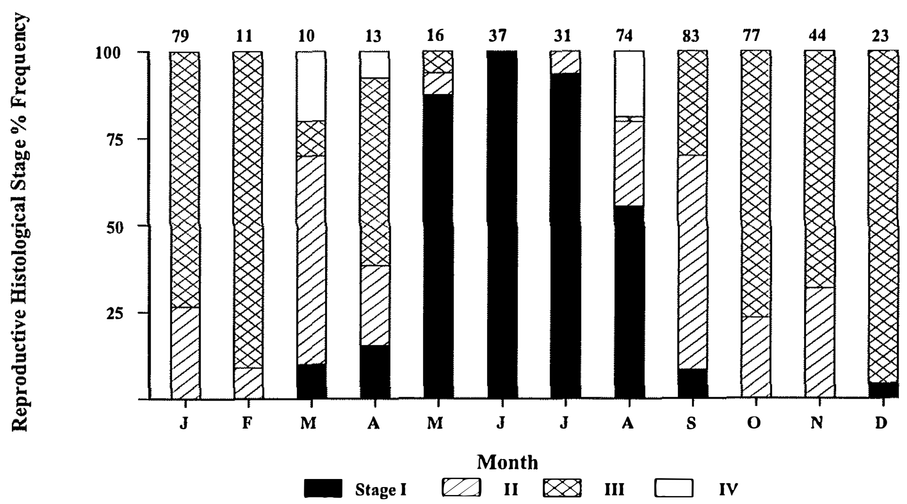
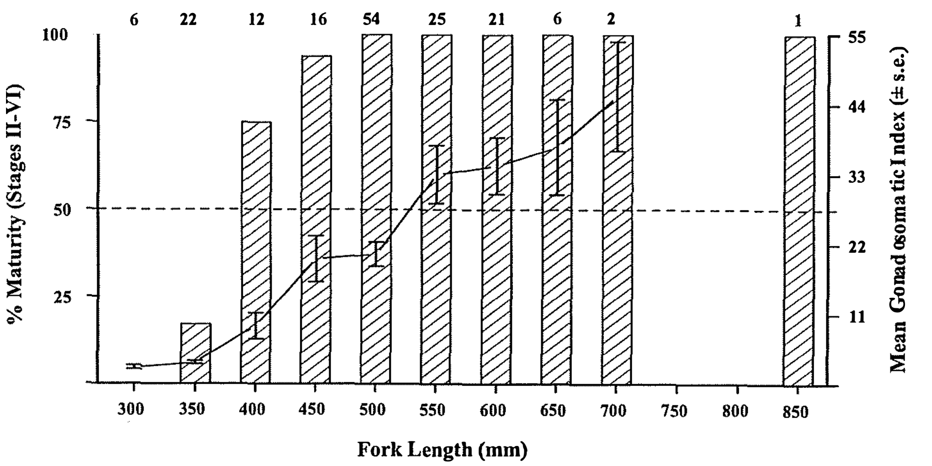


Figure 3.2.12. Monthly proportions of histological stages in school mackerel. The numbers above each bar refer to the number of fish staged for that month.

Females



Males

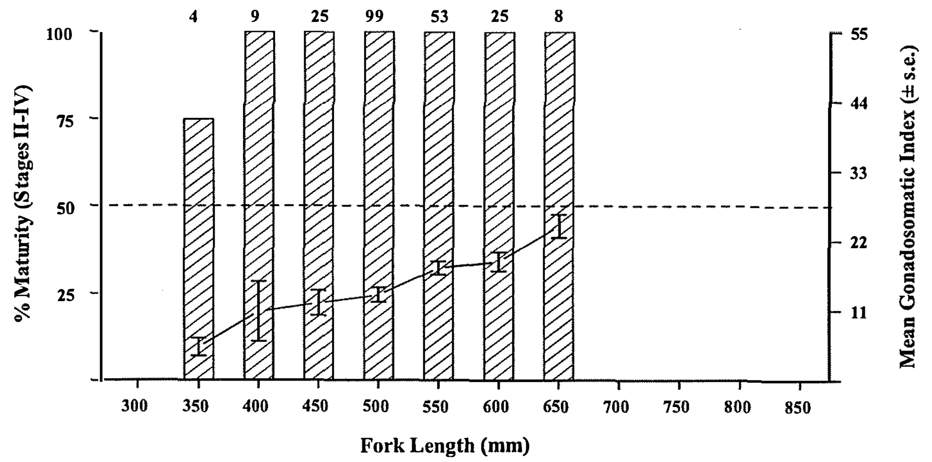


Figure 3.2.13. Fork length (mm) of school mackerel at first maturity detennined by 50% histological maturity stage and mean gonadosomatic index (± standard error) for peak spawning months of October to January. The numbers above each bar refer to the number of fish staged for each length class.

The school mackerel sex ratio was skewed towards males during November (χ^2=9.47, d.f.=1, P<0.05), January (χ^2=13.78, d.f.=1, P<0.05) and February (χ^2=6.75, d.f.=1, P<0.05) and female biased in December (χ^2=11.25, d.f.=1, P<0.05). All school mackerel captured over 750 mm were females. Males were more abundant in the length classes of 450 (χ^2=6.84, d.f.=1, P<0.05) and 550 mm (χ^2=5.02, d.f.=1, P<0.05). Females were caught in greater proportions between 350 and 399 mm (χ^2=7.85, d.f.=1, P<0.05) (Figure 3.2.14.).

In school mackerel there is a significant linear relationship between mean advanced stage oocyte diameter and fish length. Advanced staged oocyte diameters increased with fish length, during the species' peak spawning months of October to January (Figure 3.2.15.). A significant linear relationship existed between fish length and total potential fecundity for school mackerel. The larger the fish, the greater was its oocyte carrying potential (Figure 3.2.16.).

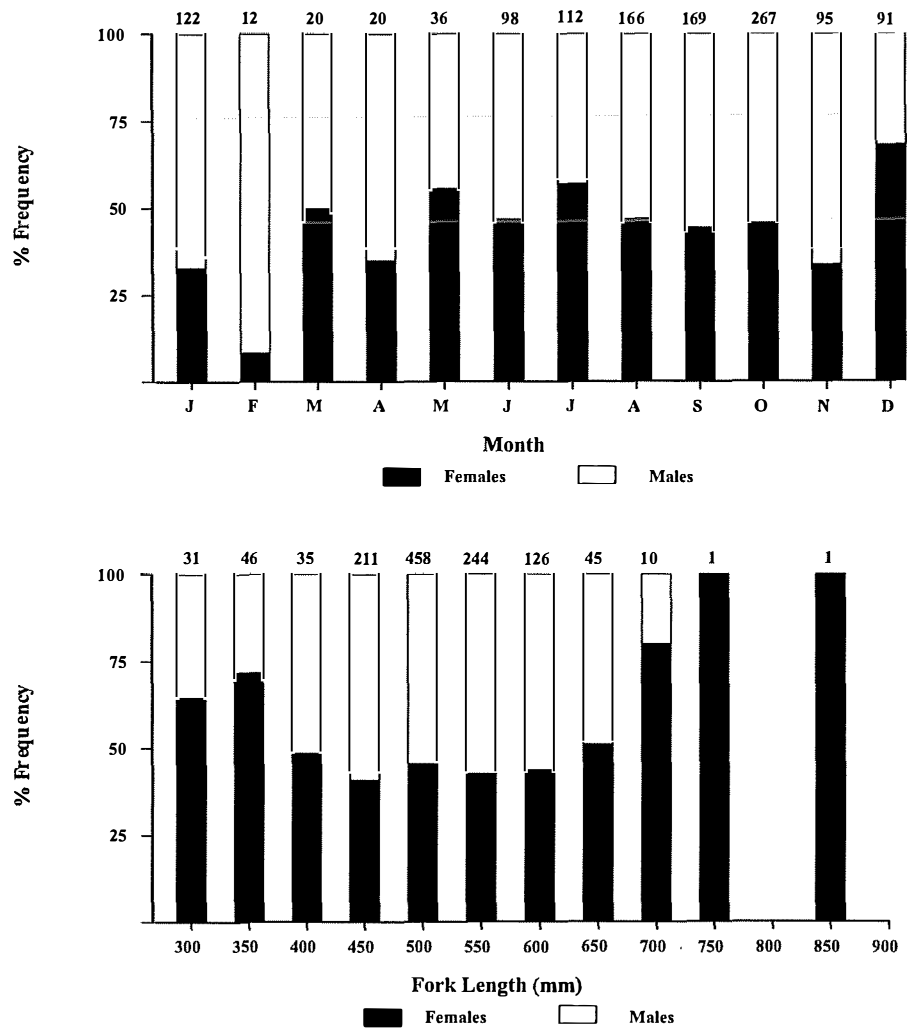


Figure 3.2.14. Percent frequency of monthly and length based sex ratios of school mackerel. The number above each bar refers to the number of fish sampled for that month.

Oocyte Diameter

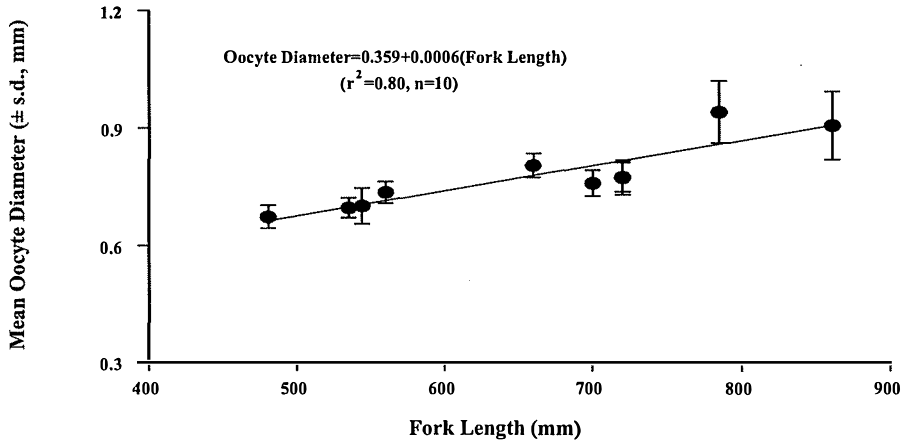


Figure 3.2.15. Mean oocyte diameter (± standard deviation) related to fork length (mm) of school mackerel for spawning months of October to January based on histological stages IV and V.

Total Potential Fecundity

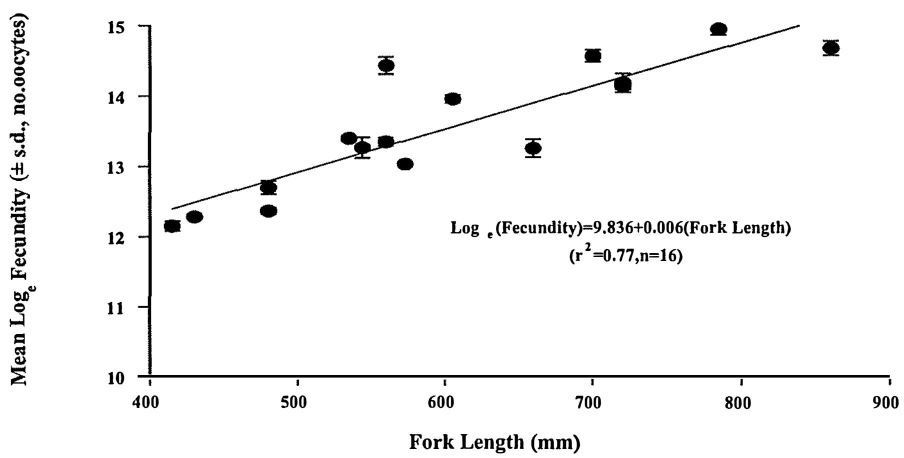


Figure 3.2.16. Total potential fecundity ('000 oocytes) (± standard deviation) related to fork length (mm) of school mackerel for spawning months of October to January based on histological stages IV and V.

3.2.1.3. Movements

A total of 4941 school mackerel were tagged in Queensland east coast waters between 1985 and 1995. About 2.1% of the tagged and released school mackerel were recaptured. (Table 3.2.10.). A total of 224 school mackerel were double tagged. Two of the nine recaptured school mackerel retained both tags. These fish had been at liberty for 22 and 203 days. Of the 320 school mackerel injected with oxytetracycline for age validation purposes, 10 were recaptured. Validation of ageing techniques via examination of otoliths from fish injected with oxytetracycline was unsuccessful due to inadequate time at liberty of recaptured fish which was insufficient to allow any substantial growth.

Table 3.2.10 . Total tag-recapture information.

Condition	School Mackerel	
	No. Tagged	No. (%) Recaptured
Total fish tagged	4941	102 (2.1)
Double tagged	224	9 (4.0)
Oxytetracyclined	320	10 (3.1)
Commercial fishers	-	19 (18.6)
Recreational fishers	-	83 (81.4)

Tagging of school mackerel was unevenly distributed between season and areas (χ^2=1009.61, d.f. = 15, P<0.0001). School mackerel were predominantly tagged from late autumn to early spring in Moreton Bay, Rockhampton and Mackay. Recaptured school mackerel tended to be larger when they were initially tagged than tagged fish not recaptured (t=5.189, d.f.=4526, P<0.0001), with the length of tagged school mackerel varying significantly between areas (*1*-way ANOVA, F=72.6, d.f.=5,4421, P<0.0001) (Figure 3.2.17.). School mackerel tagged in Moreton Bay, Townsville and Rockhampton varied significantly in length from each other (HSD). Fish released in these localities were also significantly larger than those from Mackay and Hervey Bay (Table 3.2.11.).

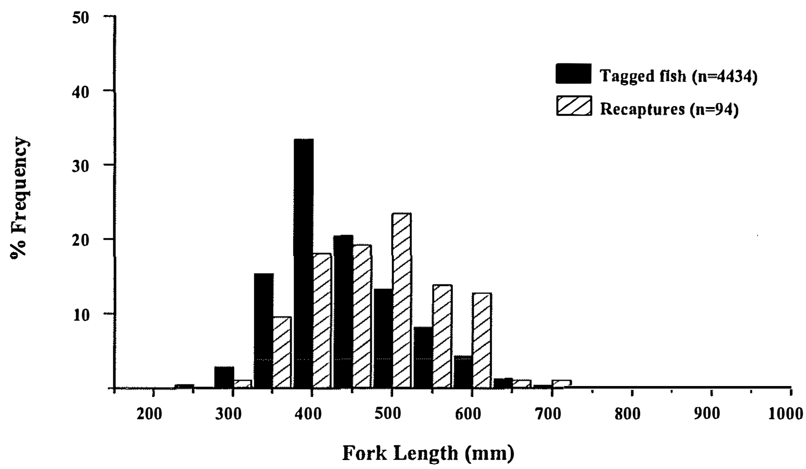


Figure 3.2.17. Frequency distribution of length at release for all tagged and recaptured school mackerel (areas combined).

Table 3.2.11. Mean fork lengths (mm) (± standard deviation) of tagged and recaptured school mackerel for the respective sampling areas.

Area	Tagged School Mackerel Fork Lengths (mm)			Recaptured School Mackerel Fork Lengths when first Tagged (mm)		
	n	mean	s. d.	n	mean	s. d.
Moreton Bay	1111	451	97	32	478	81
Hervey Bay	268	387	73	15	469	106
Rockhampton	1866	408	70	25	455	75
Mackay	1024	400	46	19	417	58
Townsville	149	430	71	3	477	112
Cairns	9	407	81	-	-	-
Total	4427	417	77	94	458	82

Tagged school mackerel movements were limited, with 85% of recaptures being less than 50 km from their respective release sites. The largest movement observed for a recaptured school mackerel was 270 km. The fish had moved north from Moreton Bay to Hervey Bay, and was at liberty for 199 days. The fish was tagged in March and recaptured in September. Only seven (7%) school mackerel recaptures had moved to a different embayment, involving a movement of over 100 km. One recaptured fish moved 150 km north from Rockhampton. The other six fish tagged in Moreton Bay and Rockhampton were recaptured in Hervey Bay between August and January (Figure 3.2.18.). Recaptured school mackerel displayed no apparent directional movement pattern throughout the year, being caught within close proximity of their release site (Figure 3.2.19.). The distances recaptured school mackerel moved were correlated to their time at liberty (r_s=0.456, d.f.=100, P<0.0001). A weak positive relationship (distance=15.33+0.12 (days at liberty), r^2=0.06) was observed between the variables (F=6.387, d.f.=1,100, P<0.013) (Figure 3.2.20.). There was no relationship between initial tagged lengths of recaptured school mackerel, and time they were at liberty (r_s=0.167, d.f.=92, N.S.).

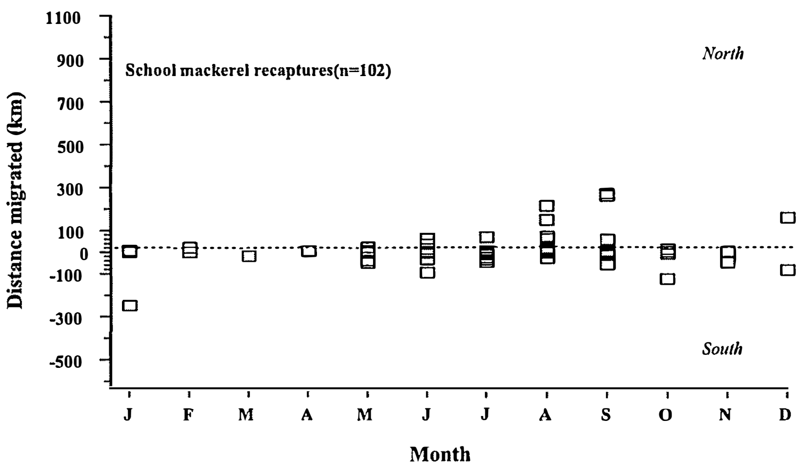


Figure 3.2.19. Monthly directional movements of recaptured school mackerel.

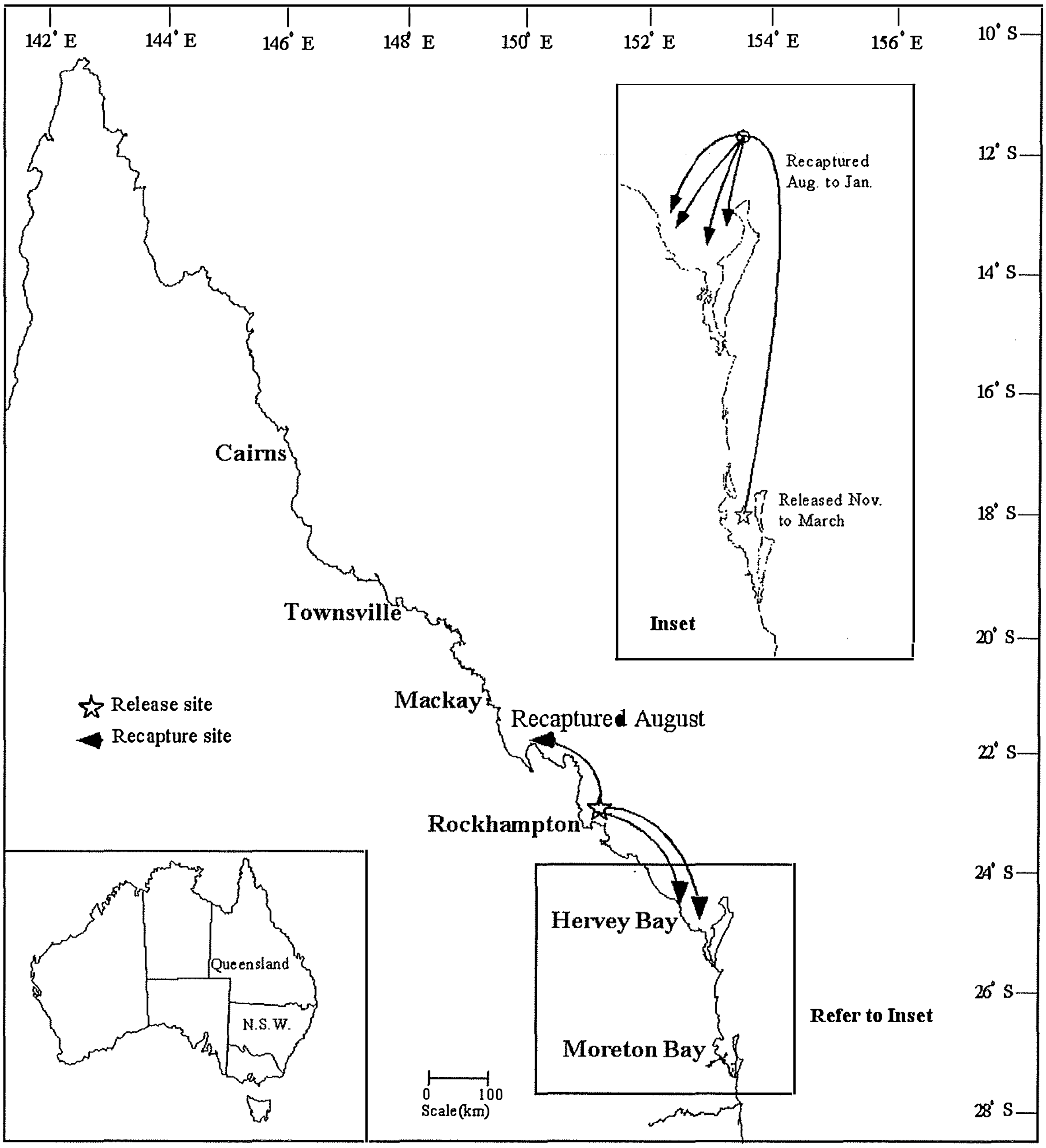


Figure 3.2.18. Large-scale (>100km) school mackerel movements from tag-recapture data (6.9% of total recaptures).

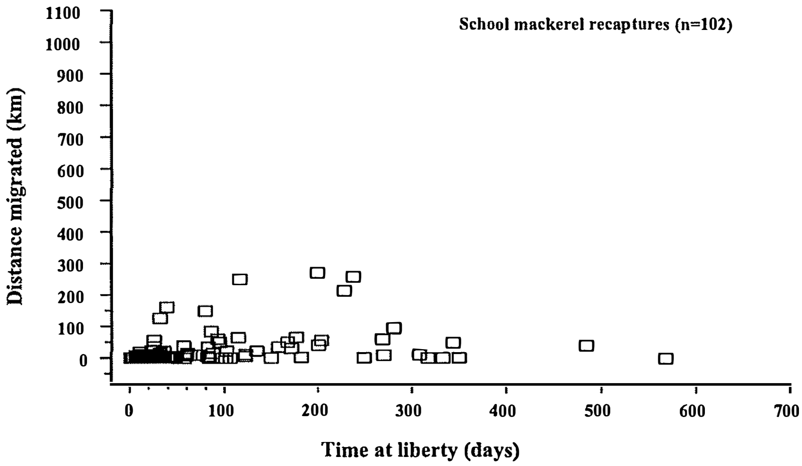


Figure 3.2.20. Movements (km) and time at liberty (days) of recaptured school mackerel.

3.2.1.4. Otolith Chemistry

The chemical composition of whole otoliths from school mackerel was determined by estimating the concentration of 11 trace elements (Table 3.2.12.). Fe and Li in school mackerel were found to be highly variable and below the detection limits of the spectrometer. These elements were therefore excluded from any further analyses. Ca (36.99 to 39.66% for all samples) was also discarded because of its high concentration which would have masked the contribution of the other trace elements in the analyses that were present in lower concentrations in the otoliths. The remaining elements were present in measurable quantities confirming their suitability for subsequent analyses.

Concentrations of elements that were detected above the minimum levels of the ICP-AES (Ba, K, Mg, Mn, Na, P, S, Sr) for school mackerel otoliths varied significantly between samples from different areas (Table 3.2.13.). The chemical composition of school mackerel otoliths from northern Australian waters had a number of elements that varied significantly in their concentrations from Queensland east coast samples. Similarly, significant differences in trace element concentrations were evident between school mackerel from the Gulf of Carpentaria (Weipa) and western Northern Territory waters (Darwin and the Joseph Bonaparte Gulf). Little variation in element concentrations were measured between samples from different locations within Queensland east coast waters, or between different age classes. Only Ba and Mn differed in concentration between one and two year old fish from Rockhampton (Table 3.2.14.).

ANCOVA results demonstrated that Na, Mn and Mg concentrations were highly correlated with length in school mackerel. Concentrations of all elements showing a significant relationship with length were subsequently corrected for size, using their respective regression coefficient for the length covariate (Tables 3.2.15. to 3.2.17.).

Clustering of length corrected element concentrations showed that school mackerel from the Queensland east coast appeared to be separated from those of northern Australia in their otolith chemical composition. Moreton Bay, Rockhampton and Bowen fish grouped together, while samples from Darwin, Weipa and Joseph Bonaparte Gulf formed a separate cluster. There appeared to be little difference in the elemental otolith composition between one and two year old fish from Rockhampton (Figure 3.2.21.).

The canonical variate analysis involving all school mackerel samples showed a large degree of overlap between fish from the different areas (Figure 3.2.22.), signified by the moderate value of Wilks' Lambda (Table 3.2.18.). Differences in Sr, S, P, Mg and Mn concentrations between samples from the different areas accounted for most of the variation (94%) explained by the discrimination model (Table 3.2.18.). The poor separation between samples may have been a result of age related effects, or the loss of power in the discriminatory analysis owing to the use of only five elements. The high degree of overlap between samples in the overall analysis was responsible for only 45% of the fish being classified into the correct group by the predicted classification functions (Table 3.2.19.).

Table 3.2.12. Mean element concentrations of school mackerel otoliths sampled from the different regions. Minimum elemental detection limits of the ICP-AES averaged from the combined acid blank results of school and spotted mackerel calculated from the minimum otolith weight used in the analyses, 0.0068 g (n=6). All units are in mg/Kg, except Ca which is measured as a % : (Ba=0.78; Ca=544; Fe=23.9; K=353; Li=15; Mg=10.9; Mn=1.10; Na=1250; P=54.1; S=191; Sr=3.24).

Region	Age (yrs)		Length (mm)	Otolith Wt. (g)	Ba	Ca	Fe	K	Li	Mg	Mn	Na	P	S	Sr
Moreton Bay	2	No.	19	19	19	19	19	19	19	19	19	19	19	19	19
		Mean	573	0.038	2.7	38.3	4.63	379	0.44	12.6	1.48	3186	115	460	2306
		Std.	33	0.004	0.73	2	11.02	41	0.8	2.1	0.39	227	12	44	142
		Range	512-614	0.030-0.044	1.80-4.94	31.4-40.9	0-46.97	313-436	0-2.67	9.8-19.2	1.04-2.43	2433-3565	90-140	369-525	1987-2501
		CV	5.8	10.7	27.1	5.2	238.1	10.9	180.9	17	26.2	7.1	10.2	9.6	6.2
Rockhampton	1	No.	25	25	25	25	25	25	25	25	25	25	25	25	25
		Mean	533	0.029	2.95	38.9	1.15	368	0.98	15.5	1.8	3315	109	431	2309
		Std.	20	0.003	0.79	2	2.78	65	1.22	4.5	0.53	184	9	43	155
		Range	492-574	0.022-0.036	1.63-4.58	36.0-44.3	0-11.79	249-465	0-3.77	12.0-35.1	1.04-2.95	2792-3664	85-127	345-537	2063-2671
		CV	3.7	12	26.9	5.2	242.1	17.7	125.1	29.1	29.3	5.6	8.5	10.1	6.7
Rockhampton	2	No.	18	18	18	18	18	18	18	18	18	18	18	18	18
		Mean	589	0.038	3.8	39.1	7.38	358	0.26	12.6	1.27	3122	120	449	2338
		Std.	29	0.004	1.05	1.8	12.04	81	0.87	3	0.3	198	12	51	184
		Range	552-640	0.031-0.049	1.62-5.59	36.8-44.2	0-45.73	193-544	0-1.72	10.3-24.0	0.67-1.70	2743-3451	95-139	389-555	2076-2707
		CV	4.9	11.8	27.8	4.6	163.3	22.5	338.2	24	23.8	6.3	10	11.3	7.9
Bowen	2	No.	22	22	22	22	22	22	22	22	22	22	22	22	22
		Mean	586	0.039	3.58	38.8	8.26	423	0.32	11	1.45	2874	131	459	2394
		Std.	23	0.005	0.68	1.9	31.68	6	0.76	0.8	0.45	157	10	35.6	153
		Range	545-632	0.0318-0.047	2.55-4.78	36.3-44.7	0-149.70	333-529	0-1.74	9.6-12.4	0.57-2.66	2612-3186	112-152	401-523	2172-2809
		CV	3.9	11.8	18.9	5	383.3	14.8	236.1	7.5	31.1	5.5	7.5	7.8	6.4
Darwin	1	No.	20	20	20	20	20	20	20	20	20	20	20	20	20
		Mean	436	0.023	2.66	38.8	1.64	409	1.17	16.6	1.99	3401	115	444	2463
		Std.	38	0.006	0.55	3.4	2.85	128	1.58	3.7	0.58	125	22	71	287
		Range	380-500	0.013-0.034	1.86-3.81	34.6-50.1	0-6.56	247-649	0-4.72	10.8-22.3	1.03-3.10	2567-4906	80-168	293-565	2023-3291
		CV	8.7	26	20.8	8.8	173.9	31.4	134.8	22.5	29.2	16.5	19.2	15.9	11.7
Weipa	1	No.	19	19	19	19	19	19	19	19	19	19	19	19	19
		Mean	447	0.023	2.77	37	1.32	352	0.89	13.1	2.13	3211	110	404	2480
		Std.	25	0.005	0.54	2.3	2.17	76	1.61	1.3	0.56	293	15	56	211
		Range	410-505	0.013-0.031	1.99-4.05	32.5-43.3	0-5.96	199-514	0-4.28	11.5-16.3	1.15-3.61	2853-4210	76-139	254-475	2043-2933
		CV	5.6	19.5	19.5	6.1	165.2	21.7	181.7	9.6	26.2	9.1	13.9	13.8	8.5
JBG	1	No.	14	14	14	14	14	14	14	14	14	14	14	14	14
		Mean	404	0.021	3.3	38	1.31	511	2.51	16.7	2.23	3688	125	474	2575
		Std.	61	0.007	1.3	1.7	4.03	201	2.11	2.8	0.65	574	24	88	299
		Range	330-500	0.013-0.036	1.69-6.41	34.9-41.3	0-9.32	208-756	0-6.85	11.4-21.2	1.04-3.33	2887-4924	80-162	367-692	2032-3298
		CV	15.1	32.9	39.4	4.5	307.8	39.4	84.1	16.5	29.2	15.6	19.6	18.5	11.6

Table 3.2.13. Trace elements that varied significantly in concentration between school mackerel otoliths from different areas. One-way analysis of variance results examined the effect of area on each trace element concentration. Each element varied significantly between areas (significant result*). All analyses had d.f.=6,130.

Element	School Mackerel ANOVA Results (d.f.=6,130)	
	F	P
Ba	6.01	0.0001*
K	3.36	0.0042*
Mg	11.10	0.0001*
Mn	9.54	0.0001*
Na	10.46	0.0001*
P	5.51	0.0001*
S	3.09	0.0074*
Sr	4.08	0.0009*

Table 3.2.14. Trace elements of school mackerel whole otoliths that differed in their concentration between areas (Tukey's studentized range test HSD). The number after the area refers to the age of the samples analysed, eg. Rock (1) refers to 1 year old fish from Rockhampton. All comparisons had d.f.=130 and were significant at $P<0.05$.

	Area (age, years)						
	JBG (1)	Darwin (1)	Weipa (1)	Bowen (2)	Rock (1)	Rock (2)	Moreton (2)
JBG (1)	-	-	-	-	-	-	-
Darwin (1)	-	-	-	-	-	-	-
Weipa (1)	K Mg Na S	Mg	-	-	-	-	-
Bowen (2)	Mg Mn Na	Ba Mg Mn Na P	Ba Mn Na P S	-	-	-	-
Rock (1)	K Na P Sr	-	P	Na	-	-	-
Rock (2)	K Mg Mn Na Sr	Ba Mg Mn	Ba Mn	-	Ba Mn	-	-
Moreton (2)	Mg Mn Na Sr	Mg Mn	Mn S	Ba Na P	-	Ba	-

Table 3.2.15. School mackerel trace element concentrations that were significantly correlated with fish length for all areas. Analysis of covariance results of the concentrations of trace elements with area (n=7, including the different age classes from Rockhampton) as a factor and length as a covariate. Analyses determined the regression coefficient for the covariate length or the correction factor "r" required to standardise the concentrations of individual elements affected by variable length (*indicates a significant result).

Element	Length*Area (d.f.=6,123)		Length (d.f.=1,129)		r
	F	P	F	P	
Ba	6.88	0.0001*	-	-	-
K	4.86	0.0002*	-	-	-
Mg	1.37	0.2330	5.25	0.0235*	-0.0177
Mn	0.79	0.5786	13.66	0.0003*	-0.0047
Na	3.50	0.0031*	-	-	-
P	1.07	0.3841	0.31	0.5792	-
S	0.79	0.5804	0.38	0.5372	-
Sr	1.53	0.1735	0.15	0.7027	-

Table 3.2.16. School mackerel trace element concentrations that were significantly correlated with fish length for Queensland east coast samples. Analysis of covariance results of the concentrations of trace elements with area (n=4, including the different age classes from Rockhampton) as a factor and length as a covariate. Analyses determined the regression coefficient for the covariate length or the correction factor (r) required to standardise the concentrations of individual elements affected by variable length (* indicates a significant result).

Element	Length*Area (d.f.=3,76)		Length (d.f.=1,79)		r
	F	P	F	P	
Ba	2.75	0.0486*	-	-	-
K	0.58	0.6274	1.40	0.2400	-
Mg	0.30	0.8257	0.00	0.9444	-
Mn	0.43	0.7311	0.73	0.3967	-
Na	1.04	0.3807	0.13	0.7216	-
P	1.62	0.1910	1.25	0.2664	-
S	0.95	0.4205	1.70	0.1963	-
Sr	0.32	0.8117	0.04	0.8502	-

Table 3.2.17. School mackerel trace element concentrations that were significantly correlated with fish length for northern Australian samples (excluding Queensland east coast). Analysis of covariance results of the concentrations of trace elements with area (n=3) as a factor and length as a covariate. Analyses determined the regression coefficient for the covariate length or the correction factor (r) required to standardise the concentrations of individual elements affected by variable length (* indicates a significant result).

Element	Length*Area (d.f.=2,47)		Length (d.f.=1,49)		r
	F	Pr>F	F	P	
Ba	4.40	0.0178*	-	-	-
K	7.16	0.0019*	-	-	-
Mg	2.85	0.0677	10.40	0.0022*	-0.0280
Mn	0.02	0.9810	13.77	0.0005*	-0.0066
Na	1.28	0.2875	17.86	0.0001*	-6.0038
P	1.03	0.3648	0.01	0.9428	-
S	0.73	0.4889	0.00	0.9968	-
Sr	2.66	0.0804	0.08	0.7754	-

Separate canonical variate analyses examined in greater detail the chemical composition of school mackerel otoliths collected from the Queensland east coast and Northern Australian waters. Queensland east coast samples separated into three main groups; (i)Bowen, (ii) Moreton Bay and Rockhampton two year old fish, and (iii) Rockhampton one year old fish (Figure 3.2.23.). Variation in Na and P concentrations were mainly responsible for the apparent separations in Queensland east coast school mackerel samples (89%) based on the first canonical variate (Table 3.2.20.). Differences in Mn concentrations between areas contributed the most in the discrimination of Queensland samples from the second significant canonical function. Bowen fish tended to have lower Na and higher P concentrations than Moreton Bay and Rockhampton samples. Approximately, 75% of the Queensland east coast school mackerel samples were classified into their correct groupings, indicating an improved classification rate for the more specific analysis (Table 3.2.21.).

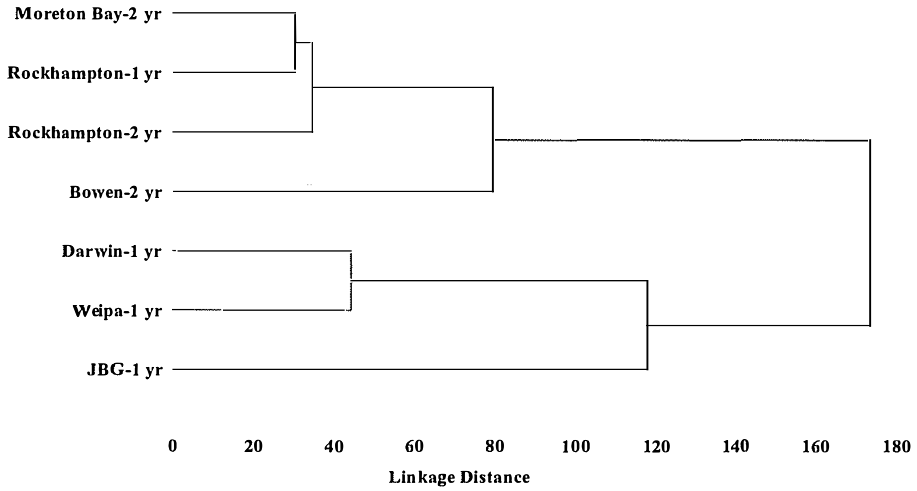


Figure 3.2.21. Classification of school mackerel samples by area, based on the concentrations of 5 elements (P, S, Sr, adjusted Mg, and adjusted Mn) in the otoliths, using an unweighted pair group mean arithmetic sorting strategy and Euclidean distance measures of association.

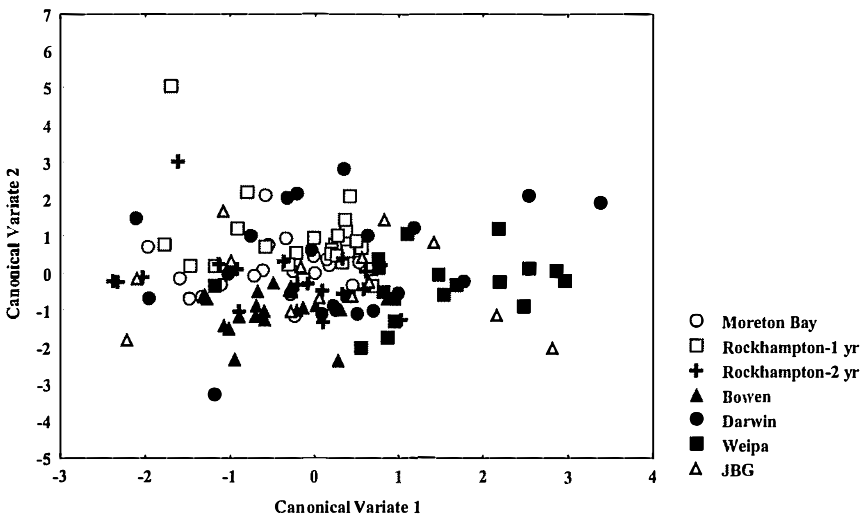


Figure 3.2.22. Discrimination between school mackerel samples from all areas based on the concentrations of the 5 suitable (length corrected) trace elements.

Table 3.2.18. Discrimination between samples of school mackerel from all areas determined by the standardised canonical coefficients for the significant ($p<0.05$) canonical variates (discriminant functions) I, II and III, and the cumulative proportion of the explained variance accounted for by each function, for the 5 significant elements (length corrected) (Wilks' Lambda for overall model=0.423).

Element	Canonical Variate		
	I	II	III
P	-0.59	-0.70	0.11
Sr	1.01	-0.14	0.61
Adj Mg	-0.33	0.70	0.44
S	-0.62	0.15	0.24
Adj Mn	0.09	0.15	-0.56
Cumulative Proportion	0.40	0.76	0.94

Table 3.2.19. Classification matrix of the frequency of assigned cases in each area determined from the discriminant model used to differentiate school mackerel samples from all areas.

Area	Classification of Individual School Mackerel by Area							
	% Correct	JBG (1)	Darwin (1)	Weipa (1)	Bowen (2)	Rock (1)	Rock (2)	Moreton (2)
JBG (1)	21	3	4	1	2	3	0	1
Darwin (1)	15	4	3	2	5	4	0	2
Weipa (1)	63	0	2	12	4	1	0	0
Bowen (2)	82	0	0	1	18	0	1	2
Rock (1)	64	0	4	1	0	16	1	3
Rock (2)	11	0	3	1	5	2	2	5
Moreton (2)	42	0	2	0	4	4	1	8
Total	45	7	18	18	38	30	5	21

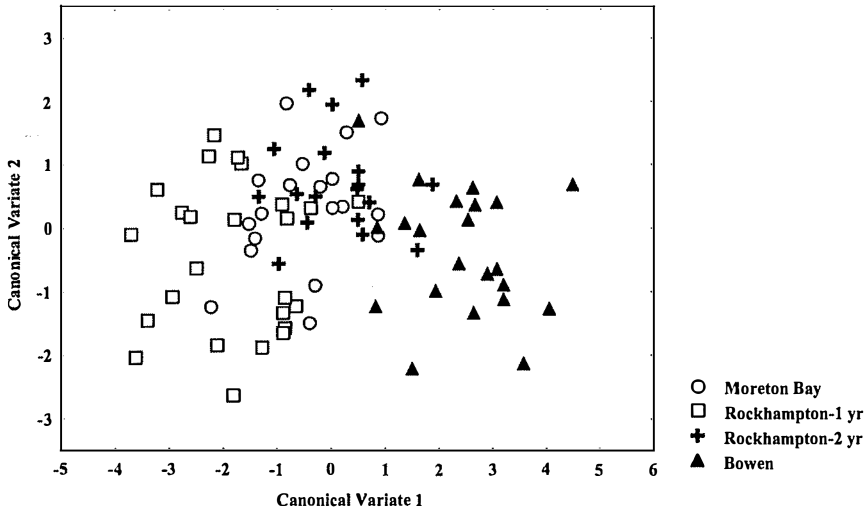


Figure 3.2.23. Discrimination between school mackerel samples from Queensland east coast areas based on the concentrations of the 7 trace elements (length corrected).

Table 3.2.20. Discrimination between samples of school mackerel from Queensland east coast areas determined by the standardised canonical coefficients for the significant ($p<0.05$) canonical variates (discriminant functions) I and II, and the cumulative proportion of the explained variance accounted for by each function, for the 7 significant elements (length corrected) (Wilks' Lambda for overall model=0.203).

Element	Canonical Variate	
	I	II
Na	-0.90	0.31
P	0.69	0.22
Mn	-0.08	-0.80
K	0.21	-0.59
Mg	-0.22	-0.18
S	0.02	0.24
Sr	0.26	-0.40
Cumulative Proportion	0.89	0.97

Table 3.2.21. Classification matrix of the frequency of assigned cases in each area determined from the discriminant model used to differentiate school mackerel samples from Queensland east coast samples.

Area	Classification of Individual School Mackerel by Area				
	% Correct	**Bowen (2)**	**Rock (2)**	**Rock (1)**	**Moreton (2)**
Bowen (2)	91	20	2	0	0
Rock (2)	50	2	9	2	5
Rock (1)	88	0	1	22	2
Moreton (2)	63	0	3	4	12
Total	75	22	15	28	19

Poor separation was observed between school mackerel samples from northern Australian waters (Wilks' lambda=0.609). Darwin and Joseph Bonaparte Gulf fish displayed almost a complete overlap in their elemental canonical distributions (Figure 3.2.24.). Differences between samples in concentrations of Mg in the first canonical variate contributed most to the discrimination (92%) specified by the overall discriminant model (Table 3.2.22.). Approximately, 75% of the northern Australian fish were classified into their correct groupings (Table 3.2.23.).

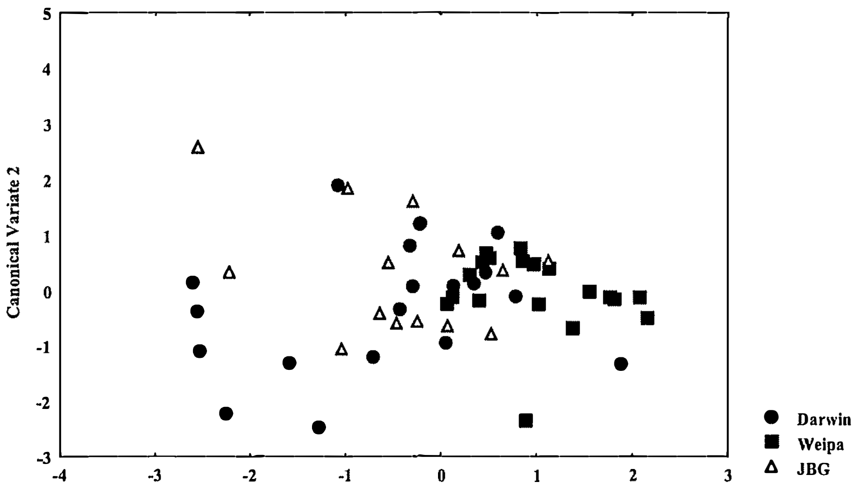


Figure 3.2.24. Discrimination between school mackerel samples from northern Australian areas (excluding Queensland east coast samples) based on the concentrations of the 6 trace elements (length corrected).

Table 3.2.22. Discrimination between samples of school mackerel from northern Australian waters (excluding Queensland east coast samples) determined by the standardised canonical coefficients for the significant ($p<0.05$) canonical variate (discriminant functions) I, and the cumulative proportion of the explained variance accounted for by each function, for the 3 significant elements (length corrected) (Wilks' Lambda for overall model=0.609).

Element	Canonical Variate	
	I	**II**
Adj Mg	-1.03	-0.55
S	-0.73	0.67
Adj Na	0.54	0.43
Cumulative Proportion	0.92	1.00

Table 3.2.23. Classification matrix of the frequency of assigned cases in each area determined from the discriminant model used to differentiate school mackerel samples from northern Australian waters (excluding Queensland east coast samples).

Area	**Classification of Individual School Mackerel by Area**			
	% Correct	**Weipa (1)**	**Darwin (1)**	**JBG (1)**
Weipa (1)	100	19	0	0
Darwin (1)	65	6	13	1
JBG (1)	57	1	5	8
Total	75	26	18	9

3.2.1.5. Genetic Variation

Eight polymorphic loci (*AAT-L*, *AAT-M*, *AH*, *G3PDH*, *GPI*, *IDH*, *LDH* and *PEP*) were selected for school mackerel owing to their apparent genetic variation and ease of interpretation (Table 3.2.24.).

Table 3.2.24. Polymorphic protein loci of school mackerel used in analyses, and conditions for electrophoresis.

Protein	Locus	Subunit Structure	Tissue	Buffer
Aconitate hydratase	*AH*	Monomer	Liver	CAME
Aspartate aminotransferase (liver)	*AAT-L*	Dimer	Liver	CAME
Aspartate aminotransferase (muscle)	*AAT-M*	Dimer	Muscle	EBT
Glucose-3-phosphate dehydrogenase	*G3PDH*	Dimer	Liver	TM
Glucose-6-phosphate isomerase	*GPI*	Dimer	Muscle	TC-1
Isocitrate dehydrogenase	*IDH*	Dimer	Muscle	TC-1
Lactate dehydrogenase	*LDH*	Tetramer	Liver	TM
Pepidase (phe-pro)	*PEP*	Dimer	Muscle	EBT

The mean observed heterozygosities (H_o) estimated for the eight polymorphic loci of school mackerel ranged between 0.080 and 0.208 (mean 0.164 ± 0.053 s.e.) (Table 3.2.25.). No significant relationship existed between sample size and mean observed heterozygosity (r^2=0.005, d.f.=1,21, F=0.106, N.S.). The total mean heterozygosity (H_t) calculated for the polymorphic loci only was 0.172 (± 0.047 s.e.), which was greater than the subpopulation heterozygosity (H_s) (0.168 ± 0.045 s.e.). These calculations resulted in an average F_{st} value of 0.025 (Table 3.2.26.).

G-tests of conformity of the observed genotypes with the expected Hardy-Weinberg distribution, for each locus from each sample, calculated from the allele frequencies, resulted in nine of 184 tests (4.9%) being significantly out of equilibrium (Hervey Bay 1990 *AAT-L**; Hervey Bay 1992 *AAT-M**; Rockhampton 1992 *PEP**; Bowen 1990 *AAT-M*, AH**; Darwin 1992 *GPI*, PEP**; Darwin 1994 *AAT-L, AH**). By chance alone this number of tests could have deviated significantly from Hardy-Weinberg's expected proportions (5% level). In addition, eight of the nine tests differed significantly owing to expected low values of uncommon alleles (noted above as *). For these reasons, it was concluded that the allele frequencies observed in school mackerel samples were consistent with those expected under Hardy-Weinberg equilibrium.

Monthly comparisons within years and areas supported a lack of temporal variation within areas. No significant differences were observed between monthly samples: spawned in 1991 from Moreton Bay and Hervey Bay, spawned in 1992 from Hervey Bay and Rockhampton, or spawned in 1994 from Darwin (Table 3.2.27.). No monthly samples differed for any individual loci, except for those fish spawned in 1992 from Hervey Bay at the *AAT-M* locus (G=8.66, d.f.=3, P<0.05). After pooling of monthly samples, these results were further confirmed by only eight of 112 tests (7.1%) being in disagreement with Hardy-Weinberg's expected values, including the significant *AAT-M* locus for Hervey Bay. All eight tests had low expected genotypes (less than five). Owing to this presumed lack of temporal variation, yearly samples were pooled within areas to increase the statistical power used in the population structure analysis.

Table 3.2.25. School mackerel allele frequencies by year and area (MB =Moreton Bay; HB = Hervey Bay; RK = Rockhampton; TO = Townsville; WE = Weipa; DA = Darwin; JB = Joseph Bonaparte Gulf).

Locus	Allele	Sample Allele Frequency																						
		MB90	MB91	MB92	MB93	HB90	HB91	HB92	HB93	RK90	RK91	RK92	RK93	TO90	TO91	TO92	TO93	WE94	WE95	DA92	DA93	DA94	JB92	JB94
AAT-L	190	0	0.013	0	0	0	0.008	0.008	0	0	0.016	0	0	0	0	0	0	0.021	0.015	0	0	0	0.017	0
	150	0.679	0.655	0.581	0.719	0.667	0.690	0.653	0.857	0.750	0.719	0.642	0.656	0.500	0.652	0.679	0.864	0.708	0.603	0.741	0.745	0.704	0.621	0.808
	100	0.321	0.332	0.412	0.250	0.333	0.286	0.334	0.143	0.250	0.266	0.348	0.336	0.500	0.348	0.321	0.091	0.271	0.382	0.207	0.245	0.294	0.328	0.192
	80	0	0	0.007	0.031	0	0.016	0.005	0	0	0	0.010	0.008	0	0	0	0.045	0	0	0.052	0.009	0.002	0.034	0
	n	*14*	*116*	*68*	*16*	*12*	*63*	*199*	*14*	*16*	*32*	*102*	*122*	*15*	*23*	*14*	*11*	*24*	*34*	*29*	*55*	*228*	*29*	*39*
AAT-M	145	0	0.030	0.029	0	0.125	0.039	0.038	0	0	0	0.009	0.004	0	0	0	0	0	0.015	0	0	0	0	0
	125	0.067	0.030	0.066	0.056	0	0.023	0.036	0	0.088	0.081	0.041	0.057	0.267	0.068	0	0.045	0.042	0.044	0.086	0.080	0.025	0.054	0.064
	100	0.933	0.936	0.897	0.944	0.875	0.930	0.921	1.000	0.912	0.919	0.941	0.934	0.733	0.932	0.962	0.955	0.958	0.926	0.914	0.920	0.968	0.946	0.923
	70	0	0.004	0.007	0	0	0.008	0.005	0	0	0	0.009	0.004	0	0	0.038	0	0	0.015	0	0	0.007	0	0.013
	n	*15*	*118*	*68*	*18*	*12*	*64*	*195*	*14*	*17*	*31*	*111*	*122*	*15*	*22*	*13*	*11*	*24*	*34*	*29*	*50*	*203*	*28*	*39*
AH	115	0	0.009	0.016	0	0.042	0.009	0.013	0	0.063	0.016	0.011	0.008	0.033	0.023	0	0	0.022	0	0.037	0.024	0.032	0.036	0.048
	100	1.000	0.935	0.960	0.969	0.875	0.931	0.911	0.929	0.844	0.938	0.937	0.934	0.900	0.909	0.964	1.000	0.891	0.985	0.889	0.915	0.903	0.893	0.887
	80	0	0.057	0.024	0.031	0.083	0.060	0.075	0.071	0.094	0.047	0.053	0.057	0.067	0.068	0.036	0	0.087	0.015	0.074	0.061	0.065	0.071	0.065
	n	*15*	*115*	*63*	*16*	*12*	*58*	*186*	*14*	*16*	*32*	*95*	*122*	*15*	*22*	*14*	*10*	*23*	*34*	*27*	*41*	*93*	*28*	*31*
GPI	106	0	0	0	0.029	0	0	0.007	0	0	0	0	0	0	0	0	0	0	0	0.019	0.012	0.028	0.022	0
	100	1.000	0.938	0.906	0.882	0.917	0.922	0.900	0.857	0.938	0.917	0.936	0.933	0.867	0.932	0.893	1.000	0.854	0.955	0.808	0.964	0.898	0.913	0.926
	88	0	0.062	0.094	0.088	0.083	0.078	0.090	0.143	0.063	0.083	0.064	0.067	0.133	0.068	0.107	0	0.146	0.045	0.173	0.024	0.075	0.065	0.059
	80	0	0	0	0	0	0	0.002	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0.015
	n	*15*	*121*	*69*	*17*	*12*	*64*	*201*	*14*	*16*	*30*	*110*	*120*	*15*	*22*	*14*	*11*	*24*	*33*	*26*	*42*	*127*	*23*	*34*
G3PDH	150	0	0.009	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
	125	0.167	0.141	0.181	0.100	0.042	0.172	0.131	0.143	0.118	0.078	0.126	0.102	0.133	0.196	0.143	0.045	0.167	0.194	0.040	0.153	0.135	0.173	0.132
	100	0.833	0.842	0.804	0.900	0.958	0.797	0.851	0.857	0.882	0.922	0.864	0.885	0.867	0.804	0.857	0.955	0.833	0.806	0.960	0.847	0.865	0.827	0.868
	80	0	0.009	0.014	0	0	0.031	0.017	0	0	0	0.010	0.012	0	0	0	0	0	0	0	0	0	0	0
	n	*15*	*117*	*69*	*15*	*12*	*64*	*202*	*14*	*17*	*32*	*103*	*122*	*15*	*23*	*14*	*11*	*21*	*31*	*25*	*49*	*74*	*26*	*19*
IDH	175	0	0	0	0	0	0	0	0	0	0	0	0	0	0.023	0	0	0	0	0	0	0	0	0
	140	0	0.016	0.007	0	0	0.023	0.012	0	0.029	0.016	0.005	0.016	0	0	0	0	0.042	0	0.034	0.026	0.002	0	0.025
	100	1.000	0.975	0.993	0.971	1.000	0.969	0.985	1.000	0.971	0.984	0.995	0.984	1.000	0.977	1.000	1.000	0.958	0.985	0.948	0.966	0.996	1.000	0.975
	70	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0.017	0	0.002	0	0
	40	0	0.008	0	0.029	0	0.008	0.002	0	0	0	0	0	0	0	0	0	0	0.015	0	0.009	0	0	0
	n	*15*	*122*	*69*	*17*	*12*	*64*	*202*	*14*	*17*	*32*	*111*	*122*	*15*	*22*	*14*	*11*	*24*	*34*	*29*	*58*	*233*	*29*	*40*
LDH	200	0	0.004	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0.015	0	0	0	0	0
	150	0	0.004	0.007	0	0	0.016	0.005	0	0	0	0.005	0.004	0	0	0.036	0	0	0	0.019	0.021	0.004	0.020	0
	100	1.000	0.992	0.993	1.000	1.000	0.984	0.995	1.000	1.000	1.000	0.990	0.996	1.000	1.000	0.964	1.000	1.000	0.985	0.981	0.979	0.996	0.980	1.000
	45	0	0	0	0	0	0	0	0	0	0	0.005	0	0	0	0	0	0	0	0	0	0	0	0
	n	*15*	*118*	*69*	*16*	*12*	*64*	*200*	*14*	*17*	*32*	*100*	*122*	*15*	*3*	*14*	*11*	*24*	*34*	*27*	*47*	*139*	*25*	*29*
PEP	111	0	0	0	0	0	0	0	0	0	0.016	0.014	0.029	0	0.023	0	0	0.021	0.029	0.089	0.027	0.027	0.054	0.014
	100	0.900	0.891	0.942	0.941	0.875	0.875	0.856	0.893	0.882	0.813	0.845	0.844	0.900	0.841	0.857	0.818	0.813	0.912	0.768	0.893	0.902	0.857	0.932
	85	0.100	0.109	0.058	0.059	0.125	0.125	0.139	0.107	0.118	0.172	0.141	0.127	0.100	0.136	0.143	0.182	0.167	0.059	0.143	0.080	0.071	0.089	0.054
	n	*15*	*119*	*69*	*17*	*12*	*64*	*202*	*14*	*17*	*32*	*110*	*122*	*15*	*22*	*14*	*11*	*24*	*34*	*28*	*56*	*219*	*28*	*37*
Mean Hs		0.127	0.169	0.174	0.143	0.168	0.187	0.188	0.132	0.175	0.165	0.169	0.168	0.215	0.189	0.166	0.089	0.203	0.160	0.210	0.165	0.160	0.193	0.150
s.e.		0.058	0.050	0.058	0.046	0.052	0.049	0.050	0.041	0.042	0.048	0.053	0.051	0.061	0.053	0.050	0.042	0.050	0.058	0.050	0.041	0.048	0.057	0.035
Mean Ho		0.129	0.171	0.167	0.153	0.208	0.162	0.172	0.152	0.205	0.162	0.164	0.162	0.142	0.205	0.188	0.080	0.182	0.150	0.175	0.168	0.140	0.210	0.132
s.e.		0.067	0.053	0.058	0.049	0.076	0.039	0.051	0.048	0.055	0.052	0.047	0.052	0.050	0.066	0.059	0.036	0.049	0.065	0.050	0.045	0.041	0.068	0.035

Table 3.2.26. Mean F-statistics for the eight polymorphic loci examined from the individual yearly school mackerel samples (N.S., not significant).

Locus	F_{is}	F_{it}	F_{st}	G	d.f.	P
AAT-L	-0.038	-0.004	0.033	89.634	66	p<0.05
AAT-M	0.238	0.269	0.041	113.627	66	p<0.001
AH	0.113	0.129	0.018	39.698	44	N.S.
GPI	0.051	0.073	0.024	68.465	66	N.S.
G3PDH	-0.024	-0.005	0.018	54.396	66	N.S.
IDH	-0.028	-0.012	0.015	58.424	88	N.S.
LDH	-0.020	-0.006	0.013	27.830	66	N.S.
PEP	-0.016	0.001	0.016	78.446	44	p<0.01
Mean	0.022	0.046	0.025			
Total				530.481	506	N.S.

Table 3.2.27. Contingency log likelihood ratio (G) tests for temporal comparisons between school mackerel samples (N.S., not significant).

Comparison	Total Loci			Significant Loci			
	G	d.f.	P	Locus	G	d.f.	P
Moreton Bay 1991(Jan; Nov; Dec)	32.315	40	N.S.	-	-	-	N.S.
Hervey Bay 1991(Sep; Oct)	24.659	21	N.S.	-	-	-	N.S.
Hervey Bay 1992 (Sep; Oct)	25.522	21	N.S.	*AAT-M*	8.655	3	p<0.05
Rockhampton 1992 (Jun; Jul)	23.260	2	N.S.	-	-	-	N.S.
Darwin 1994 (Aug; Sep)	15.580	20	N.S.	-	-	-	N.S.
Moreton Bay (90; 91; 92; 93)	54.709	63	N.S.	-	-	-	N.S.
Hervey Bay (90; 91; 92; 93)	38.618	66	N.S.	-	-	-	N.S.
Hervey Bay (91; 92)	11.857	22	N.S.	-	-	-	N.S.
Rockhampton (90; 91; 92; 93)	31.330	60	N.S.	-	-	-	N.S.
Rockhampton (92; 93)	7.191	20	N.S.	-	-	-	N.S.
Townsville (90; 91; 92; 93)	51.169	51	N.S.	-	-	-	N.S.
Weipa (94; 95)	21.953	18	N.S.	-	-	-	N.S.
Darwin (92; 93; 94)	62.907	40	N.S.	*GPI*	10.529	4	p<0.05
Darwin (93; 94)	25.395	20	N.S.	N.S.	N.S.	N.S.	N.S.
Joseph Bonaparte Gulf (92; 94)	19.798	19	N.S.	*AAT-L*	9.136	3	p<0.05

The overall F_{st} value of 0.025 calculated for all samples was lower than the equivalent G_{st} measure (0.062), averaged for a range of marine species (Ward *et al.* 1994). Significant variation existed between areas when yearly samples within areas were pooled (G=250.00, d.f.=138, P<0.001), while the F_{st} population differentiation measure decreased to 0.005 (Table 3.2.28.).

Significant spatial variation was present at *AAT-M*, *GPI*, *G3PDH* and *PEP* loci. Confirmation of pooled results was supported by most of the loci for the pooled samples being in agreement with Hardy-Weinberg expected proportions. Seven tests conflicted with expected values (Moreton Bay *AAT-M*; Hervey Bay *AAT-M*; Townsville *AAT-M*; Weipa *GPI*; Darwin *AAT-L*, *AH*, *GPI*), although six of the tests differed significantly owing to expected low values of uncommon alleles.

Table 3.2.28. Mean *F*-statistics for the eight polymorphic loci examined from the pooled yearly school mackerel samples (N.S., not significant).

Locus	F_{is}	F_{it}	F_{st}	*G*	d.f.	P
AAT-L	0.017	0.021	0.005	24.840	18	N.S.
AAT-M	0.278	0.283	0.007	60.761	18	p<0.001
AH	0.164	0.168	0.005	15.337	12	N.S.
GPI	0.106	0.108	0.002	31.150	18	p<0.05
G3PDH	0.010	0.014	0.004	29.344	18	p<0.05
IDH	-0.015	-0.012	0.002	23.293	24	N.S.
LDH	-0.008	-0.006	0.001	12.624	18	N.S.
PEP	-0.006	0.000	0.006	52.650	12	p<0.001
Mean	0.061	0.065	0.005			
Total				249.998	138	p<0.001

Relationships between pooled spatial samples and population structuring are evident in the UPGMA dendrogram, based on Rogers' genetic distance (Figure 3.2.25.). Northern Territory fish form a distinct genetic group from Queensland east coast and Weipa samples. Areas within the east coast group tended to be more closely related to their neighbouring regions, except for Moreton Bay samples that clustered with the small Weipa sample.

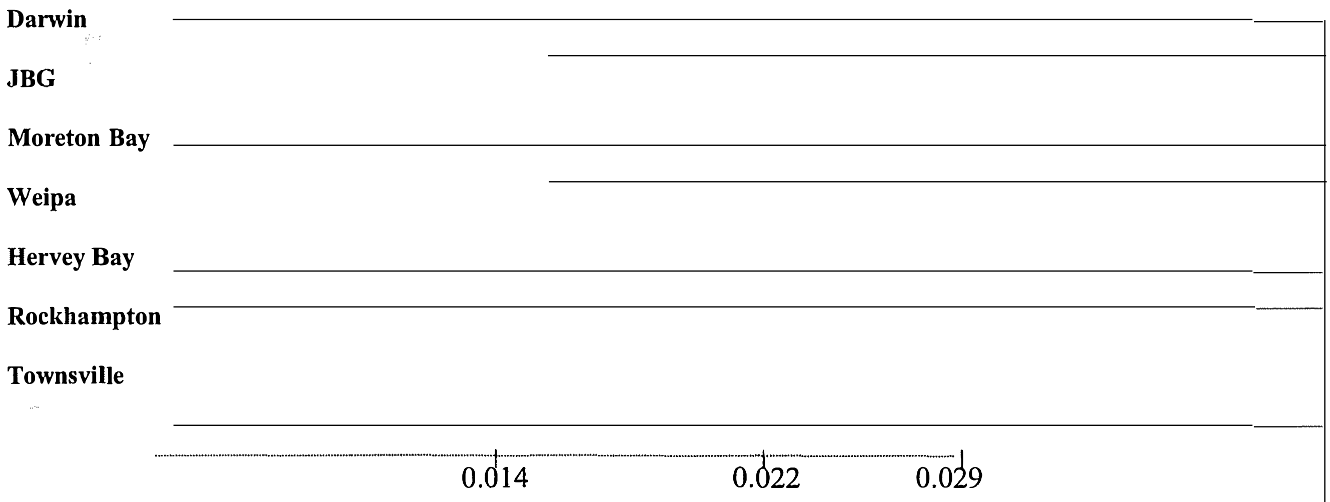


Figure 3.2.25. UPGMA dendrogram of pooled yearly school mackerel samples by area, based on Rogers' genetic distance.

Individual pairwise comparisons between areas were used to interpret these spatial genetic differences (Table 3.2.29.). No significant differences were found between Darwin and Joseph Bonaparte Gulf samples, confirming their validity as a separate cluster. Weipa fish differed from the pooled Northern Territory samples at the *AAT-L* locus, although this difference may have been an artefact of low sample sizes and the locus itself deviating from Hardy-Weinberg expected values. Weipa samples differed significantly from those for Moreton Bay at the *PEP* locus suggesting that these are from isolated genetic stocks.

Areas along the Queensland east coast were differentiated from each other by a single locus. Moreton Bay samples were significantly different than those from Hervey Bay and

Rockhampton at the *PEP* locus. Similarly, Rockhampton samples varied from Townsville specimens at the *IDH* locus. In contrast, Hervey Bay collections differed significantly from Rockhampton samples overall, and at the *AAT-M* and *PEP* loci. These differences at the individual loci were supported by all of them being in agreement with Hardy-Weinberg's expected values, except for *AAT-M* (Table 3.2.29.).

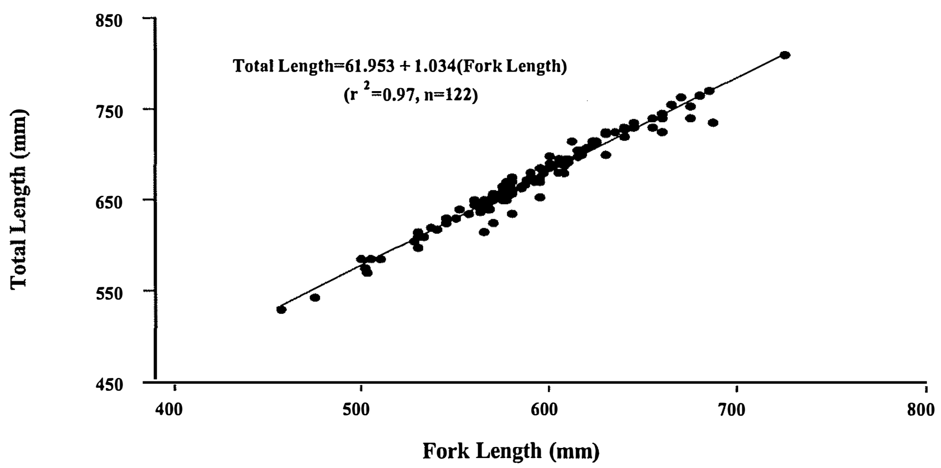
Table 3.2.29. Contingency log likelihood ratio (*G*) tests for spatial comparisons between pooled yearly school mackerel samples (N.S., not significant).

Comparison	**Total Loci**			**Significant Loci**			
	G	**d.f.**	**P**	**Locus**	***G***	**d.f.**	**P**
Moreton Bay vs Hervey Bay	28.440	22	N.S.	*PEP*	7.456	2	p<0.05
Moreton Bay vs Rockhampton	49.160	22	p<0.001	*PEP*	18.130	2	p<0.001
Moreton Bay vs Weipa	19.415	21	N.S.	*PEP*	9.786	2	p<0.01
Moreton Bay vs (Darwin and JBG)	89.109	22	p<0.001	*AAT-M*	21.229	3	p<0.001
				AH	9.387	2	p<0.05
				GPI	8.895	3	p<0.05
				G3PDH	8.557	3	p<0.05
				PEP	23.053	2	p<0.001
Hervey Bay vs Rockhampton	48.220	23	p<0.005	*AAT-M*	21.538	3	p<0.001
				PEP	7.364	2	p<0.05
Rockhampton vs Townsville	16.008	20	N.S.	*IDH*	6.211	2	p<0.05
Darwin vs Joseph Bonaparte Gulf	12.095	21	N.S.	-	-	-	N.S.
Weipa vs (Darwin and JBG)	31.568	21	N.S.	*AAT-L*	8.653	3	p<0.05

3.2.2. Spotted Mackerel

3.2.2.1. Age, Growth and Mortality

Spotted mackerel have a significant linear relationship between total length and fork length (F=3393.21, d.f.=1, 120, P<0.0001). Similar length-weight regression slopes (ANCOVA, F=1.53, d.f.=1, 500, N.S.) and intercepts (ANCOVA, F=2.94, d.f.=1, 501, N.S.) were estimated for spotted mackerel sexes (Figure 3.2.26. and Table 3.2.30.).



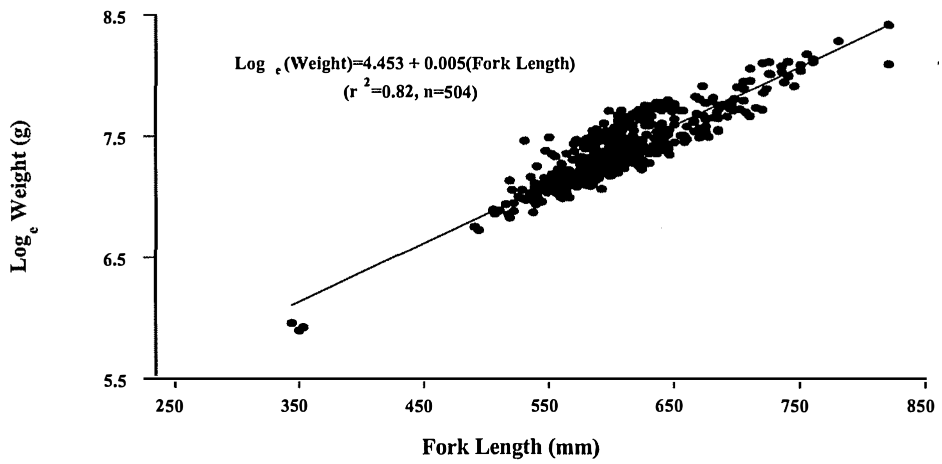


Figure 3.2.26. Total length (mm), log$_e$ transformed weight (g)-fork length (mm) relationships of spotted mackerel (sexes and regions combined).

Table 3.2.30. Total length (mm), $\log_e$ transformed (Ln) weight (g)-fork length (mm) relationships of spotted mackerel (regions combined).

Species	Relationship	Intercept s. e.	Slope s. e.	n	r^2
Females	Log_e(weight)=4.469+0.005(fork length)	0.066	0.0001	223	0.90
Males	Log_e(weight)=4.316+0.005(fork length)	0.129	0.005	281	0.66
Combined	Log_e(weight)=4.453+0.005(fork length)	0.063	0.0001	504	0.81
Combined	Total Length=61.953+1.034(fork length)	10.500	0.018	122	0.97

Whole otoliths were more precisely aged than sectioned ones for spotted mackerel owing to their greater readability and clarity. A total of 1368 (91%) spotted mackerel whole otoliths were aged identically between readers. Whole otoliths were therefore used for age and growth assessments. Monthly differences in the marginal increments of one year old spotted mackerel otoliths, indirectly validated the use of whole otoliths as annual ageing structures (*1*-way ANOVA, F=35.38, d.f.=6,392, P<0.0001). Additional age classes for spotted mackerel could not be assessed for marginal analyses as the final band of older fish typically extended to the edge of the otolith. Otolith marks appeared to be formed from August to December. Marginal increments were significantly lower in the later months of the year (HSD) (Figure 3.2.27.).

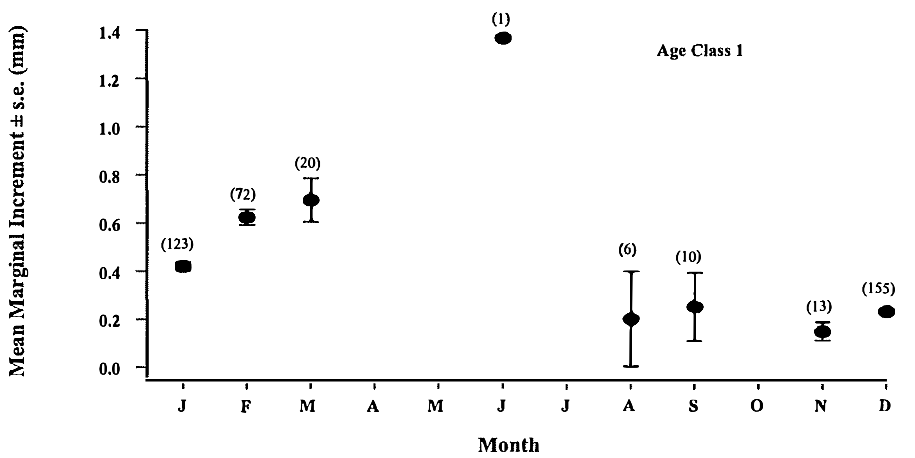


Figure 3.2.27. Monthly mean marginal increments (mm) ± standard errors of spotted mackerel age class 1. The numbers in parentheses above each data point refer to the numbers of fish for which marginal increments were measured.

Female spotted mackerel aged were between 410 and 860 mm. Males aged ranged in length from 360 to 751 mm. Spotted mackerel females were aged to five and males to seven years (Figure 3.2.28.). Distinct sex specific growth curves were observed for spotted mackerel (χ^2=1061.3, d.f.=3, P<0.0001), with females appearing to grow faster and reaching a greater theoretical maximum length than males (Table 3.2.31.). Fish of each sex displayed similar growth characteristics regardless of the region in which they were caught (Figure 3.2.29.).

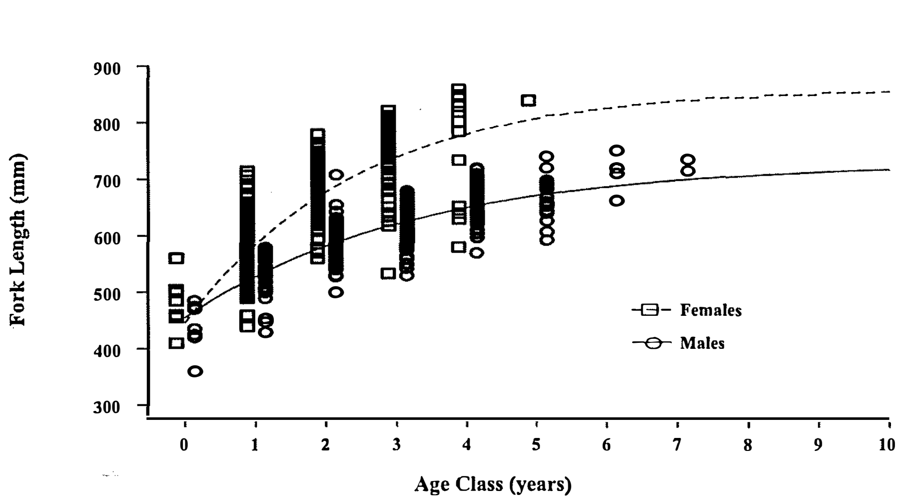


Figure 3.2.28. Von Bertalanffy growth curves fitted to observed age and fork length (mm) data of each spotted mackerel sex (regions combined).

Table 3.2.31. Von Bertalanffy growth parameters (± 95% confidence intervals) calculated from direct length-at-age data of spotted mackerel.

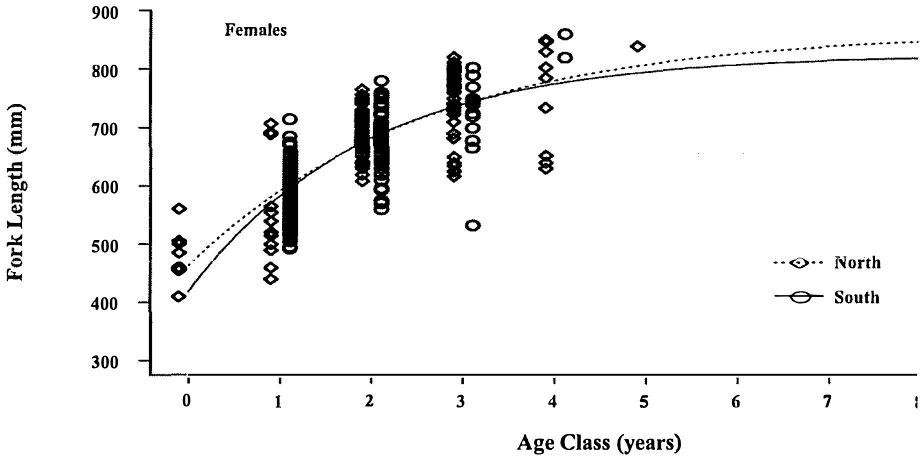
Sex	Region	n	L_∞ (95% c. i.)	K (95% c. i.)	t_0 (95% c. i.)
Females	Northern	169	866 (772, 959)	0.390 (0.222, 0.558)	-1.960 (-2.647, -1.273)
	Southern	497	826 (724, 928)	0.521 (0.209, 0.833)	-1.357 (-2.213, -0.500)
	Combined	674	862 (804, 919)	0.410 (0.296, 0.524)	-1.783 (-2.224, -1.342)
Males	Northern	351	734 (702, 766)	0.339 (0.261, 0.418)	-2.531 (-3.126, -1.936)
	Southern	340	727 (666, 788)	0.272 (0.142, 0.401)	-3.998 (-5.593, -2.402)
	Combined	694	729 (702,756)	0.313 (0.246, 0.380)	-3.134 (-3.765, -2.503)

Spotted mackerel otolith radius-fork length regression slopes were significantly different between sexes (ANCOVA, F=4.66, d.f.=1, 1314, P<0.0310), and for their intercepts (ANCOVA, F=160.04, d.f.=1, 1315, P<0.0001). Male spotted mackerel have a significantly faster otolith growth rate than females (Figure 3.2.30. and Table 3.2.32.).

Back-calculated data suggested spotted mackerel grew more quickly than school mackerel in their first year of life. Comparable annual growth increments were observed between species after that early phase. The mean length at age of female spotted mackerel was greater than that of males at all ages (Tables 3.2.33. and 3.2.34.). Estimated von Bertalanffy growth parameters from back-calculated length at age data were generally larger than direct length at age computed parameters (Tables 3.2.31. and 3.2.35.). Confidence in estimates from back-calculated values was lower than for direct length-at-age estimates owing to the greater variation in back-calculated values, particularly for males. Different growth curves were evident for spotted mackerel sexes. Females grew at a faster rate and attained a greater maximum length than males (Figure 3.2.31.).

Otolith weight was a more precise estimator of age than otolith radius for spotted mackerel (Table 3.2.36.). Male spotted mackerel grew at faster rates than females both in otolith weight (ANCOVA, F=193.89, d.f.=1,1093, P<0.0001) and radius (ANCOVA, F=49.02, d.f.=1,1298, P<0.0001) (Figures 3.2.32. and 3.2.33.).

Females



Males

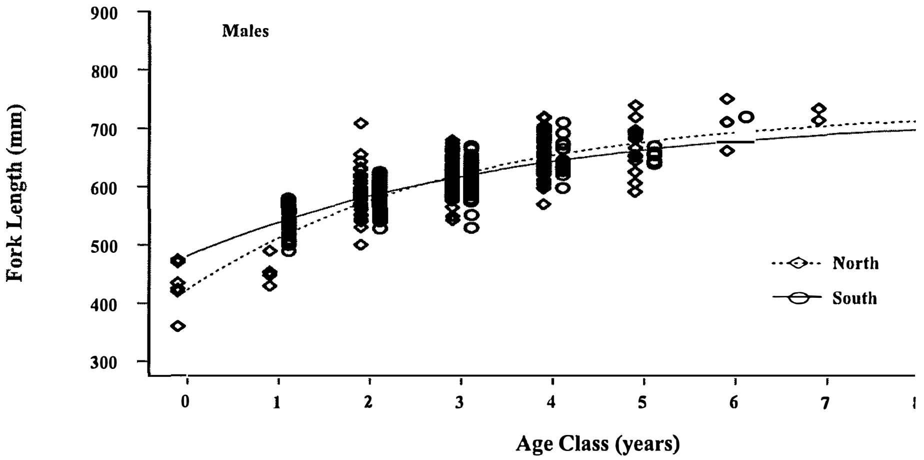
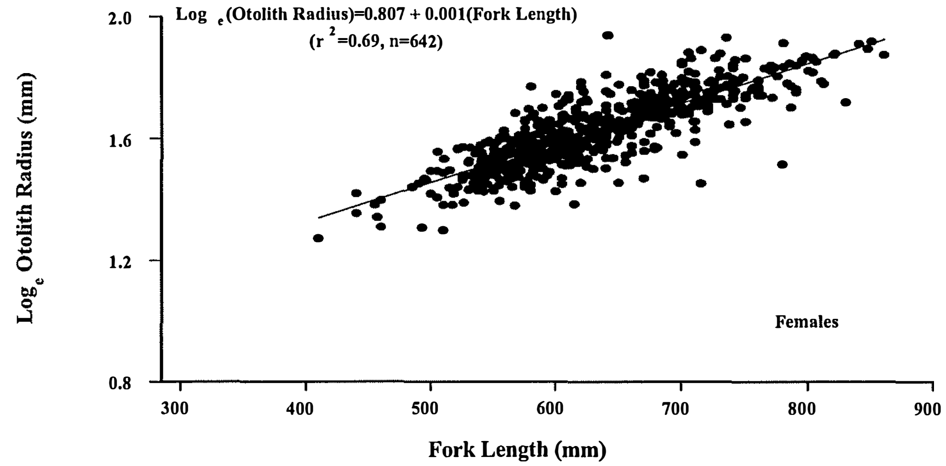


Figure 3.2.29. Von Bertalanffy growth curves fitted to observed age and fork length (mm) data of each spotted mackerel sex and region.

Females



Males

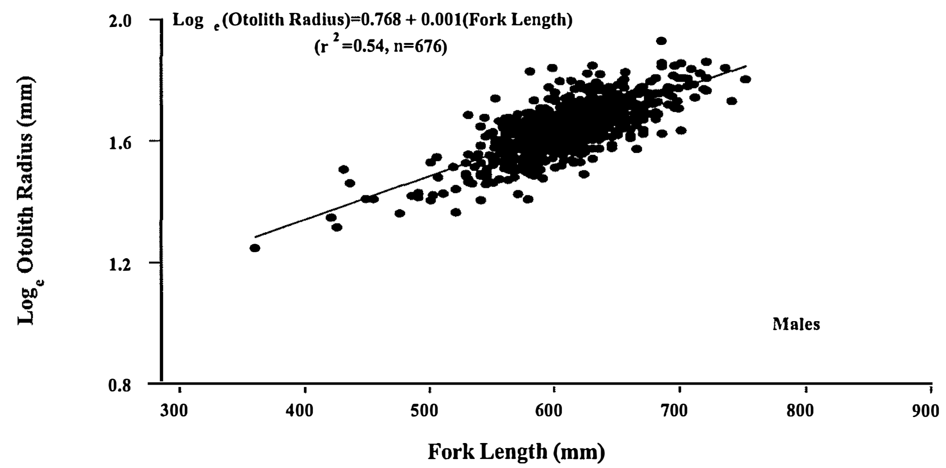


Figure 3.2.30. Log_e transformed otolith radius-fork length (mm) relationships for back-calculation purposes of spotted mackerel (regions combined).

Table 3.2.32. Log_e transformed (Ln) otolith radius-fork length (mm) relationships for back-calculation purposes of spotted mackerel (regions combined).

Species	Relationship	Intercept s. e.	Slope s. e.	n	r^2
Females	Ln(ot.rad.)=-3.711+0.829 Ln(fork lgth)	0.141	0.022	642	0.69
Males	Ln(ot.rad.)=-3.763+0.844 Ln(fork lgth)	0.194	0.030	676	0.54

Table 3.2.33. Mean back-calculated fork lengths (mm) of female spotted mackerel (regions combined).

Age (years)	n	Mean length at capture (mm)	Mean back-calculated length (mm) at age (years) 1	2	3	4	5
1	357	584	515				
2	203	684	514	694			
3	37	753	510	686	756		
4	5	787	513	707	782	819	
5	1	840	514	703	794	832	849
n			603	246	43	6	1
Mean length (mm)			513	698	777	825	849
Annual growth increment (mm)			513	185	80	48	24

Table 3.2.34. Mean back-calculated fork lengths (mm) of male spotted mackerel (regions combined).

Age (years)	n	Mean length at capture (mm)	Mean back-calculated length (mm) at age (years) 1	2	3	4
1	41	534	471			
2	226	583	455	579		
3	442	620	436	583	627	
4	30	658	453	589	645	683
n			739	698	472	30
Mean length (mm)			454	584	636	683
Annual growth increment (mm)			454	130	53	47

Table 3.2.35. Von Bertalanffy growth parameters (± 95% confidence intervals) calculated from mean back-calculated length at age data of spotted mackerel (regions combined).

Species	L_∞ (95% c. i.)	K (95% c. i.)	t_0 (95% c. i.)
Females	867 (834,899)	0.711 (0.527,0.894)	-0.263 (-0.570,0.043)
Males	718 (319,1118)	0.633 (-1.502,2.769)	-0.585 (-4.894,3.725)

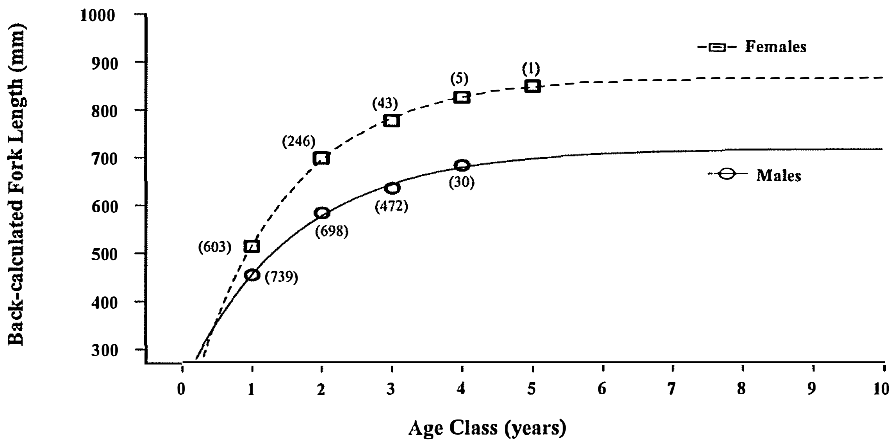
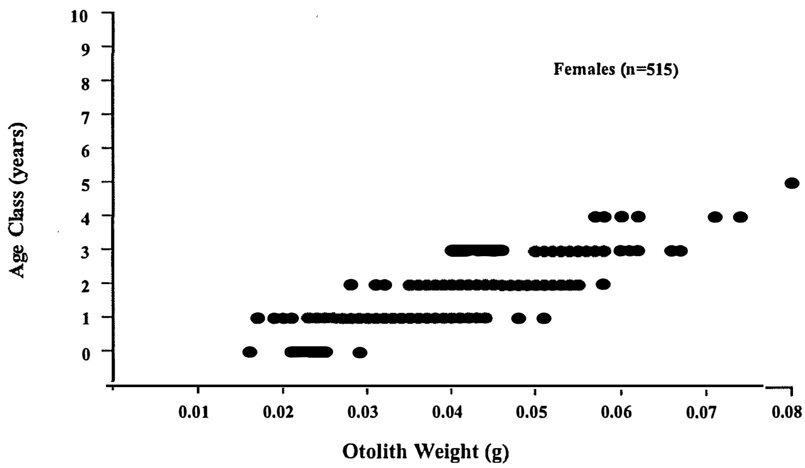


Figure 3.2.31. Von Bertalanffy growth curves fitted to mean back-calculated age and fork length (mm) data of each spotted mackerel sex (regions combined). The numbers in parentheses adjacent to each data point refer to the number of fish of each sex for which back-calculated lengths at each age were estimated.

Table 3.2.36. Otolith weight (g), radius (mm) and age (years) relationships of spotted mackerel (regions combined).

Sex	Relationship	n	r^2
Females	Age=-0.925+64.5(otolith weight)	514	0.75
Females	Age=-3.013+0.888(otolith radius)	632	0.52
Males	Age=-1.807+116.2(otolith weight)	581	0.65
Males	Age=-4.422+1.388(otolith radius)	668	0.40

F emales



Males

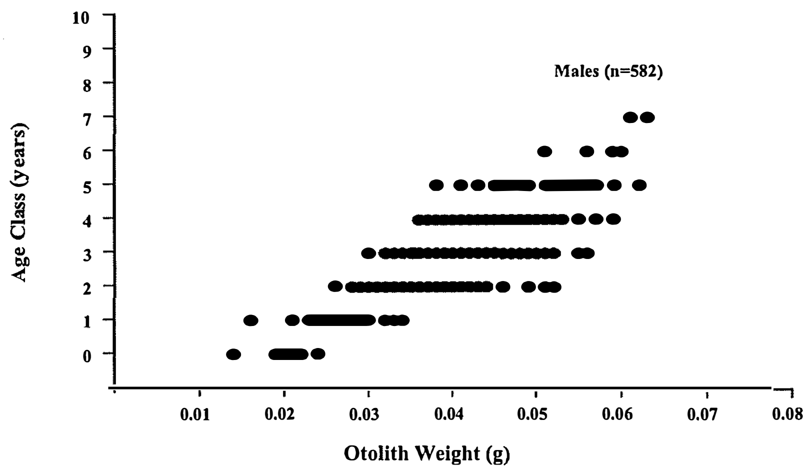
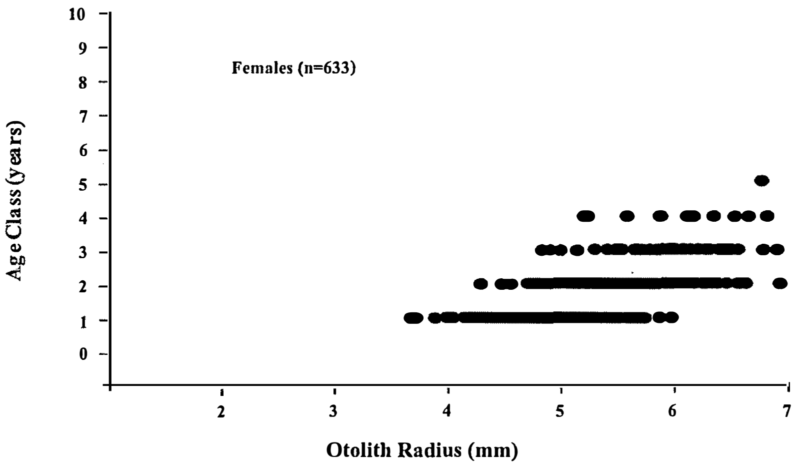


Figure 3.2.32. Relationships of otolith weight (g) and age (years) of spotted mackerel (regions combined).

Females



Males

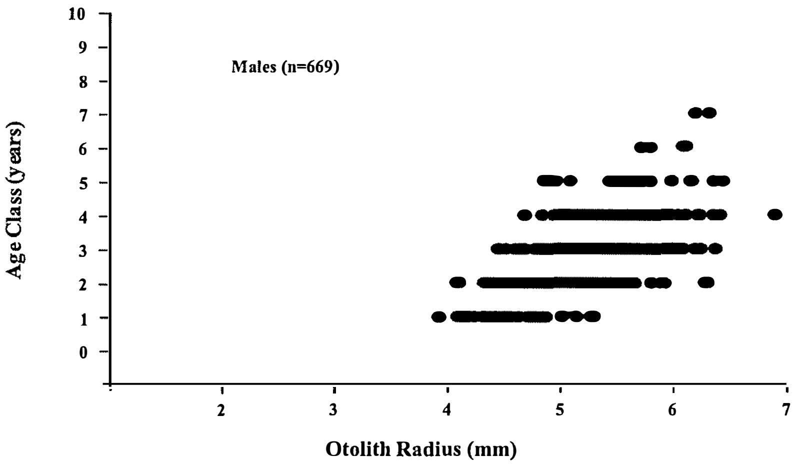


Figure 3.2.33. Relationships of otolith radius (mm) and age (years) of spotted mackerel (regions combined).

Instantaneous mortality rates of spotted mackerel ranged from 0.579 to 1.839. Female spotted mackerel appear to have a greater mortality rate than males. Approximately 33% of the total population appear to survive each year. Spotted mackerel were recruited to all fishing practices by three years of age (Table 3.2.37.).

Table 3.2.37. Spotted mackerel instantaneous mortality and survival rates by sex, region and gear type (*Z*=total instantaneous mortality rate; *S*=e^{-z} survival rate; A=1-e^{-z} annual mortality rate).

Sex	Capture method and region	n	Recruitment age (years)	Mortality estimates		
				Z	S	A
Females	Line	187	1	1.037	0.355	0.645
	10 cm net	353	1	1.839	0.159	0.841
	12.5 cm net	117	2	1.282	0.277	0.723
	Northern region	146	2	1.184	0.306	0.694
	Southern region	497	1	1.765	0.171	0.829
	Total	663	1	1.167	0.311	0.689
Males	Line	93	2	0.579	0.560	0.440
	10 cm net	263	2	1.085	0.338	0.662
	12.5 cm net	248	3	1.183	0.306	0.694
	Northern region	294	3	1.239	0.290	0.710
	Southern region	296	2	1.112	0.329	0.671
	Total	639	2	1.079	0.340	0.660

3.2.2.2. Reproduction

Reproductive development was differentiated into six macroscopic and histological stages for females, and four stages for males (Tables 3.1.1. and 3.1.2.). A logical pattern of increasing weight change in the gonads (up to stage V for females and III for males) represented by GSIs was observed for each stage, supporting the validity of the development schemes (Figures 3.2.34. and 3.2.35.). Female (G=396.7, d.f.=25, P<0.001; V=0.537) and male (G=148.6, d.f.=9, P<0.001; V=0.319) macroscopic and histological staging schemes were closely related, further confirming the validity of the staging schemes for spotted mackerel.

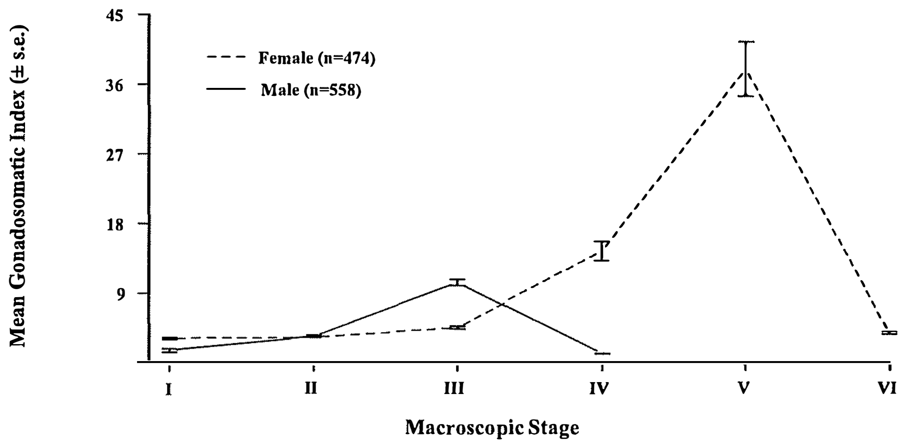


Figure 3.2.34. Pattern of mean gonadosomatic index (± standard error) with increasing macroscopic stage of spotted mackerel gonads.

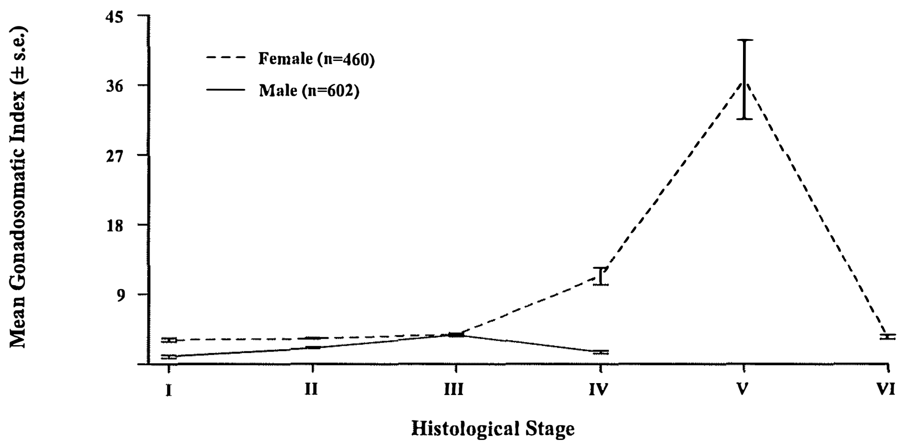


Figure 3.2.35. Pattern of mean gonadosomatic index (± standard error) with increasing histological stage of spotted mackerel gonads.

Monthly GSIs did not differ between regions within the same year for spotted mackerel. Monthly samples were therefore pooled across regions. However, monthly differences in GSIs were evident between years, particularly at the initial and final periods of spawning. GSIs of female spotted mackerel differed significantly between years during August (modified unequal variances t=2.7423, d.f.=77.9, P<0.008) and December ($\log_e$ transformed 1-way ANOVA, F=3.55, d.f.=2,187, P<0.05). Males differed throughout August (modified unequal variances t=2.8493, d.f.=33.0, P<0.008), September (t=4.4803, d.f.=166, P<0.0001) and December ($\log_e$ transformed 1-way ANOVA, F=6.34, d.f.=2,126, P<0.01).

Spotted mackerel have increased GSIs from August to October (Figure 3.2.36.). The bulk of the stock appear to aggregate for spawning in northern Queensland waters from Mackay to Townsville.

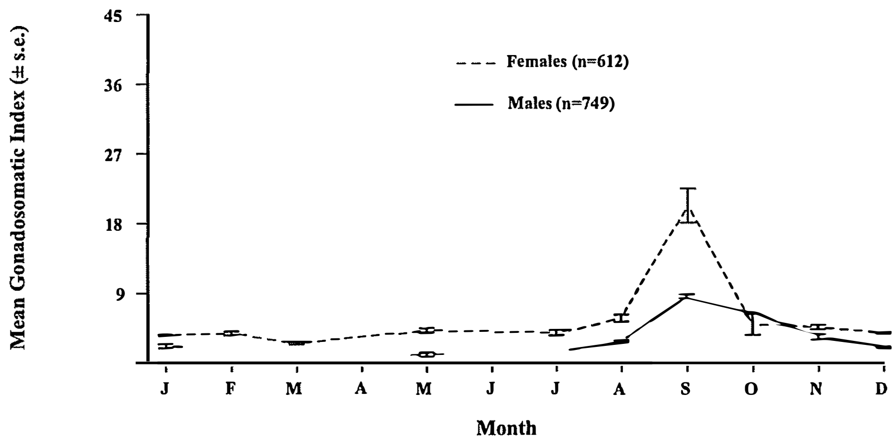
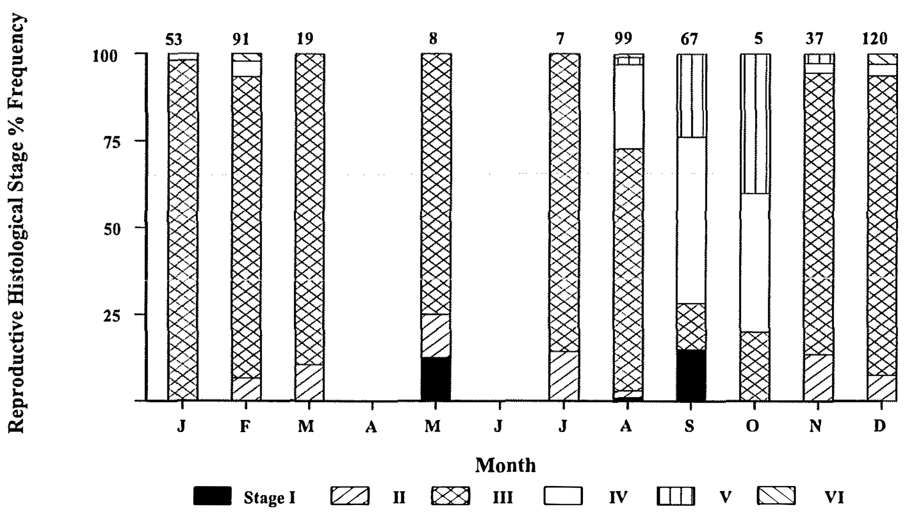


Figure 3.2.36. Monthly mean GSIs (± standard errors) of mature spotted mackerel (female histological female II-VI, and male stages II-IV).

Similar trends in GSIs were evident for both sexes throughout the year. Female spotted mackerel had peak GSIs during September, which was significantly greater than the rest of the year (HSD). Female GSIs were also significantly greater in August than the summer months (HSD). Males were significantly more developed during August, September and October compared to the remaining months (HSD). Male GSIs were also significantly greater in November than in the summer, autumn and early winter periods (HSD). Female spotted mackerel were in spawning condition from August to November, which coincided with the months in which GSIs were highest. In contrast, males were in advanced stages of maturity for most of the year (Figure 3.2.37.).

Females



Males

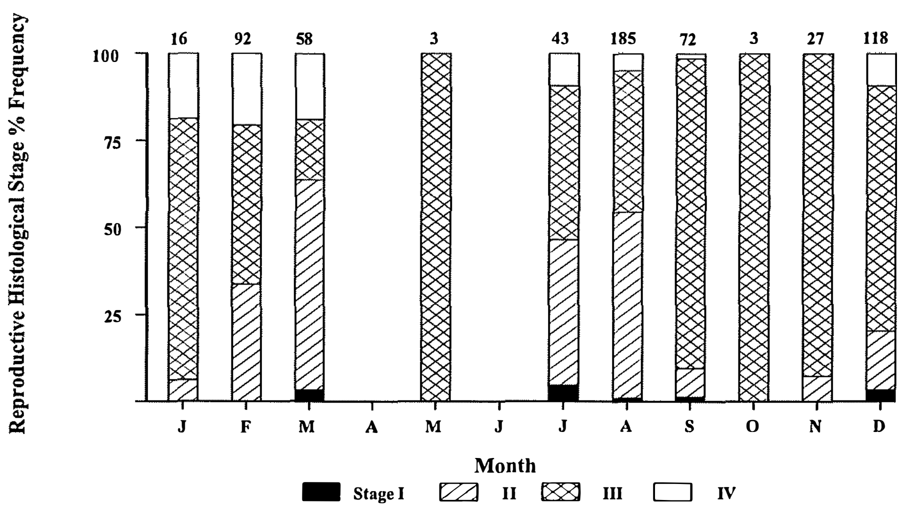
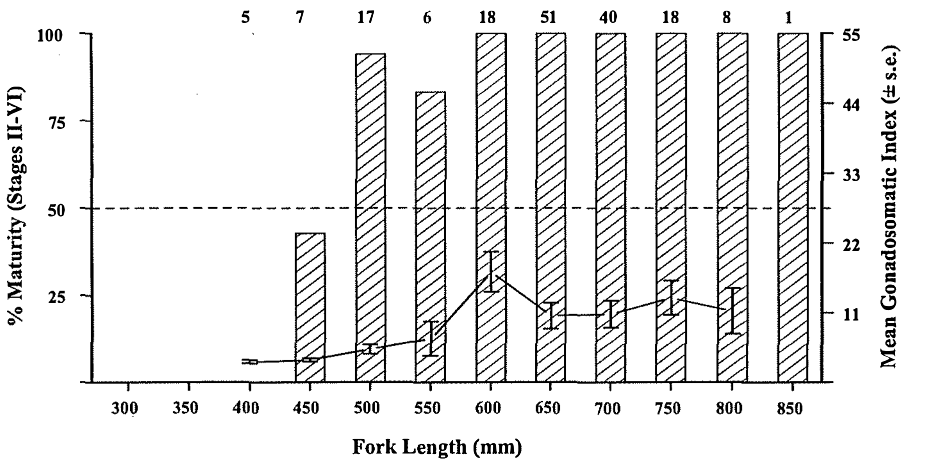


Figure 3.2.37. Monthly proportions of histological stages in spotted mackerel. The numbers above each bar refer to the number of fish staged for that month.

The smallest ripe female spotted mackerel caught was 465 mm and the largest immature female was 580 mm (see Materials and Methods section - all lengths referred to are fork lengths in mm, unless otherwise stated). The smallest mature male measured 420 mm, and the largest immature male 454 mm. At least 50% of the females between 500 to 549 mm reached first maturity throughout their peak spawning months of August to October. The length class was 400 to 449 mm when 50% of males were classified as mature. Females between 550 to 600 mm fork lengths was when the greatest size-related difference in GSIs occurred between consecutive size classes. Males have the largest size-related difference in GSIs between 450 and 500 mm (Figure 3.2.38.). Most spotted mackerel captured by the dominant gear types were larger than the estimated sizes at sexual maturity. The current legal minimum length of 500 mm total length was greater than the initial maturity length for male spotted mackerel, but not for females (Figure 3.2.38.).

Females



Males

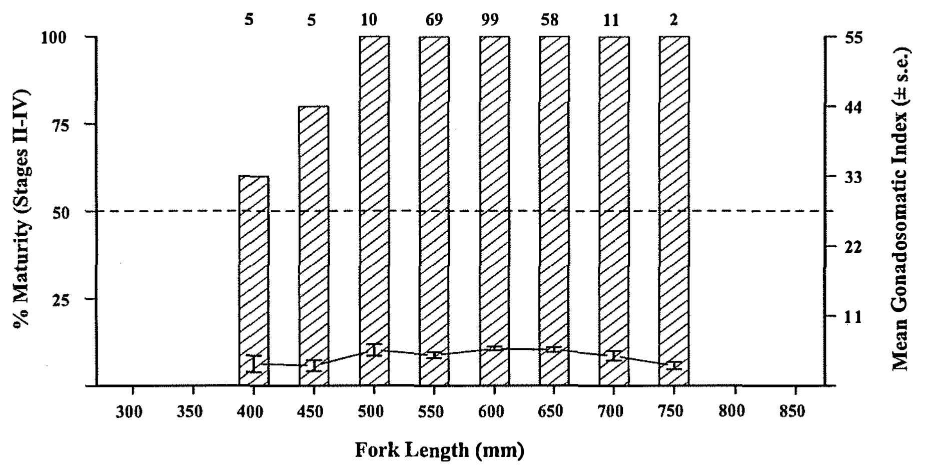


Figure 3.2.38. Fork length (mm) of spotted mackerel at first maturity determined by 50% histological maturity stage and mean gonadosomatic index (± standard error) for peak spawning months of August to October. The numbers above each bar refer to the number of fish staged for each length class.

Spotted mackerel catches were female biased in January (χ^2=39.84, d.f.=1, P<0.05) and December (χ^2=18.23, d.f.=1, P<0.05) and male biased during March (χ^2=19.50, d.f.=1, P<0.05), July (χ^2=25.41, d.f.=1, P<0.05), August (χ^2=28.50, d.f.=1, P<0.05) and September (χ^2=10.93, d.f.=1, P<0.05). Spotted mackerel caught over 800 mm were all females. Females were also more abundant between 700 to 749 mm (χ^2=45.01, d.f.=1, P<0.05), 750 to 799 mm (χ^2=38.52, d.f.=1, P<0.05) and 500 to 549 mm (χ^2=10.20, d.f.=1, P<0.05). Males were more abundant between 550 to 599 mm (χ^2=7.25, d.f.=1, P<0.05) and 600 to 649 mm (χ^2=53.23, d.f.=1, P<0.05) (Figure 3.2.39.).

Spotted mackerel have a significant linear relationship between mean advanced stage oocyte diameter and fish length (Figure 3.2.40.). Significant linear relationships also existed between fish length and total potential fecundity for spotted mackerel (Figure 3.2.41.).

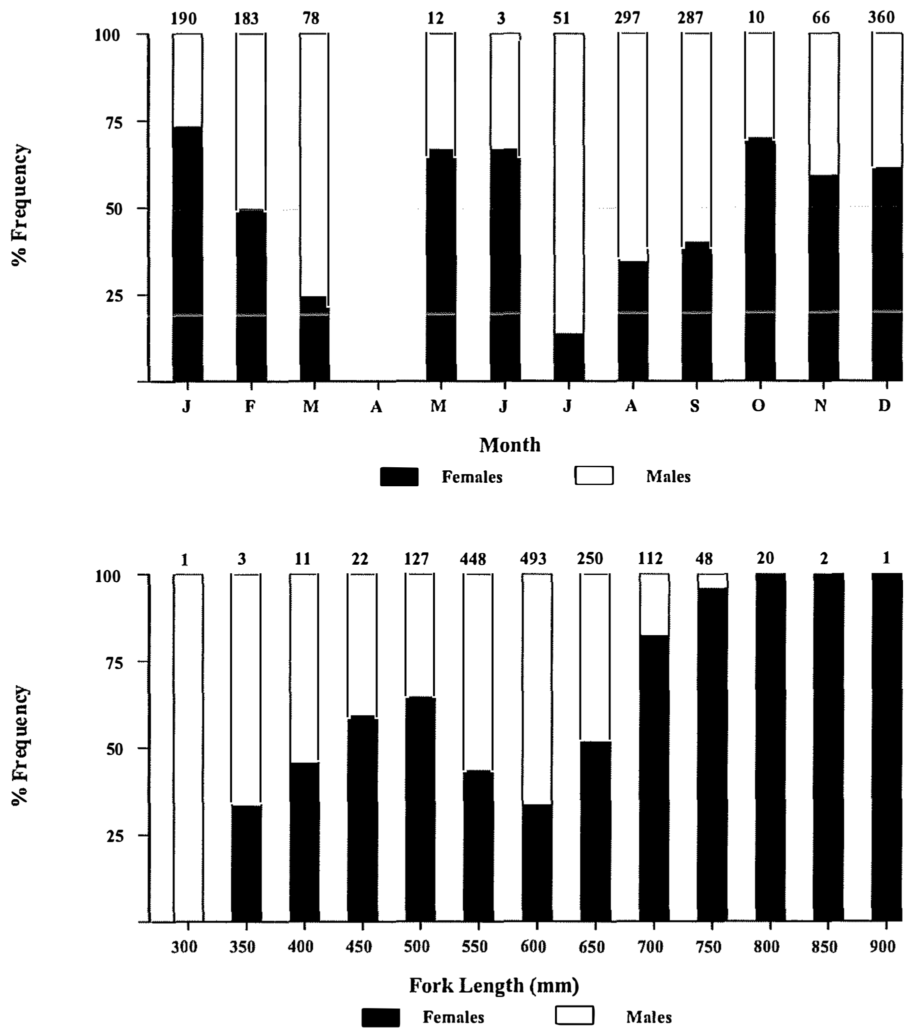


Figure 3.2.39. Percent frequency of monthly and length based sex ratios of spotted mackerel. The number above each bar refers to the number of fish sampled for that month.

Oocyte Diameter

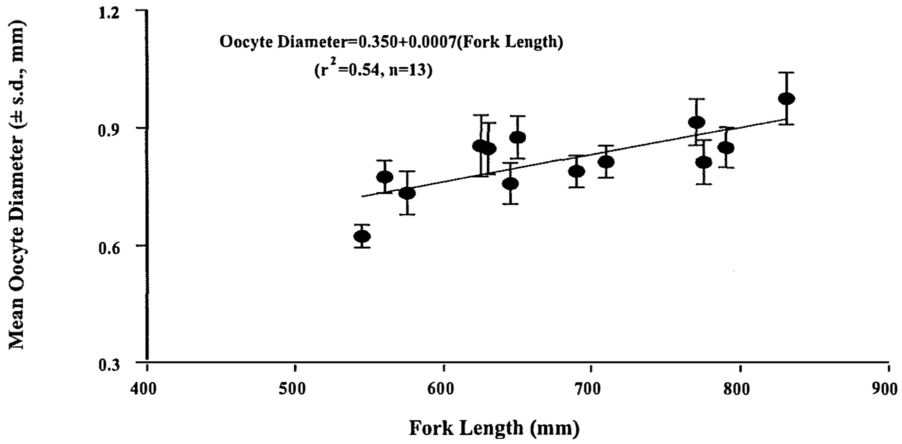


Figure 3.2.40. Mean oocyte diameter (± standard deviation) related to fork length (mm) of spotted mackerel for spawning months of August to October based on histological stages IV and V.

Total Potential Fecundity

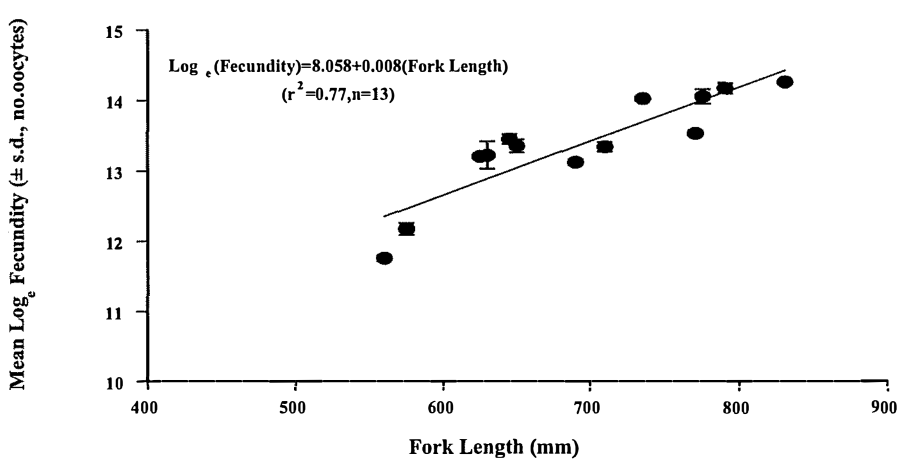


Figure 3.2.41. Total potential fecundity ('000 oocytes) (± standard deviation) related to fork length (mm) of spotted mackerel for spawning months of August to October based on histological stages IV and V.

3.2.2.3. Movements

A total of 2385 spotted mackerel were tagged in Queensland east coast waters and northern New South Wales waters. Spotted mackerel were recaptured at a rate of 1.8% (Table 3.2.38.). A total of 338 spotted mackerel were double tagged. Of these, two of the three recaptured spotted mackerel possessed both tags. These fish had been at liberty for two and 39 days. Of the 708 spotted mackerel injected with oxytetracycline for age validation purposes, 15 were recaptured.

Table 3.2.38. Tag-recapture information.

Condition	Spotted Mackerel	
	No. Tagged	No. (%) Recaptured
Total fish tagged	2385	43 (1.8)
Double tagged	338	3 (0.9)
Oxytetracyclined	708	15 (2.1)
Commercial fishers	-	25 (58.1)
Recreational fishers	-	18 (41.9)

Tagging of spotted mackerel was unevenly distributed between season and location (χ^2=1726.59, d.f.=15, P<0.0001). The majority of fish were tagged during summer in Hervey Bay, with minimal tagging effort at other locations during the remainder of the year. Recaptured spotted mackerel tended to be larger when they were initially tagged than tagged fish not recaptured (t=1.994, d.f.=2186, P<0.0463). The lengths of spotted mackerel tagged and released varied significantly between areas (*1*-way ANOVA, F=169.6, d.f.=6,2099, P<0.0001). The mean lengths of spotted mackerel released in Hervey Bay, Moreton Bay and New South Wales, varied significantly between locations (HSD). Fish tended to be larger the further south they were tagged. Fish released at Townsville and Mackay were similar in mean length, and significantly larger than those tagged in Cairns and Rockhampton (Table 3.2.39.).

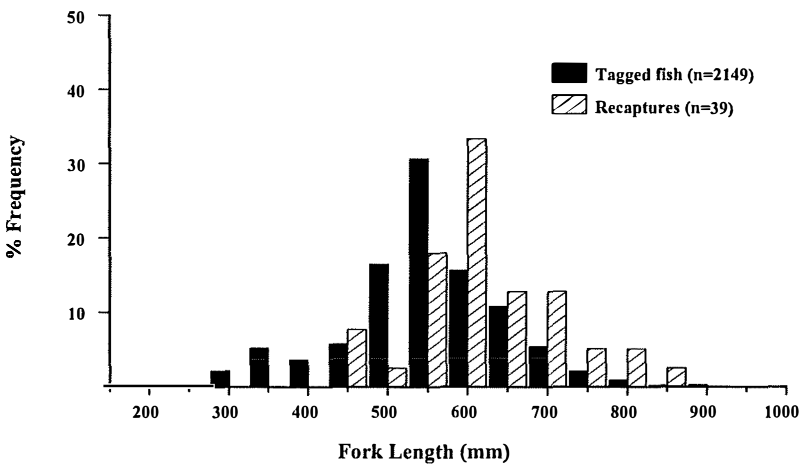


Figure 3.2.42. Frequency distributions of length at release for all tagged and recaptured spotted mackerel (areas combined).

Table 3.2.39. Mean fork lengths (mm) ± standard deviation of tagged and recaptured spotted mackerel for the respective sampling regions.

Area	Tagged Spotted Mackerel Fork Lengths (mm)			Recaptured Spotted Mackerel Fork Lengths when first Tagged (mm)		
	n	mean	s. d.	n	mean	s. d.
New South Wales	12	868	52	-	-	-
Moreton Bay	146	659	85	3	730	82
Hervey Bay	1475	584	81	31	605	69
Rockhampton	302	462	89	3	445	5
Mackay	88	506	87	2	565	21
Townsville	72	522	96	-	-	-
Cairns	11	367	25	-	-	-
Total	2106	567	101	39	600	86

Tagged spotted mackerel moved large distances, with about 39% of the total recaptures being over 100 km from their release site (Figure 3.2.43.). The largest movement observed for a spotted mackerel was 1100km. The fish had moved north from Hervey Bay to Innisfail and was at liberty for 228 days. The fish was tagged in December and recaptured the following July. Recaptured spotted mackerel movements appeared to be seasonally directed. Tagged spotted mackerel which moved more than 100 km tended to be recaptured in northern Queensland waters during winter and early spring, and in southern waters in summer (Figure 3.2.44.). Recaptured spotted mackerel moved greater distances the longer they were at liberty (r_s=0.750, d.f.=37, P<0.0001). A significant relationship was observed for spotted mackerel between the variables (F=55.21, d.f.=1,37, P<0.0001, distance=29.41+1.27(days at liberty), r^2=0.60) (Figure 3.2.45.). There was no significant relationship between initial tagged lengths of recaptured spotted mackerel, and time fish were at liberty (r_s=0.172, d.f.=36, N.S.).

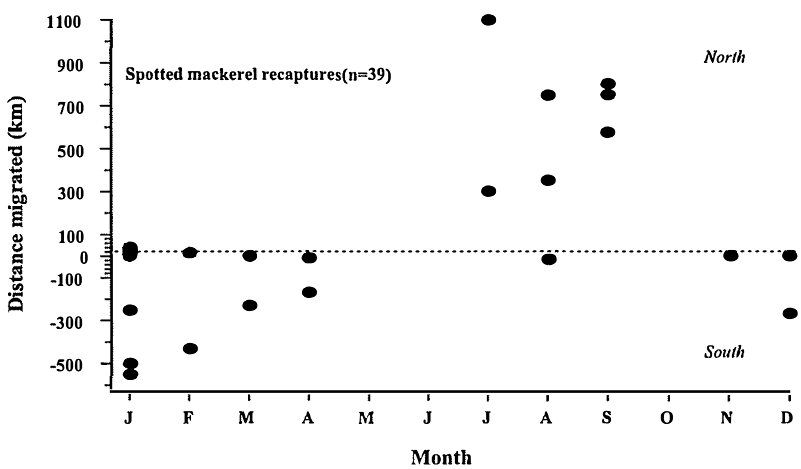


Figure 3.2.44. Monthly directional movements of recaptured spotted mackerel.

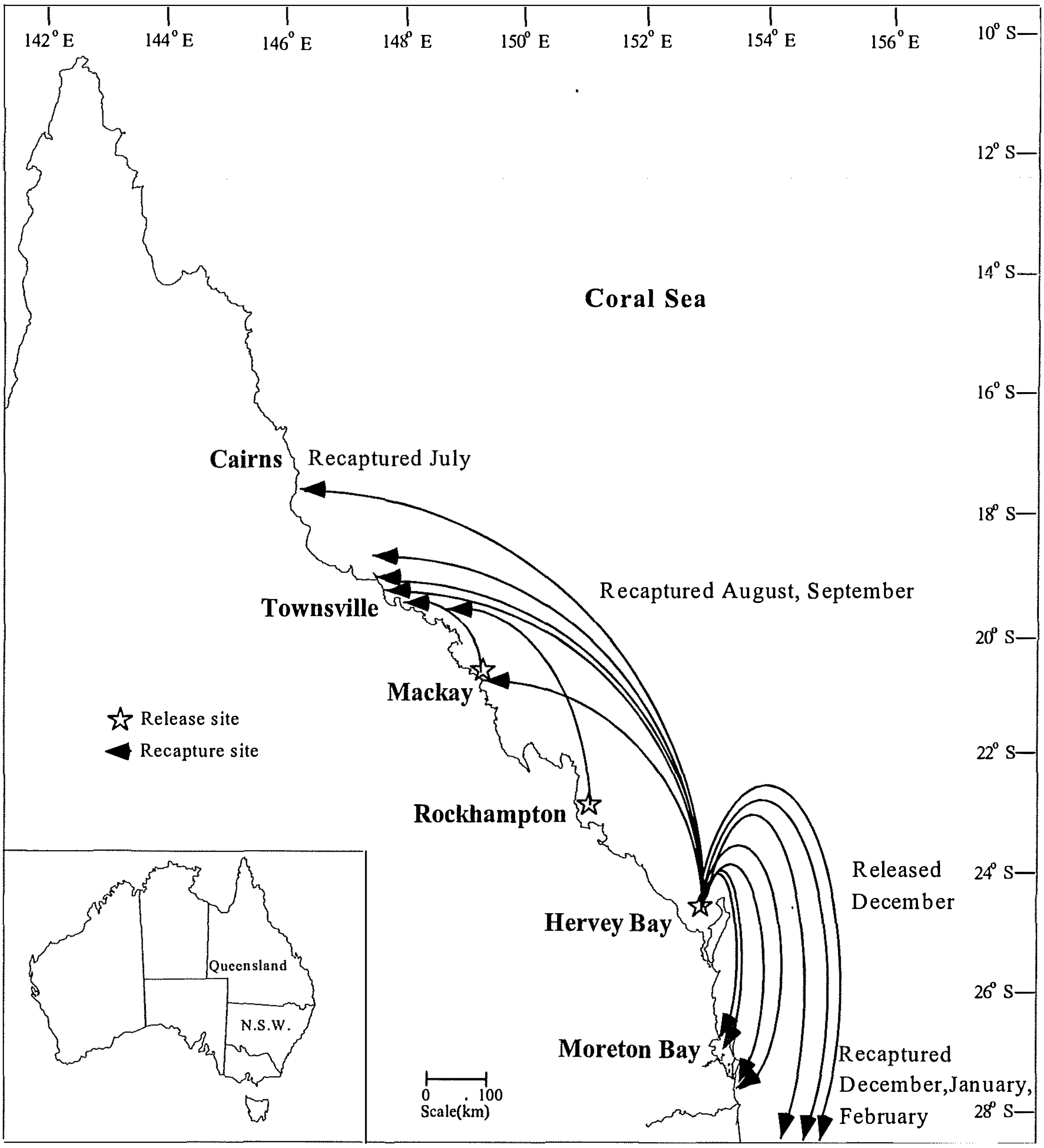


Figure 3.2.43. Large-scale (>100km) spotted mackerel movements from tag-recapture data (38.5% of total recaptures).

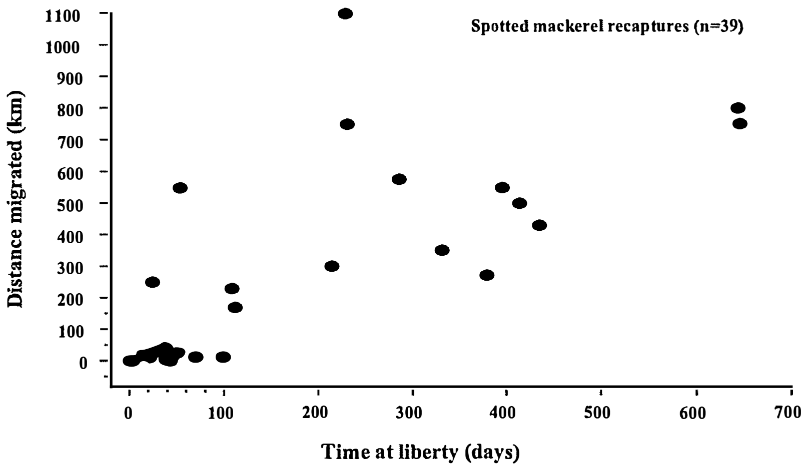


Figure 3.2.45. Movements (km) and their time at liberty (days) of recaptured spotted mackerel.

3.2.2.4. Otolith Chemistry

The chemical composition of spotted mackerel whole otoliths was determined by examining the concentration of the same 11 trace elements deposited in their otoliths that were used in the school mackerel analyses (Table 3.2.40.). Similar to school mackerel, Fe and Li were found to be highly variable and below the detection limits of the spectrometer. These elements, in addition to Ca were excluded from any further analyses.

All elements that were detected above the minimum levels of the ICP-AES (Ba, K, Mg, Mn, Na, P, S, Sr) varied significantly in their concentrations between spotted mackerel samples from different areas (Table 3.2.41.). Spotted mackerel otoliths had a number of trace elements that differed in concentration between Northern Territory and Queensland samples. Variations in elemental composition of otoliths were also evident between eastern (Gove) and western Northern Territory (Joseph Bonaparte Gulf) samples. In contrast, few differences were found between Queensland samples, except for one year old Moreton Bay fish, whose element concentration patterns resembled those of one year old fish from Hervey Bay (Table 3.2.42.).

Concentrations of K, Sr, and Na in spotted mackerel otoliths were highly correlated with length. Concentrations of all elements showing a significant relationship with length were subsequently corrected for size, using their respective regression coefficient for the length covariate (Tables 3.2.43. to 3.2.45.).

Cluster analysis of length corrected element concentrations demonstrated distinct differences in otolith chemistry between age classes (Figure 3.2.46.). Three year old Hervey Bay, Bowen and Innisfail fish appeared to have similar trace element concentrations, forming one cluster, indicating little difference in otolith chemical composition between Queensland east coast spotted mackerel of the same age. Similarly, one year old Moreton Bay and Hervey Bay fish grouped together, but were quite dissimilar from the three old Queensland samples. The dendrogram also indicated that one year old Queensland east coast spotted mackerel were more similar to fish from Gove, and conversely Joseph Bonaparte Gulf samples were more similar to three year old east coast fish in their respective element concentration patterns.

Spotted mackerel samples were discriminated into four approximate groups based on their otolith element compositions; one year old Queensland east coast, three year old Queensland east coast, Gove and Joseph Bonaparte Gulf fish (Figure 3.2.47.), confirming the pattern suggested by the initial cluster analysis (Figure 3.2.46.). Variation in P, Mg, K and Na concentrations were mainly responsible for the strong separation observed between the samples (Wilks' lambda=0.06), with most of the discriminatory power (98%) explained by the first two canonical variates (Table 3.2.46.). Approximately 63% of the total spotted mackerel samples were classified into their correct group by the predicted classification functions (Table 3.2.47.).

Table 3.2.40. Mean elemental concentrations of spotted mackerel otoliths sampled from the different regions. Minimum elemental detection limits of the ICP-AES averaged from the combined acid blank results of school and spotted mackerel, calculated from the minimum otolith weight used in the analyses, 0.0068 g (n=6). All units are in mg/Kg, except Ca which is measured as a % : (Ba=0.78; Ca=544; Fe=23.9; K=353; Li=15; Mg=10.9; Mn=1.10; Na=1250; P=54.1; S=191; Sr=3.24).

Region	Age (yrs)		Length (mm)	Otolith Wt. (g)	Ba	Ca	Fe	K	Li	Mg	Mn	Na	P	S	Sr
Moreton Bay	1	No.	30	30	30	30	30	30	30	30	30	30	30	30	30
		Mean	606	0.033	2.29	38.6	1.96	573	0.84	21	3.48	3494	112	466	1853
		Std.	23	0.003	0.52	1	3.99	94	0.95	2.5	0.7	139	11	32	126
		Range	555-685	0.026-0.040	1.61-3.50	36.7-41.3	0-21.68	430-792	0-3.28	17.9-29.2	2.24-5.36	3228-3769	88-141	403-541	1636-2076
		CV	3.7	9	22.8	2.5	203.4	16.4	113.1	11.7	20.2	4	9.9	6.8	6.8
Hervey Bay	1	No.	28	28	28	28	28	28	28	28	28	28	28	28	28
		Mean	605	0.033	2.16	38.3	3.35	516	0.76	21.4	3.17	3424	111	443	1885
		Std.	32	0.003	0.36	2.1	6.74	151	1.22	3.1	0.52	215	12	41	151
		Range	544-715	0.025-0.039	1.52-2.85	31.7-44.2	0-34.51	0-708	0-3.94	17.2-28.8	1.87-4.10	2826-4061	89-146	377-548	1529-2352
		CV	5.3	10.5	16.6	5.4	201.3	29.2	160.6	14.5	16.4	6.3	10.9	9.3	8
Hervey Bay	3	No.	29	29	29	29	29	29	29	29	29	29	29	29	29
		Mean	625	0.041	3.04	38.8	1.59	579	1.52	16.5	2.34	3076	145	499	2217
		Std.	45	0.006	0.32	1.4	2.52	91	1.33	2.4	0.5	164	16	28	166
		Range	552-790	0.033-0.060	2.45-3.69	35.2-42.2	0-8.17	422-759	0-3.58	13.5-22.8	1.35-3.81	2747-3378	124-187	437-551	1898-2576
		CV	7.3	15	10.6	3.5	158.3	15.7	87.4	14.5	21.4	5.3	11	5.7	7.5
Bowen	3	No.	32	32	32	32	32	32	32	32	32	32	32	32	32
		Mean	635	0.042	3.04	39	1.24	612	1.56	17.3	2.38	3051	158	499	2177
		Std.	20	0.002	0.37	1.2	1.45	159	1.12	2.3	0.38	101	21	38	110
		Range	605-670	0.036-0.046	2.26-3.62	36.5-41.6	0-5.05	0-813	0-3.75	12.1-22.4	1.73-3.40	2860-3251	119-214	413-570	1958-2375
		CV	3.1	5.7	12.2	3	117.3	25.9	71.8	13.4	15.9	3.3	13.6	7.7	5
Innisfail	3	No.	28	28	28	28	28	28	28	28	28	28	28	28	28
		Mean	620	0.037	3.25	39.1	2.91	553	1.39	16	2.63	3144	140	512	2160
		Std.	21	0.003	0.29	1.1	4.66	84	1.3	1.5	0.62	100	12.4	31	119
		Range	585-665	0.032-0.044	2.58-3.99	37.0-42.8	0-21.86	366-741	0-3.71	13.9-19.2	1.5-3.82	2988-3350	120-172	455-578	1909-2401
		CV	3.5	8	9	2.7	160.2	15.2	93.6	9.2	23.5	3.2	8.9	6.1	5.5
Gove	0	No.	13	13	13	13	13	13	13	13	13	13	13	13	13
		Mean	363	0.022	2.03	39.7	2.78	826	0.24	25.2	3.21	3928	114	488	1982
		Std.	45	0.005	0.27	2.3	1.53	187	1.23	2.2	0.65	348	13	64	257
		Range	320-450	0.017-0.035	1.63-2.51	34.6-44.1	0.96-5.53	599-1238	0-2.31	22.1-28.3	1.99-4.07	3254-4557	89-128	400-675	1511-2396
		CV	12.4	24.3	13.5	5.9	55.1	22.6	511.3	8.9	20.4	8.9	11.3	13.1	13
Joseph Bonaparte Gulf	0	No.	18	18	18	18	18	18	18	18	18	18	18	18	18
		Mean	432	0.023	2.6	38.9	2.2	545	0.49	20.4	2.87	3608	131	522	2245
		Std.	18	0.006	0.46	1.7	1.98	136	1.14	2.5	0.51	250	14	53	182
		Range	400-460	0.015-0.035	2.13-4.01	36.3-44.1	0-7.24	319-817	0-2.24	16.8-25.6	2.03-3.74	3190-4100	101-153	452-630	2021-2787
		CV	4.1	24.6	17.7	4.3	90.1	24.9	232.8	12.4	17.7	6.9	11	10.2	8.1

Table 3.2.41. Trace elements that varied significantly in concentration between spotted mackerel otoliths from different areas. One-way analysis of variance results examined the effect of area on each trace element concentration. Each element varied significantly between areas (significant result*). All analyses had d.f.=6,171.

Element	Spotted Mackerel ANOVA Results (d.f.=6,171)	
	F	P
Ba	39.61	0.0001*
K	10.81	0.0001*
Mg	38.63	0.0001*
Mn	17.25	0.0001*
Na	64.21	0.0001*
P	45.34	0.0001*
S	12.37	0.0001*
Sr	30.48	0.0001*

Table 3.2.42. Trace elements of spotted mackerel whole otoliths that differed in their concentration between areas (HSD). The number after the area refers to the age of the samples analysed, eg. Hervey (1) refers to 1 year old fish from Hervey Bay. All comparisons had d.f.=171 and were significant at P<0.05.

	Area (age, years)						
	JBG (0)	Gove (0)	Innisfail (3)	Bowen (3)	Hervey (1)	Hervey (3)	Moreton (1)
JBG (0)	-	-	-	-	-	-	-
Gove (0)	Ba K Mg Na P Sr	-	-	-	-	-	-
Innisfail (3)	Ba Mg Na Sr	Ba K Mg Mn Na P	-	-	-	-	-
Bowen (3)	Ba Mg Mn Na P Sr	Ba K Mg Mn Na P	P	-	-	-	-
Hervey (1)	Ba Na P S Sr	K Mg Na S	Ba Mg Mn Na P S Sr	Ba Mg Mn Na P S Sr	-	-	-
Hervey (3)	Ba Mg Mn Na Sr	Ba K Mg Mn Na P	-	P	Ba Mg Mn Na P S Sr	-	-
Moreton (1)	Ba Mn P S Sr	K Mg Na	Ba Mg Mn Na P S Sr	Ba Mg Mn Na P S Sr	-	Ba Mg Mn Na P S Sr	-

Table 3.2.43. Spotted mackerel trace element concentrations that were significantly correlated with fish length for all areas. Analysis of covariance results of the concentrations of trace elements with area (n=7, including the different age classes from Hervey Bay) as a factor and length as a covariate. Analyses determined the regression coefficient for the covariate length or the correction factor (r) required to standardise the concentrations of individual elements affected by variable length (* indicates a significant result).

Element	Length*Area (d.f.=6,164)		Length (d.f.=1,170)		r
	F	P	F	P	
Ba	0.56	0.7655	1.67	0.1985	-
K	1.79	0.1033	1.55	0.2146	-
Mg	0.88	0.5140	3.05	0.0825	-
Mn	2.94	0.0094*	-	-	-
Na	1.63	0.1423	18.46	0.0001*	-1.8877
P	0.89	0.5006	0.07	0.7926	-
S	2.65	0.0176*	-	-	-
Sr	3.41	0.0034*	-	-	-

Table 3.2.44. Spotted mackerel trace element concentrations that were significantly correlated with fish length for Queensland east coast samples. Analysis of covariance results of the concentrations of trace elements with area (n=5, including the different age classes from Hervey Bay) as a factor and length as a covariate. Analyses determined the regression coefficient for the covariate length or the correction factor (r) required to standardise the concentrations of individual elements affected by variable length (* indicates a significant result).

Element	Length*Area (d.f.=4,137)		Length (d.f.=1,141)		r
	F	P	F	P	
Ba	0.25	0.9091	3.21	0.0753	-
K	1.18	0.3218	5.29	0.0229*	-0.7728
Mg	0.82	0.5134	1.61	0.2072	-
Mn	3.86	0.0053*	-	-	-
Na	0.62	0.6486	13.38	0.0004*	-1.4725
P	1.05	0.3826	0.02	0.8816	-
S	2.13	0.0804	1.12	0.2913	-
Sr	0.96	0.4316	6.02	0.0153*	-0.9223

Table 3.2.45. Spotted mackerel trace element concentrations that were significantly correlated with fish length for northern Australian samples (excluding Queensland east coast). Analysis of covariance results of the concentrations of trace elements with area (n=2) as a factor and length as a covariate. Analyses determined the regression coefficient for the covariate length or the correction factor (r) required to standardise the concentrations of individual elements affected by variable length (* indicates a significant result).

Element	Length*Area (d.f.=1,27)		Length (d.f.=1,28)		r
	F	P	F	P	
Ba	0.39	0.5395	0.45	0.5081	-
K	0.62	0.4364	1.59	0.2179	-
Mg	1.53	0.2261	1.92	0.1764	-
Mn	1.30	0.2641	0.25	0.6203	-
Na	1.66	0.2084	5.21	0.0302*	-3.6370
P	0.30	0.5902	0.99	0.3286	-
S	1.43	0.2418	2.49	0.1256	-
Sr	2.56	0.1212	4.09	0.0500*	2.4072

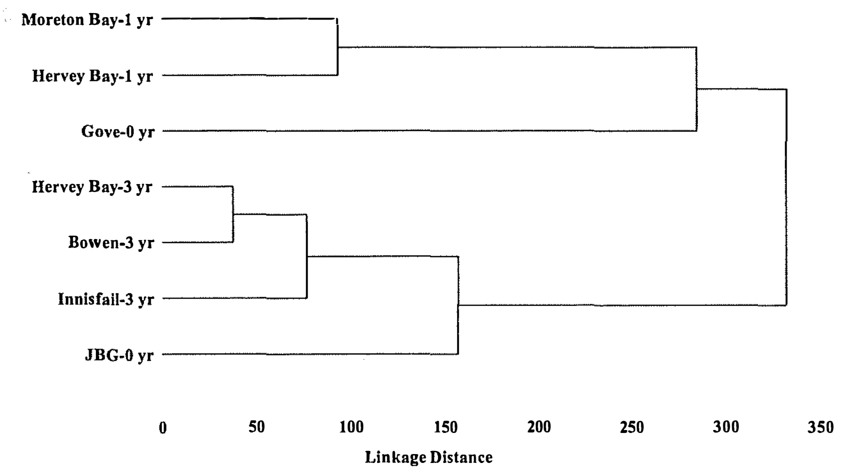


Figure 3.2.46. Classification of spotted mackerel samples by area, based on the concentrations of 5 elements (Ba, K, Mg, P and adjusted Na) in the otoliths, using an unweighted pair group mean arithmetic sorting strategy and Euclidean distance measures of association.

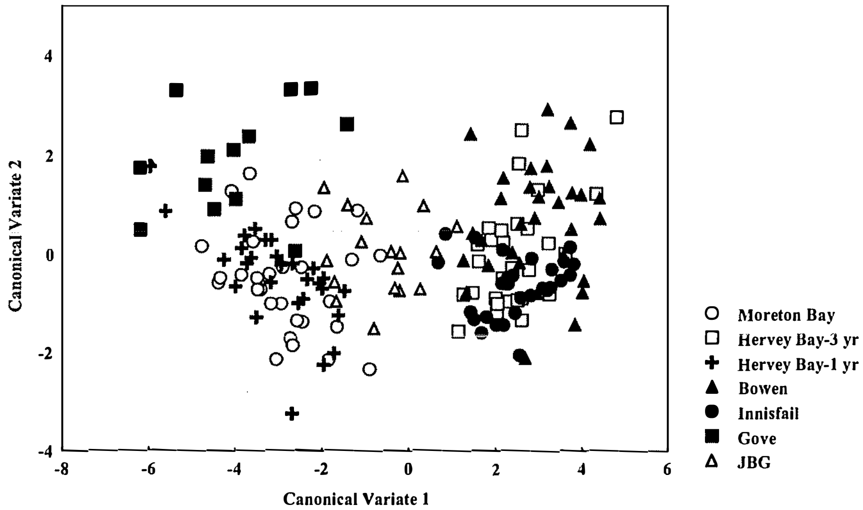


Figure 3.2.47. Discrimination between spotted mackerel samples from all areas based on the concentrations of the 5 suitable (length corrected) trace elements.

Table 3.2.46. Discrimination between samples of spotted mackerel from all areas determined by the standardised canonical coefficients for the significant ($p<0.05$) canonical variates (discriminant functions) I, II and III, and the cumulative proportion of the explained variance accounted for by each function, for the 5 significant elements (length corrected) (Wilks' Lambda for overall model=0.062).

Element	**Canonical Variate**		
	I	**II**	**III**
P	0.76	0.33	-0.55
Mg	-0.71	0.42	-0.36
Ba	0.58	-0.28	0.47
Adj Na	-0.51	-0.50	0.24
K	0.13	0.70	0.74
Cumulative Proportion	0.92	0.98	0.99

Table 3.2.47. Classification matrix of the frequency of assigned cases in each area determined from the discriminant model used to differentiate spotted mackerel samples from all areas.

Area	**Classification of Individual Spotted Mackerel by Area**							
	% Correct	**JBG (0)**	**Gove (0)**	**Innisfail (3)**	**Bowen (3)**	**Hervey (1)**	**Hervey (3)**	**Moreton (1)**
JBG (0)	67	12	0	1	0	3	1	1
Gove (0)	85	0	11	0	0	1	0	1
Innisfail (3)	75	0	0	21	2	0	5	0
Bowen (3)	63	0	0	5	20	0	7	0
Hervey (1)	64	0	2	0	0	18	0	8
Hervey (3)	34	0	0	11	8	0	10	0
Moreton (1)	70	2	2	0	0	5	0	21
Total	63	14	15	38	30	27	23	31

More detailed analyses isolating Queensland and northern Australian spotted mackerel samples emphasised the aggregations suggested by the overall model, as the analyses involved a greater number of elements because of the reduced size and age related effects on element concentration patterns. Queensland east coast samples were strongly separated into one and three year old groups, by the first canonical function (Figure 3.2.48.). Na, Mg, Sr and P were the main elements causing the grouping patterns in the first discriminant function (Table 3.2.48.). One year old Queensland east coast spotted mackerel tended to have higher Na and Mg concentrations, while possessing lower Sr and P concentrations than three year old fish. The separation patterns observed in the individual discriminations resulted in 67% of Queensland east coast samples being correctly classified into their respective groups (Table 3.2.49.). Gove and Joseph Bonaparte Gulf samples were discriminated into separate groups mainly because of the strong effect of K in the first canonical variate (Table 3.2.50.). The strong separation patterns observed resulted in 97% of northern Australian samples being correctly classified into their respective groups (Table 3.2.51.).

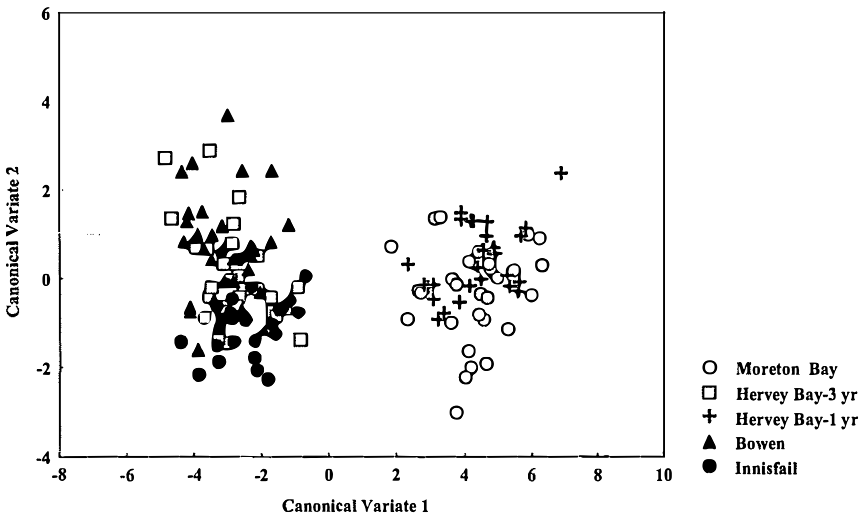


Figure 3.2.48. Discrimination between spotted mackerel samples from Queensland east coast areas based on the concentrations of the 7 (length corrected) trace elements.

Table 3.2.48. Discrimination between samples of spotted mackerel from Queensland east coast areas determined by the standardised canonical coefficients for the significant ($p<0.05$) canonical variates (discriminant functions) I, II and III, and the cumulative proportion of the explained variance accounted for by each function, for the 7 significant elements (length corrected) (Wilks' Lambda for overall model=0.046).

Element	**Canonical Variate**		
	I	**II**	**III**
Adj Sr	-0.57	0.16	-0.71
Adj Na	0.68	-0.37	0.32
P	-0.57	0.57	0.55
Ba	-0.53	-0.53	0.10
Mg	0.66	0.41	-0.20
Adj K	-0.25	0.07	0.55
S	-0.11	-0.52	0.25
Cumulative Proportion	0.96	0.99	1.00

Table 3.2.49. Classification matrix of the frequency of assigned cases in each area determined from the discriminant model used to differentiate spotted mackerel samples from Queensland east coast samples.

Area	**Classification of Individual Spotted Mackerel by Area**					
	% Correct	**Innisfail (3)**	**Bowen (3)**	**Hervey (1)**	**Hervey (3)**	**Moreton (1)**
Innisfail (3)	82	23	2	0	3	0
Bowen (3)	72	2	23	0	7	0
Hervey (1)	61	0	0	17	0	11
Hervey (3)	41	9	8	0	12	0
Moreton (1)	77	0	0	7	0	23
Total	67	34	33	24	22	34

Table 3.2.50. Discrimination between samples of spotted mackerel from northern Australian waters (excluding Queensland east coast samples) determined by the standardised canonical coefficients for the significant ($p<0.05$) canonical variates (discriminant functions) I, and the cumulative proportion of the explained variance accounted for by each function, for 4 significant elements (length corrected) (Wilks' Lambda for overall model=0.166).

Element	**Canonical Variate**
	I
Mg	0.63
P	-0.71
K	0.85
Ba	-0.52
Cumulative Proportion	1.00

Table 3.2.51. Classification matrix of the frequency of assigned cases in each area determined from the discriminant model used to differentiate spotted mackerel samples from northern Australian waters (excluding Queensland east coast samples).

Area	**Classification of Individual Spotted Mackerel by Area**		
	% Correct	**Gove (0)**	**JBG (0)**
Gove (0)	92	12	1
JBG (0)	100	0	18
Total	97	12	19

3.2.2.5. Genetic Variation

Six polymorphic loci (*AAT-L*, *AK*, *GPI*, *IDH*, *MDH* and *PGM*) were selected for spotted mackerel owing to their apparent genetic variation and ease of interpretation (Table 3.2.52.).

Table 3.2.52. Polymorphic protein loci of spotted mackerel used in analyses, and conditions for electrophoresis.

Protein	Locus	Subunit Structure	Tissue	Buffer
Adenylate kinase	*AK*	Monomer	Liver	TC-1
Aspartate aminotransferase (liver)	*AAT-L*	Dimer	Liver	TC-1
Glucose-6-phosphate isomerase	*GPI*	Dimer	Muscle	TC-1
Isocitrate dehydrogenase	*IDH*	Dimer	Liver	TC-1
Malate dehydrogenase	*MDH*	Dimer	Muscle	TVB
Phosphoglucomutase	*PGM*	Monomer	Muscle	TVB

The mean observed heterozygosity (H_o) of individual spotted mackerel samples, calculated for the six polymorphic loci investigated, varied between 0.037 and 0.177 (mean 0.101 ± 0.071 s.e.) (Table 3.2.53.). A linear regression analysis confirmed that there was no relationship between sample size and mean observed heterozygosity (r^2=0.0002, d.f.=1,16, F=0.003, N.S.). The total mean sample heterozygosity (H_t) calculated for only the polymorphic loci analyses for all samples was 0.110 (± 0.074 s.e.), which was higher than the subpopulation heterozygosity (H_s) (0.106 ± 0.071 s.e.). These calculations resulted in an average F_{st} value of 0.038 (Table 3.2.54.).

G-tests of conformity of the observed genotypes with the expected Hardy-Weinberg distribution for each locus from each sample, calculated from the allele frequencies, resulted in only four of 108 tests (3.7%) being significantly out of equilibrium (Hervey Bay 1991 *AK*; Hervey Bay 1993 *GPI*; Bowen 1991 *AK*; Darwin 1993 *GPI*). At least five of these tests could have deviated significantly from the expected proportions (5% level) by chance alone, while two of the four tests (Hervey Bay 1993 *GPI*; Darwin 1993 *GPI*) differed significantly owing to expected low values of uncommon alleles. It was concluded that the allele frequencies observed in spotted mackerel samples were consistent with those expected under Hardy-Weinberg equilibrium.

Overall, there were no significant differences (contingency *G*-tests, P<0.05) observed between years within areas, except for Hervey Bay (G=91.33, d.f.=60, P<0.01) (Table 3.2.55.). This difference was probably due to the 1991 sample that was out of Hardy-Weinberg equilibrium for *AK*, which was the only significant locus (G=27.76, d.f.=12, P<0.01). This result was made more apparent because of the non significant result obtained between samples from other years when 1991 samples were removed from the analysis. Similarly, *IDH* differed significantly between Darwin yearly samples (G=12.67, d.f.=6, P<0.05). However, this probably resulted from the low number of samples for fish in 1991 and 1992 as no differences were observed when the larger number of samples of fish in 1993 and 1994 were compared. This apparent lack of temporal variation between samples within areas was supported by monthly comparisons within years and areas. No significant differences were observed overall, or for any individual loci, between monthly samples collected from fish in 1991, 1992 and 1993 from Hervey Bay and from fish in 1990 and 1991 from Bowen (Table 3.2.55.).

Table 3.2.53 Spotted mackerel allele frequencies by year and area. (MB = Moreton Bay; HB = Hervey Bay; MK = Mackay; BO = Bowen; IN = Innisfail; IL = Iluka; DA = Darwin).

Locus	Allele	Sample Allele Frequency																	
		MB91	**MB92**	**MB93**	**HB90**	**HB91**	**HB92**	**HB93**	**HB94**	**MK92**	**MK94**	**BO90**	**BO91**	**IN90**	**IL92**	**DA91**	**DA92**	**DA93**	**DA94**
AAT-L	160	0	0	0	0.007	0	0	0.014	0	0	0	0	0	0.017	0	0	0	0	0
	130	0	0	0.013	0.007	0.005	0.002	0	0	0	0	0.003	0	0.050	0	0	0	0.006	0.008
	100	1.000	0.952	0.987	0.980	0.993	0.995	0.986	1.000	1.000	1.000	0.997	0.984	0.933	0.972	0.979	0.981	0.987	0.976
	70	0	0.048	0	0.007	0.002	0.002	0	0	0	0	0	0.016	0	0.028	0.021	0.019	0.006	0.016
	n	*24*	*21*	*39*	*74*	*209*	*211*	*109*	*101*	*15*	*15*	*143*	*91*	*30*	*18*	*24*	*27*	*77*	*62*
AK	110	0.354	0.325	0.342	0.377	0.456	0.357	0.422	0.440	0.300	0.433	0.488	0.406	0.111	0.286	0.575	0.429	0.468	0.344
	100	0.646	0.675	0.645	0.623	0.544	0.630	0.560	0.530	0.700	0.567	0.508	0.594	0.889	0.714	0.425	0.571	0.524	0.656
	90	0	0	0.013	0	0	0.012	0.018	0.030	0	0	0.004	0	0	0	0	0	0.008	0
	n	*24*	*20*	*38*	*73*	*206*	*207*	*109*	*100*	*15*	*15*	*130*	*80*	*9*	*14*	*20*	*21*	*62*	*32*
GPI	110	0.021	0	0.026	0.027	0.005	0.005	0.009	0.005	0	0	0.021	0.016	0	0.028	0	0	0.007	0.021
	100	0.979	1.000	0.974	0.966	0.979	0.991	0.986	0.980	1.000	0.967	0.965	0.967	1.000	0.972	1.000	1.000	0.978	0.979
	85	0	0	0	0.007	0.017	0.005	0.005	0.015	0	0.033	0.014	0.016	0	0	0	0	0.015	0
	n	*24*	*21*	*39*	*74*	*211*	*213*	*109*	*101*	*15*	*15*	*144*	*91*	*31*	*18*	*18*	*21*	*67*	*47*
IDH	120	0	0	0	0	0.002	0.005	0.005	0.020	0	0	0	0.011	0.029	0	0	0	0.026	0.042
	100	1.000	1.000	1.000	0.993	0.990	0.990	0.995	0.980	0.967	1.000	1.000	0.989	0.971	1.000	1.000	0.964	0.955	0.958
	80	0	0	0	0.007	0.005	0.005	0	0	0.033	0	0	0	0	0	0	0.036	0.019	0
	55	0	0	0	0	0.002	0	0	0	0	0	0	0	0	0	0	0	0	0
	n	*24*	*19*	*38*	*73*	*207*	*210*	*109*	*101*	*15*	*15*	*140*	*87*	*17*	*18*	*24*	*28*	*77*	*60*
MDH	125	0	0	0.026	0	0.002	0.005	0	0	0	0	0	0.005	0	0	0	0	0.013	0
	100	0.958	0.976	0.949	0.979	0.969	0.988	0.991	0.980	1.000	1.000	0.983	0.984	0.984	0.972	0.938	0.875	0.864	0.836
	75	0.042	0.024	0.026	0.021	0.028	0.007	0.009	0.020	0	0	0.017	0.011	0.016	0.028	0.063	0.125	0.123	0.164
	n	*24*	*21*	*39*	*73*	*211*	*213*	*109*	*101*	*15*	*15*	*144*	*91*	*31*	*18*	*24*	*28*	*77*	*58*
PGM	150	0	0	0	0	0.007	0	0.009	0	0	0	0.011	0.007	0	0	0	0	0	0
	100	1.000	1.000	1.000	1.000	0.990	0.997	0.991	0.990	1.000	1.000	0.989	0.993	1.000	1.000	1.000	1.000	1.000	1.000
	15	0	0	0	0	0.002	0.003	0	0.010	0	0	0	0	0	0	0	0	0	0
	n	*23*	*13*	*39*	*74*	*202*	*196*	*109*	*101*	*15*	*15*	*89*	*71*	*31*	*18*	*24*	*28*	*78*	*62*
Mean Hs		0.096	0.096	0.107	0.105	0.109	0.092	0.101	0.110	0.081	0.093	0.106	0.108	0.069	0.095	0.108	0.136	0.150	0.149
s.e.		0.073	0.070	0.074	0.074	0.078	0.077	0.081	0.083	0.069	0.080	0.080	0.075	0.032	0.064	0.078	0.078	0.079	0.072
Mean Ho		0.097	0.115	0.092	0.093	0.097	0.087	0.095	0.100	0.089	0.067	0.094	0.078	0.037	0.075	0.136	0.127	0.153	0.177
s.e.		0.073	0.088	0.067	0.067	0.066	0.072	0.078	0.076	0.076	0.054	0.071	0.057	0.022	0.044	0.105	0.080	0.090	0.091

These results were further supported by only two of 84 monthly tests (2.4%) being out of Hardy-Weinberg equilibrium owing to low expected values of uncommon alleles. Yearly samples were therefore pooled within areas because of the absence of significant temporal variation.

Table 3.2.54. Mean *F*-statistics for the six polymorphic loci examined from the individual yearly spotted mackerel samples (N.S., not significant).

Locus	F_{is}	F_{it}	F_{st}	G	d.f.	P
AAT-L	0.007	0.025	0.019	63.475	51	N.S.
AK	0.053	0.091	0.040	66.490	51	N.S.
GPI	0.191	0.199	0.010	34.253	34	N.S.
IDH	0.172	0.188	0.019	59.235	51	N.S.
MDH	-0.046	0.010	0.054	115.328	34	p<0.001
PGM	0.192	0.197	0.007	23.790	34	N.S.
Mean	0.052	0.088	0.038			
Total				362.570	255	p<0.001

Table 3.2.55. Contingency log likelihood ratio (*G*) tests for temporal comparisons between spotted mackerel samples (N.S., not significant).

Comparison	Total Loci			Significant Loci			
	G	d.f.	P	Locus	G	d.f.	P
Hervey Bay 1991 (Jan; Nov; Dec)	17.276	28	N.S.	-	-	-	N.S.
Hervey Bay 1992 (Jan; Feb; Mar; Dec)	44.217	42	N.S.	-	-	-	N.S.
Hervey Bay 1993 (Feb; Mar; Dec)	14.516	20	N.S.	-	-	-	N.S.
Bowen 1990 (Aug; Sep)	12.148	10	N.S.	-	-	-	N.S.
Bowen 1991 (Aug; Sep)	17.666	11	N.S.	-	-	-	N.S.
Moreton Bay (91; 92; 93)	13.938	18	N.S.	-	-	-	N.S.
Hervey Bay (90; 91; 92; 93; 94)	91.334	60	p<0.05	*AK*	27.762	12	p<0.01
Hervey Bay (90; 92; 93; 94)	59.434	42	N.S.	-	-	-	N.S.
Mackay (92; 94)	3.960	6	N.S.	-	-	-	N.S.
Bowen (90; 91)	16.840	12	N.S.	-	-	-	N.S.
Darwin (91; 92; 93; 94)	35.240	36	N.S.	*IDH*	12.670	6	p<0.05
Darwin (93; 94)	14.239	12	N.S.	-	-	-	N.S.

Overall variation in allele frequencies was highly significant when all 18 samples were examined without pooling (G=362.57, d.f.=255, P<0.001), with an overall F_{st} value of 0.038. This could be attributed to variation at *MDH*, which was the only locus that varied significantly between samples (G=115.33, d.f.=34, P<0.001). When yearly samples within areas were pooled, significant variation still existed between areas (G=201.26, d.f.=90, P<0.001), while the F_{st} increased slightly to 0.047 (Table 3.2.56.). Significant spatial variation was present at *AAT-L* and *MDH* loci. These results for the pooled samples were supported by most loci being in agreement with Hardy-Weinberg expected proportions. Four tests disagreed with those expected (Bowen *AK*; Bowen *GPI*; Darwin *IDH*; Darwin *MDH*), although only pooled Bowen *AK* samples had expected homozygous genotypes greater than five (G=6.173, d.f.=2, P<0.05).

The relationships between pooled spatial samples is summarised in the UPGMA dendrogram, based on Rogers' genetic distance (Figure 3.2.49.). Three distinct groups were found; Iluka to Bowen (Australian east coast), Innisfail, and Darwin. Areas within the Australian east coast group tended to be more closely related to their neighbouring geographical regions than those further afield. Individual pairwise comparisons between areas were used to interpret spatial genetic differences (Table 3.2.57.). No significant differences were observed between Australian east coast samples, except for Innisfail. However, care needs to be exercised in interpreting this result as the Innisfail sample was very small (n=31) and not all animals were scored for *AK* and *IDH*. Overall, across all loci, no differences were observed between Innisfail and the pooled remaining east coast samples (Iluka, Moreton Bay, Hervey Bay, Mackay and Bowen). However, there were significant differences between the Innisfail and the pooled east coast sample at the *AAT-L* and *AK* loci. Care must again be taken in the interpretation of this result because of the small number of fish from Innisfail and because not all fish from this sample were scored for *AK*. Darwin samples differed significantly from Innisfail overall, and at the *AAT-L*, *AK* and *MDH* loci. Similarly, Darwin samples differed from the pooled east coast region overall, and at individual *IDH* and *MDH* loci.

Table 3.2.56. Mean *F*-statistics for the six polymorphic loci examined from the pooled yearly spotted mackerel samples (N.S., not significant).

Locus	F_{is}	F_{it}	F_{st}	*G*	d.f.	P
AAT-L	-0.005	0.015	0.020	29.927	18	p<0.05
AK	0.148	0.195	0.055	24.788	18	N.S.
GPI	0.152	0.158	0.006	14.792	12	N.S.
IDH	0.087	0.099	0.013	28.134	18	N.S.
MDH	-0.012	0.035	0.047	92.157	12	p<0.001
PGM	0.085	0.090	0.006	11.461	12	N.S.
Mean	0.117	0.158	0.047			
Total				201.259	90	p<0.001

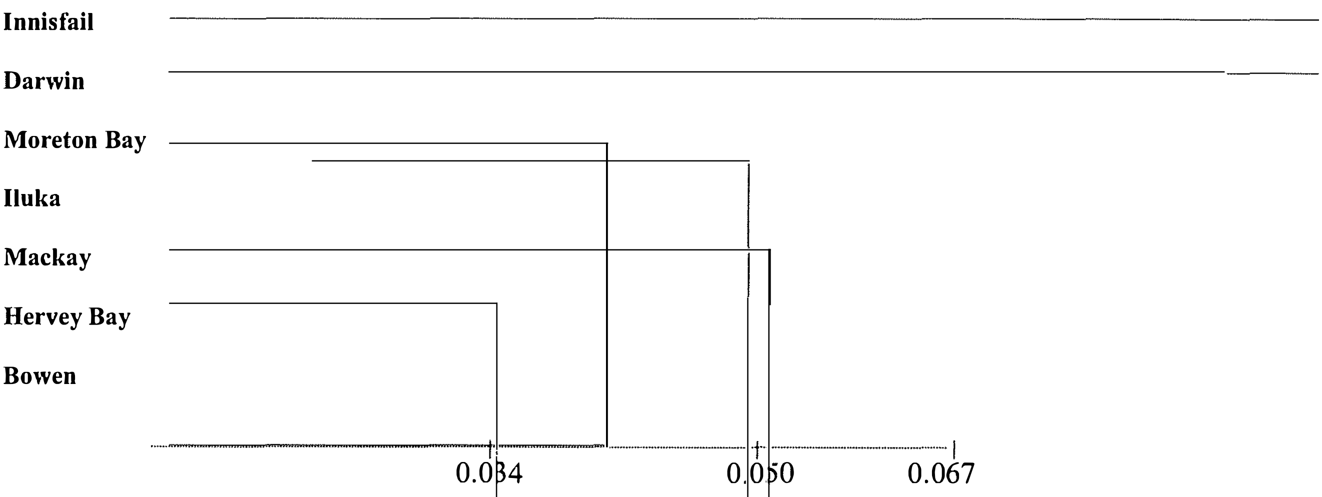


Figure 3.2.49. UPGMA dendrogram of pooled yearly spotted mackerel samples by area, based on Rogers' genetic distance.

Table 3.2.57. Contingency log likelihood ratio (*G*) tests for spatial comparisons between pooled yearly spotted mackerel samples (N.S., not significant).

Comparison	**Total Loci**			**Significant Loci**			
	G	**d.f.**	**P**	**Locus**	***G***	**d.f.**	**P**
Iluka vs Moreton Bay	2.426	9	N.S.	-	-	-	N.S.
Hervey Bay vs Bowen	21.297	15	N.S.	-	-	-	N.S.
Moreton Bay vs (Hervey Bay and Bowen)	20.911	15	N.S.	-	-	-	N.S.
(Hervey Bay and Bowen) vs Mackay	9.817	15	N.S.	-	-	-	N.S.
(Iluka and Moreton Bay) vs (Hervey Bay, Mackay and Bowen)	26.616	15	N.S.	-	-	-	N.S.
(Iluka, Moreton Bay, Hervey Bay, Mackay and Bowen) vs Innisfail	27.864	15	N.S.	*AAT-L*	13.605	3	p<0.005
				AK	8.361	3	p<0.05
(Iluka, Moreton Bay, Hervey Bay, Mackay and Bowen) vs Darwin	113.126	15	p<0.001	*IDH*	17.212	3	p<0.001
				MDH	83.653	2	p<0.001
Innisfail vs Darwin	33.793	12	p<0.001	*AAT-L*	11.387	3	p<0.01
				AK	9.362	3	p<0.05
				MDH	10.284	2	p<0.01

3.2.3. Grey Mackerel

3.2.3.1. Age, Growth and Mortality

Grey mackerel have a significant linear relationship between total length and fork length ($F=4561.75$, d.f.=1, 18, $P<0.0001$). Similar length-weight regression slopes (ANCOVA, $F=3.36$, d.f.=1, 62, N.S.) and intercepts (ANCOVA, $F=0.00$, d.f.=1, 63, N.S.) were estimated for each sex (Figure 3.2.50. and Table 3.2.58.).

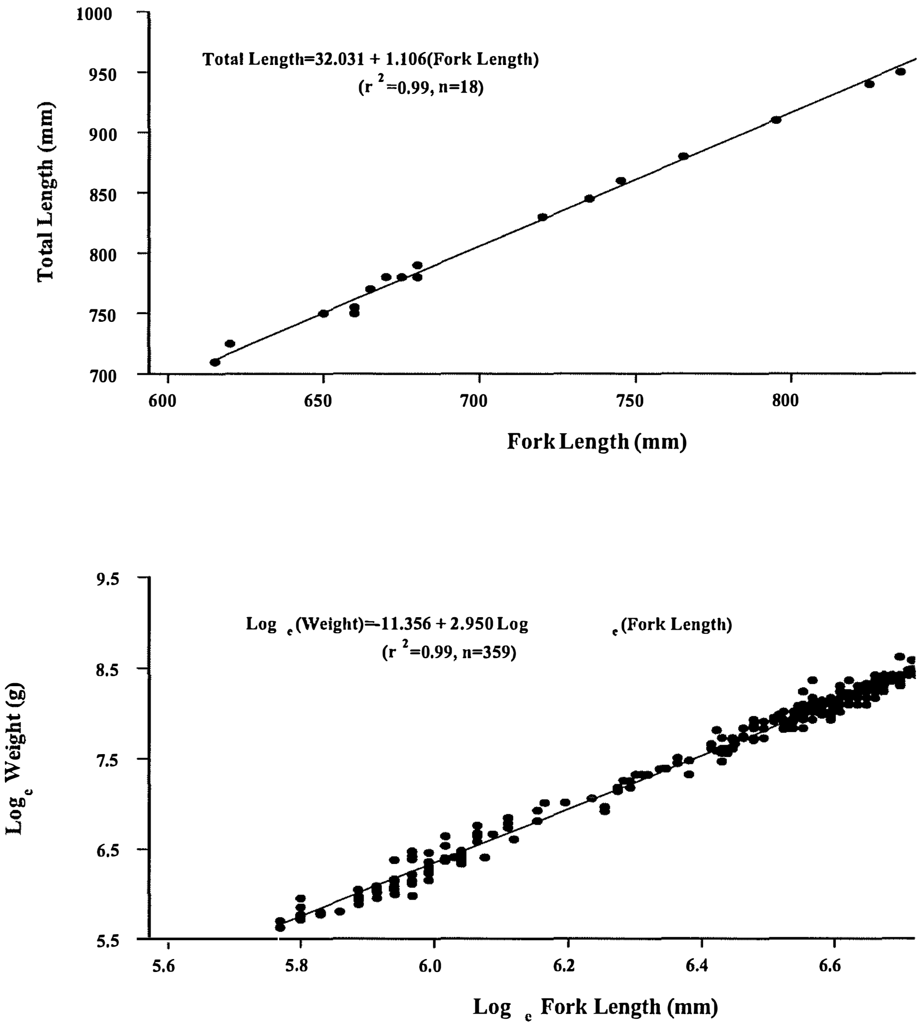


Figure 3.2.50. Total length (mm) - fork length (mm), $\log_e$ transformed weight (g) - $\log_e$ transformed fork length (mm), relationships of grey mackerel (sexes and regions combined).

Table 3.2.58. Total length (mm), $\log_e$ transformed (Ln) weight (g)-fork length (mm) relationships of grey mackerel (regions combined).

Species	Relationship	Intercept s. e.	Slope s. e.	n	r^2
Females	Log_e(weight)= -10.472+2.816(fork length)	0.527	0.083	20	0.98
Males	Log_e(weight)=-11.650+ 3.003 Ln(fork length)	0.374	0.059	44	0.98
Combined	Log_e(weight)=-11.356+ 2.950 Ln(fork length)	0.11	0.017	359	0.99
Combined	Total Length=32.031+1.106(fork length)	11.71	0.016	18	0.99

Whole otoliths were more precisely aged than sectioned ones for grey mackerel owing to their greater readability and clarity. A total of 1199 (97%) of 1232 whole grey mackerel otoliths were aged the same by two independent readers. As a result, whole otoliths were used for age and growth assessments. Monthly variation in marginal increments were observed for one (*1*-way ANOVA, F=6.03, d.f.=11, 409, P<0.0001), two (*1*-way ANOVA, F=8.56, d.f.=8, 174, P<0.0001) and three (*1*-way ANOVA, F=2.72, d.f.=10, 202, P<0.0038) year old fish. Otolith marks were formed annually from November to February in one and two year old fish (Figure 3.2.51.). Marginal increment analysis appeared to validate otolith marks as indicators of annual growth in one and two year old grey mackerel. Monthly variations in marginal increments of fish in age classes greater than two years old did not appear to be different as the proximity of later annuli to the edge reduced the effectiveness of use of marginal increments.

Age Class 1

Age Class 2

Age Class 3

Age Class 4

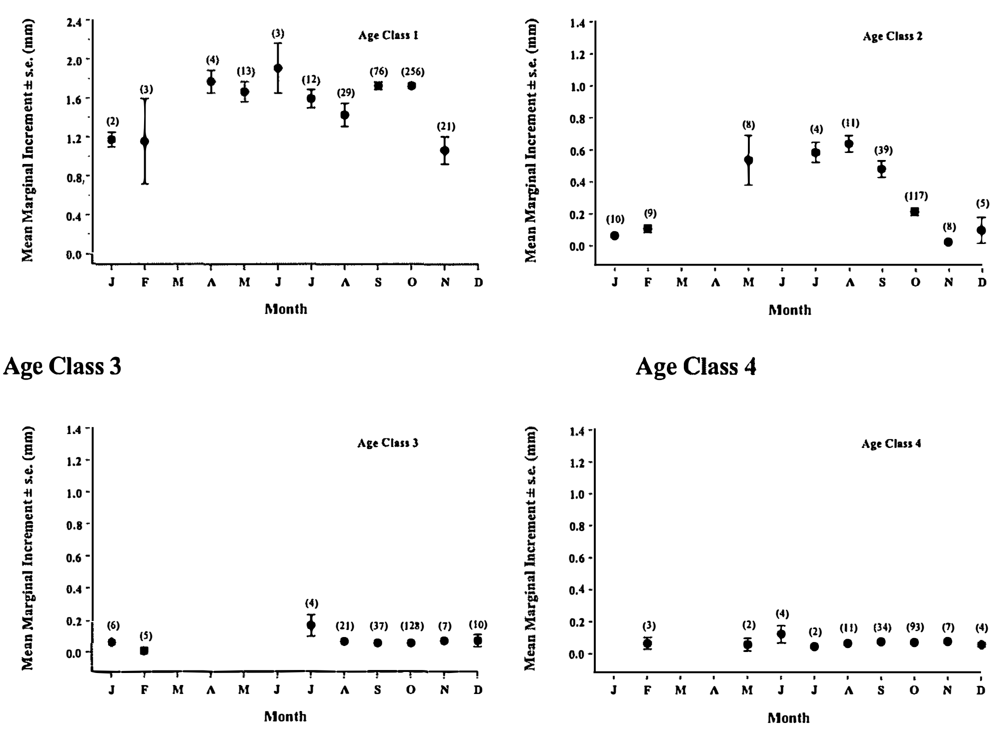


Figure 3.2.51. Monthly mean marginal increments (mm) ± standard errors of grey mackerel age classes 1 to 4 (sexes and regions combined). The numbers in parentheses above each data point refer to the numbers of fish for which marginal increments were measured.

Female grey mackerel between 380 and 990 mm were aged. Males aged ranged in length from 330 to 990 mm. Female and male grey mackerel were aged to twelve and eleven years respectively. Distinct sex specific growth curves were observed for grey mackerel (χ^2=173.3, d.f.=3, P<0.005), with males growing faster but reaching a smaller theoretical maximum length than females (Figure 3.2.52. and Table 3.2.59.). Growth curves for fish of each sex sampled from different regions appeared to be similar (Figure 3.2.53.).

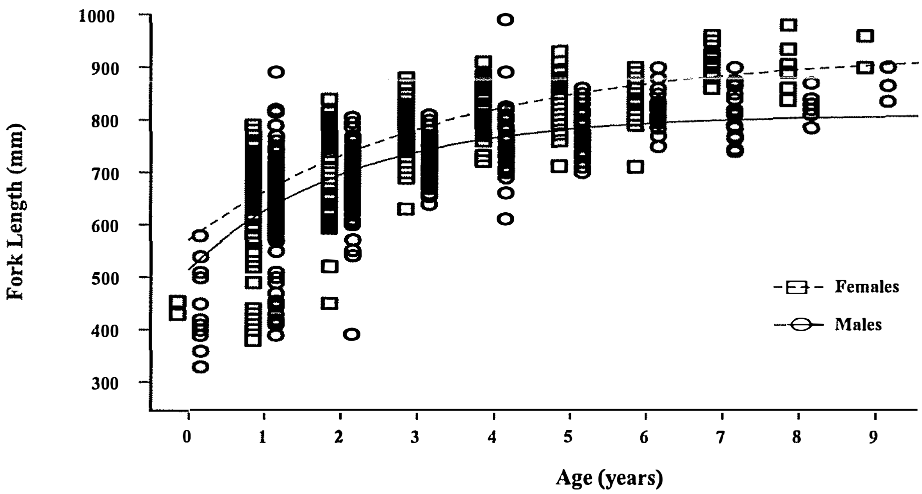


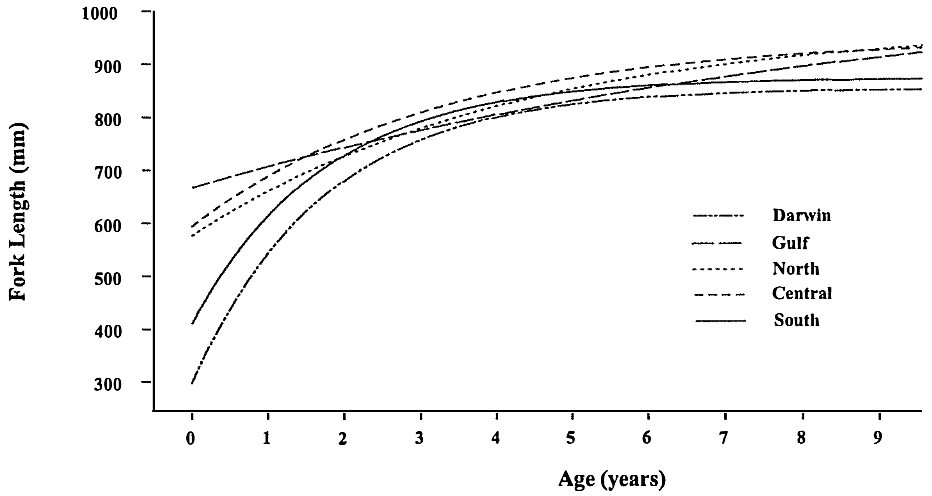
Figure 3.2.52. Von Bertalanffy growth curves fitted to observed age and fork length (mm) data of each grey mackerel sex (regions combined).

Table 3.2.59. Von Bertalanffy growth parameters (± 95% confidence intervals) calculated from direct length-at-age data of grey mackerel.

Sex	Region	n	L_∞ (95% c. i.)	K (95% c. i.)	t_0 (95% c. i.)
Females	Darwin	59	856 (783, 928)	0.583 (0.308, 0.859)	-0.735 (-1.421, -0.051)
	Gulf	154	1073 (782, 1364)	0.104 (-0.004, 0.212)	-9.364 (-15.371, -3.356)
	North	151	976 (892, 1060)	0.238 (0.130, 0.347)	-3.764 (-5.319, -2.210)
	Central	97	950 (898, 1002)	0.310 (0.188, 0.433)	-3.175 (-4.462, -1.888)
	South	17	875 (704, 1045)	0.581 (-0.030, 1.192)	-1.096 (-2.551, 0.359)
	Combined	478	928 (887, 969)	0.301 (0.215, 0.387)	-3.174 (-4.086, -2.262)
Males	Darwin	46	929 (756, 1102)	0.283 (0.104, 0.463)	-2.022 (-2.987, -1.057)
	Gulf	322	891 (808, 973)	0.170 (0.074, 0.265)	-7.259 (-10.378, -4.139)
	North	305	1080 (742, 1417)	0.090 (0.004, 0.176)	-9.153 (-13.882, -4.424)
	Central	27	898 (780, 996)	0.301 (0.026, 0.576)	-3.587 (-6.974, -0.200)
	South	22	813 (725, 902)	1.005 (0.151, 1.859)	0.012 (-0.772, 0.796)
	Combined	722	811(794, 827)	0.475 (0.390, 0.561)	-2.131 (-2.577, -1.686)

Grey mackerel otolith radius-fork length regression intercepts were significantly different between sexes (ANCOVA, F=9.71, d.f.=1, 1084, P<0.0019), but there was no difference in the regression slopes between sexes (ANCOVA, F=.28, d.f.=1, 1084, N.S.) (Figure 3.2.54.).

Females



Males

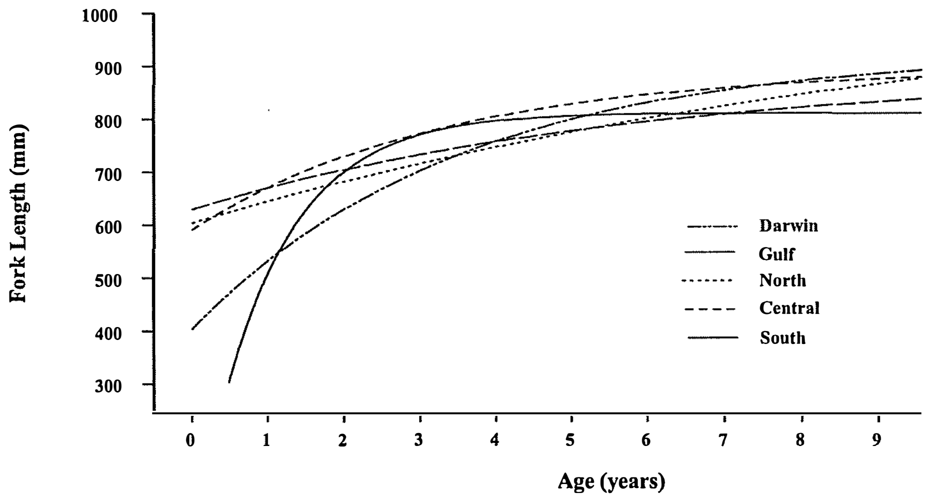
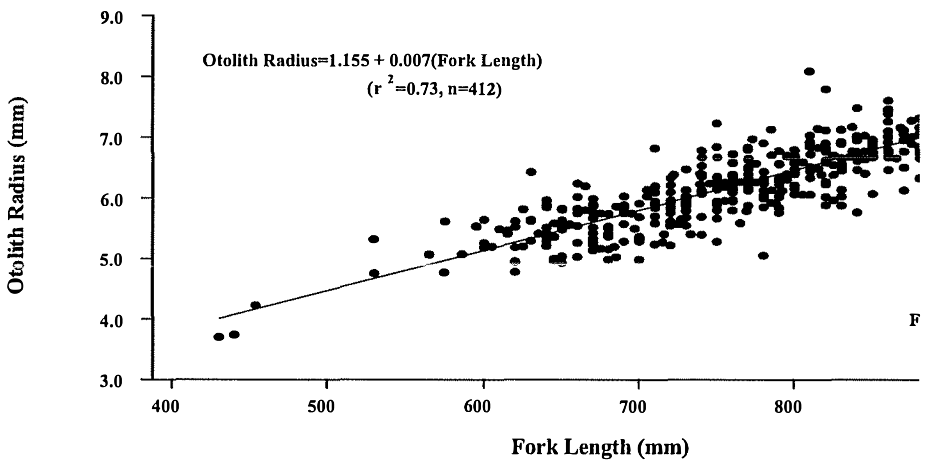


Figure 3.2.53. Von Bertalanffy growth curves fitted to observed age and fork length (mm) data of each grey mackerel sex and region.

Females



Males

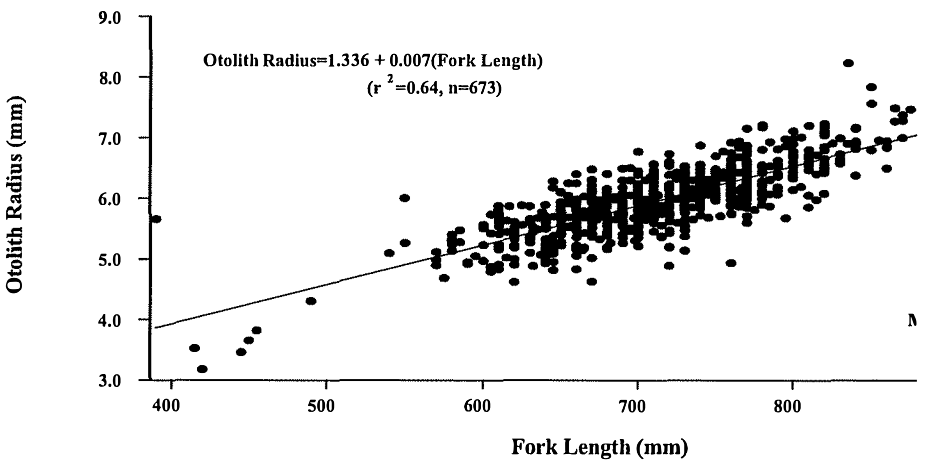


Figure 3.2.54. Otolith radius-fork length (mm) relationships for back-calculation purposes of grey mackerel (regions combined).

Male and female grey mackerel exhibited different growth curves using mean back calculated age and length data. Males grew at a faster rate than females, though males did not reach as great a theoretical maximum length as females (Figure 3.2.55.). The mean length of female grey mackerel was greater than that of males at all ages (Tables 3.2.60. and 3.2.61.). Estimated von Bertalanffy growth parameters from back-calculated length-at-age data were generally larger than direct length at age parameters (Tables 3.2.59. and 3.2.62.). Confidence in estimates from back-calculated values was lower than those for direct length-at-age estimates owing to the greater variation in back-calculated values.

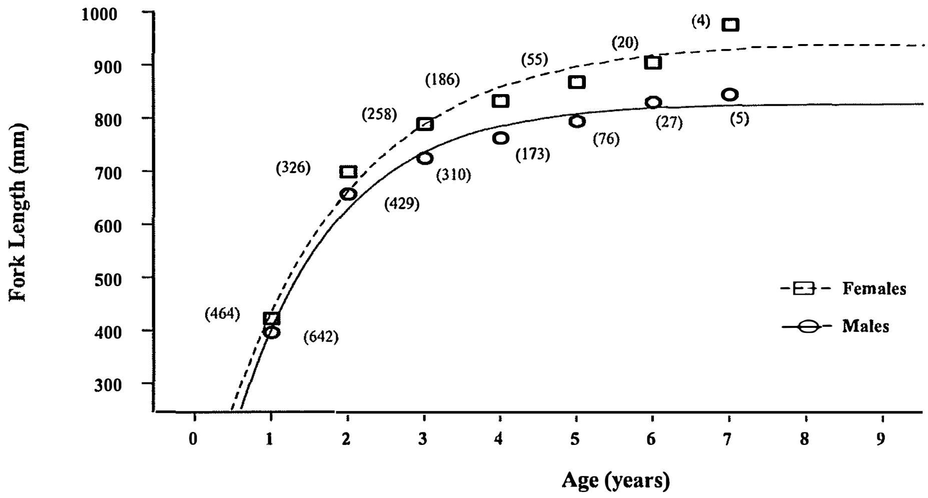


Figure 3.2.55. Von Bertalanffy growth curves fitted to mean back-calculated age and fork length (mm) data of each grey mackerel sex (regions combined). The numbers in parentheses adjacent to each data point refer to the number of fish of each sex for which back-calculated lengths at each age were estimated.

Table 3.2.60. Mean back-calculated fork lengths (mm) of female grey mackerel (regions combined).

Age (years)	n	Mean Length capture (mm)	Mean back-calculated length (mm) at age (years)						
			1	2	3	4	5	6	7
1	138	680	415						
2	68	736	402	682					
3	72	785	435	704	777				
4	131	804	406	698	776	816			
5	35	847	400	690	780	821	849		
6	16	853	426	690	763	801	833	856	
7	4	924	472	735	851	890	924	953	977
n			464	326	258	186	55	20	4
Mean length			422	700	790	832	869	904	977
Annual Growth Increment (mm)			422	277	90	43	37	36	73

Table 3.2.61. Mean back-calculated fork lengths (mm) of male grey mackerel (regions combined).

Age (years)	n	Mean Length capture (mm)	Mean back-calculated length (mm) at age (years)						
			1	2	3	4	5	6	7
1	213	653	390						
2	119	688	374	645					
3	137	725	409	659	719				
4	97	760	379	659	720	753			
5	49	780	384	647	712	745	774		
6	22	821	443	686	743	782	814	837	
7	5	832	395	654	731	770	800	826	845
n			642	429	310	173	76	27	5
Mean length			396	658	725	763	796	831	845
Annual Growth Increment (mm)			397	262	67	38	33	35	14

Table 3.2.62. Von Bertalanffy growth parameters (± 95% confidence intervals) calculated from mean back-calculated length-at-age data of grey mackerel (regions combined).

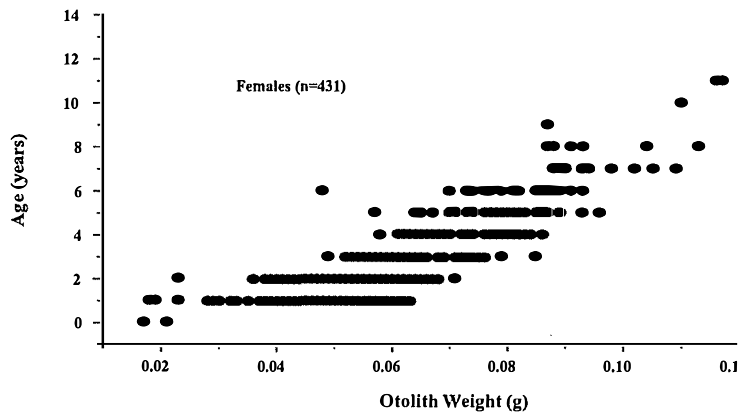
Species	L_∞ (95% c. i.)	K (95% c. i.)	t_0 (95% c. i.)
Females	944 (846,1041)	0.595 (0.206,0.984)	-0.040 (-0.812,0.733)
Males	830 (782,879)	0.759 (0.414,1.104)	0.122 (-0.344, 0.587)

Otolith weight was a more precise estimator of age than otolith radius for grey mackerel (Table 3.2.63.). The weight of otoliths of male grey mackerel increased at a greater rate (ANCOVA, F=14.98, d.f.=1, 1108, P<0.0001) and magnitude (ANCOVA, F=100.18, d.f.=1, 1109, P<0.0001) than those of females. The radius of otoliths increased at a similar rate for each sex (ANCOVA, F=0.23, d.f.=1, 1088, N.S.) (Figures 3.2.56. and 3.2.57.).

Table 3.2.63. Otolith weight (g), radius (mm) and age (years) relationships of grey mackerel (regions combined).

Sex	Relationship	n	r^2
Females	Age=-3.111+98.483(otolith weight)	430	0.76
Females	Age=-10.932+2.222(otolith radius)	415	0.60
Males	Age=-3.34+112.937(otolith weight)	678	0.73
Males	Age=-10.096+2.163(otolith radius)	673	0.50

Females



Males

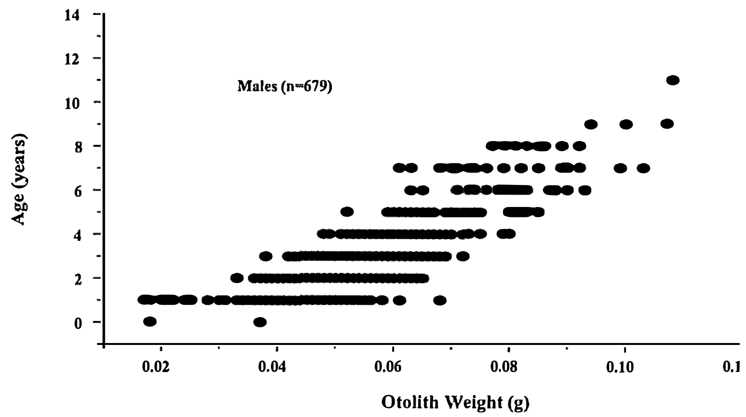
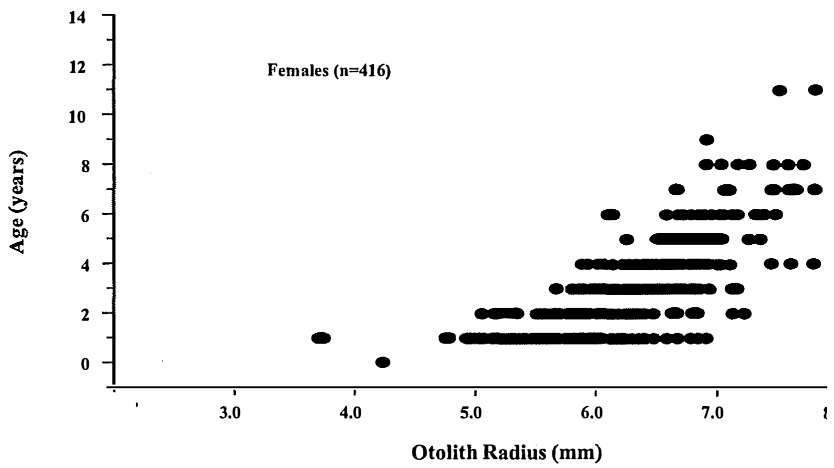


Figure 3.2.56. Relationships of otolith weight (g) and age (years) of grey mackerel (regions combined).

Females



Males

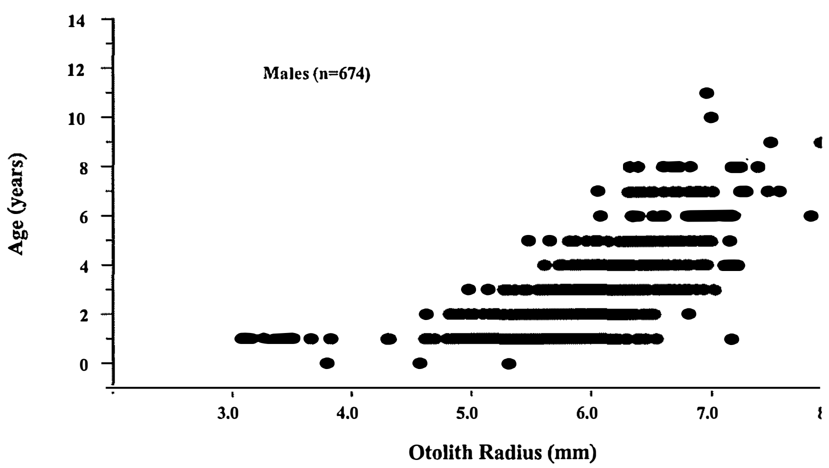


Figure 3.2.57. Relationships of otolith radius (mm) and age (years) of grey mackerel (regions combined).

Mean instantaneous mortality rates ranged from 0.297 to 0.499. Around 61 % of the total grey mackerel population appear to survive each year. Grey mackerel appear to be fully recruited to the commercial mesh net fisheries at one year of age (Table 3.2.64.).

Table 3.2.64. Grey mackerel instantaneous mortality and survival rates by sex, region and gear type (Z=total instantaneous mortality rate; S=e^{-z} survival rate; A=1-e^{-z} annual mortality rate).

Sex	Capture method and region	n	Recruitment age (years)	Mortality estimates		
				Z	S	A
Females	East Coast 15.24 cm net	258	1	0.454	0.635	0.365
	Gulf 16.51 cm net	153	1	0.406	0.666	0.334
	Total	411	1	0.482	0.618	0.382
Males	East Coast 15.24 cm net	341	1	0.499	0.607	0.393
	Gulf 16.51 cm net	320	1	0.297	0.743	0.257
	Total	661	1	0.492	0.611	0.389

3.2.3.2 Reproduction

Reproductive development was differentiated into six macroscopic and histological stages for females, and four stages for males (Tables 3.1.1. and 3.1.2.). A logical pattern of increasing weight change in the gonads (up to stage V for females and III for males), represented by GSIs was observed for each stage, supporting the validity of the development schemes (Figures 3.2.58. and 3.2.59.). Female (G=555.6, d.f.=20, P<0.001; V=0.828) and male (G=364, d.f.=9, P<0.001; V=0.720) macroscopic and histological staging schemes were closely related further confirming the validity of staging schemes for grey mackerel.

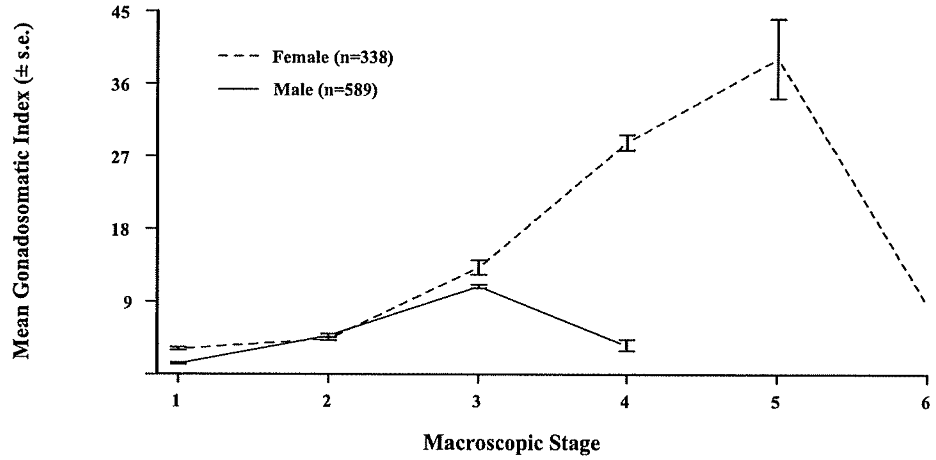


Figure 3.2.58. Pattern of mean gonadosomatic index (± standard error) with increasing macroscopic stage of grey mackerel gonads.

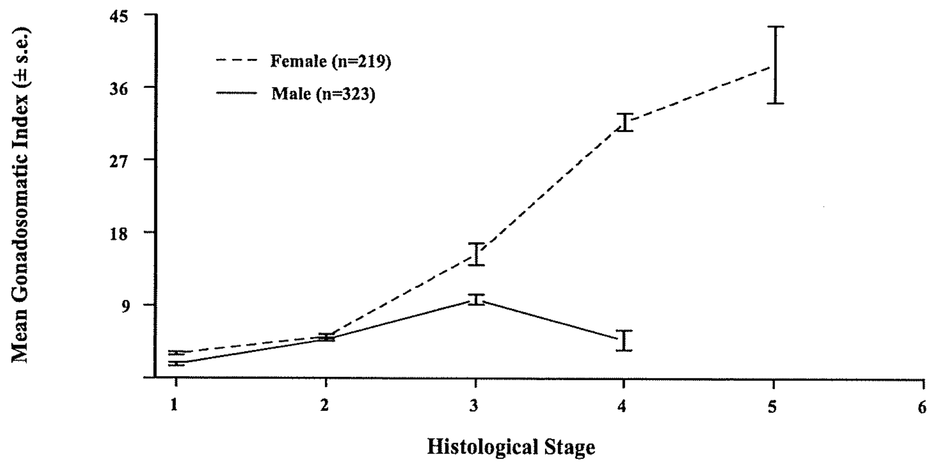


Figure 3.2.59. Pattern of mean gonadosomatic index (± standard error) with increasing histological stage of grey mackerel gonads.

Reproductive analyses for grey mackerel sampled from the east coast of Queensland and the Gulf of Carpentaria were separated due to the geographical separation between the two areas, and the genetic variation and trace elemental composition differences of fish from each area.

Monthly GSIs of either sex did not differ between east coast regions within the same year. Monthly samples were therefore pooled across these regions. Monthly differences in GSIs were evident between years for females on the east coast during September (*1*-way ANOVA, F=9.783.55, d.f.=3,63, *P*<0.0001) and October (*t*=-2.0457, d.f.=34, *P*<0.0486). Grey mackerel on the east coast have increased GSIs from September to January (Figures 3.2.60.). The majority of maturing/ripe fish on the east coast were also captured during this period (Figures 3.2.61.).

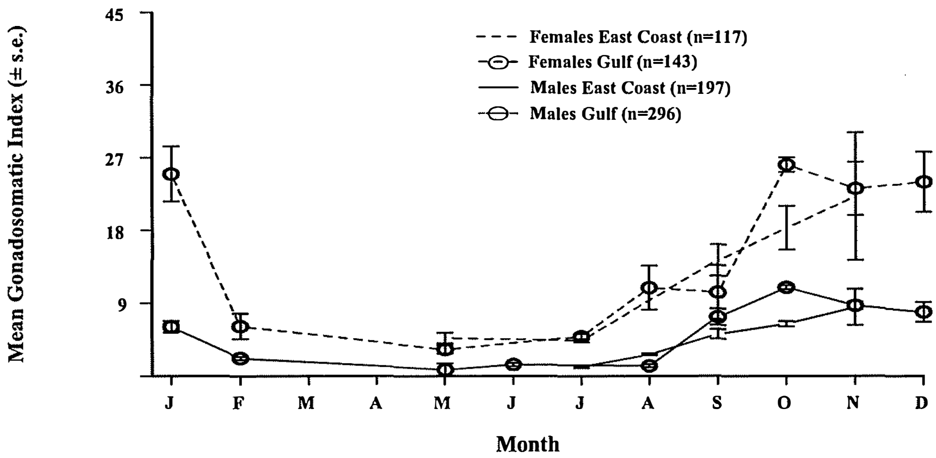


Figure 3.2.60. Monthly mean GSIs (± standard errors) of mature grey mackerel (female macroscopic female II-VI, and male stages II-IV).

The majority of maturing/ripe fish in the Gulf of Carpentaria were captured between September and January (Figures 3.2.61.). GSIs of female grey mackerel in the Gulf of Carpentaria between October and January were significantly greater than the rest of the year (HSD). Males in the Gulf of Carpentaria were generally more developed between September and January than the rest of the year (Figure 3.2.60.).

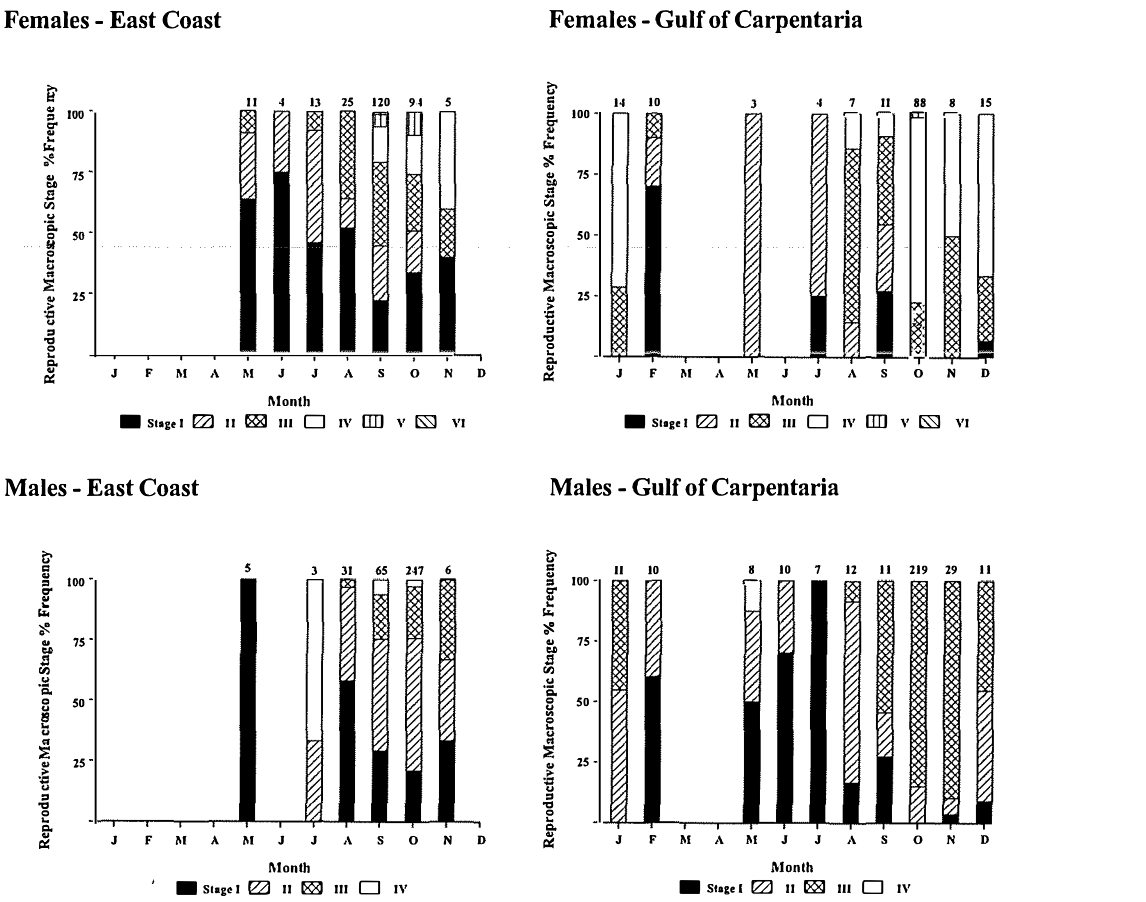


Figure 3.2.61. Monthly proportions of macroscopic stages in grey mackerel. The numbers above each bar refer to the number of fish staged for that month.

The smallest ripe female grey mackerel caught on the east coast was 720 mm and the largest immature female was 820 mm (see Materials and Methods section - all lengths referred to are fork lengths in mm, unless otherwise stated). The smallest mature male captured on the east coast was 600 mm and the largest immature male was 890 mm. In the Gulf of Carpentaria the smallest ripe female grey mackerel caught was 615 mm and the largest immature female was 810 mm. The smallest mature male caught in the Gulf of Carpentaria was 540 mm and the largest immature male was 770 mm.

On the east coast, at least 50% of female grey mackerel between 650 and 699 mm were mature. On the east coast the largest initial difference in GSIs for females during the peak spawning period occurred between 700 and 749 mm (Figure 3.2.62.). In the Gulf of Carpentaria, more than 50% of female grey mackerel of each length class captured during the spawning period, were capable of spawning (Figure 3.2.62.).

The length at first maturity of male grey mackerel on both the east coast and in the Gulf of Carpentaria was not able to be clearly established as more than 50% of all fish captured, were capable of spawning (Figure 3.2.62.). The smallest length class of fish sampled in both areas during the peak spawning period was between 550 to 599 mm fork length. Given that throughout the remainder of the year all grey mackerel less than 550 mm generally exhibited immature gonad development, the length of first maturation of male grey mackerel was estimated to be between 550 and 599 mm. There was no appreciable difference in mean GSIs between each successive length class of male fish from either the east coast or the Gulf of Carpentaria (Figure 3.2.62.). The current legal minimum length of 500 mm total length for grey mackerel was smaller than the estimated length of first maturity for female and male grey mackerel.

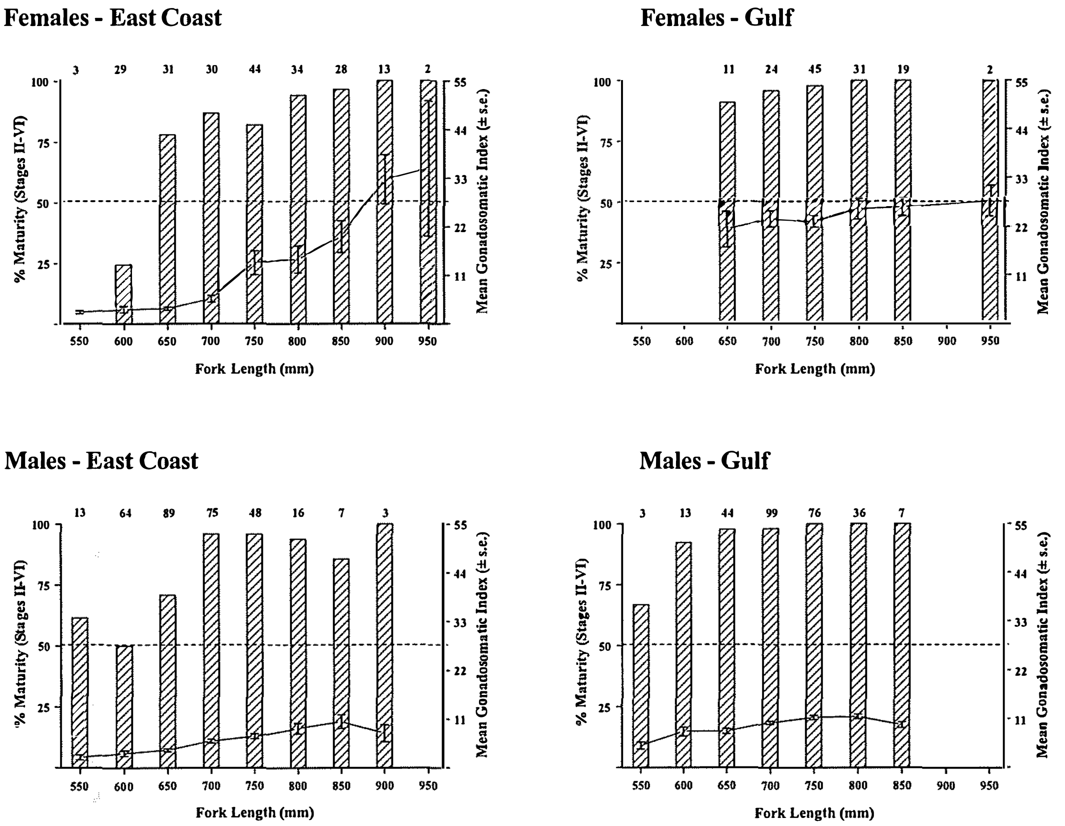
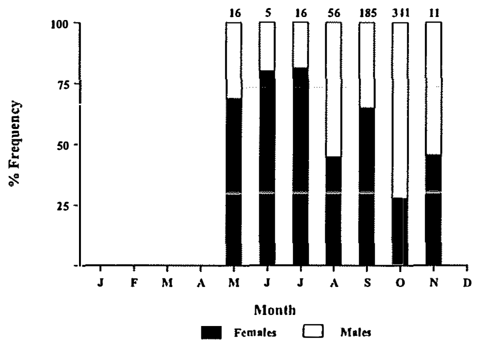


Figure 3.2.62. Fork length (mm) of grey mackerel from the east coast and Gulf of Carpentaria at first maturity determined by 50% macroscopic maturity stage and mean gonadosomatic index (± standard error) for peak spawning months of September to January. The numbers above each bar refer to the number of fish staged for each length class.

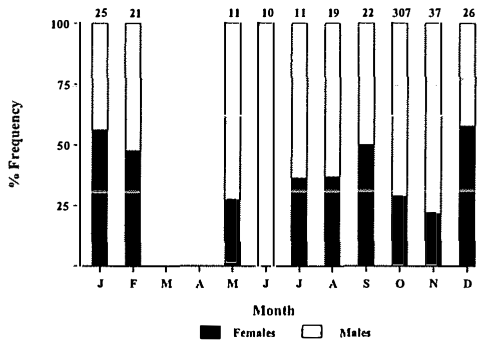
Grey mackerel catches on the east coast were female biased during July (χ^2=5.06, d.f.=1, P<0.05) and September (χ^2=15.76, d.f.=1, P<0.05) and male biased during October (χ^2=67.75, d.f.=1, P<0.05) (Figure 3.2.63.). On the east coast catches were biased towards males for the length classes between 600 to 649 mm (χ^2=14.30, d.f.=1, P<0.05), 650 to 699 mm (χ^2=20.06, d.f.=1, P<0.05), and 700 to 750 mm (χ^2=19.69, d.f.=1, P<0.05). Females were more abundant in catches on the east coast for the larger length classes between 800 to 849 mm (χ^2=7.78, d.f.=1, P<0.05), 850 to 899 mm (χ^2=16.57, d.f.=1, P<0.05), and 900 to 949 mm (χ^2=6.72, d.f.=1, P<0.05) (Figure 3.2.63.).

In the Gulf of Carpentaria, male grey mackerel dominated catches in June (χ^2=8.10, d.f.=1, P<0.05), October (χ^2=55.04, d.f.=1, P<0.05), and November (χ^2=10.81, d.f.=1, P<0.05) (Figure 3.2.63.). In the Gulf of Carpentaria catches were male biased for the length classes between 600 to 649 mm (χ^2=12.19, d.f.=1, P<0.05), 650 to 699 mm (χ^2=20.13, d.f.=1, P<0.05), 700 to 749 mm (χ^2=43.34, d.f.=1, P<0.05), and 750 to 799 mm (χ^2=11.83, d.f.=1, *P*<0.05). Females were more abundant in the Gulf of Carpentaria for the length class between 850 to 899 mm (χ^2=5.33, d.f.=1, *P*<0.05) (Figure 3.2.63.).

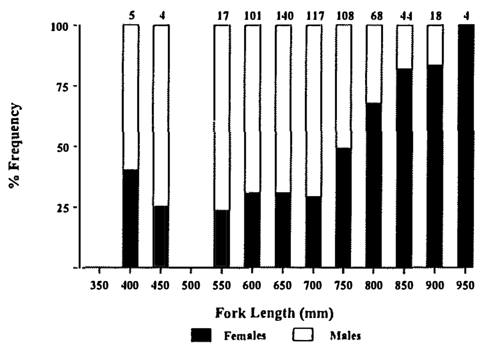
Monthly sex ratio - East Coast



Monthly sex ratio - Gulf



Length sex ratio - East Coast



Length sex ratio - Gulf

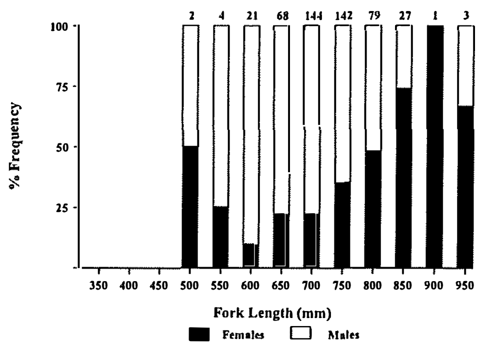


Figure 3.2.63. Percent frequency of monthly and length based sex ratios of grey mackerel. The number above each bar refers to the number of fish sampled for that month.

Grey mackerel have a significant linear relationship between mean advanced stage oocyte diameter and fish length (Figure 3.2.64.). A significant relationship also existed between fish length and estimated total oocyte carrying potential of grey mackerel (Figure 3.2.65.).

Oocyte Diameter

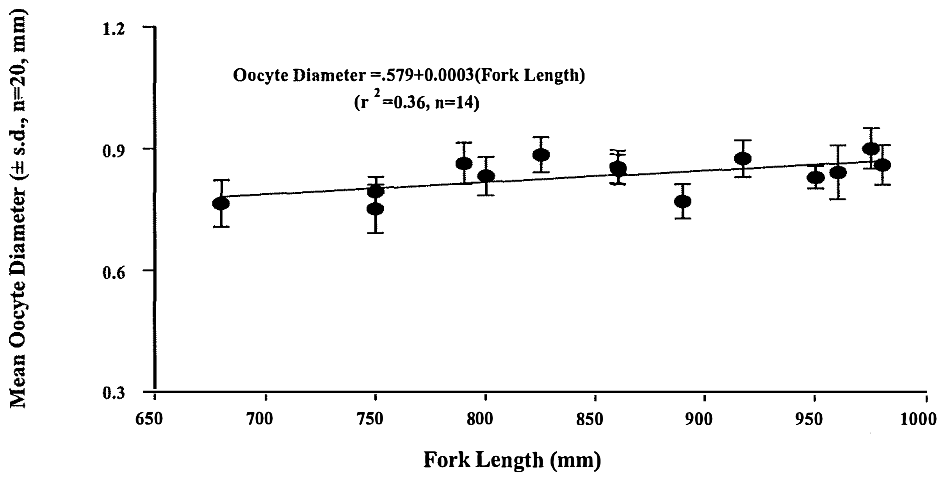


Figure 3.2.64. Mean oocyte diameter (± standard deviation) related to fork length (mm) of grey mackerel for spawning months of September to January based on histological stages IV and V.

Total Potential Fecundity

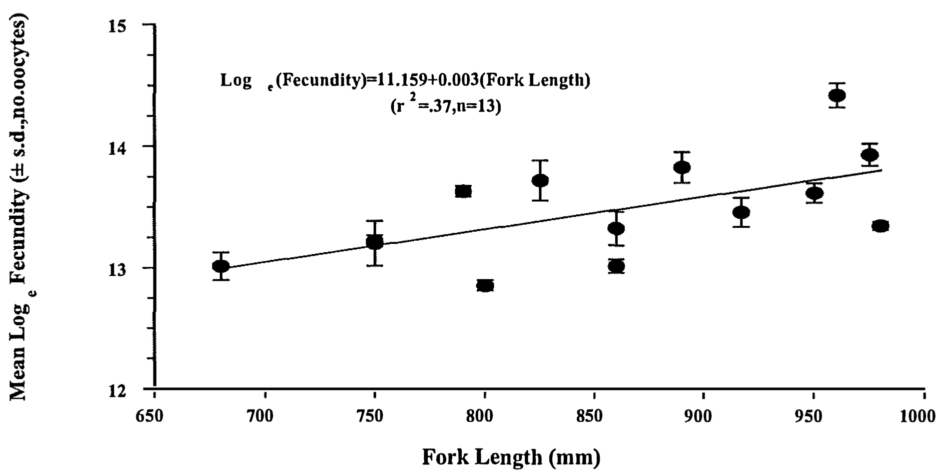


Figure 3.2.65. Total potential fecundity ('000 oocytes) (± standard deviation) related to fork length (mm) of grey mackerel for spawning months of September to January based on histological stages IV and V.

3.2.3.3. Movements

A total of 313 grey mackerel were tagged prior to and during this study. Only one recapture was reported and this was from the same area that the fish was released. This single recapture was not sufficient to provide any information on movements. A commercial net fishery targets grey mackerel and the low number tagged is believed to be indicative of the infrequency and difficulty in capturing this species using hook and line, compared to school and spotted mackerel.

3.2.3.4. Otolith Chemistry

The chemical composition of grey mackerel whole otoliths was determined by examining the concentration of the same 11 trace elements deposited in their otoliths that were used for school and spotted mackerel (Table 3.2.65.). Similar to the other small mackerel, Fe and Li were found to be highly variable and below the detection limits of the spectrometer. These elements, in addition to Ca were excluded from any further analyses.

All elements detected above the minimum detection levels (Ba, K, Mg, Mn, Na, P, S, Sr) varied significantly in their concentrations between samples from the different study areas for grey mackerel, except for K (Table 3.2.66). Grey mackerel otoliths had a number of elements that differed in concentration between Northern Territory and Queensland samples and the different age classes within each geographic region (Table 3.2.67.). No element concentrations in grey mackerel otoliths were correlated with length (Tables 3.2.68. to 3.2.70.).

Table 3.2.66. Trace elements that varied significantly in concentration between grey mackerel otoliths from different areas. One-way analysis of variance results examined the effect of area on each trace element concentration. Each element varied significantly between areas, except K (significant result*). All analyses had d.f.=6,145.

Element	Grey Mackerel ANOVA Results (d.f.=6,145)	
	F	P
Ba	16.70	0.0001*
K	1.91	0.0835
Mg	17.90	0.0001*
Mn	4.89	0.0001*
Na	9.36	0.0001*
P	11.34	0.0001*
S	8.38	0.0001*
Sr	18.78	0.0001*

Table 3.2.67. Trace elements of grey mackerel whole otoliths that differed in their concentration between areas (Tukey's studentized range test HSD). The number after the area refers to the age of the samples analysed, eg. Hervey (1) refers to 1 year old fish from Hervey Bay. All comparisons had d.f.=145 and were significant at P<0.05.

	Area (age, years)						
	Darwin (1)	Gove (2)	Gulf (2)	Townsville (2)	Mackay (1)	Mackay (2)	Hervey (1)
Darwin (1)	-	-	-	-	-	-	-
Gove (2)	Ba Mg Na P S Sr	-	-	-	-	-	-
Gulf (2)	Ba Sr	Ba Mg Na P S Sr	-	-	-	-	-
Townsville (2)	Ba P S	Mg Na P S Sr	P	-	-	-	-
Mackay (1)	Mg	Ba Na P S Sr	Ba Mg Sr	Ba Mg	-	-	-
Mackay (2)	Ba	Ba Mg Na P S Sr		Ba	Mg	-	-
Hervey (1)	Mg Mn Na	Ba Mg Mn P S Sr	Ba Mg Mn Na	Ba Mg Mn Na P	Mg Na	Mg Mn Na P	-

Table 3.2.65. Mean element concentrations of grey mackerel otoliths sampled from the different regions. Minimum elemental detection limits of the ICP-AES averaged from the combined acid blank results of school and spotted mackerel calculated from the minimum otolith weight used in the analyses, 0.0068 g (n=6). All units are in mg/Kg, except Ca which is measured as a % : (Ba=0.78; Ca=544; Fe=23.9; K=353; Li=15; Mg=10.9; Mn=1.10; Na=1250; P=54.1; S=191; Sr=3.24)

Region	Age (yrs)		Length (mm)	Otolith Wt. (g)	Ba	Ca	Fe	K	Li	Mg	Mn	Na	P	S	Sr
Hervey Bay	1	No.	15	15	15	15	15	15	15	15	15	15	15	15	15
		Mean	606	0.033	1.69	38.3	1.32	449.87	0.32	21.75	0.66	3571.4	101.67	420.47	1636.87
		Std.	23	0.003	0.53	0.93	1.64	79.82	0.45	3.24	0.23	202.84	7.99	29.98	88.83
		Range	555-685	0.026-0.040	1.08-3.00	36.8-39.7	0-5.7	262-555	0-1.2	16.3-28.9	0.3-1.1	3240-3889	89-113	361-484	1525-1762
		CV	3.7	9	31.65	2.43	124.03	17.74	143.59	14.92	34.66	5.68	7.87	7.13	5.43
Mackay	1	No.	29	29	29	29	29	29	29	29	29	29	29	29	29
		Mean	605	0.033	1.78	37.98	14.27	399.41	-0.002	17.5	0.45	3050.52	116.93	432.41	1602.52
		Std.	32	0.003	0.35	0.84	62.61	90.1	0.76	1.74	0.27	147.72	11.43	25.57	92.9
		Range	544-715	0.025-0.039	1.17-2.70	36.3-40.4	0-338.6	223-570	0-1.4	14.5-21.0	0-1.5	2719-3285	93-137	385-477	1441-1774
		CV	5.3	10.5	19.64	2.22	438.63	22.56	-44264.7	9.95	59.45	4.84	9.77	5.91	5.8
Mackay	2	No.	21	21	21	21	21	21	21	21	21	21	21	21	21
		Mean	625	0.041	2.19	37.25	3.48	366.95	-0.38	14.46	0.42	2899.1	123.48	457.24	1620.43
		Std.	45	0.006	0.47	0.57	11.21	76.02	0.95	0.91	0.22	145.41	9.65	26.14	88.23
		Range	552-790	0.033-0.060	1.54-3.41	36.2-38.7	0-52.1	283-511	0-1.1	13.3-16.7	0.1-1.2	2564-3177	109-144	410-516	1521-1939
		CV	7.3	15	21.49	1.54	322.43	20.72	-250.76	6.28	52.93	5.02	7.81	5.72	5.44
Townsville	2	No.	30	30	30	30	30	30	30	30	30	30	30	30	30
		Mean	635	0.042	2.73	37.58	1.25	405.7	-0.06	14.78	0.37	2823.4	132.07	468.07	1744.43
		Std.	20	0.002	0.45	0.89	2.264	50.46	0.81	1.35	0.22	169.45	11.99	31.67	91.73
		Range	605-670	0.036-0.046	1.55-3.81	36.0-39.8	0-9.9	316-491	0-1.1	11.9-17.9	0-0.6	2523-3323	112-159	412-576	1557-1936
		CV	3.1	5.7	16.41	2.37	181.54	12.439	-1350.06	9.15	59.46	6.002	9.09	6.77	5.26
Darwin	1	No.	28	28	13	13	13	13	13	13	13	13	13	13	13
		Mean	620	0.037	1.42	30.78	1.06	414.46	-0.14	14.6	0.26	2853	106.23	392.77	1496
		Std.	21	0.003	0.477	7.16	1.72	140.31	0.59	3.24	0.26	574.7	25.22	89.56	365.63
		Range	585-665	0.032-0.044	0.87-2.32	16.7-43.5	0-5.1	257-680	0-0.9	10-20	0-0.7	1787-3809	63-151	228-579	846-2220
		CV	3.5	8	33.53	23.25	161.84	33.85	-410.2	22.22	100.7	20.14	23.74	22.8	24.44
Gove	2	No.	13	13	16	16	16	16	16	16	16	16	16	16	16
		Mean	363	0.022	3.07	47.49	7.05	826	-0.25	17.78	0.33	3599.19	151.19	556.38	2442.75
		Std.	45	0.005	1.37	16.45	12.62	187	0.98	5.57	0.12	1228.06	51.42	199.42	823.71
		Range	320-450	0.017-0.035	1.82-7.12	30.0-91.6	0-49.5	599-1238	0-0.9	12.5-32.3	0.2-0.6	2489-6948	100-291	352-1139	1670-4674
		CV	12.4	24.3	44.59	34.64	178.9	22.6	-394.46	31.34	36.45	34.12	34.01	35.21	33.72
Gulf	2	No.	18	18	28	28	28	28	28	28	28	28	28	28	28
		Mean	432	0.023	2.45	37.79	6.05	545	0.32	14.85	0.36	2965.75	114.75	458.21	1849.79
		Std.	18	0.006	0.55	1.07	16.86	136	0.71	2.21	0.21	186.81	9.68	46.82	101.28
		Range	400-460	0.015-0.035	1.28-3.37	35.8-39.4	0-86.2	319-817	0-1.6	11.3-22.2	0-0.8	2672-3388	99-139	397-587	1566-2057
		CV	4.1	24.6	22.37	2.83	278.55	24.9	223.65	14.86	58.72	6.3	8.43	10.22	5.48

Table 3.2.68. Analysis of covariance results for grey mackerel trace element concentrations that were significantly correlated with fish length for all areas. Analysis of covariance results of the concentrations of trace elements with area (n=7, including the different age classes) as a factor and length as a covariate. Analyses determined the regression coefficient for the covariate length or the correction factor (r) required to standardise the concentrations of individual elements affected by variable length (* indicates a significant result).

Element	Length*Area (d.f.=6,137)		Length (d.f.=1,143)		r
	F	P	F	P	
Ba	1.33	0.2482	0.13	0.7157	-
K	3.51	0.0029*	-	-	-
Mg	2.83	0.0124*	-	-	-
Mn	1.02	0.4171	0.05	0.8153	-
Na	2.55	0.0227*	-	-	
P	2.00	0.0702	0.46	0.4997	-
S	2.19	0.0476*	-	-	-
Sr	3.43	0.0035*	-	-	-

Table 3.2.69. Grey mackerel trace element concentrations that were significantly correlated with fish length for Queensland east coast samples. Analysis of covariance results of the concentrations of trace elements with area (n=4, including the different age classes) as a factor and length as a covariate. Analyses determined the regression coefficient for the covariate length or the correction factor (r) required to standardise the concentrations of individual elements affected by variable length (* indicates a significant result).

Element	Length*Area (d.f.=3,86)		Length (d.f.=1,89)		r
	F	P	F	P	
Ba	1.70	0.1723	0.48	0.4896	-
K	5.05	0.0029*	-	-	-
Mg	4.48	0.0057*	-	-	-
Mn	0.21	0.8897	1.69	0.1973	-
Na	3.90	0.0115*	-	-	-
P	0.91	0.4419	0.04	0.8503	-
S	2.14	0.1011	1.51	0.2229	-
Sr	0.96	0.4160	2.99	0.0872	-

Table 3.2.70. Grey mackerel trace element concentrations that were significantly correlated with fish length for northern Australian samples (excluding Queensland east coast). Analysis of covariance results of the concentrations of trace elements with area (n=3) as a factor and length as a covariate. Analyses determined the regression coefficient for the covariate length or the correction factor (r) required to standardise the concentrations of individual elements affected by variable length (* indicates a significant result).

Element	Length*Area (d.f.=2,51)		Length (d.f.=1,53)		r
	F	P	F	P	
Ba	1.45	0.2448	0.00	0.9824	-
K	3.42	0.0403*	-	-	-
Mg	2.86	0.0664	2.40	0.1274	-
Mn	1.54	0.2235	1.47	0.2308	-
Na	2.79	0.0710	0.60	0.4434	-
P	2.47	0.0950	0.34	0.5605	-
S	2.49	0.0931	0.01	0.9368	-
Sr	3.96	0.0253*	-	-	-

There was no discrimination of grey mackerel samples based on their otolith element compositions, when all samples were analysed together (Figure 3.2.66.). Ba, Mn and P were the only elements used in the analysis which may explain the poor discriminatory power of the model (Wilks' lambda=0.37) (Table 3.2.71.). Only 50% of the total grey mackerel samples were classified into their correct group by the predicted classification functions, further confirming the poor discrimination of using only the three elements (Table 3.2.72.).

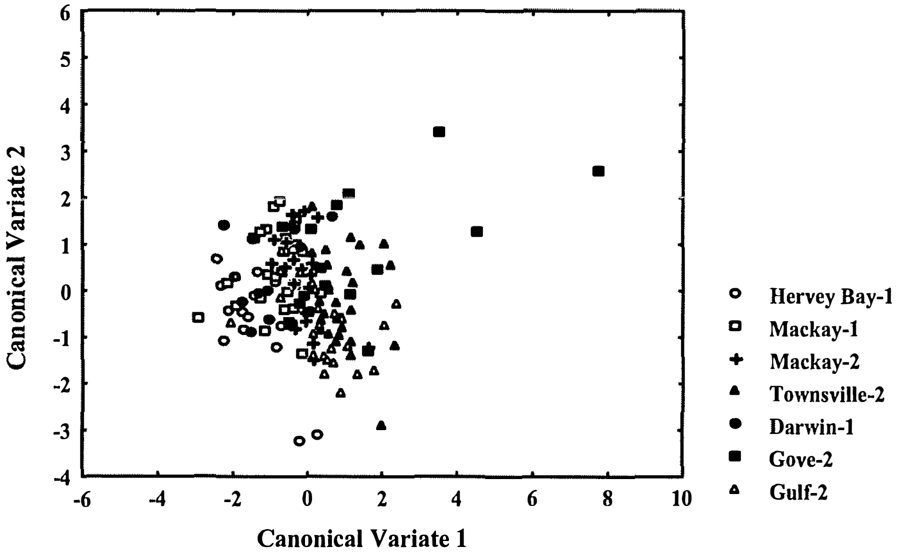


Figure 3.2.66. Discrimination between grey mackerel samples from all areas based on the concentrations of the 3 suitable trace elements.

Table 3.2.71. Discrimination between samples of grey mackerel from all areas determined by the standardised canonical coefficients for the significant ($p<0.05$) canonical variates (discriminant functions) I, II and III, and the cumulative proportion of the explained variance accounted for by each function, for the 3 significant elements (length corrected) (Wilks' Lambda for overall model=0.374).

Element	Canonical Variate		
	I	II	III
Ba	0.94	-1.03	-0.09
P	006	1.30	0.49
Mn	-0.43	-0.32	0.86
Cumulative Proportion	0.68	0.89	1.00

Table 3.2.72. Classification matrix of the frequency of assigned cases in each area determined from the discriminant model used to differentiate grey mackerel samples from all areas.

Area	Classification of Individual Grey Mackerel by Area							
	% Correct	Darwin (1)	Gove (2)	Gulf (2)	Townsville (2)	Mackay (1)	Mackay (2)	Hervey (1)
Darwin (1)	38	5	0	0	0	8	0	0
Gove (2)	38	0	6	6	3	1	0	0
Gulf (2)	64	0	0	18	3	6	0	1
Townsville (2)	66	0	2	5	19	3	0	0
Mackay (1)	69	2	0	3	1	20	0	3
Mackay (2)	5	0	0	7	1	11	1	1
Hervey (1)	40	0	0	2	0	7	0	6
Total	50	7	8	41	27	56	1	11

More detailed analyses isolating Queensland and northern Australian grey mackerel samples were used to investigate any patterns in the data as the separate analyses involved a greater number of elements.

In the Queensland east coast samples there was overlap between groups though there were major separation of some year and area combinations (Wilks' lambda=0.17) (Figure 3.2.67.). Ba, Mn and S were the main elements causing the grouping patterns in the first discriminant function (Table 3.2.73.). The separation patterns observed in the individual discrimination resulted in an improved classification of 72% for Queensland east coast samples being correctly placed into their respective groups (Table 3.2.74.).

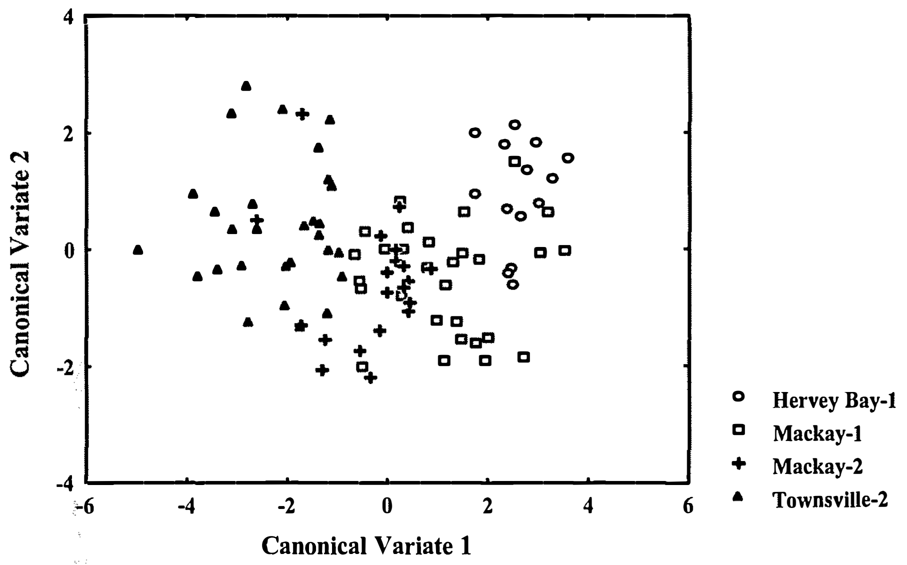


Figure 3.2.67. Discrimination between grey mackerel samples from Queensland east coast areas based on the concentrations of the 5 trace elements.

Table 3.2.73. Discrimination between samples of grey mackerel from Queensland east coast areas determined by the standardised canonical coefficients for the significant ($p<0.05$) canonical variates (discriminant functions) I and II, and the cumulative proportion of the explained variance accounted for by each function, for the 5 significant elements (Wilks' Lambda for overall model=0.174).

Element	**Canonical Variate**	
	I	**II**
Ba	-0.71	0.32
P	-0.40	-0.70
Mn	0.61	0.15
S	-0.48	-0.13
Sr	-0.16	0.83
Cumulative Proportion	0.89	0.99

Table 3.2.74. Classification matrix of the frequency of assigned cases in each area determined from the discriminant model used to differentiate grey mackerel samples from Queensland east coast samples.

Area	Classification of Individual Grey Mackerel by Area				
	% Correct	Townsville (2)	Mackay (1)	Mackay (2)	Hervey (1)
Townsville (2)	90	26	0	3	0
Mackay (1)	66	0	19	6	4
Mackay (2)	57	2	7	12	0
Hervey (1)	73	0	4	0	11
Total	72	28	30	21	15

There was also a reasonable degree of overlap in the otolith chemical patterns of grey mackerel samples collected from northern Australian waters (Wilks' lambda=0.38) (Figure 3.2.68.). As for the other analyses Ba, Mn and Na were the main elements responsible for the observed discrimination patterns (Table 3.2.75.). The separation patterns observed resulted in 74% of northern Australian samples being correctly classified into their respective groups (Table 3.2.76.).

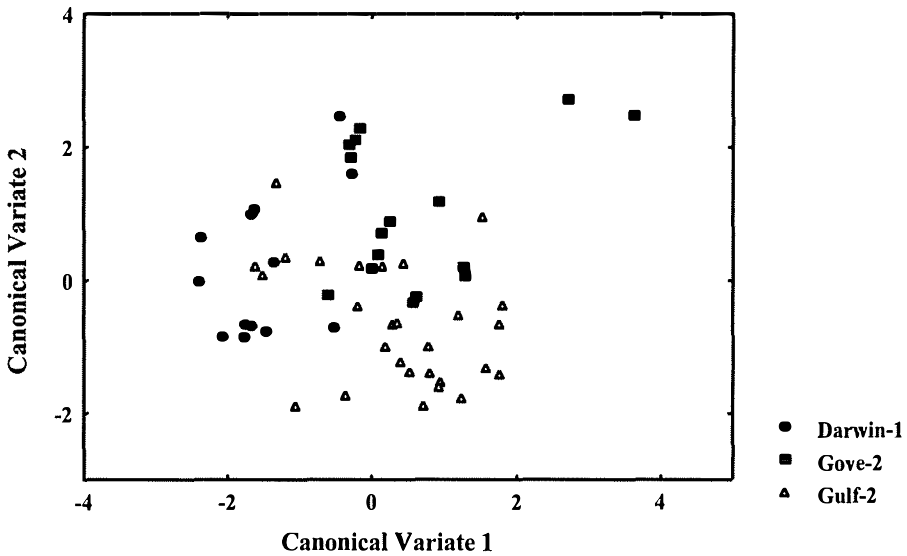


Figure 3.2.68. Discrimination between grey mackerel samples from northern Australian waters (excluding Queensland east coast samples) based on the concentrations of 6 trace elements.

Table 3.2.75. Discrimination between samples of grey mackerel from northern Australian waters (excluding Queensland east coast samples) determined by the standardised canonical coefficients for the significant ($p<0.05$) canonical variates (discriminant functions) I and II, and the cumulative proportion of the explained variance accounted for by each function, for 5 significant elements (Wilks' Lambda for overall model=0.377).

Element	**Canonical Variate**	
	I	**II**
Ba	1.49	-1.05
P	0.17	3.29
Na	-1.27	-2.83
Mn	0.34	-0.29
Mg	0.22	1.19
Cumulative Proportion	0.56	1.00

Table 3.2.76. Classification matrix of the frequency of assigned cases in each area determined from the discriminant model used to differentiate grey mackerel samples from northern Australian waters (excluding Queensland east coast samples).

Area	**Classification of Individual Grey Mackerel by Area**			
	% Correct	**Darwin (1)**	**Gove (2)**	**Gulf (2)**
Darwin (1)	77	10	2	1
Gove (2)	56	0	9	7
Gulf (2)	82	4	1	23
Total	74	14	12	31

3.2.3.5. Genetic Variation

Four polymorphic loci (*EST-D*, *GPI*, *LDH* and *PEP*) were selected for grey mackerel owing to their apparent genetic variation and ease of interpretation (Table 3.2.77.).

Table 3.2.77. Polymorphic protein loci of grey mackerel used in analyses, and conditions for electrophoresis.

Protein	Locus	Subunit Structure	Tissue	Buffer
Esterase-D	*EST-D*	Dimer	Liver	TC-1
Glucose-6-phosphate isomerase	*GPI*	Dimer	Muscle	EBT
Lactate dehydrogenase	*LDH*	Tetramer	Eye	TM
Peptidase	*PEP*	Dimer	Eye	Poulik

The mean observed heterozygosity (H_o) of individual grey mackerel samples, calculated for the four polymorphic loci investigated varied between 0.050 and 0.256 (mean 0.172 ± 0.072 s.e.) (Table 3.2.78.). The total mean sample heterozygosity (H_t) calculated only for the 4 polymorphic loci for all samples was 0.185 (± 0.080 s.e.), which was slightly higher than the subpopulation heterozygosity (H_s) (0.178 ± 0.076 s.e.). These calculations resulted in an average F_{st} value of 0.040 (Table 3.2.79.).

Table 3.2.79. Mean *F*-statistics for the four polymorphic loci examined from the individual yearly grey mackerel samples (N.S., not significant).

Locus	F_{is}	F_{it}	F_{st}	G	d.f.	P
EST-D	0.064	0.105	0.044	38.741	46	N.S.
GPI	0.024	0.063	0.040	79.680	69	N.S.
LDH	-0.048	-0.021	0.026	29.585	46	N.S.
PEP	-0.017	-0.003	0.014	14.237	23	N.S.
Mean	0.032	0.071	0.040			
Total				162.243	184	N.S.

G-tests of conformity of the observed genotypes with the expected Hardy-Weinberg distribution for each locus from each sample, calculated from the allele frequencies, resulted in only three of 96 tests (3.1%) being significantly out of equilibrium (Mackay 1990 *GPI*; Townsville 1990 *EST-D*; Townsville 1992 *GPI*). At least five of these tests could have deviated significantly from the expected proportions (5% level) by chance alone, while two of the three tests (Mackay 1990 *GPI*; Townsville 1992 *GPI*) differed significantly due to expected low values of uncommon alleles. It was concluded that the allele frequencies observed in grey mackerel samples were consistent with those expected under Hardy-Weinberg equilibrium.

Overall, there were no significant differences (contingency *G*-tests, $P<0.05$) observed between years within areas (Table 3.2.80.). This apparent lack of temporal variation between samples within areas was supported by monthly comparisons within years and areas. No significant differences were observed overall, or for any individual loci, between monthly samples collected from Townsville with estimated year of spawning between 1989 and 1993, and from the Gulf of Carpentaria with estimated year of spawning between 1991 and 1993 (Table 3.2.80.). These results were further supported by only five of 56 monthly tests (8.9%) being out of Hardy-Weinberg equilibrium owing to low expected values of uncommon alleles.

Table 3.2.78. Grey mackerel mackerel allele frequencies by year and area. (HB = Harvey Bay; MK = Mackay; TV = Townsville; G = Gulf; GO = Gove; DA = Darwin).

Locus	Allele	Sample Allele Frequency																							
		HB93	MK88	MK90	MK91	MK92	MK93	TV87	TV88	TV89	TV90	TV91	TV92	TV93	G86	G87	G88	G89	G90	G91	G92	G93	GO91	DA92	DA93
EST-D	100	0.824	0.938	0.900	0.840	0.821	0.786	0.643	0.800	0.788	0.813	0.747	0.844	0.865	0.800	0.789	0.857	0.814	0.831	0.727	0.704	0.763	0.781	0.769	0.500
	85	0.176	0.063	0.100	0.160	0.179	0.214	0.357	0.200	0.212	0.187	0.253	0.156	0.135	0.200	0.211	0.143	0.186	0.169	0.273	0.296	0.233	0.219	0.231	0.500
	60	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0.004	0	0	0
	n	*17*	*8*	*10*	*25*	*28*	*7*	*7*	*15*	*26*	*67*	*85*	*135*	*85*	*10*	*19*	*21*	*43*	*68*	*88*	*54*	*120*	*16*	*13*	*2*
GPI	125	0.075	0.136	0.364	0.177	0.172	0	0.250	0.200	0.111	0.154	0.201	0.157	0.230	0.100	0.211	0.261	0.159	0.171	0.194	0.148	0.221	0.194	0.038	0.100
	110	0	0.045	0	0.032	0	0	0	0.067	0	0.008	0.006	0.004	0.017	0	0.026	0.022	0.011	0.007	0.022	0.019	0.012	0	0	0
	100	0.925	0.818	0.636	0.774	0.828	1.000	0.750	0.733	0.889	0.838	0.787	0.839	0.753	0.900	0.763	0.717	0.795	0.815	0.769	0.815	0.764	0.806	0.962	0.900
	85	0	0	0	0.016	0	0	0	0	0	0	0.006	0	0	0	0	0	0.034	0.007	0.016	0.019	0.004	0	0	0
	n	*20*	*11*	*11*	*31*	*32*	*10*	*6*	*15*	*27*	*65*	*87*	*137*	*89*	*10*	*19*	*23*	*44*	*73*	*93*	*54*	*129*	*18*	*13*	*5*
LDH-E	100	0.925	1.000	0.917	0.976	0.962	0.857	1.000	0.900	0.912	0.955	0.975	0.924	0.954	1.000	0.917	0.957	0.987	0.953	0.943	0.942	0.950	0.944	0.958	1.000
	95	0.075	0	0.083	0.024	0.038	0.143	0	0.100	0.088	0.045	0.025	0.076	0.046	0	0.083	0.043	0.013	0.047	0.057	0.038	0.050	0.056	0.042	0
	85	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0.019	0	0	0	0
	n	*20*	*7*	*6*	*21*	*13*	*7*	*5*	*10*	*17*	*55*	*60*	*92*	*76*	*8*	*18*	*23*	*39*	*64*	*87*	*52*	*119*	*18*	*12*	*3*
PEP	100	1.000	1.000	1.000	1.000	0.983	1.000	1.000	1.000	1.000	1.000	0.991	1.000	0.996	1.000	0.974	1.000	1.000	1.000	0.989	1.000	1.000	1.000	0.994	1.000
	95	0	0	0	0	0.017	0	0	0	0	0	0.009	0	0.004	0	0.026	0	0	0	0.011	0	0	0	0.006	0
	n	*20*	*10*	*9*	*29*	*29*	*7*	*6*	*12*	*21*	*58*	*75*	*128*	*77*	*8*	*19*	*23*	*39*	*64*	*87*	*52*	*120*	*18*	*12*	*4*
Mean Hs		0.142	0.107	0.199	0.179	0.163	0.145	0.209	0.229	0.173	0.170	0.192	0.170	0.179	0.125	0.227	0.186	0.167	0.169	0.225	0.210	0.207	0.190	0.127	0.170
s.e.		0.059	0.073	0.096	0.083	0.074	0.086	0.122	0.091	0.069	0.070	0.097	0.062	0.081	0.078	0.076	0.092	0.090	0.074	0.094	0.095	0.094	0.082	0.078	0.118
Mean Ho		0.163	0.077	0.137	0.197	0.177	0.107	0.232	0.250	0.186	0.137	0.187	0.147	0.165	0.100	0.239	0.180	0.167	0.172	0.256	0.228	0.210	0.203	0.155	0.050
s.e.		0.072	0.046	0.046	0.091	0.082	0.068	0.135	0.096	0.072	0.055	0.094	0.057	0.079	0.058	0.081	0.082	0.091	0.077	0.110	0.107	0.094	0.090	0.104	0.050

Yearly samples were therefore pooled within areas because of the absence of significant temporal variation.

Table 3.2.80. Contingency log likelihood ratio (*G*) tests for temporal comparisons between grey mackerel samples (N.S., not significant).

Comparison	Total Loci			Significant Loci			
	G	d.f.	P	Locus	*G*	d.f.	P
Townsville 1989 (Sep; Oct)	0.718	3	N.S.	-	-	-	N.S.
Townsville 1990 (Sep; Oct)	5.497	4	N.S.	-	-	-	N.S.
Townsville 1991 (Sep; Oct)	1.524	4	N.S.	-	-	-	N.S.
Townsville 1992 (Sep; Oct)	3.460	4	N.S.	-	-	-	N.S.
Townsville 1993 (Aug; Oct)	6.870	6	N.S.	-	-	-	N.S.
Gulf 1991 (Oct; Dec)	1.907	6	N.S.	-	-	-	N.S.
Gulf 1993 (Oct; Nov)	3.167	6	N.S.	-	-	-	N.S.
Mackay (88; 90; 91; 92; 93)	28.387	24	N.S.	-	-	-	N.S.
Townsville (87; 88; 89; 90; 91; 92; 93)	40.615	36	N.S.	-	-	-	N.S.
Darwin (92; 93)	2.083	3	N.S.	-	-	-	N.S.
Gulf (87; 88; 89; 90; 91; 92; 93)	52.515	56	N.S.	-	-	-	N.S.

Overall there was no significant variation detected in allele frequencies when all 24 samples were examined without pooling (*G*=162.24, d.f.=184, N.S.), with an overall F_{st} value of 0.040. Similarly, when yearly samples within areas were pooled, there was still no significant variation between areas (*G*=38.64, d.f.=40, N.S.), while the F_{st} decreased to 0.015 (Table 3.2.81.). These results for the pooled samples were supported by most loci being in agreement with Hardy-Weinberg expected proportions. Two tests disagreed with those expected (Townsville *LDH*; Gulf *GPI*) owing to low expected values of uncommon alleles.

Table 3.2.81. Mean *F*-statistics for the four polymorphic loci examined from the pooled yearly grey mackerel samples (N.S., not significant).

Locus	F_{is}	F_{it}	F_{st}	*G*	d.f.	P
EST-D	-0.013	-0.004	0.009	10.139	10	N.S.
GPI	-0.027	0.002	0.028	23.525	15	N.S.
LDH	-0.026	-0.022	0.003	3.970	10	N.S.
PEP	-0.005	-0.002	0.002	1.009	5	N.S.
Mean	-0.020	-0.005	0.015			
Total				38.643	40	N.S.

The relationships between pooled spatial samples is summarised in the UPGMA dendrogram, based on Rogers' genetic distance (Figure 3.2.69.). Individual pairwise comparisons between areas were used to interpret spatial genetic differences (Table 3.2.82.). No significant differences were observed among Australian east coast or northern (Arafura Sea) samples. However, significant differences were detected over all loci between pooled northern (Arafura Sea) Australian samples and those from the east coast of Australia, and at the individual *EST-D* and *GPI* loci.

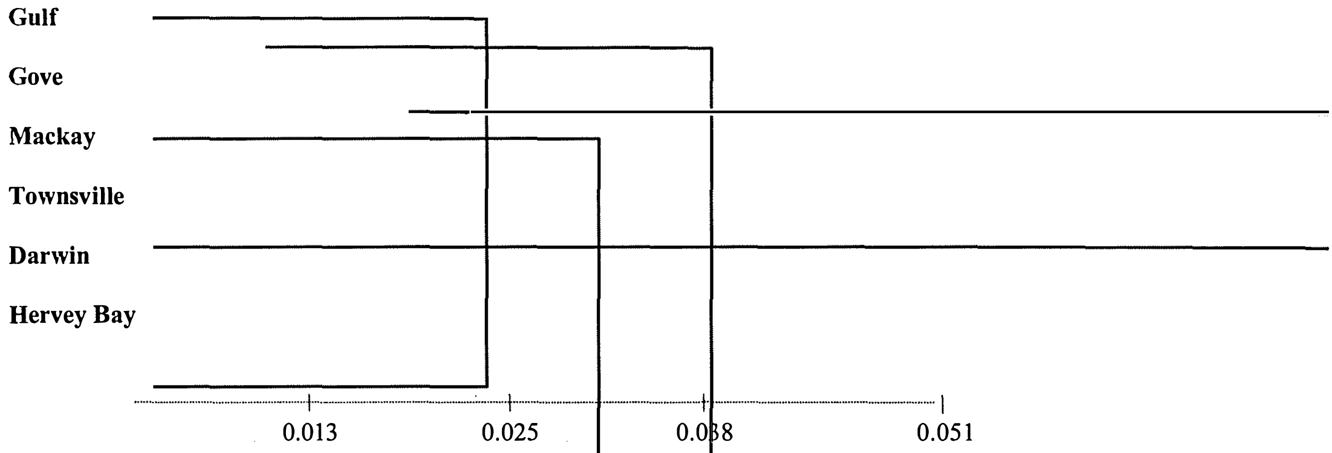


Figure 3.2.69. UPGMA dendrogram of pooled yearly grey mackerel samples by area, based on Rogers' genetic distance.

Table 3.2.82. Contingency log likelihood ratio (*G*) tests for spatial comparisons between pooled yearly grey mackerel samples (N.S., not significant).

Comparison	**Total Loci**			**Significant Loci**			
	G	**d.f.**	**P**	**Locus**	***G***	**d.f.**	**P**
Gulf vs Gove	2.429	8	N.S.	-	-	-	N.S.
Mackay vs Townsville	2.715	6	N.S.	-	-	-	N.S.
(Gulf and Gove) vs (Mackay and Townsville)	19.140	8	p<0.05	*EST-D*	8.254	2	P<0.025
				GPI	8.012	3	p<0.05
Darwin vs (Gulf and Gove)	8.301	8	N.S.	-	-	-	N.S.
Hervey Bay vs (Mackay and Townsville)	5.304	6	N.S.	-	-	-	N.S.

3.3. Discussion

3.3.1. Age, Growth and Mortality

A considerable amount of variation in length was observed for any given age for school, spotted and grey mackerel. Each species grew quickly for the first three years of life, after which growth rates tended to slow. Similar patterns have been observed for king mackerel (*S. cavalla)* (Johnson et al. 1983; Manooch et al. 1987), narrow-barred Spanish mackerel (McPherson 1992a) and Spanish mackerel (*S. maculatus)* (Fable et al. 1987b), which have rapid growth up to age five. Development patterns of *Scomberomorus* species are consistent with generalised large-prey, fast-growth strategies (Jenkins et al. 1984).

Reliable mortality estimates are difficult to obtain for *Scomberomorus* species because of their highly migratory nature, recruitment variability, size and possibly sex specific schooling behaviour, exploitation by a variety of gear types possessing different selectivity properties, and one sex living longer and attaining larger sizes than the other (Manooch *et al.* 1987). This study of three *Scomberomorus* species confirmed many of the above findings of Manooch.

School and spotted mackerel were estimated to have high mortality rates, which agrees with Manooch's (1979) hypothesis that natural selection favouring rapid growth is associated with a cost to longevity. The highest mortality rates estimated for school and spotted mackerel were estimated from commercial netting data. The mortality estimates of grey mackerel were, however, smaller than either school or spotted mackerel. All mortality estimates for grey mackerel were from commercial netting data.

It should be noted that net caught fish are likely to be subject to more narrowly defined selectivity than line captured fish and do not provide representative mortality parameters. Mortality and survivorship estimates calculated for each small mackerel species therefore, must be considered as approximations and not absolute values.

Growth patterns for each sex of each small mackerel provided evidence of differential growth and subsequent stock discrimination between regions. Similar growth patterns of spotted mackerel for each sex from different regions were estimated. In contrast, different growth patterns of school and grey mackerel for each sex from different regions were observed.

Shaklee *et al.* (1990) described distinct populations of narrow-barred Spanish mackerel in Queensland east coast and northern Torres Strait waters using electrophoretic techniques. McPherson (1992) observed differences in lengths at age for narrow-barred Spanish mackerel, further supporting separation between fish from each region. Similarly, Fable *et al.* (1987b) stated that differences in growth rates of Spanish mackerel indicated the possibility of separate stocks throughout the species' distribution. In our study, additional techniques were utilised to investigate stock structure of each small mackerel species.

3.3.2. Reproduction

School, spotted and grey mackerel appear to have spatial and temporal spawning isolation patterns that may enable them to coexist as separate species in the same coastal waters. School mackerel spawn over a protracted period from October to January along the Queensland east coast. The data agree with previous studies examining the reproductive behaviour of school mackerel (Okera 1982; Jenkins *et al.* 1985).

The spawning season and area of spotted mackerel are more restricted than those of school mackerel. Spawning extends from August to October in northern Queensland waters. Spawning grounds appear to be restricted to waters between south of Townsville and Mackay, as Jenkins *et al.* (1985) did not capture any spotted mackerel larvae during their three year study of coastal and Great Barrier Reef lagoon regions off Townsville.

Grey mackerel were observed to spawn over a similar period to that of school mackerel on both the east coast of Queensland and in the Gulf of Carpentaria. These results are supported by Jenkins *et al.* (1985) who found grey mackerel larvae in waters adjacent to Townsville between October and February. Grey mackerel appear to spawn concurrently throughout their distribution. Jenkins *et al.* (1985) found grey mackerel larvae were restricted to coastal bays and the inner margin of the lagoon which is similar habitat to where the commercial gill net fishery targets adult grey mackerel.

Jenkins *et al.* (1985) suggested that the observed inshore-offshore separation of school, grey and narrow-barred Spanish mackerel larvae was related to the distribution of spawning adults and longshore currents in the coastal lagoon. The absence of spotted mackerel larvae in Jenkins *et al.*'s (1985) study and absence of reports of larvae or juvenile spotted mackerel in estuarine or inshore habitats suggests that spotted mackerel may spawn in more offshore waters or if present, were not able to be differentiated from other mackerel. Similar separation of *Scomberomorus* larvae has been identified in other waters. McEachran *et al.* (1980) found limited competition between king and Spanish mackerel from the Gulf of Mexico and suggested species integrity maybe maintained through a possible separation of distribution by depth for larvae. Collins and Stender (1987) observed temporally similar, but geographically separate spawning activities for king and Spanish mackerel.

Not surprisingly, school, spotted and grey mackerel while displaying different growth rates, attained first maturity at different sizes. Differences in size at first maturity between each sex was also found for each species.

Each small mackerel species in this study grew to its respective initial size of maturity within their first to second year of life. Similarly, Beaumariage (1973) identified king mackerel off Florida to show sex specific first maturity, where females first spawned at four and males three years. Likewise, Sturm and Salter (1990) estimated that king mackerel of both sexes from Trinidad waters reached maturity at ages one and two. Sturm (1978) found that Spanish mackerel from Trinidad were mature by two to three years, while McPherson (1993) reported narrow-barred Spanish mackerel from Queensland east coast waters to first between two and three years of age.

School mackerel usually have equivalent sex ratios throughout the year, except during their peak spawning months. Males tended to dominate in school mackerel summer spawning catches, apart from December, when females were more prevalent. Most samples collected during summer were line caught and were likely to be fish feeding after their initial peak spawning.

Spotted mackerel samples obtained during the spawning months were mainly obtained from commercial net fishers and were male dominated. Sturm (1978) observed Spanish mackerel catches in Trinidad waters to be dominated by males during the spawning season and thought females inhabited depths below those in which the gill nets were effective. The netting procedure for spotted mackerel effectively targets fish throughout the entire water column and so discounts any suggestion that females may be zonally isolated and therefore excluded from commercial catches.

Male grey mackerel were more abundant in the commercial catch in the Gulf of Carpentaria during the peak spawning period. There was no pattern of abundance of different sexes in samples of grey mackerel obtained from the Queensland east coast fishery. Sturm and Salter (1990) suggested that female dominance in catches of king mackerel off Trinidad may be a function of gill net selectivity or behavioural differences between the sexes. Differences in the availability of fish of each sex, sex specific schooling or susceptibility to gill netting operations are all possible explanations of biased monthly sex ratios generally observed for each small mackerel species.

The proportion of female school and spotted mackerel tended to increase with length, where all school mackerel over 750 mm FL, all spotted mackerel over 800 mm FL and all grey mackerel (except one) of a fork length over 950 mm FL , were female. Similarly, Trent *et al.* (1987) estimated that the proportion of female king mackerel off Louisiana increases with fish size. Likewise, king mackerel in Trinidad waters were also dominated by females in the larger length categories (Sturm and Salter 1990). Devaraj (1983) observed female narrow-barred Spanish mackerel around the Indian Peninsula to be dominant after 1300 mm total length. Ageing data from this study indicates females grow to a larger maximum size than males for each small mackerel species. The most probable reason that females dominate the larger size classes is a combination of differential growth and mortality rates. Although the length based sex ratios may indicate the possibility of protandrous sex change, no evidence of hermaphroditism was observed in any histological gonad section for either males and females of any small mackerel species. Thomas and Raju's (1964) review of gonadal abnormalities in scombroids supports these findings, in that they found no evidence of hermaphroditism among any *Scomberomorus* species.

Female school and grey mackerel may have greater reproductive potential than spotted mackerel. Mean GSIs for female school mackerel were twice as high compared to those for spotted mackerel and a third as high as those for grey mackerel during their respective peak spawning months. Mean GSIs for male school mackerel were three times as high as those for spotted and grey mackerel.

Although the number of times mackerel may spawn in a season was not investigated in our study the potential number of eggs in female school and grey mackerel of a particular length is greater than that of spotted mackerel of the same length. Increased GSIs corresponded directly to an increased number of potential fertile eggs, as differences in oocyte diameters between the species appeared to be negligible.

3.3.3. Movements

In waters off the east coast of Australia movements of tagged school mackerel were restricted and no seasonal movement patterns were observed. Recapture information provided evidence that little mixing may occur between school mackerel in different regions along the Queensland coastline. These limited movements and temporal overlap of tagging effort indicated the likely existence of a number of stocks throughout the study area. Movements north of Townsville are unknown. Movements of a few school mackerel from Moreton Bay and Rockhampton to Hervey Bay however, suggested the existence of a single stock or a possible common feeding ground for separate stocks from central and southern Queensland. Only tentative inferences could be made owing to the low number of recaptured fish that participated in these movements.

Recaptured spotted mackerel moved nearly the length of the Queensland east coast, although their movements north of Cairns are unknown. The distances moved by tagged spotted mackerel and the seasonal shift with location of recaptured fish provided evidence of migratory behaviour and the existence of a single stock south of Cairns. The movements of tagged grey mackerel are unknown.

Cyclic migration appears to be a characteristic of some *Scomberomorus* species. Annual migrations by spotted mackerel are similar to those of narrow-barred Spanish mackerel in Australian east coast waters. A significant proportion of narrow-barred Spanish mackerel embark on a southerly migration in December at the end of their spawning season, with a return migration occurring during September each year (McPherson 1981). Analogous patterns are observed in the northern hemisphere for king mackerel where two migratory groups have been identified from tagging exercises in southeastern United States waters; a Gulf of Mexico and Atlantic stock, with a transition zone along the southern coast of Florida (Sutter *et al.* 1991; Schaefer and Fable 1994).

Overall recapture rates for school and spotted mackerel, 2.1% and 1.8% respectively, were consistent with other *Scomberomorus* tagging studies. McPherson (1981) observed a return rate of 2.5% for narrow-barred Spanish mackerel tagged in Australian waters between the Torres Strait and northern New South Wales. Similarly, average recapture rates for king mackerel tagged in waters of the southeastern United States were 2.9% (Fable 1990). Sutter *et al.* (1991), however, observed a recapture rate of 8.4% for tagged king mackerel, attributing their success to the specific use of internal anchor tags, as opposed to the commonly used dart tags. A tag retention experiment on king mackerel demonstrated little difference in return rates between internal anchor and dart tags for the first 180 days, but beyond that no dart tags were recovered (Fable 1990).

Estimation of tag loss was attempted in this study by double tagging. Few recaptures prevented any conclusions to be drawn, beyond that tag loss does occur. The collaborative nature of this project prevented the use of internal tags owing to greater insertion complexity and the possibility of higher mortality rates caused by unskilled taggers. Fable (1990) noted recreational anglers were limited to using dart tags to mark king mackerel as they found it difficult to use the scientifically preferred internal anchor tags.

Inherent problems associated with collaborative tagging programs through variable tagging experience, operating conditions and perceptions of the condition of tagged fish prior to release may be potential causes of tag loss and tag induced mortality, resulting in reduced recapture rates. In this study, mackerel greater than 700 mm in length were difficult to handle, and were often observed to convulse immediately upon landing and die shortly after. Moe (1966) stressed that speed was the most important factor for successful tagging of king mackerel and that a maximum limit of 40 seconds out of the water would ensure survival of tagged individuals. Mackerel kept out of water for greater than 20 seconds were generally not tagged and released.

The lengths at release of recaptured school and spotted mackerel were greater than the lengths at release of tagged mackerel not recaptured. This suggests that either the catchability of these mackerels increased with size or the rate of tag induced mortality was lower for the larger fish. Spotted mackerel showed a progressive size increase the further south they were tagged possibly owing to size selective tagging. Although we believe adequate numbers of fish comprising a range of lengths and representing each mackerel population were tagged, the recapture rates may have been increased if more larger mackerel were tagged.

Recapture rates may also have been influenced by failure to report recovered tags. Direct evidence of non reporting of tag recaptures by a few commercial and recreational fishers was observed in this study. Fishers claimed to discard recaptured tags owing to their personal resentment of scientific research, fisheries management and the belief that tagging had been focused on, or would benefit a fishing sector other than their own. Similarly, Fable (1990) suggested reduced recapture rates of king mackerel resulted from a decline in the initial enthusiasm shown by fishers and resentment to subsequent management closures. In addition, the Queensland coastline was a logistically difficult area to undertake a tagging project owing to its size, remoteness of some coastal communities, and limited launching facilities to fishing grounds. Lack of personal liaison and limited media exposure of the tagging study in these areas may have attributed to non-reporting of recaptured tagged fish.

3.3.4. Otolith Chemistry

Age-related differences in trace element concentrations indicated that spatial differences between individual fish may be the result of environmental influences throughout their life history. The most informative comparisons in this study were made amongst fish of the same age. Variation in the chemical composition of trace elements deposited in whole otoliths provided supported hypotheses of stock structure developed from ageing and movement studies.

There was no clear pattern of otolith elemental composition of school mackerel from different locations in Northern Australia. School mackerel from different locations on the east coast and the Gulf of Carpentaria did possess to varying degrees, some characteristic otolith elemental compositions. The composition was assumed to represent the chemical constituents of the environment in which they inhabit (Lapi and Mulligan 1981). Variation in the accumulation patterns of individual fish otoliths from different areas, presumably reflect prolonged separation of the populations, and ultimately stock divergence (Edmonds *et al.* 1991). The separation indicated by the otolith trace element composition is further supported by tag-recapture information for the Queensland east coast. Movements of tagged school mackerel have shown that there is little exchange between fish from the different areas or embayments, with most recaptures occurring within their same area of release. The population movements of school mackerel, as indicated by the tagging component of our study may also explain the overlap in the observed otolith trace element patterns from fish captured in Moreton Bay and Rockhampton as fish moved from Hervey Bay to both of these areas.

Discrimination between otolith elemental composition of school mackerel from the Gulf of Carpentaria and Northern Territory waters was less clear than it was between samples from different parts of the Queensland east coast. An almost complete overlap in the trace element composition of school mackerel otoliths from Darwin and the Joseph Bonaparte Gulf suggests that fish from these regions may comprise a common stock. In contrast, school mackerel from Weipa possessed a slightly different otolith chemical composition than those from Darwin and the Joseph Bonaparte Gulf, suggesting the fish may be subject to different environmental conditions throughout their lives, and indicating a possible stock divergence between the groups. Hypothesised stock discrimination of fish from these northern areas however, were less convincing owing to low sample sizes and lack of additional biological supporting evidence.

Accumulation patterns of trace elements in spotted mackerel otoliths indicate fish of the same age found in Queensland east coast waters reside in similar environments throughout their lives. Such trends in otolith chemical constituents imply the existence of a single stock across this geographic range. Annual large scale movement patterns of spotted mackerel along the Queensland east coast deduced from tag-recapture data, provided strong supporting evidence for this theory of a single east coast stock. Spotted mackerel from Queensland east coast waters have different otolith trace element concentrations than those fish from the Northern Territory. These differences suggest that the groups of spotted mackerel occupy discrete environments that may lead to the isolation of separate stocks. Differential otolith trace element patterns between fish from Gove and the Joseph Bonaparte Gulf suggest that they also may be distinct stocks. Stock differentiation of spotted mackerel from the Northern Territory compared to the Queensland east coast however, as for school mackerel, was less conclusive owing to lack of supporting biological data and more importantly age related biases between samples from the different areas.

Pooled analysis of grey mackerel otolith elemental composition did not allow descrimination of fish between Queensland east coast, Gulf of Carpentaria or Northern Territory waters. Interpretation of the progressive overlap in trace element samples from the east coast of Queensland was also not conclusive. The importance of incorporating year classes into analyses of otolith trace element work was clearly demonstrated by work on grey mackerel on the east coast as though there was some overlap, fish of different ages from Mackay exhibited different otolith elemental compositions. Otolith trace element analyses offered no indication that grey mackerel from the Gulf of Carpentaria and Northern Territory waters differed.

3.3.5. Genetic Variation

Genetic variation found in specific enzymes enabled the discrimination of school, spotted and grey mackerel stocks throughout northern Australian waters. School mackerel appeared to comprise a number of geographically isolated breeding populations, each being associated with a distinct portion of coastline or possible water circulation pattern. In contrast, spotted mackerel formed a single stock in eastern Australian waters that was found to be genetically discrete from a Northern Territory stock. There was little genetic variation found in specific enzymes of grey mackerel although it must be stressed that only four polymorphic loci were able to be used in analyses for the species. In each species the largest genetic differences were found between the Queensland east coast and Arafura Sea/Gulf of Carpentaria populations. These stock discrimination patterns determined from genetic variation supported trends in population differentiation suggested by tagging, ageing, reproductive, and otolith elemental chemistry information.

Identification of genetic variation in migratory, pelagic species, such as mackerel, tuna and billfish, is difficult. Adequate sample sizes of 100 individuals of a similar size or age class from a specific time-area stratum, that would provide allele frequencies within acceptable limits of precision, are often difficult to accumulate for species which form sparse schools over a wide geographical area (Lewis 1981b). This was a problem encountered in this study for each species, and was responsible for the need to pool yearly samples within regions to give the corresponding analyses sufficient statistical power. Large sample sizes were generally obtained using commercial catches, which had their own specific problems, such as single school sampling and size selectivity. Lewis (1981b) suggested schooling species present a particular uncertainty as there is the possibility that a school comprises a unique genetic unit. This concern was addressed by temporal replicate sampling that ensured individuals were collected from a number of different schools within a particular region. There was no evidence of temporal variation at any location. General collection difficulties caused by fluctuations in fish availability also tend to be increased in pelagic species, owing to their migratory behaviour patterns (Lewis 1981b).

School mackerel appear to have a complex stock structure, with each genetic stock being associated with a portion of the coastline, that may be suitable for larval retention. Genetic dissimilarity tended to increase with distance, with neighbouring areas generally showing variation at only one or two loci. King mackerel in the Gulf of Mexico showed a similar pattern, with an eastern and western Gulf stock differentiated on the basis of a single dipeptidase locus (Johnson *et al.* 1994). Similarly, Iles and Sinclair (1982) found that the number of genetically distinct stocks of Atlantic herring was determined by the amount of discrete, geographically stable, larval retention areas. Discrimination of stocks of school mackerel from the Northern Territory and Gulf waters, however, was less convincing owing to low sample sizes compared to those obtained from the Queensland east coast. These possible northern stocks were however, significantly different from the Queensland east coast stocks at a number of loci, indicating their divergence and genetic isolation from the east coast stocks.

Spotted mackerel appeared to comprise a single stock in Australian east coast waters, that was genetically isolated from fish sampled in the Northern Territory. The lack of significant differences in allele frequencies between samples collected from Iluka to Bowen indicated that fish from these regions may form a common gene pool or unit stock. However, as Lewis

(1981b) correctly pointed out, non significant differences imply that no differences between groups have been detected, not that the groups are necessarily the same.

Significant differences in allele frequencies between Northern Territory and Australian east coast spotted mackerel samples suggest the presence of a northern stock, although the extent of its distribution is unknown. More detailed sampling from a number of regions in northern Australia would be required to confirm this hypothesis. Shaklee *et al.* (1990) determined a similar stock structure for narrow-barred Spanish mackerel in Australian waters. One main stock was identified along the east coast from Moreton Bay to Cairns, whilst a northern stock was recognised between Darwin and the Gulf of Carpentaria. Stock discrimination of narrow-barred Spanish mackerel in the Torres Strait and northern Queensland east coast waters was however, unclear, possibly being an isolated stock in its own right or a mixture between the Australian and Papuan New Guinea stocks. Preliminary results of Fisheries Research Development Corporation Project 98/151 "Stock Structure of Northern and Western Australia Spanish Mackerel" indicate these species may form a mosaic of sub-stocks in northern Australia. The extent of the northern distribution of the spotted mackerel Australian east coast stock is uncertain.

Spotted mackerel sampled from Innisfail were significantly different in allele frequencies overall and at a number of separate loci from Darwin individuals, providing strong evidence of genetic isolation between the regions. However, the difference between allelic patterns in Innisfail fish and those collected from the rest of the east coast was not as clear. Though samples from these regions differed in gene frequencies at the *AAT-L* and *AK* loci, suggesting genetic divergence, the observed values for the *AK* locus disagreed with those expected in Hardy-Weinberg equilibrium.

The only genetic variation detected in analyses of grey mackerel was that between pooled Arafura Sea / Gulf of Carpentaria and pooled Mackay / Townsville samples. Differences were detected for these samples over all loci and at individual *EST-D* and *GPI* loci. There were no significant differences detected between the individual, area specific Arafura Sea and Gulf of Carpentaria samples and between those individual, area specific samples from the Queensland east coast. The absence of genetic differences detected between samples from each of these areas should not necessarily be considered as evidence of composite, single stocks of grey mackerel in the Arafura Sea / Gulf of Carpentaria or Queensland east coast areas. Regardless of the actual genetic variation which may exist in grey mackerel in each of these areas, the use of only four polymorphic loci in analyses greatly reduces the probability of detecting finer stock structure compared to analyses for school and spotted mackerel.

3.3.6. Biology and Stock Discrimination Summary

The life history characteristics and stock structure found in our study for school, spotted and grey mackerel are summarised in Table 3.3.1.

Table 3.3.1. Life history characteristics and stock structure of school, spotted and grey mackerel.

Life History Characteristic	School Mackerel	Spotted Mackerel	Grey Mackerel
Movements (Australian East Coast)	restricted no seasonal patterns	extensive seasonal (north in winter, south in summer)	Unknown
L_∞	722 mm (f); 698 mm (m) TL	953 mm (f); 816 mm (m) TL	1058 mm (f); 929 mm (m) TL
K	0.59 (f); 0.70 (m)	0.41 (f); 0.31 (m)	0.30 (f); 0.48 (m)
S	0.42 (f); 0.48 (m)	0.36 (f); 0.56 (m)	0.62 (f); 0.61 (m)
Spawning Data (Not obtained for Northern Territory)	October to January entire Queensland east coast distribution - inshore	August to October between Mackay and Townsville on east coast - offshore	September to January entire east coast and Gulf of Carpentaria distribution studied.
First maturity	484 mm (f); 430 mm TL (m) 2 years of age	605 mm (f); 500 mm TL (m) 2 years of age	806 mm (f); 668 mm TL (m) 2 years of age
Instantaneous egg counts theoretical estimates at 500 mm TL	262,000 eggs	94,000 eggs	250,000 eggs
Stock structure	multiple stocks along east coast. northern (Arafura Sea) stock.	single east coast stock. northern (Arafura Sea) stock.	Unknown stock structure along east coast and northern (Arafura Sea) stock. East coast fish distinct from northern (Arafura Sea) stock.

An important component of this research was the use of a number of complementary stock identification techniques to describe the identity and distribution of individual populations of fish. Stock identification is necessary for effective fisheries management as from a resource sustainability perspective, management has to ensure that adequate recruitment within each stock will sustain the harvest from each population. Identification of the stock structure of a species, therefore, is fundamental to the conservation and rational exploitation of fisheries resources (Rounsefell 1975; Smith 1990). Numerous methodologies currently exist for stock discrimination, with examination of the chemical composition of biogenic carbonates such as otoliths being a recent, complementary and potentially successful technique. However, considering the importance of identifying a species' stock structure there is still no single method that can be used to emphatically discriminate fish populations (Kutkuhn 1981; Thresher *et al.* 1994; Campana and Gagné 1995). However, the combined information from tag-recapture, life history parameters, otolith chemistry, and genetic studies provided evidence for the identification and discrimination of school, spotted and grey mackerel stocks throughout northern Australian waters. In Queensland, except for policy relating to translocation of genetic stocks, there are few fisheries that are fundmentally and deliberately managed on the basis of stock structure. Management arrangements considering geographical, social and economic factors, that fortunately in some cases may reflect stock structure, along with the manner in which fisheries have evolved, are commonplace for fisheries, before any consideration of stock structure. Fisheries managers and industry representatives should recognise the importance of identified stock structures in the management of school, spotted and grey mackerel.

4. COMMERCIAL FISHERIES

4.1. Records of Commercial Harvest

4.1.1. Introduction

Small mackerel are harvested by commercial fishers in Queensland east coast waters, with smaller landings in the Northern Territory, New South Wales and Western Australia. Mackerel is generally marketed and retailed either frozen, fresh or chilled as gilled and gutted whole fish, trunks, fillets or cutlets (Kailola *et al.* 1993). Since 1997, a growing export market in Japan and to a lesser extent other Asian countries requires whole un-processed chilled small mackerel. Small mackerel together with narrow-barred Spanish mackerel form major commercial finfish fisheries in northern Australia. Information on the commercial harvest of fish species in Australia has become available after the establishment of data collection programmes and databases in all states and territories. Commercial fisheries data is required to establish the magnitude and importance of mackerel fisheries, monitor fluctuations in catch and effort and obtain time series of data suitable for subsequent stock assessments. Information on the commercial harvest of fisheries resources such as mackerel, which are exploited by both commercial and recreational sectors, is becoming increasingly important in negotiations determining the allocation of fisheries resources.

The commercial harvest of, and effort for major mackerel species in Queensland is discussed in more detail in Williams (2002) Queensland Fisheries Resources Current Conditions and Recent Trends 1988 - 2000. This study focused on small mackerel species. Information on the harvest of and effort for narrow-barred Spanish mackerel, shark mackerel and unspecified mackerel has been included to assist comparison of harvest and effort levels for all mackerel species (where available) in northern Australia.

4.1.2. Methods

Commercial fisheries data was obtained for Queensland, Northern Territory, Western Australia and New South Wales. All data presented are totals of catch as identified in each database and a day of effort is recorded when one or more individuals of a particular fish species or grouping is reported as being landed on a given day. In this presentation of commercial data no attempts to standardise catch or effort data have been made. Catch per unit effort (CPUE) data were not investigated owing to the absence of data on days when fishing was targeted towards a species and there was no catch of that species, inadequate background information on vessels and fisheries which is essential to interpret changes in catch per unit effort, and further problems encountered in interpreting CPUE fluctuations in fisheries which target pelagic schooling finfish. No data has been recorded in this report for the Torres Strait Protected Zone, Northern Prawn Fishery or foreign fishing vessels that have operated in Australian waters.

As this project was based in Queensland the most specific commercial data obtained were from the QFISH Database managed by the Queensland Fisheries Service and the former Queensland Fisheries Management Authority. Annual catch and effort summaries by fishing method for each mackerel species was obtained for the whole of Queensland between 1988 and 2000. Annual summaries were obtained for nine regions defined around the entire Queensland coast (Figure 4.1.1.). The coordinates of these nine regions are described in

Table 4.1.1. An indication of the historical significance of mackerel to commercial fisheries in Queensland was obtained from Annual Reports from the Chief Inspector of Fisheries between 1932 to 1969.

Table 4.1.1. Coordinates and descriptions of nine regions around Queensland coastline for which commercial harvest data is summarised.

Region	Geographical Feature	Minimum Latitude	Maximum Latitude	Minimum Longitude	Maximum Longitude
Gulf South	Nassau River to NT Border	15°S	18.5°S	138°E	142.5°E
Gulf North	Cape York to Nassau River	10.5°S	15°S	140°E	142.5°E
Far North	Cape York to Cape Flattery	10.5°S	15°S	142.5°E	155°E
Northern Wet	Cape Flattery to Moongobulla	15°S	19°S	142.5°E	155°E
Northern Dry	Moongobulla to Cape Conway	19°S	20.5°S	142.5°E	155°E
Central	Cape Conway to Cape Manifold	20.5°S	23°S	142.5°E	155°E
Rockhampton	Cape Manifold to Baffle Creek	23°S	24.5°S	142.5°E	155°E
Fraser	Baffle Creek to Moreton Bay	24.5°S	27°S	142.5°E	155°E
Moreton	Moreton Bay to NSW Border	27°S	28.5°S	142.5°E	155°E

Annual commercial catch data from the Northern Territory and Western Australia were obtained from 1983 to 2000 and 1980 to 2000 respectively. Annual commercial catch and effort data from New South Wales were available from 1984 to 1999.

Additional historical commercial landings data of mackerel throughout Australia was available in a Bureau of Resource Sciences (BRR) Report by Stewart *et al.* (1991). Only the data obtained from each state and territory as previously described was included in our study. The historical data in the report by Stewart *et al.* (1991) was excluded because: there were anomalies between years in some data in the BRR report and recent commercial data obtained from each state and territory; there was a list of disclaimers which questioned the accuracy of the data in the BRR report; there was an absence of effort data; and there was insufficient separation of catches of each mackerel species.

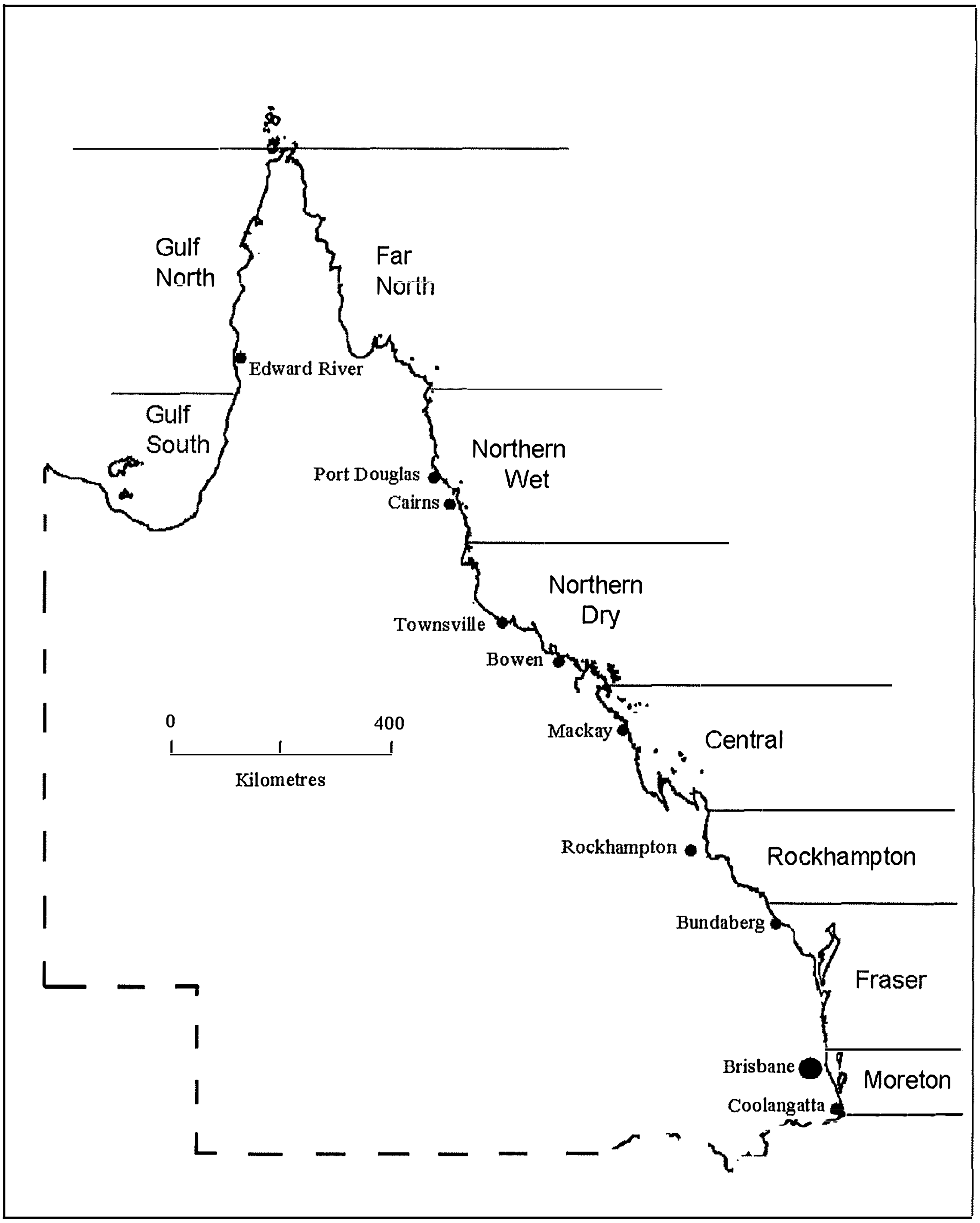


Figure 4.1.1. Regions around Queensland coast with referred cities and localities for commercial catch information.

4.1.3. Results

4.1.3.1. Queensland

School Mackerel

The mean annual commercial school mackerel harvest between 1988 and 1995 was about 14t. The mean annual commercial school mackerel harvest between 1988 and 2000 had increased to about 31t. The harvest of school mackerel increased markedly in 1999 and 2000 to about 88t and 93t respectively (Appendix 3. Table 1.). School mackerel are predominantly harvested by commercial fishers in waters south of Rockhampton. The Fraser region contained about 65% of overall fishing effort yielding about 70% of the school mackerel harvest with a mean annual harvest of about 20t (Appendix 3. Table 1.). Most commercial harvests of school mackerel occur during late autumn, winter and spring.

Commercial fishers primarily capture school mackerel using monofilament bottom set gill nets. Commercial gill nets used in Hervey Bay and Moreton Bay, where the majority of the State's catch is landed, usually comprise 9.5 cm mesh. Increased mesh sizes (12.7 to 15.2 cm) used by commercial fishers in waters north of Rockhampton enables the capture of other target species such as grey mackerel and shark. Sharks form an important part of the catch in these operations, and are often favoured over school mackerel depending on availability and market demand (Kailola *et al.* 1993). Small quantities of school mackerel are also captured commercially using hook and line and in the spotted mackerel ring net and grey mackerel gill net fisheries.

Spotted Mackerel

The mean annual harvest of spotted mackerel between 1988 and 1995 was about 58t. The mean annual harvest of spotted mackerel between 1988 and 2000 had increased to about 118t. The record harvest in 2000 of over 405t was more than double that of previous years. The harvest of, and effort for spotted mackerel has increased markedly in the last three to four years (Appendix 3. Table 2.). Spotted mackerel fisheries are focused on a single migrating population. The fisheries for spotted mackerel are highly localised and spatially and temporally separated from one other. Spotted mackerel are captured in northern Queensland waters during winter and early spring, and in southern waters throughout summer. The Fraser region contains 54% of overall effort which yields about 55% of the total spotted mackerel harvest with a mean annual harvest of about 65t (Appendix 3. Table 2.).

Nearly all of the commercial spotted mackerel harvest is taken using gill nets. Much of this gill netting effort is using ring netting techniques as detailed in section 4.3. In northern Queensland waters, particularly around Bowen, commercial fishers traditionally use 12.7 cm mesh, while in Hervey Bay, the major area where spotted mackerel are harvested, 10.2 cm mesh is preferred. Spotted mackerel are vulnerable to ring netting techniques as they tend to aggregate in schools in near surface waters where they are easily seen by fishers. Ring netting is usually highly specific in capturing spotted mackerel with little by-catch, except for small quantities of school and grey mackerel, shark, trevally (Carangidae) and tuna species. Commercial fishers also capture spotted mackerel using hook and line.

Grey Mackerel

The mean annual harvest of grey mackerel between 1988 and 1995 was about 220t. The mean annual harvest of grey mackerel between 1988 and 2000 has increased to about 329t. The harvest of grey mackerel peaked in 1997. Grey mackerel are generally harvested north of Rockhampton between July and October and were previously harvested in southern Queensland waters between November and March. There has been a major geographical change in the harvest of grey mackerel since the mid 1990s (Appendix 3. Table 3.). In 1990, about 88% of the annual harvest and 79% of the effort for grey mackerel occurred on the east coast of Queensland while in 1995 about 75% of the annual harvest and about 47% of the effort occurred in the Gulf of Carpentaria. In 2000 about 93% of the annual harvest and about 62% of the effort for grey mackerel in Queensland occurred in the Gulf of Carpentaria (Appendix 3. Table 3.). The dramatic decline in harvests on the east coast of Queensland is masked when the overall harvests of grey mackerel throughout Queensland, but including the Gulf of Carpentaria is assessed.

Gill netting is the main method used to harvest grey mackerel. In the Gulf of Carpentaria, the minimum mesh size in nets used to capture grey mackerel is 16.5 cm, though 15.2 cm mesh is used mainly on the east coast of Queensland. At Hervey Bay mesh as small as 10.2 cm is used to capture grey mackerel.

Narrow-barred Spanish Mackerel

The mean annual harvest of narrow-barred Spanish mackerel between 1988 and 2000 was about 695t. Total landings and fishing effort for narrow-barred Spanish mackerel peaked in 1999 (Appendix 3. Table 4.). Narrow-barred Spanish mackerel are harvested mostly in northern Queensland waters between September and December. About 42% of the harvest and 37% of the effort for the species occurs in the Northern Wet region. It is illegal to capture narrow-barred Spanish mackerel by netting in Queensland waters. Much of the line fishing used to harvest narrow-barred Spanish mackerel is using trolling techniques.

Shark Mackerel

The mean annual harvest of shark or salmon mackerel between 1988 and 2000 was about 65t. Total landings and fishing effort for shark mackerel peaked in 1990, 1991 and 1997 (Appendix 3. Table 5.). The fishery for shark mackerel appears to be focused in waters adjacent to coral reefs, with the majority of shark mackerel harvested in two regions. The Central region is responsible for 37% of the harvest and 28% of the effort and the Northern Dry region has 36% of the harvest and 37% of the effort (Appendix 3. Table 5.). Shark mackerel are almost exclusively caught by line fishing.

Unspecified Mackerel

All unspecified mackerel are entered on the QFISH database as mackerel. This is a result of problems in identification of mackerel species and lack of mandatory requirements or incentives for commercial fishers to record the harvest of mackerel to species level. Failure to identify species of mackerel has not generally improved since the logbook program commenced. The mean annual harvest of unspecified mackerel between 1988 and 1995 was about 59t (Appendix 3. Table 6.). The mean annual harvest of unspecified mackerel between 1988 and 2000 had increased to about 81t. Total landings and fishing effort for unspecified mackerel peaked in 1997. Unspecified mackerel appear to be mainly harvested by gill netting. The unspecified mackerel harvest occurs principally in two regions; Fraser (30% of the harvest and 27% of the effort) and Northern Dry (35% of the harvest and 22% of the effort) (Appendix 3. Table 6.).

Historical Mackerel Landings

The historical landing records of the Queensland Fish Board between 1944 and 1981 reported the estimated mean annual landings of unspecified mackerel and school mackerel as 430t and 38t respectively. Annual reports from the Chief Inspector of Fisheries, Department of Harbours and Marine record the total receipted catch of all seafood at Fish Board markets fluctuated from 3300t in 1933 to about 4780t in 1968. Narrow-barred Spanish mackerel which was referred to as north Queensland giant mackerel in these reports, formed a large proportion of the states combined mackerel catch between 1930 and 1956, equalling 10% to 13% of the total catch. Decline in the north Queensland giant mackerel catch to 8% of the total catch in 1957 reportedly coincided with the introduction of gill netting for school mackerel throughout Moreton Bay. After the expansion of gill netting into Hervey Bay in 1959, the mackerel catch increased to 14% of the total catch in 1968, though it is not known what species of mackerel these reports refer to.

4.1.3.2. Northern Territory

Commercial harvests of school and spotted mackerel in the Northern Territory are very small and are mainly line caught (Appendix 4. Table 2.). The mean annual harvest of grey mackerel between 1983 and 2000 was about 122t. Similar to fisheries in Queensland, grey mackerel are mainly harvested by netting methods. Narrow-barred Spanish mackerel are mainly line caught with a mean annual harvest of about 179t though the harvest has been well over 200t annually since 1995. Unspecified mackerel are mostly netted with a mean annual harvest between 1983 and 2000 of about 31t (Appendix 4. Table 1.).

4.1.3.3. Western Australia

The Western Australian commercial logbook information does not differentiate between small mackerel species. The mean annual unspecified mackerel harvest between 1980 and 2000 was about 63t. The mean annual harvest of narrow-barred Spanish mackerel in the same period was about 260t with the annual harvest being well over 300t since 1993 (Appendix 5.).

4.1.3.4. New South Wales

The New South Wales (NSW) mackerel (Scomberomorus spp.) harvest is mainly taken in waters adjacent to the northern third of the state. Nearly all spotted mackerel and narrow-barred Spanish mackerel harvested in NSW are taken in these waters north of the Macleay River. The mean annual catch of spotted mackerel and narrow-barred Spanish mackerel between 1984 and 1999 was about 15t and 25t respectively (Appendix 6.). The mean annual harvest of unspecified mackerel for the same period was about seven t. The mean annual commercial harvest of spotted mackerel since 1997 has exceeded 40t annually. It is believed that very little of the unspecified mackerel harvest may be attributed to either spotted mackerel or narrow-barred Spanish mackerel as most unspecified mackerel is recorded in southern most waters of NSW where occurrence of either species would be considered infrequent.

4.1.4. Discussion

The precision of data summaries obtained from each state or territory varied depending on the structure of databases maintained, the quality and quantity of harvest information fishers were required to submit, and policy for release of information to the public adopted by the custodian of each commercial fisheries database. Analyses or interpretation of harvest and effort data were also not possible due to inadequate identification of each small mackerel species and inability to standardise units of recorded effort. The simplest of stock assessments of small mackerel will not be able to be undertaken until record of commercail harvests of small mackerel are identified to a species level.

Though the fisheries for narrow-barred Spanish mackerel are substantially larger than any commercial fisheries for small mackerel species, grey mackerel are of major importance in Queensland, Northern Territory and Western Australia. Grey mackerel in the Gulf of Carpentaria and spotted mackerel on the east coast of Australia have become an important commercial target species for commercial fisheries in recent years. Concerns over the status of spotted mackerel and grey mackerel are discussed in Section 1 of this report. In Queensland it is also likely that spotted and grey mackerel comprise a significant portion of the unspecified mackerel catch. The magnitude of commercial fisheries for school and shark mackerel in Queensland and Northern Territory, though important, is less than other species and is unknown in other states.

4.2. Description of Commercial Spotted Mackerel Fishery in Queensland

4.2.1. Introduction

The 1993 Queensland State Government Inquiry into Recreational Fishing (Anon. 1994) and many commercial and recreational fishers have expressed concern over the practice of using encircling mesh nets (also known as ring nets) to harvest spotted mackerel. Concerns were focused on the threat ring netting may have on the continued sustainability of the spotted mackerel resource, and the perceived conflict between recreational and commercial fishers. Commercial fishers at Moreton Bay, Hervey Bay and Bowen primarily use ring nets to harvest spotted mackerel. Previously there has been no description of the fishers, vessels, apparatus, fishing methodologies and marketing of product related to the ring netting of spotted mackerel in Queensland. This information was required to provide a better understanding of the fishery. This survey was therefore undertaken to describe the commercial fishery which harvests spotted mackerel using ring nets in Queensland waters.

4.2.2. Materials and Methods

A mail survey of commercial fishers who were known to participate in the ring net fishery for spotted mackerel was undertaken in July 1994. Many of the fishers who were sent the mail survey were telephoned prior to and after receipt of the survey to explain its objectives and benefits. Personal contact was undertaken to encourage the accurate completion and return of survey forms. The Queensland Commercial Fishermen's Organisation (QCFO) (now the Queensland Seafood Industry Association) supported this survey and all components of this research. Commercial fishers who harvested spotted mackerel were made aware of the support from the QCFO. The survey was voluntary and all questions related to the number of days targeting small mackerel were requested for operations in the 1993/94 financial year. All other questions required the fisher to provide information recorded in personal fishing logbooks or to recall their involvement in the commercial fishing industry. During the course of this investigation extensive liaison with commercial fishers was required to obtain biological samples and practical knowledge of fishing operations. This close consultation enabled discussion with fishers to assist in evaluation of the results of the mail survey.

4.2.3. Results

A sample of 33 licensed commercial fishers who target spotted mackerel using ring nets were mailed a survey form, of which 24 completed and returned the survey. Completed survey forms represented about 56 % of the 43 licensed commercial fishers who harvested spotted mackerel by netting methods in 1994 according the Queensland commercial fisheries database (QFISH). A total of five survey forms were completed by fishers from Bowen, 16 from Hervey Bay and three from Moreton Bay. Two commercial fishers did not participate in the survey as their fishing activities formed part of a family operation with other licensed commercial fishers who completed the survey. All subsequent estimates and data in this section are related to the sample of fishers who responded to the survey.

A total of 79% of the respondents were full-time commercial fishers. The remaining 21% devoted about half of their working time to commercial fishing activities. At Bowen and Hervey Bay an average of two boats per licensed fisher were used to target spotted mackerel using ring nets. In contrast, one boat per licensed fisher was used for this activity at Moreton

Bay. Throughout all regions, the mean boat length used to net spotted mackerel was 6.1 ± 0.2 m (± s.e.). The mean maximum quantity of spotted mackerel that was able to be harvested, stored and transported by these boats on a single fishing trip was 1292 ± 224 kg (± s.e.). At some locations, particularly Bowen, fishers are able to undertake several fishing trips on the one day. The mean maximum quantity of spotted mackerel that had been harvested, stored and transported on board these boats on any given day (ie. multiple trips) was 1605 ± 314 kg (± s.e.). The fishing boats at Bowen had the greatest storage capacity and had been used to harvest individually, greater quantities of mackerel on any given day than individual boats at Hervey Bay or Moreton Bay (Figure 4.2.1.). The number of fishing crew required to target spotted mackerel using ring nets was about five at Bowen, three at Hervey Bay and two at Moreton Bay.

The mean stretched mesh aperture of ring nets used to target spotted mackerel varied from 9.1 cm at Moreton Bay to 12.7 cm at Bowen. Only the larger mesh was used by fishers in the Bowen region. The mean depth of net varied between 13.1 and 17.4 m (Figure 4.2.2.) and the mean length varied between 358 m and 433 m (Figure 4.2.2.).

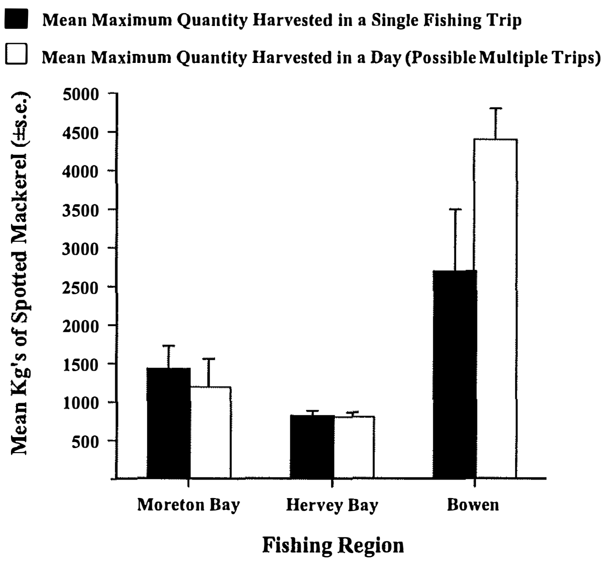


Figure 4.2.1. Mean maximum quantities of spotted mackerel able to be harvested on a single trip trip and harvested in a day at each region (± standard error).

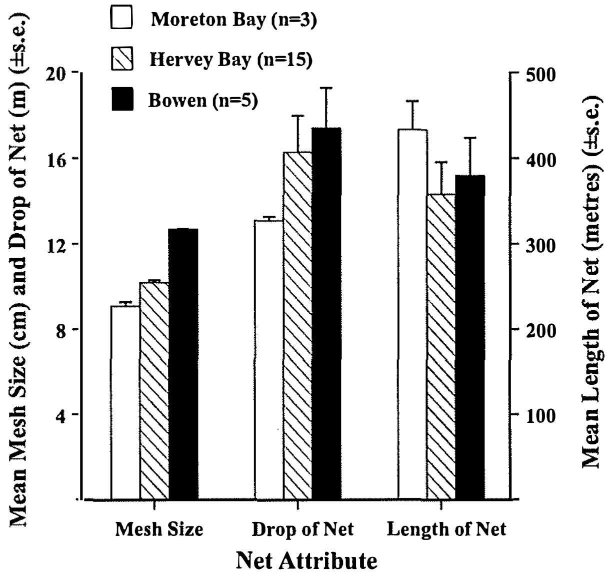


Figure 4.2.2. Mean mesh size, drop and length of ring nets used to target spotted mackerel at each fishing region (± standard error).

The length of the fishing season for spotted mackerel differed between each region. At Bowen the season encompassed mainly August to September. The mean number of days in the season was 78 ± 12 days (± s.e.). The season at Hervey Bay usually commenced in November and concluded in early March, with the mean number of days in the fishing season estimated at 95 ± 7 days (± s.e.). The Moreton Bay season usually extended from December to March, with the mean length of the season reported to be 128 ± 31 days (± s.e.).

The number of days in each fishing season where fishers targeted spotted mackerel using ring nets were substantially fewer than the total number of days fishers perceive the season to be. On average, fishers only use ring nets to target spotted mackerel on about 40 % of the days in each season. The mean number of days spotted mackerel were targeted varied between 18 days at Moreton Bay to 50 days at Hervey Bay (Figure 4.2.3.). At Bowen and Hervey Bay, spotted mackerel were also targeted using set mesh nets.

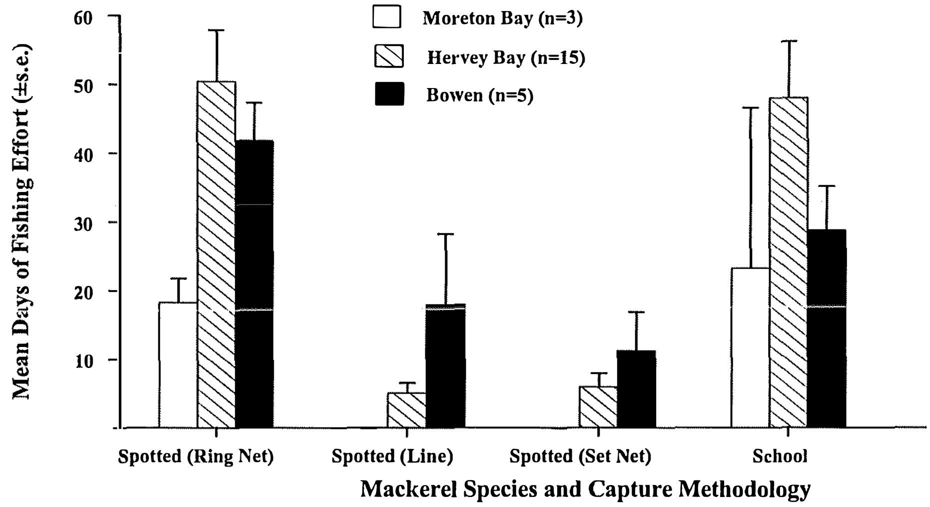


Figure 4.2.3. Mean annual days of fishing effort for small mackerel species by each capture method at each fishing region (± standard error).

About 29% of the gross fishing income of all respondents was derived from the spotted mackerel ring net fishery. The mean gross income per fisher, derived from this fishery varied from 25% at Hervey Bay to 37% at Moreton Bay (Figure 4.2.4.). The gross income derived from all other mackerel species was less than income derived from the spotted mackerel fishery.

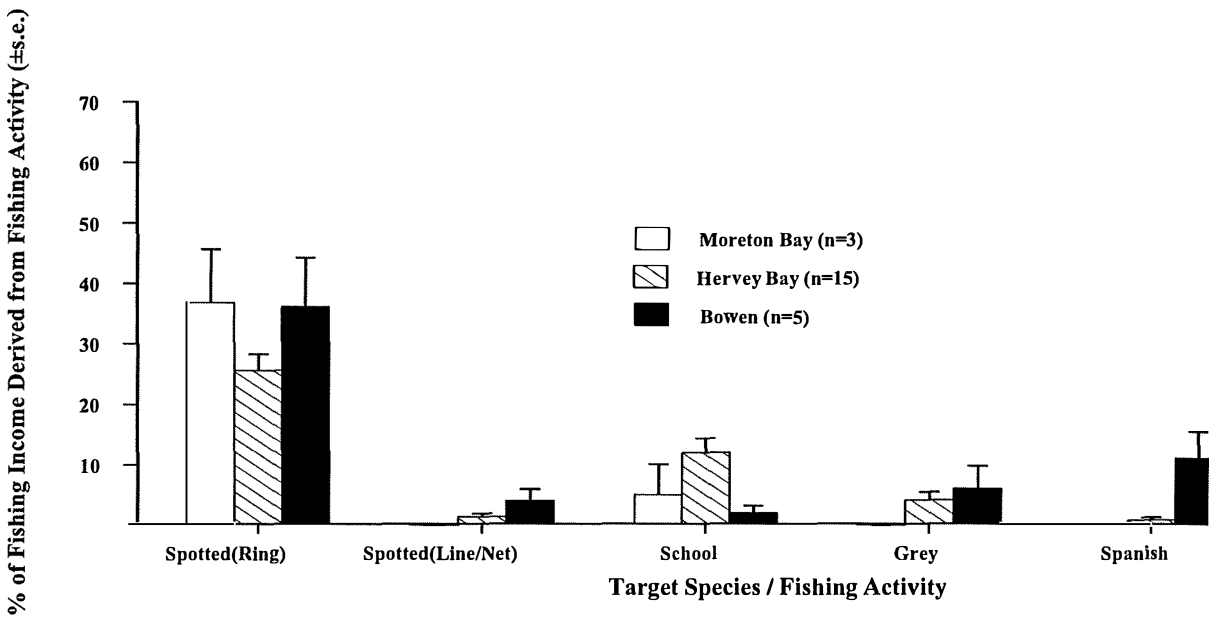


Figure 4.2.4. Mean percentage of fishing income derived from various fishing activities at each fishing region (± standard error).

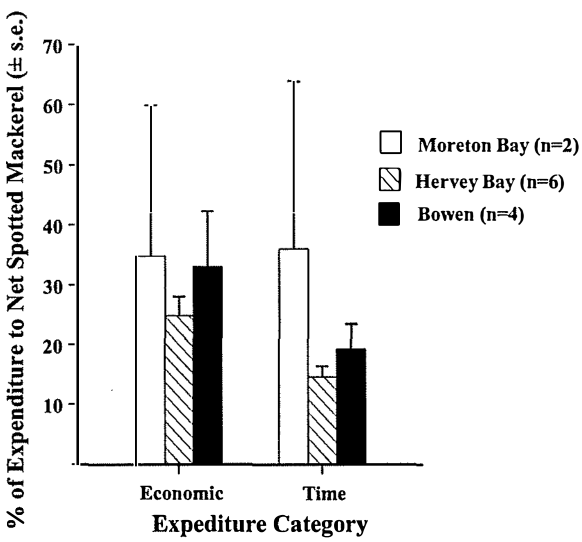


Figure 4.2.5. Mean percentage of economic and fishing time expenditure targeting spotted mackerel with ring nets at each fishing region (± standard error).

The relative cost of targeting spotted mackerel using ring nets (excluding the purchase of boats and equipment) appeared to be similar to the relative economic return for the activity (Figures 4.2.4. & 4.2.5.). At Hervey Bay and Bowen, the relative fishing time expended targeting spotted mackerel using ring nets appeared to be considerably smaller than the relative fishing income derived from the activity (Figures 4.2.4. & 4.2.5.).

In the survey mackerel fishers referred to the gross price received for their mackerel harvest in different forms. Product at Bowen was generally referred to in terms of trunks (head off and gutted), however, several fishers fillet and freeze their harvest and demand a higher price per kg throughout the year. Hervey Bay fishers sell most of their spotted mackerel product as trunks, with occasional fillets. Moreton Bay fishers sell spotted mackerel product whole and fresh. (Preferred product type has changed since the development of export markets for spotted mackerel).

The minimum mean price received for spotted mackerel trunks at Hervey Bay and Bowen were about $2.30 and $4.30/kg respectively. The minimum price received for whole product from Moreton Bay was $3.50/kg (Figure 4.2.6.). The minimum price all fishers received was only slightly less than the expected price received at each location. The minimum return for which fishers would continue to fish for spotted mackerel varied from about $1.75/kg at Hervey Bay to about $2.90/kg at Bowen (Figure 4.2.6.). In 2001 fishers were reported to have recieved prices as high as $8.50/kg for whole, chilled spotted mackerel destinied for export markets.

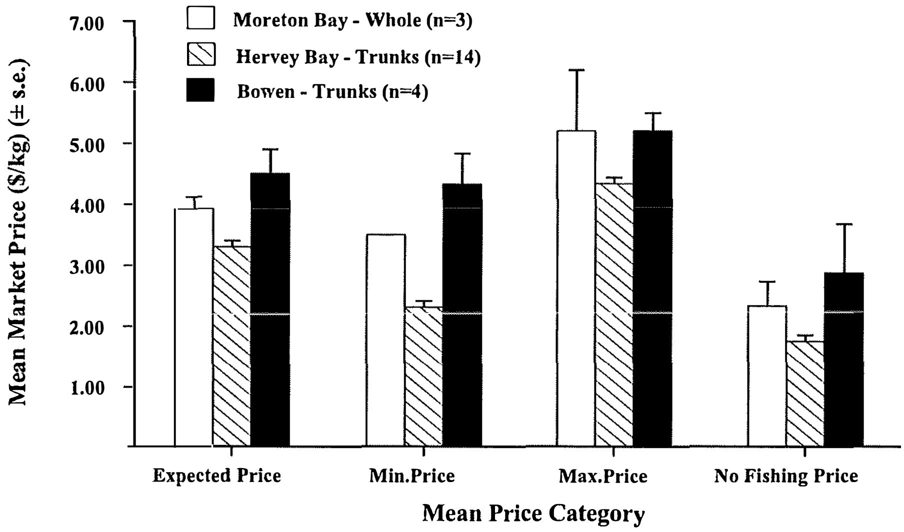


Figure 4.2.6. Mean prices received for spotted mackerel at each fishing region (± standard error).

Fishers targeting spotted mackerel at Bowen indicated that current market price had no influence on their fishing activities. At Hervey Bay nearly half of the fishers, and at Moreton Bay two of the three fishers indicated price influenced their decision to target spotted mackerel. Only fishers from Hervey Bay who said that they did not go fishing because of the current market price indicated that they did not go fishing in the previous season due to insufficient market price. Half of these fishers indicated that they did not go fishing on an average of 6 days in the previous fishing season.

At Bowen, 60% of fishers believed prices obtained for spotted mackerel were influenced by the quality of product. Only 38% of fishers at Hervey Bay and 34% of fishers at Moreton Bay believed prices obtained were influenced by the quality of product. All fishers at Bowen believed that the illegal sale of spotted mackerel by unlicensed fishers was a problem and caused reduced prices. At Hervey Bay, only 15% of fishers and at Moreton Bay, 34% believed the illegal sale of spotted mackerel by unlicensed fishers caused reduced prices.

At Bowen, commercial mackerel fishers perceived the commercial and recreational fishing sectors harvested spotted mackerel in similar quantities. Commercial fishers perceived their harvest of spotted mackerel at Hervey Bay to be greater than the recreational harvest (Figure 4.2.7.).

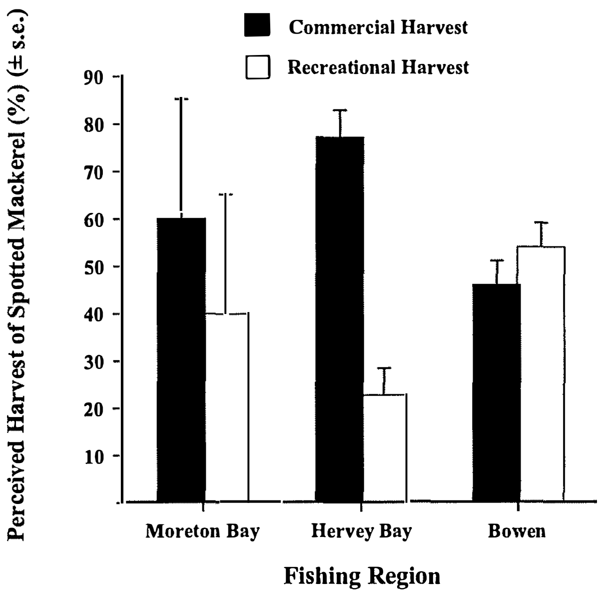


Figure 4.2.7. Relative proportions of the recreational and commercial spotted mackerel harvest at each fishing region as perceived by sample of commercial fishers (± standard error).

4.2.4. Discussion

The magnitude of the commercial spotted mackerel fishery and market forces influencing the fishery has changed markedly since this survey of participants in the commercial spotted mackerel fishery was undertaken. The development of export markets for whole fresh and frozen mackerel, changes in gear configurations, technological advances, greater incentives and willingness of commercial fishers to travel to distant spotted mackerel fishing areas, amongst other factors, have changed the dynamics of the fishery. Informal discussions with commercial spotted mackerel fishers indicate some data obtained in this survey and many of the views expressed by fishers in this survey may have altered. Nevertheless, this survey provides valuable information to enable comparison of the fishery in the early and mid 1990s to the fishery that operates in the early 2000s.

Most commercial fishers who target spotted mackerel using ring nets are full time fishers. The commercial ring net fisheries for spotted mackerel at Bowen, Hervey Bay and Moreton Bay, though targeting the same stock of migratory fish, are quite different. At Bowen, at the time of the survey, only the larger mesh nets were used, whilst smaller meshes were used at Hervey Bay and Moreton Bay. In the late 1990s, anecdotal reports indicate an increase in the use of smaller meshes in Bowen, such as those mesh sizes used at Hervey and Moreton Bay.

The fishing grounds for spotted mackerel at Bowen are close to boat launching facilities and one operation utilises a large displacement hull vessel as a processing and storage facility on the fishing grounds. At Bowen the fishing season lasts only a couple of months; there is a year long demand for frozen mackerel fillets; and crews of up to 5 people are required to harvest and process the large quantities of mackerel. In contrast, fishers at Hervey Bay and Moreton Bay have to travel greater distances to fishing grounds; the fishing season is more extended; the market was predominantly for fresh, chilled product or frozen whole fish of high quality; and only two crew are usually required. The differences in distances, and marketing and processing strategies are demonstrated in the way licensed fishers at Bowen have a greater carrying capacity and generally harvest greater quantities of spotted mackerel than fishers at Hervey Bay and Moreton Bay. Changes in the late 1990s with the development of the lucrative export market for small mackerel species, including spotted mackerel, in the whole chilled form, fishers are not required to spend considerable time processing their harvest as in previous years. Fishers in the early 2000s are motivated by increased economic returns, and are available and physically capable of fishing more days in succession, if weather conditions allow, in the commercial spotted mackerel fishery than ever before.

The availability of spotted mackerel to fishers at each fishing ground is dependent on the status of the spotted mackerel resource and seasonally restricted by the migratory behaviour of the fish and the environmental factors that influence such behaviour, and weather and sea conditions that affect fishing. The number of days on which spotted mackerel are actually targeted in the recognised fishing season at each location was less than half the number of days in each season. The actual number of days expended fishing fluctuated substantially. In 1995 and 1996 at Hervey Bay weather conditions appeared to have been more unfavourable than past years and spotted mackerel fishers reported that they have only been able to fish about 20% of the days in each fishing season, whilst in 1997 the extended temporal availability of fish and suitable sea conditions enabled more days than usual to be fished. Though restriction of effort is primarily due to availability of fish and unsuitable sea conditions, unprofitable market prices was sometimes a contributing factor at Hervey Bay prior to the late 1990s.

At Bowen, Hervey Bay and Moreton Bay, netting of spotted mackerel is a extremely important source of income to commercial fishers. The seasonal occurrence of fisheries for all mackerel species, however, appears to prevent fishers from obtaining an annual income from fisheries based on mackerel species alone. Diversification of fishing practices and target species is essential for these commercial fishers to remain viable. Sustainable fisheries resources on which the fisheries depend are essential and should be considered of greater importance than the ability to diversify. No amount of diversification can assist longer-term economic viability if fisheries resources are subject to unsustainable levels of fishing effort or degradation and destruction of fisheries habitat.

The "minimum fishing price" quoted by fishers in the survey appears to be greater than prices we have observed and been advised has been paid to fishers on several occasions. Fishers have advised us in conversation prices as low as $0.50 -1.00 /kg have been obtained. The disparity between these prices are most probably due to fishers preferring to ignore extremely low prices most probably obtained for poor quality product when the market has been flooded. Most fishers believe that the price obtained for their harvested spotted mackerel is not dependent on product quality. This belief does not encourage an ethic of high post-harvest quality for maximum financial return. The historical high prices that have been received for spotted mackerel destined for export markets in the late 1990s and early 2000s indicate that unless there is another major economic crises in the Asia region, it is unlikely that prices for spotted mackerel will decline to historical lows. The implications of the economic incentives to target spotted mackerel and recent drastic increases in target fishing effort and harvest of the species and associated management concerns for the fishery are discussed in Sections 1 and 6 of this document.

4.3. Gill Net Drop Out in Commercial Spotted Mackerel Ring Net Fishery in Queensland

4.3.1. Introduction

In Queensland, commercial fishers mainly harvest spotted mackerel using ring nets (encircling mesh nets) and to a lesser extent, set gill nets, and hook and line usually using trolling techniques. In commercial ring netting operations, fishers in outboard powered boats, encircle schools of spotted mackerel swimming near the sea surface, with gill nets. Mackerel trapped inside the encircled net are meshed as the net is retrieved. The stretched mesh size of ring nets used to target spotted mackerel was 12.7, 10.2, and 9.5 cm at Bowen, Hervey Bay and Moreton Bay respectively. In Queensland mackerel fisheries most conflict occurs between the commercial gill net fishers and recreational anglers targeting spotted mackerel. Sections of the recreational fishing sector perceive that commercial ring net fisheries for spotted mackerel waste considerable quantities of fish due to gill net drop out.

"Gill net drop out" is the term used for the non-capture mortality of fish owing to the effects of gill netting. Gill net drop out has been reported as occurring in king mackerel fisheries in Florida and is suspected to occur in the narrow-barred Spanish mackerel fishery in the Torres Strait, although no conclusive or supporting data is available on drop out in either fishery (McPherson 1986). Investigation of gill net drop out in the southern shark fishery was unsuccessfully attempted by Walker (1997). The only other investigation of gill net drop out documented was in the herring roe fishery in Canada where about 2% of herring that encountered the net, died and dropped out of gill nets (Hay *et al.* 1982).

Gill net drop out is most likely caused by fatal injuries sustained by a fish on encounter with the net. The fish does not mesh properly and dies of injuries on escaping from the net or falls out of the net on retrieval. These fish are not utilised by the fishery. Spotted mackerel do not possess a swim bladder (Munro 1943) and spotted mackerel have been observed to sink to the sea bed when dead (pers. obs.). In this study, the incidence of gill net drop out in the commercial spotted mackerel ring net fishery in Queensland was investigated. Only mortality which occurs during, or immediately after the retrieval of the gill net was investigated.

4.3.2. Materials & Methods

Gill net drop out in the commercial spotted mackerel ring net fishery was investigated at Bowen, Hervey Bay and Moreton Bay using underwater video equipment, diver observations and otter trawling. The investigations were conducted in cooperation with three major netting operations in Bowen, twelve in Hervey Bay and one in Moreton Bay. Length frequency measurements of spotted mackerel harvested by commercial gill nets and recreational hook and line methods were obtained on four days when investigations of gill net drop out occurred between September 1995 and February 1996.

Little commercial netting for spotted mackerel was undertaken and consequently no investigation of gill net drop out occurred on those days when wind speed was predicted to exceed 15-20 knots. Research investigations were, however, often undertaken in disturbed sea conditions as winds greater than 15 knots often occurred on the fishing grounds after fishing commenced. All spotted mackerel fishing occurred in depths of 10 to 12 m in Bowen and 14 to 23 m in Hervey Bay and Moreton Bay. A 5.2 m inboard diesel powered boat was used as a platform for the video and diving components of this study. A 13.5 metre timber inboard diesel powered vessel was used for all trawling investigations. Underwater filming, diving observations and otter trawling were only undertaken adjacent to successful net shots.

Underwater Video

Consultation with experienced underwater camera operators indicated that a Remote Operating Vehicle (ROV) would be an inappropriate tool to investigate gill net drop out in the spotted mackerel fishery. Major concerns expressed in relation to the use of a ROV for this task were the inability for a ROV to move at required speeds and to avoid entanglement with the gill net. There were also doubts that a ROV would be able to be successfully deployed from a small vessel required for manoevability and further concerns a ROV could effectively operate in currents or moderate to rough sea conditions adjacent to retrieved gill nets. In appreciation of this advice, video images were subsequently obtained using a high resolution Cunard Technologies™ underwater colour camera fitted with a 6 mm lens and powered by a 240 volt generator. A video recorder and monitor enabled recording and real time viewing of the sea bed. The camera was attached to a weighted aluminium sled, which was deployed and towed along the sea bed via a small gantry and hydraulic winch on the platform boat (Figure 4.3.1.). An electrical cable connecting the camera to surface operations was attached to the sled cable on each deployment via quick release clips and plastic ties.

The underwater camera was initially mounted on a weighted paravane, but was unstable in moderate sea conditions. This apparatus frequently came into contact with the sea bed and there was unacceptable variation in the field of view of the camera while mounted on the paravane. The sled was considered to be a more appropriate vehicle for the camera as it ensured more consistent fields of view of the sea bed and was more easily handled on the platform boat due to its lighter weight. The sled was towed at approximately 1.9 knots. The field of view of the camera in the sled was about 38^{o} either side of the lens centre which provided a viewing width of 3 m. All recorded video footage was timed and viewed in the laboratory to assess the incidence of dead mackerel on the sea bed.

Logistical and safety factors precluded the use of a structured transect survey. At Bowen, in particular, there was heavy recreational boating traffic amongst commercial netting operations. Consequently, the sled was towed as close to the net as possible. After completion of a successful net shot by commercial fishers, the platform boat was manoeuvred to within 100 metres of the net and the camera sled was deployed. Often several nets were shot within a few hundred metres of each other and gill nets drifted. Sampling time was evenly partitioned viewing the sea bed over which the gill net had passed, downcurrent of the gill net, and that parallel to the gill net and the prevailing current. This strategy was necessary, as the mobility and rate of drift of dying or dead mackerel was unknown and subsequently all sea bed in close proximity to netting operations required assessment.

Diving Investigations

Divers observations of the sea bed adjacent to and underneath net shots were used to verify the underwater video recordings. Divers and snorkellers also observed the behaviour of meshed spotted mackerel and those swimming inside the net. No diving or snorkelling was done in Moreton Bay because spotted mackerel failed to appear in the 1995/96 season in numbers which normally support both commercial and recreational fisheries. Sampling mainly relied on underwater video observations because of the presence of sharks and other perceived dangers posed to divers.

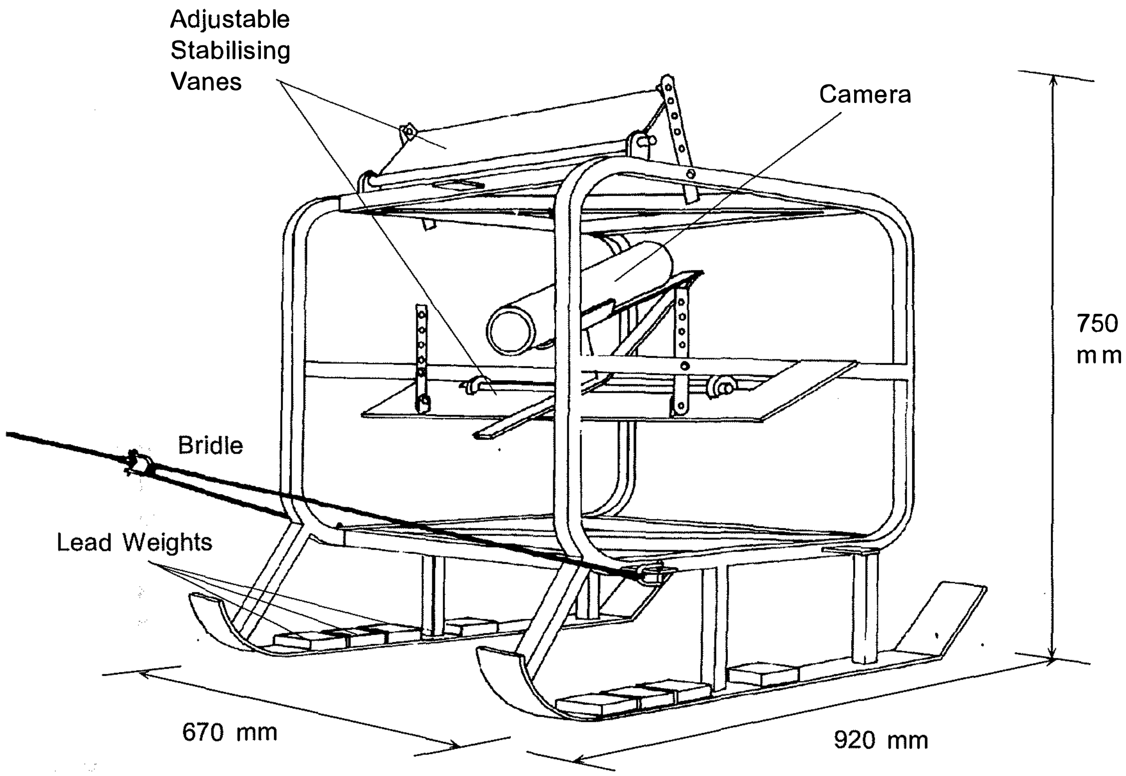


Figure 4.3.1. Diagram of underwater sled used with mounted underwater camera

Trawling

Trawling could only be undertaken at Hervey Bay because of the presence of numerous recreational fishing boats at Bowen, and the failure of spotted mackerel schools to appear in Moreton Bay. After successful deployment of the gill net, a chartered trawler steamed within 10 m of the net enabling the location of the net to be fixed using a global positioning system (GPS) receiver. As the gill nets often drifted, a second GPS position was obtained near completion of the net retrieval. After retrieval of the net and completion of the underwater video recording, trawl gear was towed several times between and through the beginning and end positions of where the net was deployed. If several net deployments were made within a few hundred metres of each other, trawls were undertaken on sea bed over which it was determined nets were most likely to have passed. Usually between two to four parallel trawl transects between 400 and 1000 m in length were performed through the area of gill netting operations.

The trawl gear comprised 3 x 15 m scallop nets of a stretched mesh of 100 mm and constructed of 60 ply polyethylene. The cod ends were 87 mm mesh and constructed of 150 ply polyethylene. There were no bycatch reduction devices or turtle exclusion devices fitted to the trawl nets. The gear was towed at 2.6 knots and a drop chain was rigged ahead of the foot rope to ensure the net fished "hard" on the bottom. The width of sea bed swept by these trawl nets was estimated to be 30 m. This net configuration and trawling procedure was chosen to capture and retain any dead mackerel which may have dropped out of the gill nets.

The skipper of the trawl vessel was instructed to retain all mackerel collected. On the 10th December 1995 the entire catch of the trawl shot was retained, identified and counted

(Appendix 2.). The trawl catch was examined for the presence of benthic fauna to determine whether the trawl was fishing "hard" against the bottom as requested. Fishing in this manner would have the maximum chance of trawling up any dead mackerel present. The trawl skipper indicated that he rarely captured juvenile spotted mackerel when trawling the area where gill net drop out investigations were undertaken, and never captured fish of a size found in the schools of spotted mackerel being targeted and captured by gill net and line fishers. It was assumed that any dead spotted mackerel of a size being captured by gill net and line fishers, retained in the trawl gear, were those which had dropped out of gill nets.

Comparison of line and net captured fish

Fork length measurements of spotted mackerel harvested by commercial and recreational methods were obtained at Bowen and Hervey Bay and grouped into 50 mm length classes. Measurements were obtained at random from as many commercially captured mackerel as possible. On the same day, measurements of spotted mackerel captured by recreational hook and line were recorded prior to tag and release or collection of biological samples. Hook and line harvesting methods were assumed to be less selective in the length of fish captured than commercial netting methods. The distribution of length frequency measurements of spotted mackerel harvested by commercial and recreational fishers were compared using Kolmogorov-Smirnov tests.

4.3.3 Results

Underwater Video

Only one dead spotted mackerel was recorded on the sea bed adjacent to gill netting activities. This fish was observed on a sand substratum in about 12 metres of water at Bowen on 3 September 1995. On this day it was estimated that in excess of 2000 individual spotted mackerel were caught in commercial operations in the area where the underwater camera was deployed.

More than 10 hours of effective video footage of the sea bed was recorded with the minimum area of sea bed surveyed during gill netting operations, estimated to be in excess of 100,000 m^2 (Table 4.3.1.). A further 10% of recorded underwater footage was non-effective bottom time. This non-effective time filmed the water column and was due to fluctuating tow speeds, turning and 'bouncing' of the sled and paravane caused by disturbed sea surface conditions.

Table 4.3.1. Time expended and approximate area of seabed filmed during underwater camera investigations in conjunction with commercial spotted mackerel gill netting operations.

Camera Platform	Date	Location	Effective Bottom Time (mins)	Approx. Sea Bed Area Filmed (m^2)	Ineffective Bottom Time (mins)	Dead Mackerel Observed
Paravane	2 Sept 1995	Bowen	67	11800	22	0
Sled	3 Sept 1995	Bowen	73	12800	14	1
Sled	4 Sept 1995	Bowen	31	5400	4	0
Sled	23 Nov 1995	Hervey Bay	102	17900	4	0
Sled	24 Nov 1995	Hervey Bay	127	22300	4	0
Sled	9-10 Dec 1995	Hervey Bay	29	5100	2	0
Sled	11 Dec 1995	Hervey Bay	36	6300	1	0
Sled	21Jan 1996	Hervey Bay	104	18300	2	0
Sled	22 Jan 1996	Hervey Bay	25	4400	0	0
Sled	8 Feb 1996	Moreton Bay	15	2600	7	0
		Total	**609**	**106900**	**60**	**1**

Diving Investigations

Divers and snorkellers did not observe any dead spotted mackerel on the sea bed. There were no mackerel observed dropping out of gill nets, either on encounter with the net or on retrieval of the net. Two divers spent 25 minutes searching for dead mackerel on the sea bed immediately adjacent to and under gill nets at both Bowen and Hervey Bay. Two divers spent a further 25 minutes observing from underneath fishing boats the incidence of mackerel drop out on retrieval of the gill nets at both Bowen and Hervey Bay.

Spotted mackerel were observed to swim into the net at high speed and then further propel themselves forward as their body was progressively more firmly wedged in the mesh. All observed fish were effectively meshed after contact with the net, and usually died within a few minutes of meshing. Healthy fish were often seen to escape over the float line when a school was encircled by a gill net. These escapes occurred when several fish charged towards the net just below the float line, meshing themselves and causing the float line to submerge briefly. Mackerel not already meshed were then able to escape over the floatline before the meshed mackerel stopped their initial struggle, and the positive buoyancy of the float line caused the net to once again fully encircle the school.

There were no sharks observed while diving at Bowen. Several large sharks were seen by divers monitoring the sea bed underneath gill nets on one occasion in Hervey Bay.

Trawling

There were no mackerel captured during the 225 minutes trawled (Table 4.3.2.).

Table 4.3.2. Daily bottom times trawled at Hervey Bay.

Date	Number of gill net localities trawled	Total Bottom Time of Trawls (Mins)	Estimated Sea Bed Area Trawled (Hectares)	Depth (Metres)
24 Nov 1995	3	75	18	21
25 Nov 1995	3	105	25	22
10 Dec 1995	1	75	18	21-23
	Total	**255**	**61**	

A total of 18 species of fish comprising 137 individuals, 12 holothurians, 2 cuttlefish and a Moreton Bay bug were captured in the trawl undertaken on 10 December 1995 (Appendix 2.).

Length frequency of spotted mackerel

The range of fork length classes of spotted mackerel captured at Bowen was between 400 mm and 750 mm in the recreational catch and 600 mm to 900 mm in the commercial catch (Figure 4.3.2.). The length frequency distributions for each method of capture were significantly different (Kolmogorov-Smirnov, D=0.76, $P<0.001$). Fork length classes of spotted mackerel harvested by recreational and commercial methods at Hervey Bay were between 500 mm and 700 mm. Relative frequencies of length classes of fish harvested by each sector at Hervey Bay were not significantly different on any day (Kolmogorov-Smirnov, N.S.) (Figure 4.3.2.).

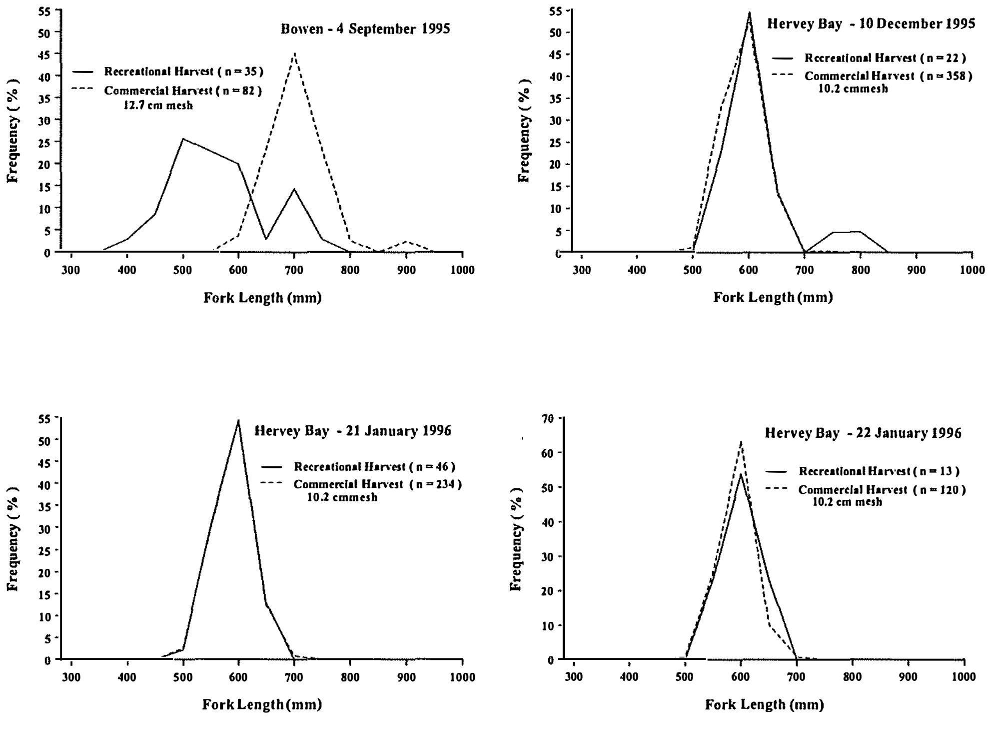


Figure 4.3.2. Percentage fork length frequencies of spotted mackerel captured by commercial and recreational fishing methods on days where underwater investigations were undertaken.

4.3.4. Discussion

Underwater video camera, diver observations and trawling of the sea bed provided no evidence that dead spotted mackerel litter the sea floor after ring netting operations. The substantial sea bed area surveyed by various methods adjacent to and underneath successful gill net shots and the observation of a single dead spotted mackerel indicated investigations were adequate to detect dead mackerel had they been present.

Diver recorded observations of the meshing behaviour of spotted mackerel and retrieval of nets also dispelled concerns about drop out. Regardless of mesh size used, most spotted mackerel were firmly meshed between a point immediately past the gill covers and the position of maximum body girth. The maximum body girth in spotted mackerel is around the trunk of the fish between the base of the second dorsal fin and the anal fin.

Recreational fishers from more than 20 boats were targeting spotted mackerel with hook and line among commercial netting operations when the dead spotted mackerel was filmed on the sea bed at Bowen. Upon completion of the days' fishing, creel interviews and measurement of recreational catches indicated that about 30 spotted mackerel were caught from each recreational boat. Consequently it was not possible to conclude from the underwater video footage, whether the observed spotted mackerel died due to an encounter with a commercial gill net, or with the hook and line of a recreational fisher.

The recovery of dead fish by trawling has been previously undertaken in studies of lake trout predated by sea lampreys (Bergstedt and Schneider 1988; Schneider *et al.* 1996). The trawl capture of benthic invertebrates such as holothurians and several benthic orientated fish indicated that the trawl gear was fishing the bottom in a manner suitable for the capture of dead mackerel had they been present. Sharks were present during and after some gill net shots. Sharks have been seen eating meshed spotted mackerel and it is almost certain that they would eat recently dead mackerel. However as sharks were generally not observed during this study, we suggest that the absence of dead spotted mackerel on the bottom is a real phenomenon rather than due to scavenging by sharks prior to survey observations or trawling.

In Bowen, spotted mackerel harvested by commercial netting are generally larger than those caught by recreational methods. The large size range of spotted mackerel captured by the different methods indicated that gill nets used at Bowen have the potential to impact on fish, other than those of length classes selected by gill nets. The presence of a large size range of spotted mackerel at Bowen was not only supported by length frequency data, but also underwater observations of schools of spotted mackerel comprising fish of variable sizes. Spotted mackerel harvested by recreational and commercial methods in Hervey Bay were similar in size. Gill nets appear to have the potential to impact on a narrow range of sizes of spotted mackerel at Hervey Bay compared to Bowen.

Delayed mortality may occur due to internal and external injuries incurred on encounter with a gill net. Skin and tissue damage may result in secondary infections. A gill net drop out study of the herring roe fishery in Canada investigated non-capture mortality for up to three weeks after the cessation of gill netting activity (Hay *et al.* 1982). Numbers of dead herring observed immediately after closure of the fishery were fewer than numbers observed on the sea bed three days after gill netting ceased. In our study divers saw several spotted mackerel swim through 12.7 cm gill net meshes at Bowen without any immediate ill effect. McPherson (1986) reported from different sources, the capture of large proportions of narrow-barred Spanish mackerel and king mackerel exhibiting marks, cuts and bruises which were consistent with injuries incurred on encounter with gill nets. In this study, it was not possible to investigate longer term netting induced mortality due to currents, predators, the inability to follow mackerel over long periods after encounter and escapement from gill nets, and the requirement to investigate short term drop out mortality.

It was not possible in the absence of any measurements from drop out fish to make conclusions as to what size spotted mackerel would most likely drop out of different sized mesh nets. Hay *et al* (1982) found no significant difference in the size of herring which dropped out and those which were retained in the gill net. We believe that given the way large spotted mackerel were seen to be retained around the head by smaller meshes, such fish may be dislodged from the net. Commercial fishers repeatedly shaking the net on retrieval to discard unwanted catch or weed, and less than ideal sea conditions, are likely to increase the chances of drop out of spotted mackerel.

The evidence for the lack of drop out of spotted mackerel is valuable in providing fishing sectors with factual information on an issue debated on perceptions and hearsay. It is not possible, however, due to logistical constraints of working in small boats at sea, and the movement of large nets with wind and currents, to use the methods utilised in this study to provide a quantifiable estimate of the rate of gill net drop out.

Gill net drop in the spotted mackerel fishery, if it does occur, is likely to be infrequent. It is stressed that these conclusions are based on observations of ring netting operations for spotted mackerel using nets made of particular mesh sizes and line strengths at three distinct geographical areas. The selective properties of a particular net configuration is likely to alter when used in another area on spotted mackerel exhibiting different behaviour and reproductive development. The potential for drop out of spotted mackerel from gill nets may also alter with changes in the selective properties of nets. Alteration of gill net configurations may be considered an appropriate management tool in the future. Selective properties of nets currently used to harvest spotted mackerel should be assessed prior to any legistlative change in the configuration of nets used.

Conclusions of negligible drop out of spotted mackerel from gill nets in this study were subsequently only appropriate for ring net configurations and methods employed in each specific fishing area. These conclusions should not be extrapolated to the use of set mesh nets used to target spotted mackerel. Additional studies would be required to investigate gill net drop out from set mesh nets.

4.4. Gill Net Selectivity in Spotted Mackerel Fishery in Queensland

4.4.1. Introduction

Gill net fisheries in Queensland target spotted mackerel at Bowen in late winter and early spring using 12.7 cm (stretch measurement) mesh nets and at Hervey Bay and Moreton Bay in summer using 10.2 and 9.5 cm mesh nets. Selectivity of gill nets used at these locations was investigated to determine the probability of retaining spotted mackerel smaller than the current minimum legal length and the length at first maturity.

Retention in gill nets occurs when a fish penetrates a mesh beyond its gill covers, but does not completely pass through (Hamley 1975). Mackerel (*Scomberomorus spp.*) are usually retained in gill nets at a point on the trunk well behind the opercular region. Ehrhardt and Die (1988) reported that Spanish mackerel captured in Florida are fusiform in shape, and lack protuberances and spines that may tangle or wedge a fish in the net before it enters a mesh beyond its gill covers. Spotted mackerel are similar in shape and body characteristics to Spanish mackerel, and few become tangled or wedged by their teeth, maxillaries or tail.

Morphometric measurements of Spanish mackerel have been used by Ehrhardt and Die (1988) to estimate theoretical selectivity curves for gill nets in accordance with the model of Sechin (1969). This model assumes that selection curves are determined by knife edge girth selection. It also assumes that fish are only retained when the opercular girth is smaller than the mesh perimeter and the maximum girth is larger. A further assumption is that entrapment occurs only by wedging, not by gilling or entangling. This component of our study describes the selectivity of gill nets used to target spotted mackerel at Bowen, Hervey Bay, and Moreton Bay.

4.4.2. Materials and Methods

Length and girth measurements of spotted mackerel harvested by commercial fishers were collected at random during the fishing season (Table 4.4.1). Measurements were recorded to the nearest 5 mm. Data were not separated by sex. There are no morphological differences between the sexes and each sex was assumed to have equal probability of capture in a gill net.

Table 4.4.1. Details of spotted mackerel measured for gill net selectivity study.

Date	Location	Mesh Size of Net(cm)	n	Length Range (mm)
7 February 1993	Moreton Bay	9.5	28	550-710
2 February 1994	Hervey Bay	10.2	50	520-695
7 February 1994	Moreton Bay	9.5	40	560-695
9 December 1994	Hervey Bay	10.2	31	545-765
30 January 1995	Hervey Bay	10.2	50	530-735
2 September 1995	Bowen	12.7	125	570-890
3 September 1995	Bowen	12.7	347	550-885
4 September 1995	Bowen	12.7	82	555-870
23 November 1995	Hervey Bay	10.2	122	480-690
24 November 1995	Hervey Bay	10.2	48	480-835
25 November 1995	Hervey Bay	10.2	301	480-770
26 November 1995	Hervey Bay	10.2	136	495-700
10 December 1995	Hervey Bay	10.2	216	490-700
21 January 1996	Hervey Bay	10.2	234	490-675
22 January 1996	Hervey Bay	10.2	120	500-655
6 February 1996	Moreton Bay	9.5	53	590-720

Selection probabilities P for spotted mackerel were estimated according to the model described by Sechin (1969) and utilised by Ehrhardt and Die (1988) :

$$P\{G_{c,j} \leq 2m_i\} = \Phi\left(\frac{2m_i - K_{c,i}G_{c,j}}{\sqrt{\sigma^2_{c,j} + \sigma^2_i}}\right)$$

for the length distribution of fish small enough to pass into a mesh beyond the operculum, and

$$P\{G_{\max,j} \leq 2m_i\} = 1 - \Phi\left(\frac{2m_i - K_{\max,i}G_{\max,j}}{\sqrt{\sigma^2_{\max,j} + \sigma^2_i}}\right)$$

for that of too large to pass through the mesh. A combination of the above formulations gives

$$S_{i,j} = \Phi\left(\frac{2m_i - K_{c,i}G_{c,j}}{\sqrt{\sigma^2_{c,j} + \sigma^2_i}}\right) \cdot \left[1 - \Phi\left(\frac{2m_i - K_{\max,i}G_{\max,j}}{\sqrt{\sigma^2_{\max,j} + \sigma^2_i}}\right)\right]$$

for the length distribution of fish that are retained by mesh i

In the above formulations:

$S_{i,j}$ = Probability of retention of fish of sizeclass j encountering mesh size i;
$G_{c,j}$ = mean opercular girth for fish of sizeclass j;
$\sigma^2_{c,j}$ = variance of $G_{c,j}$;
$K_{c,i}$ = factor combining the elasticity of the twine and tissue at the point of opercular girth for mesh size i;

$G_{\max,j}$ = mean maximum girth for fish of sizeclass j;
$\sigma^2_{\max,j}$ = variance of $G_{\max,j}$;
$K_{\max,i}$ = factor combining the elasticity of the twine and tissue at the point of maximum girth for mesh size i;

$2m_i$ = inside mesh perimeter of mesh size i;
σ^2_i = variance of mesh perimeter for mesh i; and
Φ = cumulative distribution function of the standard normal distribution.

The relationship between G_c and $G_{\max}$ measurements for each mesh perimeter are the derived elasticity-compressibility factors K where:

K = mesh perimeter (cm) / girth (cm)

Girth measurements required by the model were made using a loop of non-stretchable synthetic measuring tape. Opercular girth (G_c) was measured around the plane where the maximum measurement around the opercular/head region was obtained (Figure 4.4.1.).

Maximum girth (G_{max}) was measured at the plane around the body immediately in front of the second dorsal and anal fin. Retention girth was measured around the mark left by the mesh on capture of the fish (Figure 4.4.1.). The retention mark is clear on *Scomberomorus* species netted in Australian waters. If several marks were apparent on a fish, the retention girth was the most defined mark.

$K(G_c)$ and $K(G_{max})$ were estimated only for fish where the retention girth was within 10 mm of G_c and G_{max} respectively. If the retention girth was further than 10 mm from G_c and G_{max} for a particular fish, the derived K-factor was not estimated owing to the differing compression properties around the fish. K-factors are inversely related to compressibility of the fish, with the less compressible bony opercular structure relative to the softer retention region in the body, resulting in larger $K(G_c)$ factors (Ehrhardt and Die 1988). Variance of mesh size from the manufacturer's specifications were not considered in this study.

The probability of retention for each mesh size was estimated, using the previously described parameters, according to Sechin's (1969) model. The selectivity curves based on girth measurements for each mesh size were plotted with the length frequency distributions of spotted mackerel captured in each corresponding mesh size.

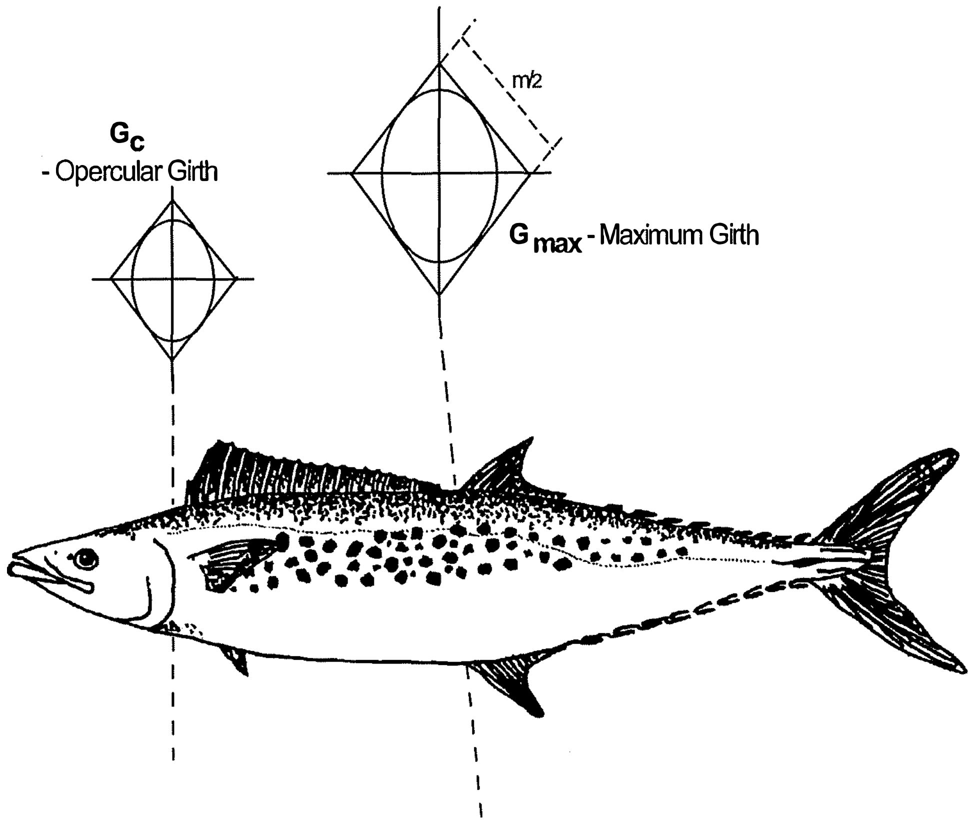


Figure 4.4.1. Region of spotted mackerel between points of the opercular girth (G_c) and maximum girth (G_{max}) where fish are retained by gill nets with mesh perimeter equal to "2m" (After Collette and Nauen 1983; Ehrhardt and Die, 1988).

4.4.3. Results

Data obtained from all mesh sizes were pooled to obtain the relationship between fork length and G_c and G_{max} (Figure 4.4.2.).

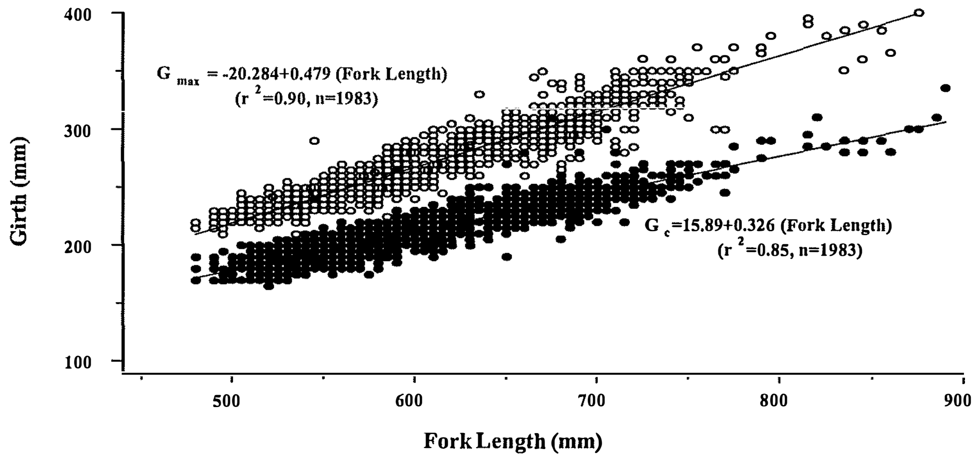


Figure 4.4.2. Relationship of maximum girth (G_{max}) and opercular girth (G_c) to fork length of spotted mackerel (all mesh sizes and regions combined).

Variances of G_{max} and G_c showed significant differences with respect to fork length (Bartlett's $\chi^2 = 183.45$, df = 61, P < .0001 for G_{max}; Bartlett's $\chi^2 = 414.71$, df = 61, P < 0.0001 for G_c.). The linear relationships between variances of G_{max} and G_c with fork length were:

$$\text{Var}\left(G_{max}\right) = -360 + 0.8\ (\text{Fork Length})$$

$$\text{Var}\left(G_{c}\right) = -40 + 0.2\ (\text{Fork Length})$$

The number of fish captured in all meshes where the retention girth was within 10 mm of the G_c were few (Table 4.4.2.). Subsequently, mean K-factors for G_c's for all meshes and mean K-factors for G_{max}'s for the 9.5 cm mesh net were calculated from too few fish to be considered accurate. Mean K-factors calculated from morphological data pooled across each mesh size studied were considered appropriate for inclusion in respective selectivity models.

Table 4.4.2. Mean estimated K-factors for each mesh size and combined for all meshes. Sample sizes and proportion of total selectivity sample retained within 10 mm of G_{max} and G_c included.

Stretched Mesh Size (cm)	$K(G_c)$			$K(G_{max})$		
	Mean	No. of Fish	% of total sample	Mean	No. of Fish	% of total sample
9.5	0.833	37	30.6	0.727	10	8.3
10.2	0.910	26	2.0	0.840	1103	84.3
12.7	0.840	8	1.4	0.841	476	86.0
All meshes	**0.863**	**71**	**3.6**	**0.840**	**1588**	**80.0**

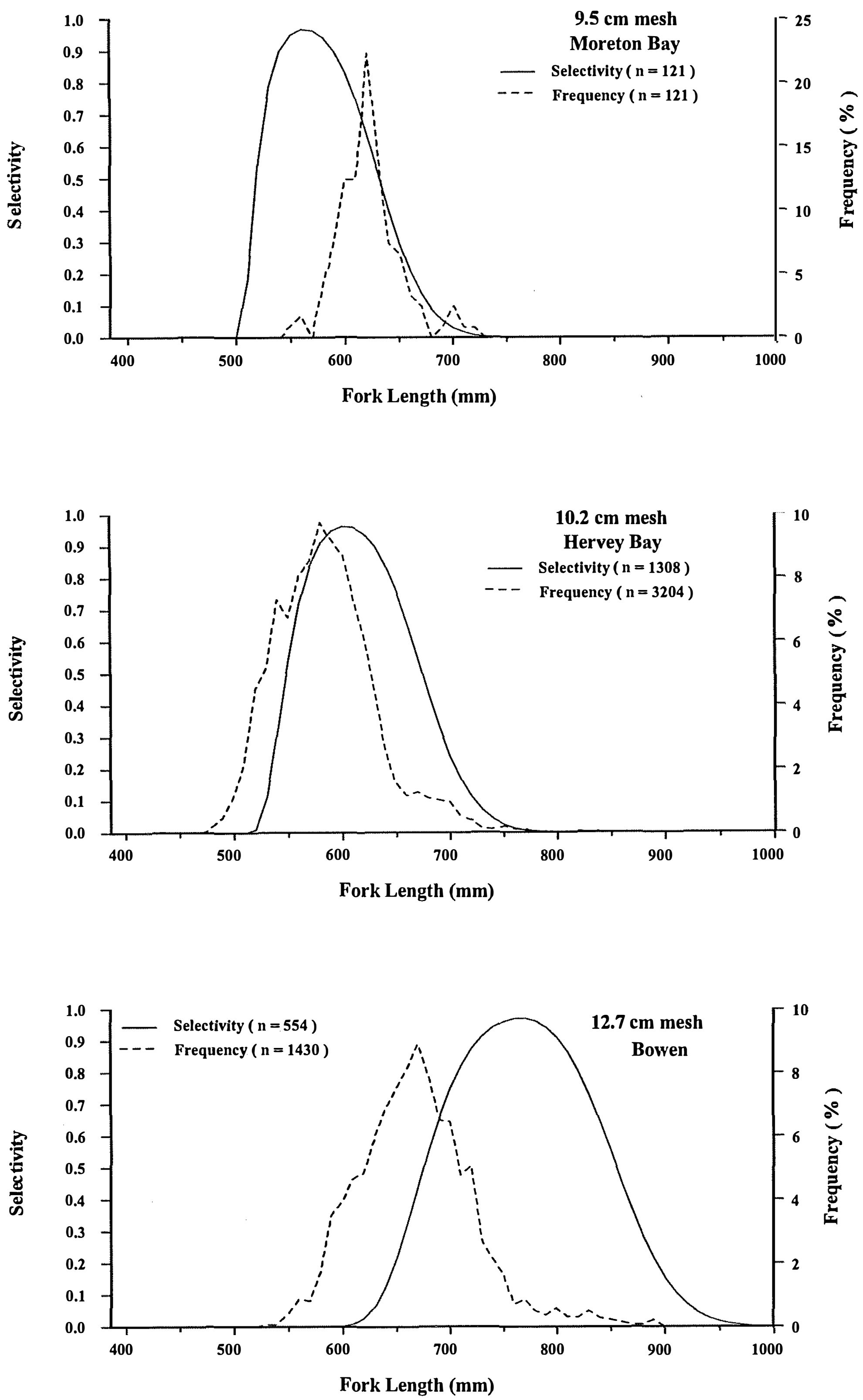


Figure 4.4.2. Selection curves and observed fork length frequencies for mesh sizes of gill nets used in the ring net fishery for spotted mackerel in Queensland.

The highest probabilities of retention were .969, .964, and .971 for the 9.5, 10.2, and the 12.7 cm meshes respectively. Theoretical optimum selection lengths for these mesh sizes at the highest probabilities of retention were 560, 600, and 770 mm fork lengths respectively.

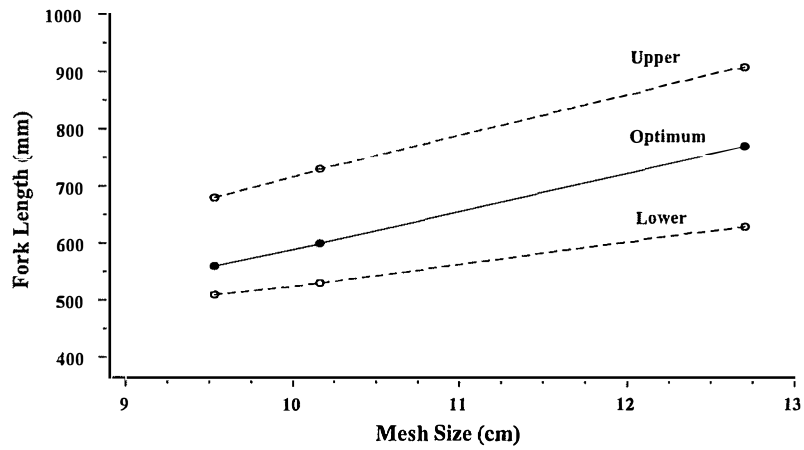


Figure 4.4.3. Theoretical optimum selection lengths with upper and lower selection ranges (95 percentiles) for a range of mesh sizes. Symbols represent lengths corresponding to mesh sizes investigated in this study.

Table 4.4.3. Mean observed and theoretical retention lengths of spotted mackerel (and associated standard deviations for each mesh size).

Stretched Mesh Size (cm)	Mean Retention Length (mm) (Fork Length)				Mean Retention Length (mm) (Total Length)			
	Observed	**s.d.**	**Theoretical**	**s.d.**	**Observed**	**s.d.**	**Theoretical**	**s.d.**
9.5	622	29	582	44	706	30	663	44
10.2	584	46	617	48	666	48	700	50
12.7	668	53	769	66	753	55	857	69

Mean observed and theoretical fork lengths of retained spotted mackerel increased as the mesh size of net used increased (Table 4.4.3).

4.4.4. Discussion

Most spotted mackerel retained in each mesh size were of lengths within the range of lengths expected from their corresponding selectivity curves, except for the 12.7 cm mesh. Most fish retained in the 9.5 cm mesh at Moreton Bay were situated on the right side of the selection curve. This shift was attributed to the small sample size and the large proportion of fish captured in Moreton Bay which were larger than those usually encountered. The large proportion of these fish retained near the G_c and the small proportion retained near the G_{max} demonstrated these fish were larger than would normally be expected to be targeted with a 9.5 cm mesh net.

In contrast, most fish retained in the 10.2 cm mesh used in Hervey Bay were situated slightly to the left side of the selection curve. This small shift is likely due to the abundance of spotted mackerel smaller than the theoretical length captured by this mesh.

The greater shift left of the majority of spotted mackerel retained in the 12.7 cm mesh at Bowen is attributed to two main factors. The first is the decrease in abundance of fish near the asymptotic lengths for each sex (males 730 mm fork length; females 860 mm fork length), which is near the theoretical mean retention length for the mesh. The capture of numerous fish less than 650 mm, which corresponds to a probability of retention of only about 0.22, suggests that at Bowen there was a high abundance of spotted mackerel smaller than the theoretical optimum length selected by this mesh. The abundance of smaller fish and left shift of length frequencies of fish retained in the larger mesh compared to the estimated selectivity curve is further supported by length frequency measurements of fish harvested by hook and line, netting and underwater observations. This data and observations at Bowen indicated exploited schools comprise fish of a large range of lengths (Figure 4.3.2.). Similar shifts in length frequencies of captured Spanish mackerel in meshes which optimally select for small and large mackerel were observed by Ehrhardt and Die (1988).

Important in the estimation of selectivity curves in our study, was the assumption that G_c - fork length and G_{max} - fork length relationships were constant. This assumption may have been a source of error in the calculation of gill net selectivity curves for spotted mackerel as the assumption was likely violated owing to the use of different mesh sizes used to capture mackerel that are separated on a large spatial and temporal scale. Tagging studies, otolith chemistry and genetic studies indicated spotted mackerel comprised a single stock along the eastern coast of Queensland. At Bowen, in August and September the fish are in spawning condition, while during summer at Hervey Bay and Moreton Bay, spotted mackerel exhibit no reproductive development and are feeding. The energy requirements of a large scale migration and the expected fluctuation of G_{max} for a fish of a given length during both peak spawning and feeding periods would be expected to alter the likely position of the retention girth around the body.

The selectivity curves estimated for a particular size mesh in each region are likely to be indicative of the selectivity properties of the same size net in another region owing to the pooling of G_c - fork length and G_{max} - fork length relationships for all fish. We encouraged without success, commercial fishers in Hervey Bay and Bowen to use 12.7 and 10.2 cm mesh nets respectively when concurrent net shots using traditional mesh sizes for each region were undertaken. Selectivity and length measurements of fish captured in each mesh size in each region would then have been able to be directly compared. Fishers were reluctant to use nets comprising unfamiliar mesh sizes because they feared they would capture large quantities of small fish that they would be unable to successfully process and market or alternatively, capture insufficient quanitiies of fish to make the fishing trip worthwhile.

Selectivity curves and length measurements of spotted mackerel captured in 9.5, 10.2, and 12.7 cm mesh nets demonstrated it was unlikely that many fish less than the current minimum total legal length of 500 mm (422 mm fork length) would be retained in these sized mesh nets. The optimum selection length for each mesh size was also greater than the length at first maturity for either sex. However, it is likely, female spotted mackerel smaller than the length at first maturity will be captured in the 9.5 cm mesh. The use of 9.5 cm mesh to target spotted mackerel should be prohibited if the capture of spotted mackerel smaller than the length at first maturity is to be avoided.

It is apparent from estimated selectivity curves and lengths of harvested fish at Bowen, the 12.7 cm mesh is greater than the optimum for the efficient capture of spotted mackerel. Resident fishers from Bowen choose to harvest spotted mackerel with this larger mesh as they rightly believe that it avoids the capture of substantial quantities of small mackerel that would otherwise be captured in smaller meshes. Bowen fishers also prefer the use of the larger mesh to optimise the catch of larger fish which are preferred for marketing and processing.

5. RECREATIONAL MACKEREL FISHERIES IN QUEENSLAND

5.1. Identification of survey frame

5.1.1. Introduction

Anecdotal evidence, personal observations and advice from fishers indicated that small mackerel captured by recreational fishers in Queensland were predominantly targeted or captured from boats. There were no quantitative data available to confirm the use of recreational boats to target or capture small mackerel. In order to obtain a reliable estimate of the magnitude of recreational small mackerel fisheries in Queensland, a suitable survey frame of persons was needed for an intensive survey. Quantitative data on the type of fishing platforms used to target or capture small mackerel was essential to determine this survey frame.

Prior to the commencement of this project, in 1992 a telephone survey of random households throughout Queensland was undertaken by the Australian Bureau of Statistics on behalf of the Queensland Department of Primary Industries. The survey aimed to compile a list of 300 recreational fishers in each Statistical Division in Queensland (Figure 5.1.1.) who would be willing to provide information on their individual recreational fishing activities. Telephone calls were made to persons in each Statistical Division until a list of desired cooperative recreational fishers was compiled. Questions in the survey were directed to the person in each household who did the most recreational fishing.

A total of 3142 people identified themselves as having fished in the 12 months prior to the 1992 telephone survey. In 1994, it was assumed that these people constituted as near a random sample of recreational fishers in Queensland as possible. Few mackerel fishers were identified from the North-West Statistical Division or any inland Statistical Divisions. Nearly all of the fishers who indicated that they had been involved in mackerel fishing in the 12 months prior to the 1992 survey were from the seven Australian Bureau of Statistical Divisions situated on the coast between Coolangatta and the Edward River (western Cape York). There were 413 of these mackerel fishers.

In Queensland, it is a legislative requirement that all recreational boats (other than tender vessels) with a motor capacity greater than 2.98 KW or 4 hp are registered. Nearly all boats greater than 3 m in length have motors of a capacity which requires the boat to be registered. Over 95% of all registered recreational boats in Queensland are registered in the coastal Statistical Divisions between Coolangatta and the Edward River. This survey was undertaken to determine if a register of recreational boat owners from these Statistical Divisions would be a suitable survey frame to investigate the recreational small mackerel fishery in Queensland.

5.1.2. Materials and Methods

In early 1994, attempts were made to telephone all of the recreational fishers in coastal Statistical Divisions between Coolangatta and the Edward River (Figure 5.1.1.) who indicated in the 1992 survey that they had been involved in mackerel fishing in the 12 months prior to the survey. Initial low incidence of mackerel fishers and financial constraints precluded the

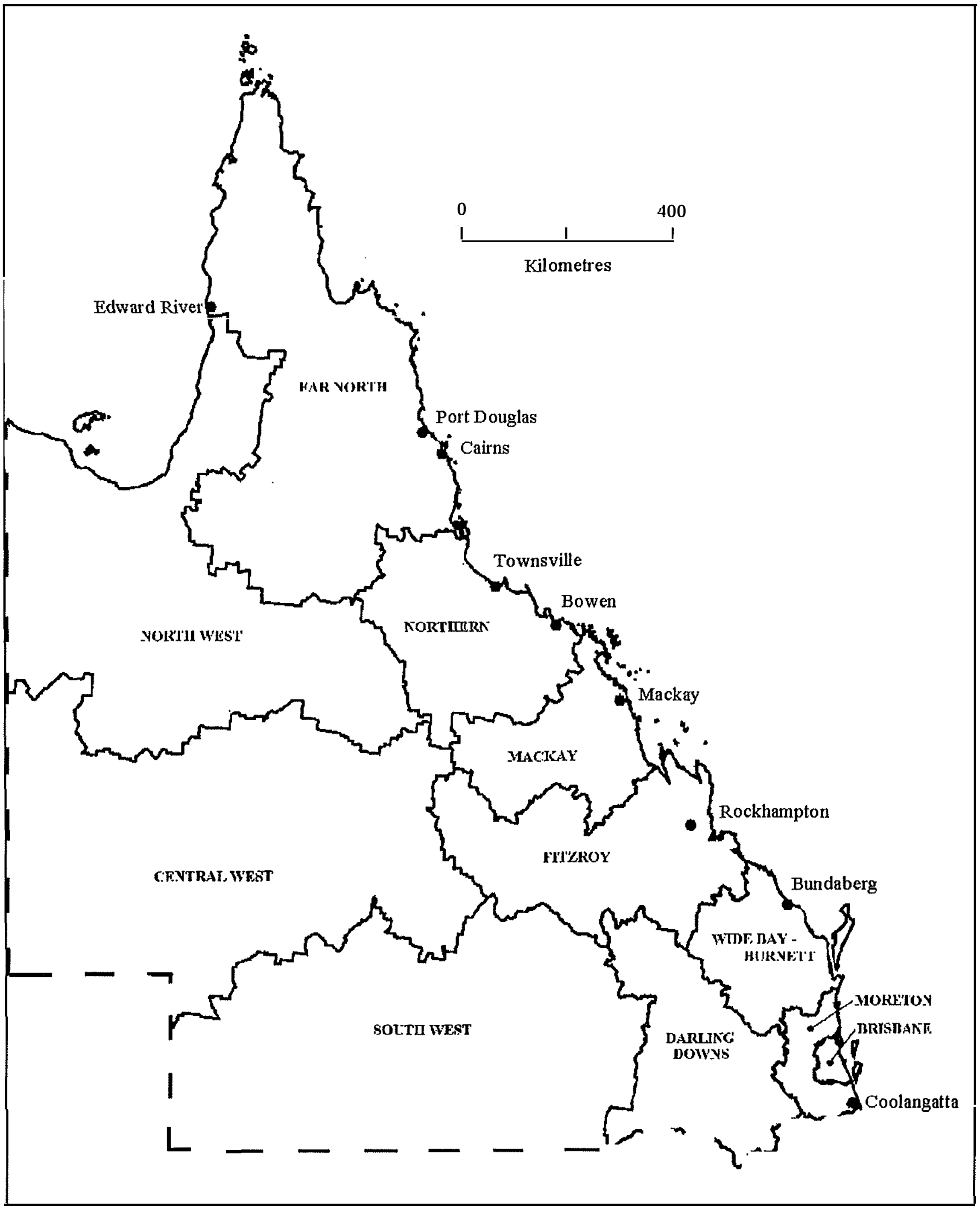


Figure 5.1.1. Australian Bureau of Statistics Statistical Divisions in Queensland with referred cities and localities.

telephone contact of mackerel fishers from the North-West Statistical Division or any inland Statistical Division. Upon successful telephone contact, fishers were reminded of the survey that they had participated in two years before. Fishers were then asked a few questions in relation to their targeting or capture of small mackerel in 1993.

Our prior experience in the identification of mackerel species by recreational fishers indicated that they could not readily distinguish between individual small mackerel species. Fishers were however able to identify individual spotted, school and grey mackerel as being small mackerel which were distinct from narrow-barred Spanish mackerel. All survey questions were related to either small mackerel as a grouping, or narrow-barred Spanish mackerel, so as to avoid uncertainty in the interpretation of questions by respondents.

It was decided a fisher who targeted or captured small mackerel during 1993 was a fisher who qualified as being representative of general recreational small mackerel fishers. Fishers who satisfied this criterion were asked what was the platform from where they fished or captured small mackerel. If the platform was a recreational boat, the length of the boat used was also recorded. Some fishers targeted or captured small mackerel from more than one type of platform, so in rare cases, the total number of fishers who used particular platforms was greater than the total number of fishers in the sample.

If no response was obtained from a person's telephone number after six attempts over several days at various times of the day, the person was excluded from the survey. Persons to whom an initial unsuccessful telephone contact was made because the number was disconnected, or forwarding address or telephone number unknown, were also excluded from the survey.

5.1.3. Results

A total of 75 of the initial 413 recreational fishers who had been involved in mackerel fishing in the 12 months prior to the 1992 survey were unable to be contacted. A further 57 fishers indicated that they no longer wished to provide any information on their fishing activities or indicated that they no longer fished. A total of 11 fishers did not wish to provide information on their mackerel fishing activities and five fishers captured narrow-barred Spanish mackerel only. Of the remaining 265 fishers who had previously indicated some involvement in mackerel fishing, 108 did not satisfy the criteria of having targeted or captured small mackerel in 1993. Information from the remaining 157 recreational fishers was used to address the objective of the survey.

Of the 157 mackerel fishers who satisfied all criteria, 131 of these targeted or captured small mackerel exclusively from a single platform type. About 70% of these fishers fished from their own recreational boat, 26% from a friend's recreational boat and 4% from the shore or hire/charter vessel. A total of 96% of all the recreational fishers in the survey who targeted or captured small mackerel in 1993, therefore, undertook the activity from a recreational boat.

When the responses of the 26 mackerel fishers who satisfied the criteria, but fished from more than one platform is included with the 131 mackerel fishers who fished exclusively from a single platform, a similar dominance of fishing for small mackerel from recreational boats emerges. Of the 177 different responses, about 61% fished from their own recreational boat, 26% from a friend's recreational boat, and 13% from the shore or a hire / charter vessel. A total of 87% of the 157 recreational mackerel fishers in the survey fished from a recreational boat. The length of recreational boats used by recreational fishers to target or capture small mackerel ranged between 3 m and 8 m.

5.1.4. Discussion

This survey provided evidence that small mackerel in Queensland are essentially targeted or captured by recreational anglers using boats. A register of all recreational boat owners from the major coastal Statistical Divisions would contain the contact names and phone numbers of people who owned a boat from which small mackerel were targeted or captured. A well designed intensive survey of all owners of registered recreational boats, from these Statistical Divisions, would therefore provide a reliable estimate of the magnitude of recreational small mackerel fisheries in Queensland.

5.2. Telephone and mail survey

5.2.1. Introduction

Telephone interviews of recreational mackerel fishers identified from a QDPI survey in 1992, revealed that nearly all fishers in Queensland who targeted or captured small mackerel in 1993, undertook the activity from a recreational boat. Nearly all recreational boats, other than tender vessels, that were used by fishers identified in the 1992 survey to target or capture small mackerel, were required to be registered. Registered recreational boat owners from the seven Australian Bureau of Statistical Divisions situated on the coast between Coolangatta and the Edward River (Figure 5.1.1.) were determined to be an appropriate survey frame for recreational fishers who targeted or captured small mackerel. There were comparatively few registered recreational boat owners residing in inland Statistical Divisions, or interstate or overseas, and these were not included in the survey frame.

This survey was undertaken to describe the recreational small mackerel fishery, estimate the recreational fishing effort for mackerel undertaken from boats, and estimate the harvest of mackerel from recreational boats in Queensland. Additional objectives of the survey were to estimate the proportion of small mackerel fishers who were willing to participate in "panels of expertise" to discuss the management of the small mackerel fisheries and compile a contact list of fishers willing to complete diaries of daily fishing activities.

5.2.2. Materials and Methods

A telephone and mail survey of registered recreational boat owners from the Australian Bureau of Statistical Divisions situated on the coast between Coolangatta and the Edward River (Figure 5.1.1.) was undertaken between May and October 1994. All registered recreational boat owners were sampled randomly without replacement within each Statistical Division. This survey was undertaken by the Queensland Government Statisticians' Office under the direction of the Queensland Department of Primary Industries.

The survey was targeted towards the person who did most of the fishing in a household where a recreational boat was registered. It was anticipated that the person who fished the most in the household, would have the best knowledge of fishing activities undertaken on board the particular recreational boat registered in their household. Generally, the owner of the registered recreational boat was the person in the household who undertook the most fishing.

If the boat registered in the household was used to go fishing, a series of questions related to the targeting or capture of small mackerel was asked. It was anticipated that successful mackerel fishers were most likely to be specialist fishers. The distinctions between targeting and capture of small mackerel were required to ensure appropriate effort estimates were obtained for use with fishing diary catches collected at a later time. If the boat owner who fished was a mackerel fisher, further questions in relation to their cooperation with proposed research projects and knowledge of mackerel fishing were asked. Questions relating to the quantity of mackerel harvested were based on the total quantity landed on board the recreational boat by all persons fishing on board their boat. All questions required fishers to recall the activities undertaken by fishers on board the registered boat in the household in the 12 month period prior to the survey. All estimates are subsequently based on the responses provided by the fishers for this 12 month period. Estimates were obtained for each Statistical

Division and pooled for the whole of Queensland. Though estimations are usually on a per recreational boat basis, it is implicit that the harvests and fishing efforts expended are undertaken by the fishers on board the recreational boat and not by the boat itself.

There were no data available on the proportion of recreational boats used to target or capture small mackerel, nor any data on the proportion of mackerel fishers who would be willing to participate in "panels of expertise" or complete diaries of their daily fishing activities for a 12 month period. Subsequently, and owing to the restricted number of phone calls and mail outs able to be made in the survey, and the survey requirement for a minimum of 100 mackerel fishers in each Statistical Division willing to complete fishing diaries, sampling was not proportional to the number of recreational boat owners in each Statistical Division.

The survey was undertaken using computer assisted telephone interviewing (CATI) with mail follow up for those boat owners without a phone or who were unable to be contacted by phone after five attempts. Several mail reminders were sent to recreational boat owners who failed to return mail questionnaires within 2 weeks of initial mailing. Recreational boat owners who were found to have moved address and were not able to be contacted, or were unavailable to complete a mail survey during the survey period, were not sent a mail survey.

Data Analysis

Estimation of population totals, means, variances and population proportions were calculated in accordance to the formulae used by Cochran (1977) and Pollock *et al.* (1994). Variance of the estimates were expressed as the standard error (s.e.). Comparisons between Statistical Divisions were undertaken using the Bonferroni *t*-test procedure. Pairwise tests were undertaken at a significance level of $\alpha = 0.5 / 21$ (ie. 0.024). The smallest sample size tested using this procedure was in excess of 1000. A two tailed test was used and the critical *t* value used for all tests was $t_{\infty,\,0.0012} \sim 3.09$. The incidence of there being more than one registered recreational boat in a household was rare, thus, no adjustments were made to the total population estimates on this basis. It was also assumed that all fishing undertaken by a recreational boat registered in a particular Statistical Division would occur in waters within or adjacent to that particular Division.

5.2.3. Results

The total sample of registered recreational boat owners selected was 5675. This sample represented 5.4% of the total population (Table 5.2.1.). A total of 3743 owners were contacted in the telephone component of the survey. All of the remaining 1932 owners in the sample were sent a questionnaire by mail, except for 247 who were unavailable, or for whom there was no valid phone number or postal address. A total of 84% of owners completed the survey by phone or mail questionnaire. Only 3.6% of owners sampled refused to participate in the survey and no data were obtained from the remaining 12.4% who were unable to be contacted by phone or mail, did not return the mail questionnaire, were unable to complete the mail questionnaire, or were ill.

Table 5.2.1. Number of registered recreational boats in Queensland registered in each Statistical Division and sampled in survey.

Statistical Division	No. of Boats Registered	No. of Boats Surveyed
Brisbane	35681	1022
Moreton	21345	1365
Wide Bay / Burnett	12802	754
Fitzroy	7983	630
Mackay	8146	528
Northern	9124	506
Far North	10342	870
TOTAL	**105423**	**5675**

It was estimated about 68% of the registered recreational boats in the sampled population were used for fishing (Table 5.2.2.). The percentage of recreational boats used to go fishing varied from 61% in Moreton to 76% in the Northern Statistical Division. There were no significant differences in the estimated number of boats used for fishing between Fitzroy and either the Mackay, Northern and Far Northern Statistical Divisions or between Northern and Far Northern Statistical Divisions. There were significant differences in the estimated number of boats used for fishing between all other Statistical Divisions (Bonferroni *t*-test).

An estimated 19000 registered recreational boats were used to target small mackerel in Queensland (Table 5.2.2.). Of those recreational boats used for fishing in the 12 months prior to the survey the estimated proportion used to target small mackerel varied from 15% in the Moreton Statistical Division to 41% in the Northern Statistical Division. The estimated number of recreational boats used to target small mackerel was significantly different between Brisbane and all other Statistical Divisions, and between Northern and both Moreton and Far North Statistical Divisions (Bonferroni *t*-test).

Table 5.2.2. Estimation of number of registered recreational boats, with associated standard errors, used for fishing and used to target small mackerel in Queensland.

	Recreational Boats used for Fishing		Recreational Boats used to Target Small Mackerel	
Statistical Division	**Number**	**s.e.**	**Number**	**s.e.**
Brisbane	23753	475	5014	451
Moreton	12910	258	1915	172
Wide Bay / Burnett	9248	185	2350	188
Fitzroy	6229	187	2470	173
Mackay	5819	1233	2333	163
Northern	6979	209	2965	208
Far North	6880	206	1949	156
TOTAL	**71818**	**718**	**18996**	**570**

It was estimated about 20600 registered recreational boats captured small mackerel (Table 5.2.3.). The estimated number of recreational boats that captured small mackerel was similar to the estimated number that targeted small mackerel (Tables 5.2.2. and 5.2.3.). About 5250 registered recreational boats in Queensland captured small mackerel, but did not target them (Table 5.2.3.). The estimated number of boats used to capture small mackerel, but which did not target them, was significantly different between both Brisbane and Wide Bay / Burnett and all Statistical Divisions north of the Wide Bay/Burnett Statistical Division. Estimated numbers were also significantly different between Moreton and the Northern Statistical Division (Bonferroni *t*-test).

Table 5.2.3. Estimation of number of registered recreational boats, with associated standard errors, used to capture small mackerel in Queensland.

Statistical Division	Recreational Boats which Captured Small Mackerel		Recreational Boats which Captured Small Mackerel but did not Target	
	Number	**s.e.**	**Number**	**s.e.**
Brisbane	5146	412	1487	238
Moreton	2505	200	774	116
Wide Bay / Burnett	3153	221	1089	131
Fitzroy	2506	175	392	74
Mackay	2574	195	601	102
Northern	2631	210	312	81
Far North	2068	145	600	90
TOTAL	**20583**	**617**	**5255**	**368**

Only about 8000 recreational boats were estimated to have harvested narrow-barred Spanish mackerel (Table 5.2.4.). There was no significant difference in the estimated number of recreational boats that captured narrow-barred Spanish mackerel between each Statistical Division (Bonferroni *t*-test).

Table 5.2.4. Estimation of number of registered recreational boats, with associated standard errors, used to capture narrow-barred Spanish mackerel in Queensland.

Statistical Division	Recreational Boats used to Capture Narrow-Barred Spanish Mackerel	
	Number	**s.e.**
Brisbane	1603	256
Moreton	921	129
Wide Bay / Burnett	841	118
Fitzroy	1239	124
Mackay	868	113
Northern	1070	139
Far North	1484	1336
TOTAL	**8026**	**401**

The mean annual number of days fished per recreational fishing boat varied from about 14 days in the Far North to about 20 days in the Brisbane Statistical Division (Table 5.2.5.). Recreational boats which were used for fishing, but fished zero days in the 12 months prior to the survey were included in this estimate calculation. The mean annual number of days fished in both Brisbane and Moreton Statistical Divisions was significantly different to that of Fitzroy, Mackay, Northern and Far North Statistical Divisions (Bonferroni *t*-test).

The mean annual number of days targeting small mackerel per recreational fishing boat varied from about 5 days in the Northern to about 9 days in the Moreton Statistical Division (Table 5.2.5.). Only the number of days fished by recreational boats which target small mackerel were included in this estimate calculation. The mean annual number of days targeting small mackerel in Moreton was significantly different to that of Brisbane, Northern and Far North Statistical Divisions (Bonferroni *t*-test).

Table 5.2.5. Mean annual number of days, with associated standard errors, fished and targeted towards small mackerel per recreational boat.

Statistical Division	Annual Days Fished per Recreational Fishing Boat		Annual Days Targeted towards Small Mackerel per Recreational Fishing Boat	
	Mean Number	**s.e.**	**Mean Number**	**s.e.**
Brisbane	19.81	1.03	5.33	0.48
Moreton	19.07	0.89	9.43	1.10
Wide Bay / Burnett	17.34	1.02	7.14	0.97
Fitzroy	14.52	0.79	7.05	0.58
Mackay	14.26	1.02	6.57	0.74
Northern	14.66	0.96	5.20	0.44
Far North	13.56	0.93	5.29	0.51
TOTAL	**17.32**	**0.43**	**6.31**	**0.25**

An estimated 1.4 million recreational boat days of fishing effort were expended during the 12 months prior to the survey. It was estimated that over 59% of the annual recreational boat days of fishing effort expended in Queensland waters occurred from boats registered in the Moreton Bay region (Brisbane and Moreton Statistical Divisions combined) (Table 5.2.6.). Significant differences in the estimated recreational boat days of fishing effort were found between all Statistical Divisions, except between Fitzroy, Mackay, Northern and Far North Statistical Divisions (Bonferroni *t*-test).

An estimated 118000 recreational boat days of fishing effort were targeted towards small mackerel (Table 5.2.6.). This represented 8.4% of the total estimated number of fishing days expended by recreational boats during the 12 months prior to the survey. Generally, the proportion of the estimated number of boat days targeted towards small mackerel was significantly less in the Brisbane, Moreton, Wide Bay / Burnett and Far North Divisions than the Fitzroy, Mackay or Northern Statistical Divisions (Bonferroni *t*-test). These proportions varied from about 5% in Brisbane to 18% in the Fitzroy Statistical Division. Significant differences in the estimated number of recreational boat fishing days targeting small mackerel were found between the Far North and both the Brisbane and Fitzroy Statistical Divisions (Bonferroni *t*-test).

Table 5.2.6. Estimate of annual recreational boat days of effort, with associated standard errors, expended to fish and target small mackerel

Statistical Division	Recreational Boat Days Fished		Recreational Boat Days where Small Mackerel Targeted	
	Number	**s.e.**	**Number**	**s.e.**
Brisbane	550623	30835	26513	3287
Moreton	286251	14312	17367	2587
Wide Bay / Burnett	179591	11134	16088	2541
Fitzroy	96451	6076	17314	1869
Mackay	98129	7752	15103	2038
Northern	112749	8005	15295	1697
Far North	114871	8155	10237	1269
TOTAL	**1408666**	**36625**	**117917**	**6013**

The mean annual harvest of small mackerel, per recreational boat which captured small mackerel throughout Queensland, was about 18 mackerel (Table 5.2.7.). The annual harvest rate was highest in the Mackay and Fitzroy Statistical Divisions. The annual harvest rates per recreational boat were significantly different between the Far North and both the Fitzroy and Mackay Statistical Divisions and between the Fitzroy and Brisbane Statistical Divisions (Bonferroni *t*-test). The mean annual harvest of narrow-barred Spanish mackerel, per recreational boat which captured small mackerel throughout Queensland, was about 9 mackerel (Table 5.2.7.). Differences in the harvest rate of narrow-barred Spanish mackerel between Statistical Divisions were not detected (Bonferroni *t*-test).

Table 5.2.7. Estimation of mean annual harvest rate, with associated standard errors, of small and narrow-barred Spanish mackerel by registered recreational boats

	Annual Harvest Rate of Small Mackerel per Recreational Fishing Boat		**Annual Harvest Rate of Narrow-Barred Spanish Mackerel per Recreational Fishing Boat**	
Statistical Division	**Number**	**s.e.**	**Number**	**s.e.**
Brisbane	13.55	1.99	8.31	2.96
Moreton	17.10	2.95	6.86	1.32
Wide Bay / Burnett	17.53	2.87	9.65	2.17
Fitzroy	30.06	3.69	5.27	0.70
Mackay	24.02	3.55	18.29	8.69
Northern	17.18	2.33	8.06	2.05
Far North	11.78	1.42	6.76	0.74
TOTAL	**18.20**	**1.05**	**8.57**	**1.20**

Estimates of total harvest based on self reporting and a recall period of 12 months should be considered with caution. A total of 371000 small mackerel were estimated to be harvested by fishers from registered recreational boats (Table 5.2.8.). The estimated number of small mackerel harvested was significantly different between the Far North Division and either the Brisbane, Fitzroy and Mackay Statistical Divisions (Bonferroni *t*-test). Fishers from registered recreational boats harvested about 52000 narrow-barred Spanish mackerel (Table 5.2.8.). Differences in the harvest of Spanish mackerel between Statistical Divisions were not detected (Bonferroni *t*-test).

Table 5.2.8. Estimation of mean annual harvest, with associated standard errors, of small and narrow-barred Spanish mackerel by registered recreational boats

	Small Mackerel Harvested from Recreational Boats		**Narrow-barred Spanish Mackerel Harvested from Recreational Boats**	
Statistical Division	**Number**	**s.e.**	**Number**	**s.e.**
Brisbane	68524	11649	10215	4587
Moreton	42505	8076	5801	1473
Wide Bay / Burnett	55258	9780	7547	2106
Fitzroy	74442	10496	6085	1071
Mackay	61794	10010	8100	3580
Northern	44814	7035	7201	2441
Far North	24191	3435	6910	1292
TOTAL	**371531**	**23778**	**51861**	**7001**

The establishment of "panels of expertise" comprising recreational small mackerel fishers to discuss management of small mackerel was supported by about 85% of small mackerel fishers (Table 5.2.9.). Differences in the proportion of small mackerel fishers supporting the establishment of "panels of expertise" were not detected (Bonferroni *t*-test). The proportion of small mackerel fishers who supported the establishment of panels of expertise and actually willing to participate in voluntary panels of expertise was about 58% (Table 5.2.9.). The proportion willing to participate was significantly less between the Northern Statistical Division and each of the Brisbane, Moreton, Wide Bay and Fitzroy Statistical Divisions (Bonferroni *t*-test).

Table 5.2.9. Proportion of small mackerel fishers, with associated standard errors, supporting the establishment of "panels of expertise" and willing to participate in "panels of expertise"

	Proportion Supporting Establishment of "Panels of Expertise"		Proportion Willing to Participate in "Panels of Expertise"	
Statistical Division	**%**	**s.e.**	**%**	**s.e.**
Brisbane	83.3	3.3	64.9	4.5
Moreton	87.5	2.6	65.4	3.9
Wide Bay / Burnett	89.1	2.7	58.2	3.5
Fitzroy	89.1	2.6	58.8	3.5
Mackay	82.6	3.3	52.8	4.2
Northern	85.6	3.4	40.7	4.5
Far North	81.9	3.3	54.4	4.4
TOTAL	**85.5**	**0.9**	**57.5**	**1.7**

The proportion of small mackerel fishers who were willing to complete a daily fishing diary for 12 months was about 88% (Table 5.2.10.). Differences in the proportion from different Statistical Divisions willing to complete the diaries were not detected (Bonferroni *t*-test).

Table 5.2.10. Proportion of small mackerel fishers, with associated standard errors, willing to complete daily fishing diaries for 12 months

	Proportion Willing to Complete Daily Fishing Diaries	
Statistical Division	**%**	**s.e.**
Brisbane	92.2	8.3
Moreton	89.5	8.9
Wide Bay / Burnett	88.6	8.0
Fitzroy	90.6	6.3
Mackay	85.5	6.8
Northern	81.2	6.5
Far North	83.0	7.5
TOTAL	**87.8**	**3.5**

5.2.4. Discussion

A well planned telephone and mail survey of owners of recreational boats has enabled valuable information on recreational fisheries for small mackerel to be gained. The extrapolated results of the survey were likely to be accurate in terms of fishing effort due to negligible non-response bias (Fisher 1996) but inaccuracies are likely to occur in relation to total harvest owing to unquantifiable recall bias evident in similar angler surveys (Connelly and Brown, 1995). Other biases in self reporting surveys as detailed by Pollock *et al.* 1994 and and Steffe *et al.* 1996 include prestige bias, rounding bias, intentional deception and question misinterpretation, all of which should be taken into consideration when interpreting data obtained from this survey. The high response rate achieved during the survey was acquired due to background knowledge of recreational fishing activities in Queensland and planning, dedication and communication skills of all staff and volunteers involved in the survey.

It was estimated in excess of 70000 recreational boats were used for fishing in Queensland and of these 20500 captured small mackerel. Most fishers who captured small mackerel, actually targeted them, however an estimated 5000 recreational boat owners captured small mackerel but did not target them. An estimated 8000 boats were used to capture narrow-barred Spanish mackerel. The importance of small mackerel to recreational fishers is demonstrated where 8.4% of the annual estimated 1.4 million recreational boat days of effort are targeted towards small mackerel. Monitoring and analyses of the activities of charter fishing vessels required to provide more precise estimates of recreational small mackerel catch and effort, was not possible in this study.

Though these results could not be directly compared to estimates of boat based fishing activity and recreational fishing effort as described in QFMA (1996) and QFMA (1999) the results of the surveys are complementary. Estimates of annual boat days of fishing effort, recreational harvest rates and total harvest derived from recall of fishing activities over 12 months in this survey should however, be treated as indicative only. Participation rates have provided valuable estimates of recreational fishing effort for small mackerel. These estimates when combined with more accurate harvest rates will provide more acceptable estimates of total harvest. In the absence of resources to undertake a Statewide creel survey of boat based recreational fishers, the most appropriate off-site method to obtain more accurate harvest rate information, while minimising recall bias, is likely to be a daily fishing diary exercise over 12 months. The majority of small mackerel fishers indicated that they would be willing to complete a daily diary of their fishing activities for 12 months.

Most small mackerel fishers supported the concept of establishment of "panels of expertise" to discuss the management of small mackerel fisheries in Queensland. When given the opportunity to participate in the "panels of expertise", considerably fewer of these fishers expressed a willingness to participate.

5.3. Daily Fishing Diaries

5.3.1. Introduction

This fishing diary exercise aimed to estimate the recreational harvest, and catch and release of small mackerel species between December 1994 and November 1995 by resident recreational fishers with boats in Queensland waters. Estimates were required by fisheries managers and industry representatives to allow comparisons of commercial and recreational harvests.

A telephone and mail survey of registered recreational boat owners in 1994 provided estimates of the numbers of boats in each Queensland Statistical Division that targeted small mackerel, and also the number that harvested small mackerel but did not target them. The survey required fishers to recall their fishing activities over the previous 12 months. The estimated number of boats was considered an appropriate measure of effort applied to harvesting small mackerel in Queensland.

The 1994 survey identified a representative sample of boat fishers who targeted and harvested small mackerel and were willing to complete fishing diaries for 12 months. Angler diaries have previously been utilised to estimate recreational fishing effort and harvest (Anderson and Thompson 1991). Daily diary data from recreational fishers who targeted and harvested small mackerel were considered likely to provide more accurate catch estimates than standard telephone and mail surveys, as recall bias would be expected to be reduced.

Weithman (1991) collected statewide angler data using telephone contact and data record forms. These techniques were considered appropriate for our study. Catch estimates for recreational boat-based fisheries are calculated by the multiplication of mean effort estimates by mean catch estimates for a given stratum. The estimates for each stratum are then added to provide catch estimates for the required combination of strata.

Problems in computing confidence limits around the catch estimates were encountered using the diary catches, as data were not normally distributed. Confidence limits on catch estimates can be calculated using bootstrapping techniques (Efron 1979, 1982; Efron and Tibshirani 1986; Brown 1993a, 1993b; Porch 1993). Bootstrapping involves drawing a random sample of data, with replacement, from a sample of the population. Confidence limits estimated by bootstrapping reflect the degree of uncertainty in the effort and catch rate data obtained by the surveys. Bootstrapping techniques were used in analysis of diary data to estimate recreational mackerel harvest and catch.

5.3.2. Materials and methods

Diary Procedures

Most contacted fishers who targeted or captured small mackerel in the 12 months preceding the 1994 survey indicated that they were willing to complete daily fishing diaries. These fishers were enlisted to participate in a diary exercise from 1 December 1994 to 30 November 1995 and were assumed to be representative of mackerel fishers during this period. Recreational mackerel fishers included those fishers who targeted or captured small mackerel using angling and spearfishing apparatus. These mackerel fishers were mailed fishing diaries and were required to complete details of all effort and catch (eg. fish harvested and released) for all recreational fishing trips they undertook. Diary participants were also required to identify all mackerel captured to a species level on the basis of identification pictures in the diary. The total length of each harvested mackerel was requested to enable length frequency distributions of recreational harvest to be obtained. Diarists were telephoned every 4 -12 weeks with more frequent contact directed to less avid or enthusiastic fishers. Upon successful telephone contact, diary catch information was obtained over the phone or arrangements were made for the participating diarist to mail or fax completed diary entries for data entry and analysis. Entries received were immediately copied and returned to the participating diarist with replacement diaries and additional information relevant to recreational fishing as requested.

Categorisation of catch and effort data by fisher type

Fishers targeting small mackerel differ from those who capture small mackerel without targeting, in both their fishing behaviour and their catch (pers. obs.). Consequently, catch and effort were categorised as either:

(a) Group 100 - comprising fishers who targeted small mackerel, regardless of whether they harvested, captured and released, or did not capture small mackerel in the 12 months preceding the survey and

(b) Group 200 - comprising fishers who did not target small mackerel, regardless of whether they harvested, or captured and released small mackerel in the 12 months preceding the survey. Fishers in this group had captured small mackerel in the 12 months preceding the survey.

Group 200 fishers should ideally have been diarists selected at random from any persons identified in the 1994 telephone survey as a fisher. Inadequate sampling design failed to identify perspective dairists who did not have a history of capturing mackerel and Group 200 fishers were assumed to be representative of resident recreational boat owners who fished and had not captured mackerel in the preceding 12 months. It was not possible to test this assumption, but viewing the lack of mackerel fishing success of Group 200 diarists it is likely the sample diarists were representive of resident recreational boat owners who fished and had not captured mackerel in the preceding 12 months.

Fishing Effort

Fishing effort was determined to be the number of boats which were potentially involved in the capture of small mackerel in the 12 months preceding the 1994 telephone and mail survey (Table 5.3.1.). Effort in this 12 month period was assumed to be the same in each season that the diaries were completed between 1 December 1994 to 30 November 1995.

Catch Data

Effort estimates were specific for recreational boats targeting or capturing small mackerel in Queensland. It was essential to include only catch data appropriate for use in the estimation of total harvest of small mackerel. Catch data for each season was only included in analyses when:

(a) the fisher participated in the fishing diary exercise for a complete season;

(b) fishing trips were undertaken onboard the diarists' boat, and;

(c) fishing trips were undertaken in Queensland estuarine / marine waters.

Table 5.3.1. Estimation of number of recreational boats, with associated standard errors, used to target small mackerel and used to capture but not target small mackerel.

Statistical Division	Number of Recreational Boats used to target small mackerel	s.e.	Number of Recreational Boats which captured small mackerel but did not target	s.e.
Brisbane	5014	451	1487	238
Moreton	1915	172	774	116
Wide Bay / Burnett	2350	188	1089	131
Fitzroy	2470	173	392	74
Mackay	2333	163	601	102
Northern	2965	208	312	81
Far North	1949	156	600	90
TOTAL	**18996**	**570**	**5255**	**368**

Representation of the Diarists

In this study, similar to concerns of Anderson and Thompson (1991), there was a potential source of bias in the differences in fishing characteristics between diary participants and those mackerel fishers who declined to participate in the diary exercise. Concern was also held about the possible differences between the fishing characteristics of continuing diary participants and those who dropped out as the diary exercise progressed.

Data on the number of recalled fishing days in the 12 months prior to the 1994 survey was assumed to indicate the fishing behaviour of diary participants and mackerel fishers. It was determined that diarists could only be considered representative of the survey sample, and thus of Queensland small mackerel fishers in general, if all fishers exhibited similar fishing behaviours measured by the recalled number of days fished in the 12 months prior to the 1994 survey. It was assumed that biases in the recalled number of days fished would be consistent between small mackerel fishers who did not want to complete the fishing diaries, and those that initially did. Multiple two way ANOVAs were used to compare differences in this indicative behaviour between persons participating in the telephone survey and the diary exercise for each season with respect to target group categorisation and region.

Catch Estimation

Catches of each mackerel species were stratified by fisher type, season and Statistical Division. Total catch (ie., number of mackerel species harvested, and captured and released) within each stratum was estimated by multiplying the mean catch per boat by the number of boats. Aggregate estimates of catch across all strata were also calculated.

Four thousand bootstrap estimates of mean catch per boat were obtained by resampling N boat catches from a stratum with replacement, where N was the number of catches in the stratum. Each estimate of mean catch per boat was then multiplied by a random variate taken from a distribution with mean B, and standard deviation s. B and s were the mean and standard deviation respectively, of the estimated number of boats used to fish for mackerel in the stratum, as estimated from the 1994 survey. The bootstrap estimates of total catch were then used to calculate 90% confidence intervals via the bootstrap-t method (Efron and Tibshirani 1986). Simulations using a number of bootstrap methods have been undertaken to calculate intervals and the bootstrap-t method was found to be the most reliable (Hoyle and Cameron (In press - Fisheries Management and Ecology).

Weight of Recreational Harvest

Total length measurements of harvested mackerel recorded in diaries throughout Queensland between 1 December 1994 and 30 November 1995 were converted to fork length according to the relationship for each species (Figures 3.2.1., 3.2.26., and 3.2.50.). Length measurements of mackerel smaller than the minimum legal total length of 50 cm were omitted from calculations of total harvest weight because measurements of illegally harvested mackerel were unlikely to be accurately recorded in voluntary diaries. Fork lengths were grouped into 50 mm length classes and the proportions of each length class calculated. The length distribution of the recreational harvest was assumed to be uniform throughout Queensland, within each species.

The proportion of harvested mackerel in each length class was multiplied by the bootstrapped estimates of numbers of each mackerel species harvested with 90% confidence limits. The weight of one fish at a length corresponding to the median measurement of each length class was estimated using the respective length-weight relationship calculated for each species (Figures 3.2.1., 3.2.26., and 3.2.50.). The estimated number of mackerel harvested in each length class was then multiplied by the weight of a mackerel of a length corresponding to the median measurement of each respective length class. Total harvest of each species was calculated by summing the estimated weights of all length classes for all mackerel harvested. Confidence limits were also calculated. These estimates did not take into consideration the variability in length-weight relationships.

Comparison with Commercial Harvest

The total commercial harvest of each identified small mackerel species in Queensland was obtained for the period between 1 December 1994 and 30 November 1995 (QFISH Database). The estimated recreational harvests of spotted, school and grey mackerel, with 90% confidence limits, were compared to the total commercial harvest for each respective species. On the basis of commercial fishing method used to capture unspecified mackerel during 1995, discussions with commercial fishers submitting logbook returns, and knowledge of commercial small mackerel fisheries obtained in our study, commercial harvest of unspecified mackerel during the survey period was assigned to specific small mackerel species. Unspecified mackerel harvested during the survey period were assigned to specific species on the basis of 40% spotted mackerel, 40% grey mackerel and 8% school mackerel. The remaining 12% of the unspecified mackerel harvest could not be confidently assigned to a particular small mackerel species.

5.3.3. Results

In the 12 month period when the diary exercise was undertaken, details of mackerel harvested and/or captured and released were obtained for 3897 boat days of fishing effort. A total of 970 fishers were issued daily fishing diaries at the start of the survey period. The numbers of diarists who participated in the exercise gradually reduced as each season progressed. A total of 626 diarists participated in the diary exercise for the last spring season (Appendix 7.).

Comparisons between the number of days recalled fished in the 1994 telephone survey by participating and non-participating diarists from each region and each season indicated that no significant differences within each region for each season were detected. However, significant differences in the number of days recalled fished by diarists from each region were identified. As effort was calculated by region, and catch estimates were by region and season, differences between the number of recalled days fished by diarists in each region had no bearing on how representative participating diarists for each region were of the original telephone survey respondents. Participating diarists for each region remained representative of the original telephone survey respondents for the duration of the diary survey (Appendix 8.).

The distribution of catches of all mackerel species was heavily skewed with the vast majority of diarists not capturing mackerel of any species. Between 13-16% of Group 100 diarists captured at least one individual of any small mackerel species in any season during the survey period. Only 1-3% of Group 200 diarists captured at least one individual of any small mackerel species in any season during the survey (Appendix 9). Such patterns of recreational small mackerel catch necessitated the use of alternative statistical methods such as bootstrapping to calculate confidence intervals for catch and effort estimates.

The estimated numbers (with 90% confidence intervals) of mackerel of each species harvested and captured and released by fishers from registered recreational boats between December 1994 and November 1995 in Queensland are detailed in Appendix 10. There were marked differences in the estimated numbers of mackerel species harvested or captured and released by fishers in each Statistical Division and during each season of the survey.

The estimated numbers of small mackerel harvested were 31000 spotted mackerel, 26200 school mackerel, and 4200 grey mackerel. The 90% confidence intervals around each estimate were 23200 - 41800 for spotted mackerel, 20600 - 33500 for school mackerel and 2600 - 6100 for grey mackerel. The total harvest of small mackerel was estimated to be 68000 fish with a 90% confidence interval between 53500 and 83200 fish.

The estimated numbers of each small mackerel species captured and released was smaller than estimated numbers of fish harvested. The estimated numbers of small mackerel captured and released were 6400 spotted mackerel, 22000 school mackerel, and 2100 grey mackerel. The 90% confidence intervals around each estimate were 4400 - 8800 for spotted mackerel, 12600 - 36800 for school mackerel and 700 - 4500 for grey mackerel (Appendix 10. Table 1.). The total number of small mackerel captured and released was estimated to be 37200 fish with a 90% confidence interval between 23000 and 56500 fish (Appendix 10. Table 2.).

Effort estimates were expressed in terms of the number of boats used to target or capture small mackerel species so the use of this effort to calculate total harvest or capture estimates for other mackerel species should be treated cautiously. The estimated numbers of narrow-barred Spanish mackerel harvested were 7300 with 90% confidence intervals between 5200 and 11300 fish. Similar estimated numbers of narrow-barred Spanish mackerel were captured and released with the estimate being 5300 with 90% confidence intervals of between 2800 and 9400. The estimated numbers of shark mackerel harvested or captured and released were insignificant in comparison to other mackerel species. The estimated numbers of unspecified mackerel harvested were 5200 with 90% confidence intervals between 2800 and 8600 fish. Similar estimated numbers of unspecified mackerel were captured and released with estimates being 6700 with a 90% confidence interval between 4000 and 10400 fish (Appendix 10).

The estimated weights, with 90% confidence intervals, of small mackerel harvested by fishers from registered recreational boats are detailed in Table 5.3.2. Spotted mackerel comprised the largest recreational harvest of the small mackerel species, followed by school mackerel and then to a lesser extent, grey mackerel. The weight of small mackerel harvested by fishers from registered recreational boats could only be estimated for school, spotted and grey mackerel because these were the only species for which adequate length frequency distributions were obtained from catches reported by diarists. The concerns that effort estimates pertained only to boats used to target or capture small mackerel species also further discouraged the inappropriate estimation of recreational harvest by weight of other mackerel species.

Table 5.3.2. Estimation of Queensland statewide harvest by weight, with associated 90% confidence intervals, of school, spotted and grey mackerel, taken by resident recreational fishing boats between 1 December 1994 and 30 November 1995.

Mackerel Species	Estimated Harvest (kg)		
	Weight	Lower 90% Confidence Interval	Upper 90% Confidence Interval
Spotted	69521	52075	93868
School	43772	34331	55956
Grey	12372	7808	18119

Table 5.3.3. Comparison of Queensland statewide recreational harvest by weight, with their associated 90% confidence intervals, of school, spotted and grey mackerel, taken by resident recreational fishing boats with Queensland commercial harvest between 1 December 1994 and 30 November 1995.

Mackerel Species	Estimated Recreational Harvest (kg)	Commercial Harvest (kg)			Harvest Ratio
		QFISH Database	Assigned portion of unspecified mackerel harvest	Total	Recreational / Commercial incorporating 90% Confidence Intervals
Spotted	69521	115576	52840	168416	.412 (.309 - .557)
School	43772	28414	10568	38982	1.123 (.881 - 1.435)
Grey	12372	221965	52840	274805	0.045 (.028 - .066)

There were marked differences in the relative harvest of each small mackerel species between the recreational and commercial fishing sectors (Table 5.3.3.). The harvest of spotted mackerel by resident recreational fishing boats was estimated to be between 31 - 56% of the harvest of this species by the commercial fishing sector. The harvests of school mackerel by each sector were similar. The recreational harvest of grey mackerel was very small in comparison to the harvest of this species by the commercial fishing sector.

5.3.4. Discussion

A recreational fishing diary exercise by voluntary fishers combined with a statewide telephone and mail survey provided a mechanism to estimate the total recreational harvest of various mackerel species in Queensland. It is difficult in such longitudonal surveys to obtain catch and effort data from the same temporal sampling period. Persons must be aware of the major assumption in using estimates of effort from 1994 to be representative of 1995 and then multiplying catch rates from 1995 to obtain total harvest estmates. The use of bootstrapping techniques to provide confidence intervals around recreational harvest and catch estimates has been demonstrated and should be further utilised. Confidence intervals are however only as accurate as the data on which they are based. Maintenance of representative recreational fishing diarists and maintenance of as full a complement of diarists for the entire 12 month period as began completing the diaries, is of major importance in conduct of diary surveys. High rates of completion can only be achieved by regular telephone contact and other means of encouragement by the survey managers and survey support staff and volunteers. Off-site and self-reporting surveys such as telephone, mail and diary surveys are of major benefit in obtaining baseline recreational fishing information. However, such surveys should not be used as substitutes for more expensive and resource demanding on-site survey methods that are required to investigate specific fisheries.

Estimates of total recreational harvest of mackerel from this survey are underestimates as no data on the harvest of shore-based fishers, charter boat fishers, fishers from interstate and inadeqaucies in sampling design to monitor the catches of of resident recreational boat owners who fished and had not captured mackerel in the 12 months preceding the survey were incorporated in analyses. It may be appropriate to also consider in the estimation of total harvest the number of small mackerel released by recreational fishers. It is likely that a portion of these fish do not survive and it is reasonable upon further investigations to allocate such mortality to recreational harvest estimates.

Subsequent recreational fishing diary surveys undertaken by the QFMA (1997) and QFS (2001) in 1997 and 1999 respectively, estimated the numbers of mackerel captured and/or harvested to be more than estimates from the 1995 survey. Though the overall catch estimates in 1997 and 1999 surveys of 540 000 and 390 000 mackerel respectively, included narrow-barred Spanish mackerel, both years were substantially larger than the combined 1995 estimated harvest of small mackerel of 68 000 fish and the capture and release of 37 200 fish. As different sample frame designs were used in the 1995 diary survey detailed in this report, compared to the 1997 and 1999 surveys, the reasons for the different estimates are many and varied. Nevertheless, the data from the three surveys with associated confidence intervals and standard errors is of a nature to provide valuable historical estimates of the recreational catch of mackerel species in Queensland.

The other comparable estimate of recreational harvest of mackerel species in Australia are those for trailer boat anglers at large access points in New South Wales between September 1993 and August 1995 (Steffe *et al.* 1996). Spotted, school and narrow-barred Spanish Mackerel were harvested only by trailer boat anglers in this period in the North Coast Region of New South Wales. This region is generally considered the southern limit of distribution for *Scomberomorus* species on the east coast of Australia.

Steffe *et al.* (1996) reported that the estimated harvests of spotted mackerel in NSW were 3139 and 652 fish in the two survey years. The harvest numbers corresponded to a harvest weight of 12133 kg and 3679 kg respectively in each year and were considerable less than the estimated recreational boat based harvest in Queensland. The recreational/commercial harvest ratios for spotted mackerel in New South Wales were .452 and .488 for each survey year (Steffe *et al.* 1996). These ratios were very similar to the estimated .412 recreational/commercial harvest ratio for spotted mackerel in Queensland.

Recreational school mackerel catches in NSW were rare in contrast to the recreational and commercial harvests for the species in Queensland that were substantially larger. Grey mackerel are rarely harvested south of the Sunshine Coast region in southern Queensland and as expected there was no recreational harvest of this species in New South Wales waters. The estimated harvest of narrow-barred Spanish mackerel in New South Wales was 538 and 696 fish in the two survey years. These numbers were high in comparison to estimated harvest numbers for the species in Queensland where the species is more common, and where the recreational harvest for the species would be expected to be substantially larger than in New South Wales. A possible reason for this is that Queensland resident boat fishers who target small mackerel and who were represented by diarists, do not generally target narrow-barred Spanish mackerel. Another survey frame or more intensive survey such as that undertaken by the QFMA (1997) and QFS (2001) may be more appropriate to obtain more accurate catch data for this fishery.

5.4. Interstate Fisher Survey

5.4.1. Introduction

Telephone, mail and diary surveys of recreational boat owners in Queensland provided estimates of the total small mackerel harvest by Queensland residents, other than shore based or charter boat fishers. Prior to this study there were no Queensland data on the fishing activities or small mackerel harvest of fishers from interstate. The relative harvest of small mackerel by shore based or charter boat fishers was considered small and it was deemed more appropriate to obtain information on the importance of small mackerel to interstate recreational fishers. Fishers from interstate usually occupied caravan parks between Mackay and Port Douglas during winter and early spring. Previous surveys undertaken as part of this research project indicated that most recreational fishers harvested mackerel from a boat. This survey aimed to obtain qualitative information on the numbers of recreational fishers from interstate who possessed a boat, their behaviour and the small mackerel harvest of these fishers in Queensland.

5.4.2. Materials and Methods

A register of caravan parks between Mackay and Port Douglas was obtained from local community phone directories and advice from residents and Queensland Fisheries and Boating Patrol Officers in coastal communities. The survey area was stratified according to the Australian Bureau of Statistics Statistical Divisions - Mackay, Northern and Far North (Figure 5.1.1.). Data on the number of nights spent by interstate visitors in caravan parks throughout Queensland were obtained from the Bureau of Tourism Research. Specific data on the occupancy rates and site nights occupied in caravan parks in the Statistical Divisions during the months surveyed were obtained from the Australian Bureau of Statistics. Only occupants in caravan parks in close proximity to coastal waters were surveyed.

All site counts and interviews were undertaken in June and July 1995. Upon arrival at a caravan park, permission to enter and interview occupants was obtained from the owner or manager. A visual count of the number of occupied sites was conducted to determine the number and home state of occupants. Home state of residence was determined from the number plate on their caravan, vehicle and boat trailer. The presence or absence of a boat at each site was recorded. Many fishers at caravan parks, for security reasons, often parked their car and empty boat trailers close to their caravan when they went fishing in their boat. Neighbouring caravan park tenants would often verify the caravan park visitor with the empty boat trailer was away fishing. Though counts at caravan parks undoubtedly produced an underestimate of persons with boats fishing as some would have been fishing at the time of the survey and their vehicle and boat trailer was parked distant to the carvan park, these underestimates would not have been as great as first anticipated. Permanent caravan sites, on-site rental vans, cabins and flats were advised to be unlikely places of accommodation for fishers from interstate and so were not included in the counting procedure. Counts and interviews were completed at a minimum of three caravan parks per survey day.

After the site count was completed, the occupants of any site, where a boat was present, were asked to participate in an interview. The person interviewed was the one who demonstrated the most knowledge about the activities undertaken on the boat. Occupants were shown pictures of different species of mackerel harvested in Queensland waters to ensure that the occupant was familiar with the identification of the relevant species. Attempts were made to randomly interview all occupants from interstate and Queensland who possessed a boat. As the survey was focused on fishers from interstate, if time was limited, boat owners from interstate were interviewed before boat owners from Queensland. Fishers from Queensland were interviewed to provide comparisons to fishers from interstate.

All results and discussion, unless otherwise stated, are based on the sample of occupants in caravan parks in north Queensland who possessed a recreational boat on site during the survey period.

Data Analysis

The site count data was divided according to the Statistical Division the caravan park was in, the state of residence of the site occupant, and the presence or absence of a boat. Interview data was separated in the same way as site count data. ANOVAs were used to examine the effect of Statistical Division, origin of occupant and month of interview on the demographics and behaviour of fishers in caravan parks. χ^2 tests were used to compare the awareness and knowledge of output controls for mackerel. Mean values were obtained by back transformation of the log mean and its standard error.

5.4.3. Results

The mean annual number of site nights occupied throughout Queensland by visitors for the financial years from 1984/85 to 1993/94 was estimated to be 4.76 million. The percentage of site nights occupied by visitors from interstate varied from 42% to 62.5% annually for the same period (Bureau of Tourism Research). During the months of June and July in 1995 the total estimated site nights occupied in each Statistical Division for powered and unpowered sites was between 46050 and 83035 (Australian Bureau of Statistics) (Table 5.4.1.).

Table 5.4.1. Caravan park occupancy data for powered and unpowered sites in 1995 - excluding on-site rental vans, cabins and flats (Australian Bureau of Statistics).

Division	Month	Number of Caravan Parks	Total Site Capacity	Occupancy (%)	Site Nights Occupied
Mackay	July	47	2896	51.5	46050
Northern	June	43	2916	59.8	49733
Northern	July	43	2912	61.3	52608
Far North	June	93	5713	49	83035

Surveys were undertaken in 62 caravan parks. About 63% of all sites counted were occupied by persons from interstate with the remainder from Queensland (Figure 5.4.1.). Of the 1603 sites counted, about 17% of occupants possessed a boat at their respective site. About 60% of these site occupants who possessed a boat were from interstate (Figure 5.4.2.).

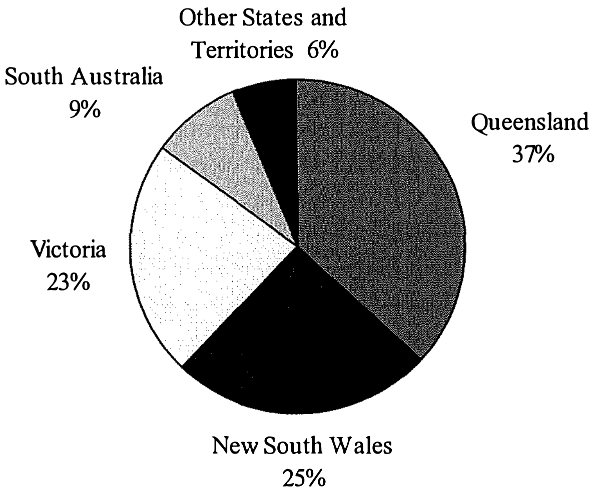


Figure 5.4.1. Percent of occupants from respective State and Territories in caravan parks between Mackay and Port Douglas surveyed in June and July 1995 (n = 1603 sites).

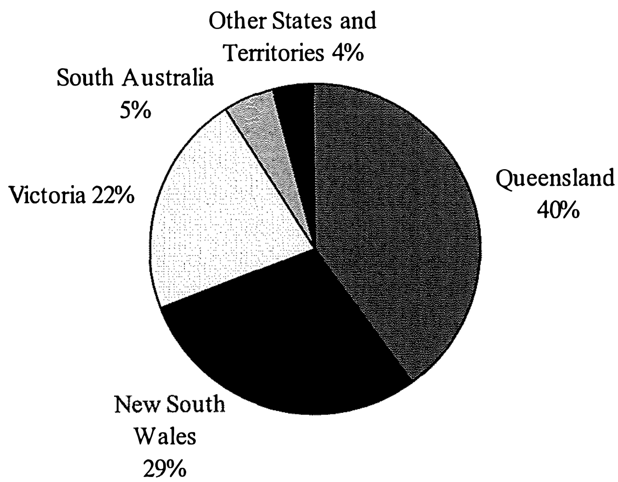


Figure 5.4.2. Percent of occupants from respective State and Territories possessing a boat in caravan parks between Mackay and Port Douglas surveyed in June and July 1995 (n = 269 sites).

There were differences in the proportion of occupants who possessed a boat between the three divisions, with the proportion in the Mackay and Northern Divisions higher than the Far North Division . The percentage of interstate occupants who possessed a boat on site was about 10 % throughout the Statistical Divisions surveyed (Table 5.4.2.).

Table 5.4.2. Percentage of occupants in caravan parks who possessed a boat.

Division	Site Counts with Boat	All occupants with Boat (%)	Site Counts with Boat - Interstate	Interstate Occupants with Boat (%)	Site Counts with Boat - QLD	QLD Occupants with Boat (%)
Mackay	38	18.81	23	11.39	15	7.43
Northern	163	19.45	101	12.05	62	7.4
Far North	68	12.07	39	6.93	29	5.15
Overall	269	16.78	163	10.17	106	6.61

A total of 103 occupants who possessed a boat on site were interviewed. Only one of these advised that they had not been or did not intend to go fishing while staying in caravan parks in Queensland (Table 5.4.3.). All of the remaining occupants interviewed said that they usually went fishing from their boat. Of the occupants interviewed, 26 were from Queensland and 76 were from interstate. A total of 12 interstate occupants registered their boat in Queensland.

Table 5.4.3. Site counts and interviews of occupants completed in each Statistical Division.

Statistical Division	Establishments Surveyed	Site Counts	Interviews Completed
Mackay	7	202	16
Northern	39	838	59
Far North	20	563	27
Overall	62	1603	102

The number of occupants at each caravan site who go fishing was significantly lower for those from interstate than those from Queensland. The number of weeks occupants intended to stay in Queensland caravan parks was significantly higher for occupants from interstate than those from Queensland. There was no significant difference in the number of occupants who go fishing and the number of weeks occupied between the three Statistical Divisions and the two months sampled (Table 5.4.4.). There was no significant difference in the number of caravan parks fishers intended to visit in 1995 in Queensland or in the number of years fishers had been visiting the caravan park that they were currently staying in, between the three Statistical Divisions, the occupants origin and the two months sampled (Table 5.4.4.).

Table 5.4.4. Analysis of variance results for the number of fishers at each caravan site, number of weeks the fishers intended to holiday in caravan parks, number of caravan parks fishers intended to visit and the number of years that occupants had been visiting the particular caravan park in Queensland in 1995 (* $P < 0.01$, ^{ns} $P > 0.05$).

Variable	People		Weeks		Caravan Parks		Years Visiting	
	Mean (s.e.)	F	Mean (s.e.)	F	Mean (s.e.)	F	Mean (s.e.)	F
Statistical Division		0.81^{ns}		0.94^{ns}		0.82^{ns}		0.24^{ns}
Mackay	2.32 (1.12)		9.80 (1.22)		2.90 (1.45)		4.60 (0.97)	
Northern	2.08 (1.06)		10.75 (1.09)		2.96 (1.15)		5.48 (0.75)	
Far North	1.94 (1.09)		13.03 (1.15)		2.13 (1.24)		4.28 (0.93)	
Occupants Origin		9.08^{*}		10.34^{*}		3.28^{ns}		0.01^{ns}
Interstate	1.93 (1.05)		12.76 (1.08)		3.04 (1.14)		5.18 (0.62)	
Queensland	2.59 (1.09)		7.78 (1.14)		1.98 (1.2)		4.63 (0.97)	
Month -		1.13^{ns}		0.35^{ns}		0.79^{ns}		2.84^{ns}
June	2.06 (1.05)		11.59 (1.08)		3.37 (1.31)		5.35 (0.83)	
July	2.15 (1.1)		9.53 (1.17)		2.58 (1.13)		3.90 (0.63)	

Fishers from interstate in caravan parks were not as discriminating in the species of fish they targeted as were fishers from Queensland. Although important to interstate fishers, mackerel were targeted by only 28% of these fishers. In contrast, about 47% of fishers from Queensland in caravan parks targeted mackerel (Figures 5.4.3. and 5.4.4.).

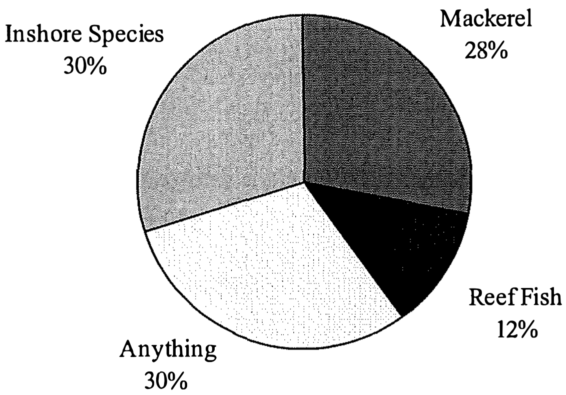


Figure 5.4.3. Percentage of interstate fishers in caravan parks which target specific fish types.

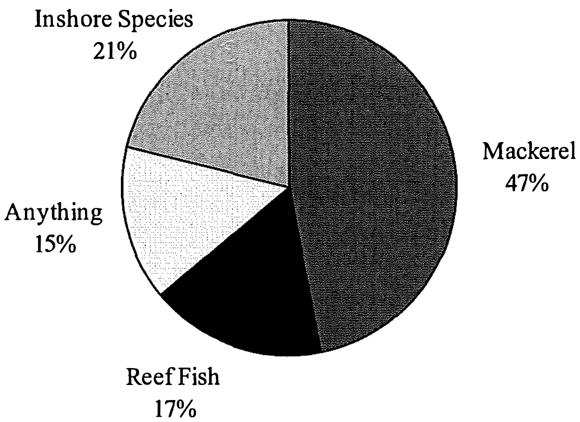


Figure 5.4.4. Percentage of Queensland fishers in caravan parks which target specific fish types.

A total of 67 of the 102 occupants who fished, had been fishing in the two week period preceding the interview. Of these fishers, 12% had not harvested a fish, 28% had harvested up to five fish, 48% had harvested between five and 50, and 12% had harvested more than 50. Small mackerel species comprised about 17% of the fisher's total harvest by number in the two week period preceding the interview (Table 5.4.5.). At the time of interview the total mackerel harvest in Queensland of all fishers was dominated by spotted mackerel (Table 5.4.6.).

Table 5.4.5. Total harvest (numbers of fish) of each fish species for each type of fisher in northern Queensland for two weeks preceding interview (n = 103 site occupants, QLD = 26 Interstate = 76).

Species	Number of fish harvested by Interstate fishers	Number of fish harvested by Queensland fishers	Total Number of fish	Total Harvest (%)
Whiting (all)	996	129	1125	48.8
Small Mackerel	226	155	381	16.5
Pikey Bream	179	56	235	10.2
Grunter	133	31	164	7.1
Flathead (all)	90	11	101	4.4
Tropical Snappers and Emperors	54	20	74	3.2
Trevally	64	3	67	2.9
Salmon	28	12	40	1.7
Cod (all)	31	4	35	1.5
Coral Trout	14	3	17	<1
Spanish Mackerel	8	6	14	<1
Shark	11	1	12	<1
Barramundi	1	0	1	<1
Others	38	1	39	1.7
Total	1873	432	2305	100

Table 5.4.6. Composition and total mackerel harvest by fishers during 1995 holiday period at time of interview (Up to time of interview, the holidays expended to obtain the harvest were 487 weeks for interstate fishers and 191 weeks for Queensland fishers, n = as in Table 5.4.5.).

Mackerel Species	Tourist Catch		
	Interstate	Queensland	Total
Spotted	237	142	379
School	7	1	8
Grey	1	3	4
Spanish	12	6	18
Mackerel (unspecified)	0	25	25
Total	257	177	434

There was no significant difference between fishers from interstate and Queensland who were aware of regulations for various mackerel species in Queensland (χ^2=3.299, df=2, P=0.192). About 47% and 63% of fishers from interstate and Queensland respectively said they knew the specific regulations (Table 5.4.7.). Of these occupants 100% knew the minimum legal lengths, and 77% and 80% of fishers from interstate and Queensland respectively knew the bag limits for each mackerel species (Table 5.4.7.).

Table 5.4.7. The number and percent of responses (in brackets) for questions on a) are you aware of the minimum legal lengths and bag limits for mackerel; If response was yes in a), then b) and c) are the correct/incorrect responses when asked to specify the actual regulations for different mackerel species.

Response	Interstate			Queensland		
	a) Rules (No. ; %)	b)Legal Length (No. ; %)	c) Bag Limits (No. ; %)	a) Rules (No. ; %)	b)Legal Length (No. ; %)	c) Bag Limits (No. ; %)
Yes	34 (47)	31 (100)	24 (77)	17 (63)	15 (100)	12 (80)
No	20 (28)	0 (0)	7 (23)	3 (11)	0 (0)	3 (20)
On Brochure	18 (25)	-	-	7 (26)	-	-

5.4.4. Discussion

A considerable number of visitors from interstate and Queensland holiday in Queensland caravan parks each year. In northern Queensland during winter, about 17% of these visitors use boats to participate in recreational fishing activities. The majority of these fishers are residents of New South Wales and Victoria. In 1995 most of these fishers from interstate were planning to holiday in Queensland for more than 12 weeks and visit between two and three caravan parks.

Mackerel are one of the major fish species targeted by visitors using boats in northern Queensland. Mackerel were the second most common species harvested behind whiting (*Sillago spp.*). Mackerel are likely to contribute most to the weight of the recreational harvest of these fishers compared to other commonly harvested species, owing to their larger size and greater minimum legal length. In northern Queensland, spotted mackerel predominate the mackerel harvest of boat-based recreational fishers staying at caravan parks. Anecdotal reports from northern Queensland recreational fishers and caravan park operators indicate that seasonal fisheries for spotted and school mackerels that attract interstate anglers have been poor in the late 1990s and early 2000s compared to historical catches in the 1980s and early 1990s.

It should be noted that the sample of tourists interviewed was small and that the survey was severely restricted on both a temporal and spatial scale. Although total catch and effort of these fishers were not estimated, mackerel are obviously an important component of the recreational harvest of interstate visitors. The harvest of fish by interstate fishers should, however, not be ignored in total recreational harvest estimates. Telephone and mail surveys of residents are often used to estimate total recreational fisheries effort and harvest. Fisheries and survey managers should realise the inadequacies of such a sample frame in neglecting the effort and harvest of visitors from interstate. The 2000/2001 National Recreational and Indigenous Fishing Survey that was being finalised at the time of publication of this report may provide further information regarding the catch and effort of small mackerels by non-resident anglers. Greater extension and education of fishery regulations should also be directed towards interstate fishers to ensure compliance with fisheries legislation.

6. BENEFITS

6.1. Recommendations

- **Small mackerel species should be managed with utmost caution until detailed stock assessments are undertaken.**

In northern Australian waters since the mid 1990s there has been a dramatic increase in commercial fishing effort targeting small mackerel species to satisfy expanding domestic and export markets. This expansion is particularly noticeable for commercial fisheries targeting spotted mackerel in east coast waters of Australia and grey mackerel in the Gulf of Carpentaria. In Queensland there is also the enormous potential (particularly in east coast waters) for additional licenced commercial fishers who have not previously harvested small mackerel, to target small mackerel species in the future.

- School, spotted and grey mackerel are considered as separate species for management purposes.

- The respective stock structures of school, spotted and grey mackerel should be integral in considering management arrangements for each species.

- The current minimum legal length of 50 cm for school, spotted and grey mackerel in Queensland should be maintained.

Many recreational fishers are unable to discriminate between school, spotted and grey mackerel. A small increase in the minimum legal length of spotted mackerel and a large increase in the minimum legal length of grey mackerel is warranted if recreational fishers can, subject to the following considerations, readily distinguish between each small mackerel species. Any consideration in increasing the minimum legal length of any small mackerel species should consider that many fish are likely to die after being captured by hook and line, even after being subject to careful and skilled handling practices. Small mackerel species also die very quickly after encountering a gill or mesh net and so release after capture in a gill or mesh net is a pointless exercise.

Except at Hervey Bay, and to a lesser extent on the Sunshine Coast, grey mackerel are predominantly harvested by commercial fishers using gill nets of a stretch mesh usually greater than 6 inches (150 mm). Most grey mackerel captured in these nets are in excess of the length at first maturity. At Hervey Bay and the Sunshine Coast commercial fishers target school mackerel using nets comprising mesh around 95.2 mm and incidental catches of grey mackerel of a size significantly smaller than the length of first maturity are taken. Such fish are dead and the imposition of a miniumum legal size above 50 cm for grey mackerel in these areas is likely to see discard of dead grey mackerel. The recognition by commercial fishers at Hervey Bay and the Sunshine Coast of the inappropriateness of taking immature grey mackerel and the education of recreational fishers in the identification of small mackerel would be beneficial for future management initiatives.

- The use of gill nets with a stretch mesh of 95.2 mm (3.75 inches) or smaller by the commercial fishery to target spotted mackerel should be prohibited as some fish smaller than the length at first maturity will be captured in such nets.

- Consideration be given to the prohibition of the use of gill nets with a stretch mesh smaller than 127 mm (5 inches) to target spotted mackerel in the Bowen region. Setting this mesh size as the minimum used to target spotted mackerel at other locations should also be considered.

- Investigate appropriateness of amendment to Fisheries Regulation prohibiting the use of a ring net north of Baffle Creek in Queensland recognising intent of legislation and historical and existing commercial netting activities.

- Consideration be given to the usefulness of the current recreational bag limit of 30 small mackerel per person in Queensland as it is inadequate to have any effect on the harvest in the recreational fishery and does not reflect the social and economic importance of the species to the recreational fishing sector.

- The present data obtained from the Queensland Commercial Logbook (QFISH) Program is inadequate to monitor or undertake an accurate assessment of small mackerel populations and fisheries. The use of unstandardised current catch per unit effort (CPUE) summaries as an indicator of the status of mackerel stocks should be undertaken only with caution. Recommendations to improve the QFISH logbook system to enable ulisation of data for stock assessment purposes include:

  (a) Introduction of an education program or simple identification sheets to assist commercial fishers to identify school, spotted, grey, narrow-barred Spanish and shark mackerel;

  (b) Requirement for all commercial fishers to identify catches of mackerel to species level;

  (c) Method of capture in logbooks should be specific enough to enable distinction between ring netting and other netting methods;

  (d) Mandatory requirement to record details and configuration of net used including number of net shots, length, drop and mesh size of net;

  (e) All commercial fishing effort targeted towards specific mackerel species, including non-profitable search time and net shots should be recorded in logbooks;

  (f) Encourage all commercial catch and effort information for mackerel species to be reported for 36 (thirty-six) square nautical mile sites and not just 900 (nine hundred) square nautical mile grids.

- Access point and on-site surveys investigating recreational harvest and effort for small mackerel species should be designed and undertaken to validate and compare recreational harvest estimates obtained in this study and subsequent RFISH surveys. Off-site and self reporting surveys such as the telephone, mail and diary surveys conducted in this study and RFISH statewide surveys are of major benefit in obtaining baseline recreational fishing information. However, such surveys should not be used as substitutes for more expensive on-site survey methods which are required to investigate specific fisheries.

- Develop a reliable estimator of stock abundance for each small mackerel species after the above recommendations pertaining to commercial and recreational fisheries harvest data are adopted; and

- Relevant research staff and recreational and commercial fishers should be consulted on appropriate strategies to achieve these outcomes should fisheries management agencies decide to accept advice to constrain or reduce small mackerel fishing efforts or harvests.

6.2. Benefits and Beneficiaries compared to those in Original Application

The beneficiaries of the provision of biological information and data on recreational and commercial fisheries for small mackerel in Queensland are the fisheries and aquatic natural resource managers, the participants in each fishery, and the broader community. Data and estimates on the harvest sharing arrangements of small mackerel in Queensland may be used to assist future negotiations between the recreational and commercial fishing sectors. Biological information obtained in this study is essential for future stock assessments. Information on these species will be of assistance to the Northern Territory Department of Primary Industry and Fisheries and the fisheries management agencies in each state where small mackerel species are captured. No data was obtained on the importance to or extent of mackerel harvest by indigenous fishers or traditional owners.

The benefits of using a suite of methods to discriminate stocks of fish, the suitability of phone surveys and fishing diary exercises to estimate recreational harvests over a large geographical area, and the variety of techniques used to investigate gill net drop out in the spotted mackerel fishery have application in fisheries throughout Australia and world-wide.

The temporal comparison of the stock structure of narrow-barred Spanish mackerel, as referred to in the original project was, however, not able to be undertaken. All available resources in the project were directed towards the priority investigation of the school, spotted and grey mackerel fisheries and prevented the collection of samples of narrow-barred Spanish mackerel.

6.3. Intellectual Property and Valuable Information

No patentable inventions or processes have been developed during this project.

6.4. Dissemination of Research Results

Presentation of Research Results have been made to a wide variety of audiences including -

- Subtropical and Tropical Finfish Management Advisory Committees - Brisbane, 9-10 July 1996

- Moreton Bay Fisheries Zonal Advisory Committee - Brisbane, 5 September 1996

- Sunshine Coast Fisheries Zonal Advisory Committee - Nambour, 26 November 1996

- Hervey Bay - Bundaberg Fisheries Zonal Advisory Committee - Hervey Bay, 18 October 1996
- Rockhampton - Gladstone Fisheries Zonal Advisory Committee - Rockhampton, 4 November 1996
- Mackay Fisheries Zonal Advisory Committee - Mackay, 10 September 1996
- Townsville Fisheries Zonal Advisory Committee - Townsville, 19 November 1996
- Gulf of Carpentaria Fisheries Zonal Advisory Committee - Karumba, 10 October 1996
- Karumba Branch QCFO Branch - Karumba, 11 October 1996
- Advertised Public Presentation - Hervey Bay, 1996
- Advertised Public Presentation - Mackay, 11 September 1996
- Advertised Public Presentation - Bowen, 12 September 1996
- Australian National Sportfishing Association Annual Conference (Queensland Branch) - Yeppoon, 1995 & 1996
- Australian Society for Fish Biology Annual Conference - Canberra, 1995 and Darwin, 1997

This report was utilised at a workshop to discuss the proposed development of management arrangements for the Queensland spotted mackerel fishery hosted by the Queensland Fisheries Service in Brisbane on 6 and 7 March 2002.

During the project, preliminary results have been presented in "The Queensland Fishermen", newspapers, and on a commercial television programmes focused on recreational fishing and aquatic subjects. Liaison with recreational fishing magazines regularly provided coverage of the research project to recreational fishers.

Seven peer reviewed scientific papers resulting from research in this project have been published or accepted for publication at the time of printing this report. These are:

Begg, G.A., Cameron, D.S., and Sawynok, W.S. (1997). Movements and stock structure of school mackerel (*Scomberomorus queenslandicus*) and spotted mackerel (*S. munroi*) in Australian east coast waters. *Marine and Freshwater Research* **48**, 295-301.

Begg, G.A. and Hopper, G.A. (1997). Feeding patterns of school mackerel *(Scomberomorus queenslandicus*) and spotted mackerel (*S. munroi*) in Queensland east coast waters. *Marine and Freshwater Research* **48**, 565-571.

Begg, G. A., Cappo, M., Cameron, D. S., Boyle, S., and Sellin, M. J. (1998). Stock discrimination of school mackerel (*Scomberomorus queenslandicus*) and spotted mackerel (*Scomberomorus munroi*) in coastal waters of eastern Australia using analysis of minor and trace elements in whole otoliths. *Fishery Bulletin* **96**(4), 653-666.

Begg, G. A. and Sellin, M.J. (1998). Age and growth of school mackerel (*Scomberomorus queenslandicus*) and spotted mackerel (*S. munroi*) in Queensland east-coast waters with implications for stock structure. *Marine and Freshwater Research* **49**, 109-120.

Begg, G. A. (1998). Reproductive biology of school mackerel (*Scomberomorus queenslandicus*) and spotted mackerel (*S. munroi*) in Queensland east-coast waters. *Marine and Freshwater Research* **49**, 261-270.

Begg, G.A., Keenan, C.P., and Sellin, M.J. (1998). Genetic variation and stock structure of school mackerel (*Scomberomorus queenslandicus*) and spotted mackerel (*S. munroi*) in northern Australian waters. *Journal of Fish Biology* **53**, 543-559.

Hoyle, S.D. and Cameron, D.S. Confidence Intervals on Catch Estimates From a Recreational Fishing Survey: a Comparison of Bootstrap Methods. *Fisheries Management and Ecology* **(In press 2002)**

Additional papers resulting from research in this project are being prepared for submission to scientific journals.

7. FURTHER DEVELOPMENT

Several areas of further research and development of research of northern Australian small mackerel fisheries are described in the recommendations.

Additional areas of further research and development include:

Biological

- More definitively describe the stock structure of grey mackerel throughout the eastern Queensland coast and school and spotted mackerel populations north of Cairns and throughout the Arafura Sea;
- Greater tagging efforts for school, spotted and grey mackerel in waters north of Mackay should be encouraged in accordance with strict fish handling practices and protocols. Recapture information will assist in the stock identification and movements or migration patterns of small mackerel in northern Queensland.
- Investigate and describe the localised spawning grounds, nursery areas and preferred habitat of each small mackerel species;
- Monitor the levels of juvenile recruitment and develop juvenile recruitment indices;
- Investigate the existence of larval retention areas and their role as a stock isolating mechanism;
- Age structured monitoring of small mackerel captured by commercial and recreational fishers should be continued on a regular basis to assist stock assessments.
- Investigate the biology, stock structure and fisheries for shark or salmon mackerel (*Grammatorcynus bicarinatus*) to complete base line biological information for all small mackerel species of commercial and recreational importance (funded mainly by the commercial line fishing sector).

Marketing and Quality of Product

- Investigate the quality of small mackerel product harvested by different commercial fishing techniques (harvest and post-harvest) at different locations. The results of this research would enable optimisation of use of small mackerel species for the export market and enable comparisons in value between the commercial and recreational fishing sectors.

Fisheries Investigations

- Investigate the use of gill nets with a stretch mesh equal to or smaller than 82.5 mm (3.25 inches) by the commercial fishery in southern Queensland to target school mackerel and tailor (*Pomatomus saltatrix*) to determine the selective properties of the net and determine the quantity (if any) of undersize school mackerel captured and discarded;
- Undertake a socio-economic evaluation of recreational and commercial fisheries for small mackerel;

- Investigate the bycatch mortality and discard of small mackerel by trawl fishing, comparing gear incorporating bycatch reduction devices and those without. Such investigations will provide mortality estimates that are likely to be important in the development of future stock assessments for small mackerel species.

8. FINAL COST

The final financial statement had not been submitted at the time of preparation of this report. It is anticipated that all moneys allocated to the project will be expended.

The FRDC contribution to the original project (No. 92/144) was $488 606. The FRDC contribution to the extension of the project investigating the rate of gill net drop out in the commercial spotted mackerel fishery (No. 92/144/02) was $90534.

9. STAFF

Queensland Department of Primary Industries

Name	Position	Areas of Responsibility
Darren Cameron	Joint Principal Investigator	Project, budgetary and staff supervision; biology and stock structure of grey mackerel; design, supervise and undertake all commercial and recreational fisheries investigations; extension of project results; preparation of final report.
Gavin Begg	Joint Principal Investigator	Biology of school and spotted mackerel; analyses of biology and stock structure data for each mackerel species; assist in commercial fisheries investigations and general project supervision; preparation of final report.
Michelle Sellin	Fisheries Technician	Biology and stock structure of each mackerel species; commercial and recreational fisheries.
Michael O'Neill	Fisheries Technician	Biology and stock structure of each mackerel species; commercial and recreational fisheries; editorial advice.
Eddie Jebreen	Fisheries Technician	Recreational and commercial fisheries investigations; editorial advice.
Lew Williams	Fisheries Economist	Recreational and commercial fisheries investigations; editorial advice.
Raewyn Street	Fisheries Technician	Biology and stock structure of each mackerel species; commercial and recreational fisheries.
Jason McGilvray	Fisheries Technician	Biology and stock structure of each mackerel species.

Northern Territory Department of Primary Industry and Fisheries

Rik Buckworth	Fisheries Biologist and Project Liaison	Liaise with Joint Principal Investigators and supervise Fisheries Technician in N.T.
Charles Bryce	Fisheries Technician	Collection of samples to investigate biology and stock structure of each mackerel species and commercial fisheries investigations.

Additional staff from Queensland Department of Primary Industries contributing directly to the project

Name	Position	Areas of Responsibility
Ian Brown	Senior Fisheries Biologist	Guidance, advice, encouragement and review throughout project; editorial advice.
Simon Hoyle	Fisheries Biologist	Statistical advice and programming to estimate recreational fisheries harvest; editorial advice.
Clive Keenan	Senior Fisheries Biologist	Assistance in analyses and interpretation of genetic investigations; editorial comments.
Robyn Watts	Fisheries Biologist	Assistance, advice and training in genetic investigations.
Glen Hopper	Fisheries Technician	Assistance in components of biology and stock structure investigations.
Pattie Semmens	Fisheries Technician	Histological preparation.

CSIRO Division of Marine Research

David Die	Senior Research Scientist	Advice and analyses of gill net selectivity component; editorial advice.

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12. APPENDICES

Appendix 1. Details of biological sampling.

Table 1. Details of small mackerel sampling for age determination.

	Spotted mackerel			School mackerel			Grey mackerel		
Month	**Region**	**N**	**Length range (mm)**	**Region**	**N**	**Length range (mm)**	**Region**	**N**	**Length range (mm)**
January	Southern	186	490-740	Southern	121	350-695	Gulf	25	670-890
February	Southern	183	544-820	Southern	11	405-635	Gulf	21	680-410
March	Southern	78	540-705	Southern	20	465-580	Darwin	3	790-880
							Gulf	2	530-730
April	Southern	1	780	Southern	20	473-619	Darwin	4	410-450
May	Central	9	485-820	Central	35	460-680	Gulf	11	600-805
							South	15	595-840
June	Central	2	530-675	Central	95	311-690	Gulf	10	630-830
							North	5	605-830
July	Northern	48	550-790	Northern	36	310-685	Gulf	10	630-830
				Central	54		North	15	530-990
				Southern	29				
August	Northern	293	448-840	Northern	101	449-670	Darwin	12	330-840
				Central	14		Gulf	16	620-900
				Southern	49		North	52	610-900
							South	4	420-490
September	Northern	276	360-925	Central	41	430-729	Darwin	5	380-710
				Southern	123		Gulf	22	575-975
							North	106	565-960
							Central	74	610-980
							South	1	620
October	Central	10	540-780	Central	130	338-720	Darwin	61	390-890
				Southern	135		Gulf	297	570-990
							North	277	390-920
							Central	46	600-930
							South	11	455-865
November	Southern	65	430-860	Southern	94	362-860	Darwin	20	470-910
							Gulf	36	540-785
							Central	4	770-900
							South	7	415-760
December	Southern	358	490-790	Southern	88	330-784	Gulf	25	670-850

Appendix 1. Details of biological sampling.

Table 2. Details of small mackerel sampling for reproductive characteristics.

	Spotted mackerel			School mackerel			Grey mackerel		
Month	**Region**	**N**	**Length range (mm)**	**Region**	**N**	**Length range (mm)**	**Region**	**N**	**Length range (mm)**
January	Southern	178	530-740	Southern	122	350-695	Gulf	25	670-890
February	Southern	183	544-820	Southern	12	405-635	Gulf	21	680-810
March	Southern	78	540-705	Southern	20	465-580	Gulf	2	530-730
April	Southern	1	780	Southern	20	473-619			
May	Central	12	485-820	Central	36	460-680	Gulf	11	595-870
							Southern	16	
June	Central	3	353-675	Central	98	311-690	Gulf	10	605-830
							Northern	5	
July	Northern	51	344-790	Northern	38	310-685	Gulf	11	530-990
				Central	56		Northern	16	
				Southern	30				
August	Northern	297	448-840	Northern	102	449-700	Gulf	19	420-900
				Central	14		Northern	52	
				Southern	50		Southern	4	
September	Northern	287	360-925	Central	43	430-729	Gulf	22	565-980
				Southern	126		Northern	110	
							Central	74	
							Southern	1	
October	Central	10	540-780	Central	131	338-720	Gulf	307	390-990
				Southern	136		Northern	281	
							Central	43	
							Southern	12	
November	Southern	66	430-860	Southern	95	362-860	Gulf	37	415-900
							Central	4	
							Southern	7	
December	Southern	360	490-790	Southern	89	330-784	Gulf	26	670-850

Appendix 1. Details of biological sampling.

Table 3. Origin of school mackerel samples used in otolith trace element analyses.

	Spotted mackerel				**School mackerel**				**Grey mackerel**			
Month	**Region**	**N**	**Length range (mm)**	**Age**	**Region**	**N**	**Length range (mm)**	**Age**	**Region**	**N**	**Length range (mm)**	**Age**
'92 October	Gove	13	320-450	0								
'93 June					Rockhampton	25	492-574	1				
					Rockhampton	19	552-640	2				
'93 July	Innisfail	28	585-665	3					Townsville	2	780-780	2
'93 August	Bowen	32	605-670	3	Bowen	22	545-632	2				
					J.B.G.	14	330-500	1				
'93 September									Darwin	1	380	1
									Hervey Bay	1	620	1
									Mackay	16	610-733	1
									Mackay	17	690-815	2
									Townsville	2	685-790	2
'93 October					Darwin	20	380-500	1	Darwin	10	390-450	1
									Gove	16	570-840	2
									Hervey Bay	2	632-682	1
									Mackay	13	650-740	1
									Mackay	4	750-790	2
									Townsville	26	390-795	2
'93 November	J.B.G.	18	400-460	0	Moreton Bay	19	512-614	2	Darwin	2	690-720	1
'93 December	Hervey Bay	29	552-790	3								
'94 January												
'94 February	Moreton Bay	30	555-685	1								
	Hervey Bay	28	544-715	1								
'94 May									Gulf	2	788-800	2
'94 June												
'94 July									Gulf	1	720	2
'94 August									Gulf	1	705	2
									Hervey Bay	6	420-490	1
'94 September									Gulf	4	650-765	2
'94 October									Gulf	12	670-750	2
'94 November									Gulf	5	540-730	2
									Hervey Bay	6	400-445	1
'94 December									Gulf	3	710-750	2
'95 February					Weipa	19	410-505	1				

Appendix 1. Details of biological sampling.

Table 4. Details of school and spotted mackerel sampling for genetic examination.

School Mackerel					Spotted Mackerel				
Area	**Birth Date (yr.)**	**n**	**Mean Length (mm, s.d.)**	**Mean Age (yrs., s.d.)**	**Area**	**Birth Date (yr.)**	**n**	**Mean Length (mm, s.d.)**	**Mean Age (yrs., s.d.)**
Moreton Bay	90	15	579 (45)	2.9 (0.6)	Iluka	92	18	731 (21)	2.0 (0.0)
	91	122	506 (82)	1.9 (0.7)	Moreton Bay	91	24	606 (56)	1.5 (0.8)
	92	69	501 (56)	1.3 (0.5)		92	21	615 (48)	1.4 (0.5)
	93	18	476 (54)	1.0 (0.0)		93	39	605 (27)	1.0 (0.0)
Hervey Bay	90	12	611 (25)	2.7 (0.5)	Hervey Bay	90	74	622 (43)	2.9 (0.7)
	91	64	554 (58)	1.8 (0.6)		91	211	609 (52)	2.1 (0.6)
	92	202	513 (28)	1.1 (0.3)		92	213	588 (48)	1.5 (0.5)
	93	14	484 (29)	1.0 (0.0)		93	109	584 (37)	1.0 (0.2)
Rockhampton	90	17	633 (33)	2.6 (0.8)		94	101	582 (35)	1.0 (0.0)
	91	32	576 (37)	1.9 (0.7)	Mackay	92	15	625 (62)	2.0 (0.0)
	92	111	477 (97)	0.9 (0.7)		94	15	461 (47)	0.0 (0.0)
	93	122	511 (28)	1.0 (0.0)	Bowen	90	144	654 (50)	2.9 (0.7)
Townsville	90	15	608 (16)	3.0 (0.0)		91	91	631 (59)	2.5 (0.6)
	91	23	587 (23)	2.0 (0.0)	Innisfail	90	31	623 (32)	3.0 (0.0)
	92	14	499 (30)	1.7 (0.5)	Darwin	91	24	606 (91)	2.2 (0.4)
	93	11	470 (17)	1.0 (0.0)		92	28	521 (115)	1.2 (0.6)
Weipa	94	24	447 (24)	1.0 (0.0)		93	79	381 (104)	0.3 (0.5)
	95	34	250 (30)	0.0 (0.0)		94	63	371 (71)	0.1 (0.3)
Darwin	92	29	441 (77)	1.2 (0.5)					
	93	58	416 (95)	0.4 (0.6)					
	94	234	314 (66)	0.0 (0.1)					
Joseph Bonaparte Gulf	92	29	364 (70)	1.0 (0.2)					
	94	40	305 (48)	0.0 (0.0)					

Appendix 1. Details of biological sampling.

Table 5. Proteins examined in school, spotted and grey mackerel. Each enzyme system was screened for activity in liver, muscle and retina tissues, in combination with eight buffer systems (CAME, EBT, LiOH, Poulik, TC-1, TM, Tris Glycine and TVB). "Pattern" refers to the locus' polymorphism (M=monomorphic; P=polymorphic). "Resolution" refers to the overall clarity of the banding pattern across all the systems (good=clear and scoreable bands; unscoreable=bands unclear, blurred, overstained; nothing=no bands observed).

Protein	Locus	School Mackerel		Spotted Mackerel		Grey Mackerel	
		Pattern	Resolution	Pattern	Resolution	Pattern	Resolution
Acid phosphatase	*ACP*	M	good	-	unscoreable	-	unscoreable
Aconitate hydratase	*AH*	P	good	P	unscoreable	P	unscoreable
Adenosine deaminase	*ADA*	P	unscoreable	M	good	M	good
Adenylate kinase	*AK*	M	good	P	good	M	good
Alanine aminotransferase	*ALAT*	M	good	M	good	-	unscoreable
Alcohol dehydrogenase	*ADH*	P	unscoreable	-	unscoreable	M	good
Aspartate aminotransferase	*AAT*	P	good	P	good	M	unscoreable
Creatine kinase	*CK*	M	good	P	same as AK	M	good
Enolase	*ENO*	M	good	M	good	M	unscoreable
Esterase-D	*EST-D*	M	good	P	unscoreable	P	good
Formaldehye dehydrogenase	*FDH*	-	unscoreable	-	unscoreable	-	unscoreable
Fructose-bisphosphate-aldolase	*FBALD*	-	unscoreable	-	nothing	-	unscoreable
Fumarate hydratase	*FH*	M	good	M	unscoreable	M	unscoreable
Galactosidase (-beta)	*β-GAL*	-	nothing	-	nothing	-	nothing
Glucose-3-phosphate dehydrogenase	*G3PDH*	P	good	P	unscoreable	P	unscoreable
Glucose-6-phosphate dehydrogenase	*G6PDH*	M	good	M	unscoreable	M	good
Glucose-6-phosphate isomerase	*GPI*	P	good	P	good	P	good
Glucosidase (-alpha)	*α-GLU*	P	unscoreable	P	inconsistent	-	unscoreable
Glucosidase (-beta)	*β-GLU*	-	nothing	-	nothing	-	nothing
Glutathione reductase	*GR*	P	unscoreable	P	unscoreable	-	unscoreable
Glyceraldehyde phosphate dehydrogenase	*GAPDH*	M	good	M	good	M	good
Guanine deaminase	*GDA*	P	unscoreable	-	unscoreable	-	unscoreable
Hexokinase	*HK*	-	unscoreable	P	same as AK	-	unscoreable
Iditol dehydrogenase (-L)	*IDDH*	P	unscoreable	P	unscoreable	-	unscoreable
Isocitrate dehydrogenase	*IDH*	P	good	P	good	M	unscoreable
Lactate dehydrogenase	*LDH*	P	good	M	good	P	good
Malate dehydrogenase	*MDH*	M	good	P	good	M	good
Malate dehydrogenase ($NADP^+$)	*ME*	M	good	M	good	M	unscoreable
Mannose-6-phosphate isomerase	*MPI*	M	good	M	good	M	good
Peptidase (gly-leu)	*PEP-1*	P	unscoreable	-	unscoreable	P	good
Peptidase (leu-pro)	*PEP-2*	-	nothing	-	unscoreable	-	unscoreable

Appendix 1. Details of biological sampling.

Table 5. (continued)

Protein	Locus	School Mackerel		Spotted Mackerel		Grey Mackerel	
		Pattern	Resolution	Pattern	Resolution	Pattern	Resolution
Peptidase (leu-tyr)	*PEP-3*	P	unscoreable	-	unscoreable	-	unscoreable
Peptidase (pro-leu)	*PEP-4*	P	good	-	unscoreable	-	unscoreable
Phosphoglucomutase	*PGM*	M	good	P	good	M	good
Phosphogluconate dehydrogenase	*PGDH*	M	good	M	good	M	good
Phosphoglycerate kinase	*PGK*	-	unscoreable	-	unscoreable	-	unscoreable
Triosephosphate isomerase	*TPI*	-	unscoreable	-	unscoreable	-	nothing

Appendix 2. Total harvest of trawl shot at Hervey Bay on 10 Dec 1995.

Scientific Name	Common Name	Number
Fish		
Siganus canaliculatus	Smudgespot Spinefoot	61
Paramonacanthus choirocephalus	Hair-finned Leatherjacket	27
Nemipterus celebicus	Five-lined Threadfin-Bream	12
Lethrinus genivittatus	Threadfin Emperor	8
Upeneus luzonius	Dark-barred Goatfish	6
Gerres oyena	Silver Biddy	4
Pentapodus paradisius	False Whiptail	4
Upeneus sulphureus	Sunrise Goatfish	3
Chaetodontoplus duboulayi	Scribbled Angelfish	2
Diagramma pictum	Painted Sweetlip	2
Coradion chrysozonus	Orange-banded Coral Fish	1
Dasyatis leylandi	Brown Reticulated Stingray	1
Platycephalus indicus	Bar-tailed Flathead	1
Pseudorhombus elevatus	Deep-bodied Flounder	1
Rachycentron canadus	Cobia / Black Kingfish	1
Rhynchostracion nasus	Small-nosed Boxfish	1
Scolopsis taeniopterus	Redspot Monocle Bream	1
Torquigener pallimaculatus	Orange-spotted Toadfish	1
Other		
Holothurian	Sea-cucumber	12
Sepia sp.	Cuttlefish	2
Thenus indicus	Moreton Bay Bug	1

Appendix 3. Queensland commercial catch and effort for mackerel species by location and year. (* = < 5 boat rule applied – no data for reasons of confidentiality)
Table 1. School mackerel.

		Year													
Location	**Data**	**1988**	**1989**	**1990**	**1991**	**1992**	**1993**	**1994**	**1995**	**1996**	**1997**	**1998**	**1999**	**2000**	**Grand Total**
Moreton	Boat no.	*	*	*	*	8	*	7	9	7	13	10	6	8	88
	Effort (days)	*	*	*	*	30	*	31	62	51	53	38	32	70	452
	Catch (t)	*	*	*	*	.71	*	.56	5.02	1.44	2.96	1.38	1.32	7.35	21.87
Fraser	Boat no.	*	*	10	*	18	30	32	38	45	44	48	43	36	360
	Effort (days)	*	*	57	*	150	393	371	455	595	392	665	656	735	4520
	Catch (t)	*	*	7.46	*	7.02	20.98	15.68	13.92	31.31	13.77	31.07	67.27	74.05	286.15
Rockhampton	Boat no.	6	*	*	*	*	12	13	12	19	27	25	32	17	178
	Effort (days)	16	*	*	*	*	42	63	41	68	135	85	128	49	722
	Catch (t)	0.30	*	*	*	*	1.35	5.32	0.93	1.79	9.12	2.49	10.37	2.50	37.91
Central	Boat no.	*	0	*	*	*	*	7	11	*	6	*	*	*	46
	Effort (days)	*	0	*	*	*	*	16	44	*	39	*	*	*	205
	Catch (t)	*	0	*	*	*	*	.26	.81	*	1.00	*	*	*	5.13
Northern Dry	Boat no.	*	*	*	0	0	*	6	*	*	*	*	8	*	43
	Effort (days)	*	*	*	0	0	*	15	*	*	*	*	48	*	214
	Catch (t)	*	*	*	0	0	*	.31	*	*	*	*	2.12	*	11.96
Northern Wet	Boat no.	*	0	*	*	*	8	7	6	8	*	*	15	11	78
	Effort (days)	*	0	*	*	*	55	25	11	39	*	*	67	73	379
	Catch (t)	*	0	*	*	*	3.98	1.79	.80	1.52	*	*	5.23	6.15	26.51
Far North	Boat no.	0	*	0	*	0	*	*	0	0	*	*	*	*	13
	Effort (days)	0	*	0	*	0	*	*	0	0	*	*	*	*	44
	Catch (t)	0	*	0	*	0	*	*	0	0	*	*	*	*	1.50
Gulf North	Boat no.	0	0	0	0	0	*	*	*	0	*	0	0	0	*
	Effort (days)	0	0	0	0	0	*	*	*	0	*	0	0	0	*
	Catch (t)	0	0	0	0	0	*	*	*	0	*	0	0	0	*
Gulf South	Boat no.	0	0	0	*	0	*	*	0	*	0	0	0	0	7
	Effort (days)	0	0	0	*	0	*	*	0	*	0	0	0	0	33
	Catch (t)	0	0	0	*	0	*	*	0	*	0	0	0	0	2.31
Total Boat no.		26	20	23	22	38	67	83	83	92	107	103	114	83	861
Total Effort (days)		86	114	153	95	226	559	571	658	812	713	927	993	1001	6908
Total Catch (t)		2.54	5.97	9.70	1.99	10.84	28.20	26.82	22.80	43.24	32.17	39.09	88.15	92.96	403.76

Appendix 3. Queensland commercial catch and effort for mackerel species by location and year. (* = < 5 boat rule applied – no data for reasons of confidentiality)
Table 2. Spotted mackerel.

		Year													
Location	**Data**	**1988**	**1989**	**1990**	**1991**	**1992**	**1993**	**1994**	**1995**	**1996**	**1997**	**1998**	**1999**	**2000**	**Grand Total**
Moreton	Boat no.	0	8	*	6	15	18	18	9	10	20	17	14	12	152
	Effort (days)	0	59	*	14	42	112	123	38	56	137	111	60	165	928
	Catch (t)	0	2.64	*	1.35	3.93	20.40	7.14	2.18	6.06	6.80	7.07	9.77	88.62	166.12
Fraser	Boat no.	6	7	16	16	27	53	46	48	55	75	62	70	55	536
	Effort (days)	29	46	48	109	246	565	425	475	509	719	637	595	777	5180
	Catch (t)	1.08	.97	4.13	19.31	51.60	71.04	56.97	99.67	99.97	124.04	39.88	106.10	172.30	847.06
Rockhampton	Boat no.	*	9	*	*	7	11	9	12	11	27	17	15	12	144
	Effort (days)	*	27	*	*	24	47	42	28	28	79	53	47	33	461
	Catch (t)	*	0.65	*	*	1.81	1.45	0.67	0.92	1.73	3.85	0.77	1.41	1.08	15.49
Central	Boat no.	*	*	6	*	*	6	9	11	*	13	8	7	7	85
	Effort (days)	*	*	22	*	*	11	36	30	*	40	37	33	33	411
	Catch (t)	*	*	0.90	*	*	0.69	0.95	0.75	*	1.01	5.98	1.96	5.59	22.95
Northern Dry	Boat no.	0	9	7	*	*	6	*	*	7	13	16	21	24	116
	Effort (days)	0	24	82	*	*	16	*	*	29	111	201	147	260	897
	Catch (t)	0	3.59	34.22	*	*	13.93	*	*	16.06	57.53	58.88	24.05	115.85	354.31
Northern Wet	Boat no.	*	9	*	9	16	22	12	8	19	17	10	22	24	173
	Effort (days)	*	36	*	34	91	140	44	26	128	127	39	114	162	988
	Catch (t)	*	0.56	*	2.06	10.23	15.77	2.05	1.24	6.12	8.25	0.82	8.69	21.75	78.46
Far North	Boat no.	*	0	*	0	*	0	0	0	0	0	*	*	*	7
	Effort (days)	*	0	*	0	*	0	0	0	0	0	*	*	*	27
	Catch (t)	*	0	*	0	*	0	0	0	0	0	*	*	*	0.274
Gulf North	Boat no.	0	0	0	0	0	0	0	*	0	0	0	0	0	*
	Effort (days)	0	0	0	0	0	0	0	*	0	0	0	0	0	*
	Catch (t)	0	0	0	0	0	0	0	*	0	0	0	0	0	*
Gulf South	Boat no.	0	0	0	0	*	0	*	0	*	0	0	0	0	*
	Effort (days)	0	0	0	0	*	0	*	0	*	0	0	0	0	*
	Catch (t)	0	0	0	0	*	0	*	0	*	0	0	0	0	*
Total Boat no.		18	47	46	47	76	123	105	97	117	177	142	156	142	1293
Total Effort (days)		149	285	230	264	461	956	718	691	882	1261	1189	1028	1448	9562
Total Catch (t)		7.85	19.89	40.77	26.92	80.95	128.79	69.95	127.32	135.20	213.65	118.58	153.53	405.71	1529.12

Appendix 3. Queensland commercial catch and effort for mackerel species by location and year. (* = < 5 boat rule applied – no data for reasons of confidentiality)
Table 3. Grey mackerel.

		Year													
Location	**Data**	**1988**	**1989**	**1990**	**1991**	**1992**	**1993**	**1994**	**1995**	**1996**	**1997**	**1998**	**1999**	**2000**	**Grand Total**
Moreton	Boat no.	28	45	34	53	30	9	6	6	*	*	*	*	0	220
	Effort (days)	104	228	122	266	131	18	10	6	*	*	*	*	0	899
	Catch (t)	7.73	22.92	13.73	7.40	8.08	0.37	1.24	0.77	*	*	*	*	0	62.63
Fraser	Boat no.	78	74	76	69	44	38	28	26	28	30	25	21	20	557
	Effort (days)	886	979	996	870	489	323	233	252	331	329	425	337	171	6621
	Catch (t)	78.94	84.38	109.42	91.28	74.74	26.75	10.03	9.10	15.26	23.12	23.06	25.73	6.76	578.56
Rockhampton	Boat no.	43	31	31	37	39	16	19	18	14	22	16	17	13	316
	Effort (days)	221	295	201	111	122	47	47	56	33	84	49	56	58	1380
	Catch (t)	7.56	7.37	2.90	3.65	4.85	4.71	1.96	2.89	1.98	6.97	2.34	2.02	5.47	54.66
Central	Boat no.	26	27	19	23	13	15	16	15	16	27	13	12	12	234
	Effort (days)	435	393	203	236	114	87	148	168	207	415	159	168	75	2808
	Catch (t)	9.56	8.76	13.40	4.95	17.67	12.70	10.19	10.19	13.72	26.66	15.37	21.48	9.59	174.24
Northern Dry	Boat no.	48	45	39	29	32	20	21	15	22	27	26	21	18	363
	Effort (days)	978	838	851	466	398	153	230	183	195	405	275	162	118	5252
	Catch (t)	99.12	70.93	70.43	32.17	34.46	17.61	27.96	21.46	27.36	52.52	37.53	34.08	12.87	538.48
Northern Wet	Boat no.	57	60	44	53	33	25	15	16	17	25	19	19	19	402
	Effort (days)	445	787	612	427	147	122	60	91	124	268	122	71	106	3382
	Catch (t)	31.53	38.65	61.72	12.18	11.48	18.37	10.35	7.20	15.11	36.78	5.28	5.03	4.60	258.27
Far North	Boat no.	13	7	12	16	9	9	*	*	*	0	*	*	9	90
	Effort (days)	183	128	83	146	56	27	*	*	*	0	*	*	95	843
	Catch (t)	4.32	4.52	3.81	9.30	1.67	0.75	*	*	*	0	*	*	1.81	29.97
Gulf North	Boat no.	*	7	12	7	8	8	8	21	15	23	23	19	18	170
	Effort (days)	*	107	221	92	152	66	196	435	504	1031	1067	777	748	5414
	Catch (t)	*	1.17	8.30	19.27	24.07	24.03	78.81	101.58	233.29	378.20	361.11	282.23	374.35	1886.51
Gulf South	Boat no.	0	19	35	13	18	15	17	12	24	16	14	17	16	216
	Effort (days)	0	375	635	54	183	76	139	256	359	296	410	474	279	3536
	Catch (t)	0	4.51	29.35	15.45	15.84	19.32	15.68	53.80	61.19	85.78	75.84	95.09	148.67	655.51
Total Boat no.		312	334	323	318	243	165	147	143	145	185	153	135	129	2732
Total Effort (days)		3387	4345	4075	2835	1846	953	1090	1579	1793	2872	2541	2065	1666	31049
Total Catch (t)		242.05	250.12	324.40	199.29	196.34	126.94	192.99	211.07	369.57	611.22	521.32	466.06	564.70	4276.06

Appendix 3. Queensland commercial catch and effort for mackerel species by location and year. (* = < 5 boat rule applied – no data for reasons of confidentiality)
Table 4. Narrow-barred Spanish mackerel.

		Year													
Location	**Data**	**1988**	**1989**	**1990**	**1991**	**1992**	**1993**	**1994**	**1995**	**1996**	**1997**	**1998**	**1999**	**2000**	**Grand Total**
Moreton	Boat no.	18	25	23	26	27	25	23	17	15	24	22	24	18	287
	Effort (days)	128	339	285	347	296	490	329	223	275	328	222	228	161	3651
	Catch (t)	3.73	9.62	7.96	8.42	9.09	16.91	11.02	5.63	6.79	9.99	5.30	5.18	2.68	102.31
Fraser	Boat no.	43	34	39	51	50	70	55	60	70	85	89	84	61	791
	Effort (days)	328	300	445	429	418	732	554	476	520	726	1013	1002	823	7766
	Catch (t)	12.14	15.88	21.94	19.88	27.69	35.19	18.09	20.96	30.05	28.65	44.24	55.62	42.39	372.72
Rockhampton	Boat no.	43	64	65	62	72	76	93	94	121	130	113	114	105	1152
	Effort (days)	508	690	616	668	620	742	985	928	1528	1438	1426	1163	1017	12329
	Catch (t)	19.89	30.31	33.69	38.53	34.78	37.26	41.64	40.51	77.90	68.42	76.14	70.93	61.59	631.58
Central	Boat no.	60	67	68	54	67	74	70	70	96	98	93	81	81	979
	Effort (days)	1152	1399	857	528	502	694	768	561	874	990	802	737	874	10736
	Catch (t)	25.61	37.41	26.36	16.73	22.73	28.00	34.90	20.71	30.50	37.34	32.49	44.47	42.40	399.65
Northern Dry	Boat no.	99	108	88	82	76	95	87	80	100	110	103	98	109	1235
	Effort (days)	1825	2484	1754	1423	891	1259	910	778	1046	1182	1325	1692	1355	17924
	Catch (t)	41.66	63.97	52.99	49.61	44.17	57.95	57.52	36.74	62.30	72.65	99.07	143.38	46.88	828.91
Northern Wet	Boat no.	159	154	158	144	146	164	168	156	178	213	193	206	193	2231
	Effort (days)	3738	5253	4495	3113	3438	3716	3469	2804	3385	4911	3795	4255	4039	50411
	Catch (t)	295.45	409.58	393.15	265.55	239.44	266.59	259.88	189.33	222.69	365.53	267.34	330.73	264.59	3769.85
Far North	Boat no.	43	41	46	45	42	43	50	61	68	82	88	81	84	774
	Effort (days)	843	1269	1281	1094	1111	942	998	1016	989	1881	1767	1713	1561	16465
	Catch (t)	45.21	56.02	56.55	86.16	77.52	46.66	56.60	54.09	59.29	103.76	99.82	99.15	100.73	941.57
Gulf North	Boat no.	*	*	12	13	19	22	31	42	41	39	36	35	27	323
	Effort (days)	*	*	338	377	581	793	997	1228	1153	1155	904	1097	664	9486
	Catch (t)	*	*	30.03	67.44	116.49	165.07	160.47	166.27	115.36	153.89	112.74	128.90	77.83	1324.88
Gulf South	Boat no.	0	9	19	13	12	13	17	25	25	33	21	24	26	237
	Effort (days)	0	188	583	79	169	263	283	358	379	440	274	430	423	3869
	Catch (t)	0	1.23	24.22	5.67	38.85	53.59	39.53	53.67	49.40	79.63	42.43	60.34	78.18	534.73
Total Boat no.		482	522	539	510	534	607	611	623	738	845	795	788	735	8329
Total Effort (days)		8764	12463	10932	8249	8124	9791	9458	8555	10397	13306	11786	12627	11142	135594
Total Catch (t)		451.61	672.85	656.67	567.16	617.10	713.72	686.83	596.25	663.66	933.27	791.95	957.32	728.04	9036.42

Appendix 3. Queensland commercial catch and effort for mackerel species by location and year. (* = < 5 boat rule applied – no data for reasons of confidentiality)
Table 5. Shark mackerel.

		Year													
Location	**Data**	**1988**	**1989**	**1990**	**1991**	**1992**	**1993**	**1994**	**1995**	**1996**	**1997**	**1998**	**1999**	**2000**	**Grand Total**
Moreton	Boat no.	*	*	0	0	*	0	*	0	*	*	*	*	*	21
	Effort (days)	*	*	0	0	*	0	*	0	*	*	*	*	*	52
	Catch (t)	*	*	0	0	*	0	*	0	*	*	*	*	*	0.75
Fraser	Boat no.	0	*	0	*	*	*	7	*	*	*	11	*	*	49
	Effort (days)	0	*	0	*	*	*	7	*	*	*	25	*	*	87
	Catch (t)	0	*	0	*	*	*	0.10	*	*	*	0.60	*	*	1.85
Rockhampton	Boat no.	0	*	*	*	*	*	7	8	14	13	25	21	13	117
	Effort (days)	0	*	*	*	*	*	11	24	32	51	74	50	36	325
	Catch (t)	0	*	*	*	*	*	0.13	0.36	0.30	0.39	0.63	0.86	0.29	3.82
Central	Boat no.	16	39	50	42	45	47	47	46	62	62	46	47	36	585
	Effort (days)	375	890	1111	782	450	879	626	876	1174	815	723	733	533	9967
	Catch (t)	3.65	22.52	31.26	22.35	18.61	24.29	28.67	31.68	30.75	34.95	21.73	23.38	22.42	316.27
Northern Dry	Boat no.	27	54	55	50	53	63	61	49	55	46	55	43	43	654
	Effort (days)	993	1560	1520	1296	1018	1221	729	1042	896	498	727	929	513	12942
	Catch (t)	9.89	20.08	33.90	36.69	27.14	30.86	23.42	27.91	20.68	21.76	17.12	21.24	12.47	303.13
Northern Wet	Boat no.	12	47	41	39	43	59	43	49	49	61	54	52	64	613
	Effort (days)	185	631	616	537	469	715	589	564	489	1020	690	614	910	8029
	Catch (t)	1.93	11.18	10.31	12.00	11.67	15.19	10.83	9.03	8.78	15.26	9.35	8.88	14.50	138.91
Far North	Boat no.	0	10	15	17	11	17	18	17	18	26	26	26	24	227
	Effort (days)	0	198	555	381	185	283	284	209	190	382	326	426	274	3693
	Catch (t)	0	3.5	11.16	11.63	4.29	6.56	6.35	4.34	3.66	7.89	8.12	9.70	5.13	82.33
Gulf North	Boat no.	0	0	0	0	0	*	*	0	*	*	0	0	0	7
	Effort (days)	0	0	0	0	0	*	*	0	*	*	0	0	0	15
	Catch (t)	0	0	0	0	0	*	*	0	*	*	0	0	0	0.56
Gulf South	Boat no.	0	0	0	0	0	0	0	*	0	0	0	0	0	*
	Effort (days)	0	0	0	0	0	0	0	*	0	0	0	0	0	*
	Catch (t)	0	0	0	0	0	0	0	*	0	0	0	0	0	*
Total Boat no.		57	155	163	153	163	195	185	173	206	218	223	198	185	2274
Total Effort (days)		1555	3289	3812	3012	2125	3115	2248	2722	2795	2792	2580	2779	2277	35111
Total Catch (t)		15.48	57.46	86.81	82.88	62.15	77.15	69.53	73.40	64.35	81.38	57.81	64.32	54.94	847.67

Appendix 3. Queensland commercial catch and effort for mackerel species by location and year. (* = < 5 boat rule applied – no data for reasons of confidentiality)

Table 6. Unspecified mackerel.

		Year													
Location	**Data**	**1988**	**1989**	**1990**	**1991**	**1992**	**1993**	**1994**	**1995**	**1996**	**1997**	**1998**	**1999**	**2000**	**Grand Total**
Moreton	Boat no.	*	8	*	8	13	26	22	23	31	32	23	19	19	232
	Effort (days)	*	38	*	16	27	118	107	120	142	176	101	66	199	1123
	Catch (t)	*	2.33	*	0.22	2.35	4.24	7.61	5.86	7.30	8.57	5.71	3.55	15.77	65.71
Fraser	Boat no.	12	7	6	*	33	72	54	52	57	65	55	49	40	50
	Effort (days)	84	22	10	*	289	709	367	506	468	443	430	464	406	4198
	Catch (t)	4.80	0.60	0.32	*	44.93	43.42	33.05	36.90	25.18	23.13	12.19	35.11	32.48	310.50
Rockhampton	Boat no.	10	7	*	10	7	25	31	35	30	32	28	23	20	263
	Effort (days)	36	15	*	36	15	58	78	170	109	194	109	58	83	972
	Catch (t)	0.64	0.23	*	0.52	0.19	2.03	2.53	2.89	1.22	8.01	4.64	1.66	1.52	26.25
Central	Boat no.	38	11	*	15	18	36	35	28	32	39	21	21	18	317
	Effort (days)	634	147	*	98	57	189	247	220	184	207	129	117	79	2350
	Catch (t)	17.04	1.89	*	1.91	2.13	6.66	11.28	12.87	8.68	7.27	8.37	10.95	6.52	98.22
Northern Dry	Boat no.	36	*	*	9	18	26	27	26	24	38	28	24	21	279
	Effort (days)	594	*	*	31	128	253	352	368	348	516	284	245	268	3404
	Catch (t)	13.05	*	*	5.70	11.93	30.19	42.74	36.68	50.38	69.74	34.01	27.29	37.49	369.59
Northern Wet	Boat no.	32	14	19	22	19	19	22	24	34	27	20	20	12	284
	Effort (days)	239	192	71	145	67	66	108	113	129	246	113	66	66	1621
	Catch (t)	3.93	1.31	1.11	9.24	7.18	1.61	7.86	6.44	6.30	18.94	3.24	2.98	1.72	71.85
Far North	Boat no.	7	6	6	*	7	24	22	8	8	15	18	10	7	142
	Effort (days)	88	72	84	*	33	165	75	47	53	162	121	76	35	1033
	Catch (t)	1.00	1.07	1.59	*	0.72	3.32	1.29	1.38	2.05	4.05	4.84	2.50	1.40	25.51
Gulf North	Boat no.	0	*	0	*	*	*	*	9	*	10	6	*	6	51
	Effort (days)	0	*	0	*	*	*	*	47	*	94	16	*	32	312
	Catch (t)	0	*	0	*	*	*	*	2.56	*	5.93	2.18	*	0.88	20.62
Gulf South	Boat no.	0	0	0	0	*	11	14	17	20	13	9	6	10	103
	Effort (days)	0	0	0	0	*	69	80	92	173	44	24	24	93	663
	Catch (t)	0	0	0	0	*	2.97	2.09	1.87	13.98	1.81	0.37	1.08	9.86	59.38
Total Boat no.		139	56	46	72	120	244	232	222	239	271	208	174	153	2176
Total Effort (days)		1680	499	240	415	683	1651	1458	1683	1620	2082	1327	1143	1261	15742
Total Catch (t)		40.58	7.61	8.28	36.31	95.09	95.72	111.09	117.46	116.25	147.44	75.55	88.62	107.63	1047.63

Appendix 4. Northern Territory commercial harvest of mackerel.

Table 1. Commercial catch (kg) by year 1983 - 2000 (- = catches of these species not recorded).

	Year														
Mackerel Species	**1983**	**1984**	**1985**	**1986**	**1987**	**1988**	**1989**	**1990**	**1991**	**1992**	**1993**	**1994**	**1995**	**1996**	**1997**
School	-	-	-	-	-	-	-	110	0	140	50	80	70	0	0
Spotted	-	-	-	-	-	-	-	0	10	50	460	240	150	535	462
Grey	10	27960	174670	71950	98430	35740	30440	70720	77350	76700	107670	103450	165510	277240	284855
Narrow-barred Spanish	158770	86830	146620	54030	78610	75960	124220	257350	200050	174290	132880	178890	219280	245661	245371
Unspecified	3370	24740	60780	22470	32750	84410	147000	83810	87950	6940	660	1840	1210	534	158
Total Catch (kg)	162160	139520	382060	148450	209790	196110	301660	411980	365360	258120	241730	284500	386220	523969	530846

	Year			
Mackerel Species	**1998**	**1999**	**2000**	**Total**
School	4	0	0	454
Spotted	183	204	91	2385
Grey	240812	139783	212915	2196205
Narrow-barred Spanish	224135	319987	313738	3236672
Unspecified	165	111	60	558958
Total Catch (kg)	465299	460085	526804	5994674

Table 2. Commercial catch (kg) by method between 1990 - 2000 (- = catches of these species not recorded).

	Method				
Mackerel Species	**Netting**	**Line**	**Trawl**	**Unidentified**	**Total**
School	53	392	-	0	445
Spotted	232	2159	-	0	2391
Grey	1730019	26989	14129	1804	1772941
Narrow-barred Spanish	105729	2367736	23980	56	2497501
Unspecified	127344	53365	15	2716	183440
Total Catch (kg)	1963377	2450641	38124	4576	4456718

Appendix 5. Western Australia commercial catch and effort for mackerel species.

Commercial catch by year 1980 - 2000.

	Year																
Mackerel Species	**1980**	**1981**	**1982**	**1983**	**1984**	**1985**	**1986**	**1987**	**1988**	**1989**	**1990**	**1991**	**1992**	**1993**	**1994**	**1995**	**1996**
Narrow-barred Spanish	97877	205426	190164	248786	247091	270317	195157	249357	195568	164861	163855	296707	249263	319928	320694	307915	326180
Unspecified	10797	2525	19863	3627	1815	19447	39152	23867	89332	104469	166447	115823	79469	74982	87870	55756	93811
Total Effort (Boat days)	2471	3125	3057	3750	4528	5218	3263	4537	3923	3500	2702	2895	2922	3037	3059	2972	3631
Total Catch (kg)	108674	207951	210027	252413	248906	289764	234309	273224	284900	269330	330302	412530	328732	394910	408564	363671	419991

	Year				
Mackerel Species	**1997**	**1998**	**1999**	**2000**	**Total**
Narrow-barred Spanish	423917	364331	335620	304687	5477701
Unspecified	120592	65739	72720	74569	1322672
Total Effort (Boat days)	3746	3068	2965	2332	70701
Total Catch (kg)	544509	430070	408340	379256	6800373

Appendix 6. New South Wales commercial catch for mackerel species.

Commercial catch (kg) by year* 1984 - 1999.

	Year																
Mackerel Species	**1984**	**1985**	**1986**	**1987**	**1988**	**1989**	**1990**	**1991**	**1992**	**1993**	**1994**	**1995**	**1996**	**1997**	**1998**	**1999**	**Total**
Spotted	74	317	491	665	731	717	4265	2473	12949	27163	8105	8009	31423	50061	41184	50845	239471
Narrow-barred Spanish	29062	20414	31410	33315	50923	27701	45005	15356	48003	17218	7957	9291	22605	13340	15041	7352	393992
Unspecified	7	22141	9923	1321	44	986	958	391	940	10063	52192	3967	1712	2707	6430	147	113928

* **(All harvests are for 12 month period beginning 1 July in each year.)**

Appendix 7. Number of diarists and number of days fished by participating diarists from own recreational boat by resident Queensland Statistical Division between December 1994 and November 1995.

		Summer		Autumn		Winter		Spring		
Fisher Type	**Statistical Division**	**Days Fished**	**Number of Diarists**	**Days Fished**	**Number of Diarists**	**Days Fished**	**Number of Diarists**	**Days Fished**	**Number of Diarists**	**Total Days Fished**
100 *	Brisbane	135	89	124	86	124	57	95	57	**478**
	Moreton	119	82	141	65	110	62	104	58	**474**
	Wide Bay / Burnett	170	88	162	85	99	75	102	73	**533**
	Fitzroy	171	133	164	112	129	102	120	95	**584**
	Mackay	134	100	138	84	99	79	115	74	**486**
	North	100	84	68	76	64	72	77	62	**309**
	Far North	109	72	71	74	72	73	78	70	**330**
100 Total		**938**	**649**	**868**	**582**	**697**	**520**	**691**	**488**	**3194**
200 •	Brisbane	34	26	43	21	21	19	12	18	**110**
	Moreton	31	29	30	25	30	28	26	28	**117**
	Wide Bay / Burnett	60	41	81	38	62	36	29	34	**232**
	Fitzroy	14	21	17	16	18	15	10	12	**59**
	Mackay	20	24	13	22	14	23	30	21	**77**
	North	11	9	0	6	0	5	8	5	**19**
	Far North	21	26	22	20	23	22	23	20	**89**
200 Total		**191**	**176**	**206**	**148**	**168**	**148**	**138**	**138**	**703**
Grand Total		**1129**	**825**	**1074**	**730**	**865**	**668**	**829**	**626**	**3897**

* Boat fishers who <u>targeted</u> small mackerel, regardless of whether they harvested, captured and released, or did not capture small mackerel in the 12 months preceding the survey.

• Boat fishers who <u>did not target</u> small mackerel, regardless of whether they harvested, captured and released, or did not capture small mackerel in the 12 months preceding the survey.

Appendix 8. Results of Kolmogorov-Smirnov tests to determine if diarists in Queensland between December 1994 and November 1995 were representative of the sample of fishers contacted in the 1994 survey. The tests compared the recalled number of days fished, by all participating diarists for the whole year and each season, with the recalled number of days fished respectively by all diarists and identified persons targeting or capturing small mackerel at the commencement of the diary exercise.

		Statistical Division																				
		Brisbane			Moreton			Wide Bay			Fitzroy			Mackay			Townsville			Far North		
TEST	GROUP	N	MEAN	D	N	MEAN	D	N	MEAN	D	N	MEAN	D	N	MEAN	D	N	MEAN	D	N	MEAN	D
Telesurvey	100	11	29.9	NS	12	28.8	NS	19	24.3	NS	15	13.5	NS	23	23.3	NS	30	17.4	NS	25	26.7	NS
vs all		106	31.9	0.24	91	57.8	0.31	105	31.5	0.23	145	20	0.26	108	20.5	0.14	104	15.7	0.18	103	22.6	0.23
diarists	200	4	42.3	NS	6	42.2	NS	11	16.8	NS	4	11.5	NS	5	12.2	NS	3	13.7	NS	9	7.5	NS
		32	35.9	0.25	36	34.3	0.33	47	22.5	0.14	22	17.6	0.27	29	15	0.19	11	14.7	0.3	31	13.6	0.41
Telesurvey	100	26	31.7	NS	20	26.1	SIG	36	31.6	NS	27	14.2	NS	31	21	NS	50	16.5	NS	56	27.9	NS
vs summer		89	31.8	0.2	83	61.3	0.34	88	29.8	0.07	133	20.4	0.19	100	21	0.05	84	15.9	0.13	72	20	0.17
diarists	200	10	50.1	NS	13	43.9	NS	17	16.2	NS	5	12	NS	10	22.3	NS	5	13.6	NS	14	8.2	NS
		26	31.4	0.35	29	31.6	0.25	41	23.6	0.18	21	17.8	0.29	24	11.4	0.43	9	15	0.27	26	14.4	0.37
Telesurvey	100	31	29.8	NS	37	28.2	NS	39	40.1	NS	48	16.3	NS	47	20.9	NS	58	16.5	NS	54	27.6	NS
vs autumn		86	32.4	0.2	65	54.9	0.21	85	25.9	0.15	112	20.7	0.14	84	21.1	0.17	76	15.8	0.17	74	20.4	0.14
diarists	200	15	46.3	NS	17	38.1	NS	20	16.5	NS	10	11.6	NS	12	23.8	NS	8	16.3	NS	20	9.2	NS
		21	29.7	0.26	25	33.6	0.13	38	24	0.21	16	19.8	0.38	22	9.6	0.42	6	12.2	0.25	20	15.4	0.35
Telesurvey	100	60	30.3	NS	40	28.8	NS	49	35.4	NS	58	16.1	NS	52	23.6	NS	62	16.5	NS	55	27.4	NS
vs winter		57	33.3	0.17	62	55.8	0.19	75	27	0.09	102	21.3	0.15	79	19.3	0.13	72	15.7	0.16	73	20.4	0.12
diarists	200	17	42.8	NS	14	36	NS	22	18.7	NS	11	10.5	NS	11	18.9	NS	9	15.8	NS	18	9.7	NS
		19	31	0.2	28	35.1	0.21	36	23	0.1	15	21.2	0.4	23	12.6	0.19	5	12.2	0.29	22	14.3	0.25
Telesurvey	100	60	29.9	NS	44	29.8	NS	51	34.8	NS	65	16.3	NS	57	25.1	NS	72	16.5	NS	58	27.6	NS
vs spring		57	33.8	0.2	57	40.3	0.16	73	27.2	0.11	95	21.5	0.15	74	17.9	0.15	62	15.7	0.15	70	20	0.17
diarists	200	18	41.2	NS	14	36	NS	24	22.3	NS	14	16.8	NS	13	18.6	NS	9	15.8	NS	20	11.5	NS
		18	31.9	0.22	28	35.1	0.21	34	20.8	0.13	12	16.5	0.19	21	12.1	0.26	5	12.2	0.29	20	13	0.25
All diarists	100	17	32.8	NS	8	22.1	NS	17	39.9	NS	12	15.2	NS	8	14.6	NS	20	15.2	NS	31	28.8	NS
vs summer		89	31.8	0.23	83	61.2	0.48	88	29.8	0.22	133	20.4	0.18	100	21	0.33	84	15.9	0.07	72	20	0.25
diarists	200	6	55.3	NS	7	45.4	NS	6	15	NS	1	14	NA	5	32.4	NS	2	13.5	NS	5	9.6	NS
		26	31.4	0.51	29	31.6	0.18	41	23.6	0.26	21	17.7	NA	24	11.4	0.63	9	15	0.44	26	14.4	0.41
All diarists	100	20	29.8	NS	26	65.3	NS	20	55.2	SIG	33	17.6	NS	24	18.6	NS	28	15.5	NS	29	28.4	NS
vs autumn		86	32.5	0.22	65	54.9	0.19	85	25.9	0.35	112	20.7	0.11	84	21.1	0.28	76	15.8	0.13	74	20.4	0.24
diarists	200	11	47.7	NS	11	35.9	NS	9	16	NS	6	11.7	NS	7	32	NS	5	17.8	NS	11	10.5	NS
		21	29.7	0.31	25	33.6	0.14	38	24	0.27	16	19.8	0.38	22	9.6	0.57	6	12.2	0.33	20	15.4	0.31
All diarists	100	49	30.4	NS	29	62.2	NS	30	42.5	NS	43	17	NS	29	23.8	NS	32	15.7	NS	30	28.1	NS
vs winter		57	33.3	0.16	62	55.8	0.16	75	27.1	0.21	102	21.3	0.14	79	19.3	0.2	72	15.7	0.12	73	20.4	0.22
diarists	200	13	43	NS	8	31.4	NS	11	20.5	NS	7	9.8	NS	6	24.5	NS	6	16.8	NS	3	12	NS
		19	31	0.23	28	35.1	0.18	36	23.1	0.21	15	21.2	0.4	23	12.6	0.33	5	12.2	0.43	22	14.4	0.19
All diarists	100	49	29.9	NS	34	87.1	NS	32	41	NS	50	17.2	NS	34	26.3	NS	42	15.8	NS	33	28.3	NS
vs spring		57	33.8	0.2	57	40.3	0.11	73	27.2	0.18	95	21.5	0.13	74	17.9	0.2	62	15.7	0.1	70	20	0.27
diarists	200	14	40.9	NS	8	31.4	NS	13	27	NS	10	18.9	NS	8	22.6	NS	6	16.8	NS	11	14.8	NS
		18	31.9	0.21	28	35.1	0.18	34	20.8	0.26	12	16.5	0.2	21	12.1	0.33	5	12.2	0.43	20	13	0.16
All diarists	ALL	67	32.1	NS	47	73.4	NS	49	35.6	NS	64	17.4	NS	44	25.8	NS	51	15.7	NS	53	24	NS
vs all year		71	33.6	0.18	80	38.1	0.08	103	25.4	0.15	103	21.1	0.11	93	16.3	0.18	64	15.6	0.07	81	18.3	0.22
diarists																						
Telesurvey	ALL	497	16.2	SIG	689	15.9	SIG	392	13.1	SIG	267	11.4	SIG	243	11.5	SIG	231	14.2	SIG	429	11.3	SIG
vs all iarists		138	32.9	0.34	127	51.2	0.4	152	28.7	0.34	167	19.7	0.31	137	19.4	0.32	115	15.6	0.28	134	20.6	0.33

Appendix 9. Frequency of 0 (zero) recreational harvest or capture and release of each mackerel species for diarists in Queensland for each season between December 1994 and November 1995.

Table 1. Frequency for Type 100 diarists (ie., Boat fishers who <u>targeted</u> small mackerel, regardless of whether they harvested, captured and released, or did not capture small mackerel in the 12 months preceding the survey).

		Summer		Autumn		Winter		Spring	
Mackerel Species	**Statistical Division**	**No. of Diarists**	**% Capturing 0 fish**	**No. of Diarists**	**% Capturing 0 fish**	**No. of Diarists**	**% Capturing 0 fish**	**No. of Diarists**	**% Capturing 0 fish**
Spotted	Brisbane	89	95.5	85	96.5	57	98.2	57	98.2
	Moreton	83	88	65	89.2	62	95.2	57	94.7
	Wide Bay	88	85.2	85	87.1	75	98.7	73	95.5
	Fitzroy	133	95.5	112	91.1	102	92.2	95	89.5
	Mackay	100	94	84	92.9	79	92.4	74	82.4
	Northern	84	96.4	76	98.7	72	91.7	62	88.7
	Far North	72	97.2	74	98.6	73	95.9	70	97.1
	Total	**649**	**92.6**	**581**	**93.3**	**520**	**94.6**	**488**	**91.8**
School	Brisbane	89	98.9	85	91.8	57	91.2	57	96.5
	Moreton	83	94	65	93.8	62	90.3	57	98.2
	Wide Bay	88	84.1	85	85.9	75	93.3	73	90.4
	Fitzroy	133	91	112	90.2	102	88.2	95	86.3
	Mackay	100	91	84	88.1	79	94.9	74	90.5
	Northern	84	97.6	76	97.4	72	91.7	62	91.9
	Far North	72	97.2	74	98.6	73	100	70	98.6
	Total	**649**	**93.1**	**581**	**91.9**	**520**	**92.7**	**488**	**92.6**
Grey	Brisbane	89	100	85	100	57	100	57	100
	Moreton	83	100	65	100	62	100	57	100
	Wide Bay	88	98.9	85	100	75	100	73	100
	Fitzroy	133	100	112	99.1	102	99	95	100
	Mackay	100	99	84	98.8	79	98.7	74	97.3
	Northern	84	100	76	100	72	100	62	100
	Far North	72	100	74	100	73	100	70	100
	Total	**649**	**99.7**	**581**	**99.7**	**520**	**99.6**	**488**	**99.6**
All Small	Brisbane	89	95.5	85	89.4	57	87.7	57	94.7
	Moreton	83	83.1	65	86.2	62	88.7	57	91.2
	Wide Bay	88	72.7	85	74.1	75	90.7	73	86.3
	Fitzroy	133	85.7	112	83	102	81.4	95	77.9
	Mackay	100	86	84	81	79	89.9	74	74.3
	Northern	84	91.7	76	97.4	72	80.6	62	79
	Far North	72	94.4	74	94.6	73	87.7	70	94.3
	Total	**649**	**86.7**	**581**	**84.1**	**520**	**86.3**	**488**	**84.6**

Appendix 9. Frequency of 0 (zero) recreational harvest or capture and release of each mackerel species for diarists in Queensland for each season between December 1994 and November 1995.

Table 1. (Continued).

		Summer		Autumn		Winter		Spring	
Mackerel Species	**Statistical Division**	**No. of Diarists**	**% Capturing 0 fish**	**No. of Diarists**	**% Capturing 0 fish**	**No. of Diarists**	**% Capturing 0 fish**	**No. of Diarists**	**% Capturing 0 fish**
Spanish	Brisbane	89	98.9	85	98.8	57	100	57	100
	Moreton	83	97.6	65	96.9	62	100	57	96.5
	Wide Bay	88	94.3	85	91.8	75	100	73	98.6
	Fitzroy	133	91	112	91.1	102	95.1	95	94.7
	Mackay	100	93	84	96.4	79	93.7	74	95.9
	Northern	84	91.7	76	97.4	72	93.1	62	91.9
	Far North	72	93.1	74	97.3	73	95.9	70	91.4
	Total	**649**	**94.0**	**581**	**95.4**	**520**	**96.5**	**488**	**95.5**
Shark	Brisbane	89	100	85	100	57	100	57	100
	Moreton	83	100	65	100	62	100	57	100
	Wide Bay	88	100	85	98.8	75	100	73	98.6
	Fitzroy	133	99.2	112	99.1	102	99	95	100
	Mackay	100	100	84	97.6	79	100	74	100
	Northern	84	100	76	100	72	98.6	62	96.8
	Far North	72	98.6	74	97.3	73	97.3	70	98.6
	Total	**649**	**99.7**	**581**	**99.0**	**520**	**99.2**	**488**	**99.2**
Unspecified	Brisbane	89	100	85	100	57	98.2	57	100
	Moreton	83	100	65	100	62	100	57	100
	Wide Bay	88	96.6	85	91.8	75	97.3	73	98.6
	Fitzroy	133	100	112	98.2	102	95.1	95	93.7
	Mackay	100	99	84	97.6	79	100	74	94.6
	Northern	84	98.8	76	100	72	94.4	62	95.2
	Far North	72	100	74	100	73	97.3	70	100
	Total	**649**	**99.2**	**581**	**98.1**	**520**	**97.3**	**488**	**97.1**

Appendix 9. Frequency of 0 (zero) recreational harvest or capture and release of each mackerel species for diarists in Queensland for each season between December 1994 and November 1995.

Table 2. Frequency for Type 200 diarists (ie., Boat fishers who did not target small mackerel, regardless of whether they harvested, captured and released, or did not capture small mackerel in the 12 months preceding the survey).

		Summer		Autumn		Winter		Spring	
Mackerel Species	**Statistical Division**	**No. of Diarists**	**% Capturing 0 fish**	**No. of Diarists**	**% Capturing 0 fish**	**No. of Diarists**	**% Capturing 0 fish**	**No. of Diarists**	**% Capturing 0 fish**
Spotted	Brisbane	25	100	20	100	18	100	17	100
	Moreton	29	100	25	100	28	100	28	100
	Wide Bay	41	90.2	38	92.1	36	97.2	34	97.1
	Fitzroy	21	95.2	16	93.8	15	100	12	100
	Mackay	24	95.8	22	100	23	91.3	21	90.5
	Northern	9	100	6	100	5	100	5	100
	Far North	26	100	20	100	22	90.9	20	95
	Total	**175**	**96.6**	**147**	**97.3**	**147**	**96.6**	**137**	**97.8**
School	Brisbane	25	100	20	95	18	94.4	17	100
	Moreton	29	100	25	100	28	100	28	100
	Wide Bay	41	97.6	38	84.2	36	94.4	34	91.2
	Fitzroy	21	100	16	100	15	100	12	100
	Mackay	24	100	22	100	23	100	21	95.2
	Northern	9	100	6	100	5	100	5	80
	Far North	26	100	20	100	22	100	20	100
	Total	**175**	**99.4**	**147**	**95.2**	**147**	**98.0**	**137**	**96.4**
Grey	Brisbane	25	100	20	100	18	100	17	100
	Moreton	29	100	25	100	28	100	28	100
	Wide Bay	41	100	38	100	36	100	34	100
	Fitzroy	21	100	16	100	15	100	12	100
	Mackay	24	100	22	100	23	100	21	100
	Northern	9	100	6	100	5	100	5	100
	Far North	26	100	20	100	22	100	20	100
	Total	**175**	**100**	**147**	**100**	**147**	**100**	**137**	**100**
All Small	Brisbane	25	100	20	95	18	94.4	17	100
	Moreton	29	100	25	100	28	100	28	100
	Wide Bay	41	87.8	38	73.7	36	91.7	34	88.2
	Fitzroy	21	95.2	16	93.8	15	100	12	100
	Mackay	24	95.8	22	100	23	91.3	21	90.5
	Northern	9	88.9	6	100	5	100	5	80
	Far North	26	92.3	20	95	22	86.4	20	80
	Total	**175**	**94.3**	**147**	**91.2**	**147**	**93.9**	**137**	**92.0**

Appendix 9. Frequency of 0 (zero) recreational harvest or capture and release of each mackerel species for diarists in Queensland for each season between December 1994 and November 1995.

Table 2. (Continued).

		Summer		Autumn		Winter		Spring	
Mackerel Species	**Statistical Division**	**No. of Diarists**	**% Capturing 0 fish**	**No. of Diarists**	**% Capturing 0 fish**	**No. of Diarists**	**% Capturing 0 fish**	**No. of Diarists**	**% Capturing 0 fish**
Spanish	Brisbane	25	100	20	100	18	100	17	100
	Moreton	29	100	25	100	28	100	28	100
	Wide Bay	41	97.6	38	97.4	36	100	34	100
	Fitzroy	21	100	16	100	15	100	12	100
	Mackay	24	100	22	100	23	95.7	21	100
	Northern	9	100	6	100	5	100	5	80
	Far North	26	96.2	20	90	22	95.5	20	90
	Total	**175**	**98.9**	**147**	**98.0**	**147**	**98.6**	**137**	**97.8**
Shark	Brisbane	25	100	20	100	18	100	17	100
	Moreton	29	100	25	100	28	100	28	100
	Wide Bay	41	100	38	100	36	100	34	100
	Fitzroy	21	100	16	100	15	100	12	100
	Mackay	24	100	22	100	23	100	21	100
	Northern	9	88.9	6	100	5	100	5	100
	Far North	26	92.3	20	95	22	98.5	20	90
	Total	**175**	**98.3**	**147**	**99.3**	**147**	**99.3**	**137**	**98.5**
Unspecified	Brisbane	25	100	20	100	18	100	17	100
	Moreton	29	100	25	100	28	100	28	100
	Wide Bay	41	97.6	38	92.1	36	100	34	100
	Fitzroy	21	100	16	100	15	100	12	100
	Mackay	24	100	22	100	23	100	21	100
	Northern	9	100	6	100	5	100	5	100
	Far North	26	100	20	100	22	95.5	20	90
	Total	**175**	**99.7**	**147**	**98.0**	**147**	**99.3**	**137**	**98.5**

Appendix 10. Estimates of mackerel (number of fish ± 90%C.I.) of each species captured by resident boat-based recreational fishers in Queensland between December 1994 and November 1995. All capture estimates are based on catches of diarists and estimates of the number of registered recreational boats that were used to target or capture small mackerel in the 12 months prior to the 1994 telephone and mail survey.

Table 1. Mackerel harvest (caught and kept).

		Summer			Autumn			Winter			Spring			Year Total		
Mackerel Species	**Statistical Division**	**No. Fish**	**Lower**	**Upper**	**No. Fish**	**Lower**	**Upper**	**No. Fish**	**Lower**	**Upper**	**No. Fish**	**Lower**	**Upper**	**No. Fish**	**Lower**	**Uppe r**
Spotted	Brisbane	2648	322	7468	354	57	922	0	0	0	88	0	281	3090	700	7879
	Moreton	900	399	1668	795	183	1981	124	29	289	168	39	387	1987	1127	3361
	Wide Bay	5981	1906	13914	3104	1292	6080	62	0	159	258	61	649	9404	4792	17595
	Fitzroy	297	142	502	1928	735	3725	2882	356	8401	962	303	2222	6069	2890	11762
	Mackay	352	118	743	306	79	649	266	78	551	3428	1209	6949	4351	2073	7906
	Northern	777	46	2266	39	0	126	1565	448	3317	2535	716	5874	4915	2422	8727
	Far North	81	0	211	53	0	181	862	251	1895	116	25	275	1111	471	2166
	Total	**11035**	**5520**	**19203**	**6579**	**4071**	**10005**	**5759**	**2703**	**11507**	**7553**	**4294**	**12087**	**30927**	**23166**	**41758**
School	Brisbane	0	0	0	664	245	1251	440	128	952	352	0	1016	1456	770	2355
	Moreton	323	98	681	854	152	2092	710	225	1429	2184	0	7283	4072	1371	9349
	Wide Bay	3845	1316	8428	1809	966	3093	219	60	469	2310	809	4931	8185	5046	13394
	Fitzroy	743	317	1405	1963	829	3638	630	266	1178	1170	446	2477	4505	2948	6591
	Mackay	1003	272	2259	1027	288	2413	295	62	675	754	321	1357	3080	1830	4895
	Northern	35	0	121	351	0	1067	1770	637	3633	2119	684	4516	4276	2257	7176
	Far North	460	0	1407	184	0	619	0	0	0	28	0	92	672	101	1724
	Total	**6410**	**3641**	**11108**	**6854**	**4802**	**9454**	**4065**	**2686**	**6184**	**8917**	**5106**	**14439**	**26246**	**20585**	**33551**
Grey	Brisbane	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
	Moreton	23	0	74	0	0	0	0	0	0	0	0	0	23	0	74
	Wide Bay	0	0	0	0	0	0	0	0	0	193	0	584	193	0	584
	Fitzroy	371	0	1144	617	26	1693	24	0	80	26	0	86	1039	306	2248
	Mackay	513	0	1437	389	46	1159	266	0	783	694	163	1606	1861	875	3230
	Northern	71	0	232	78	0	271	124	0	332	96	0	311	368	132	708
	Far North	0	0	0	0	0	0	294	0	943	418	0	1444	711	28	1797
	Total	**978**	**283**	**2051**	**1084**	**351**	**2260**	**707**	**227**	**1492**	**1426**	**588**	**2743**	**4196**	**2648**	**6145**
All Small	Brisbane	2588	55	7518	1014	310	1905	433	81	951	442	0	1047	4477	1585	9640
	Moreton	1238	604	2119	1649	245	3605	830	183	1651	2373	63	6951	6089	2552	11429
	Wide Bay	10058	2989	19132	5324	2628	8950	375	100	729	2952	841	5782	18710	10365	28736
	Fitzroy	1445	581	2538	4535	1767	7689	4704	1043	10515	3228	866	5913	13912	8286	20967
	Mackay	1943	649	3568	2429	798	4562	832	164	1672	5283	2077	9089	10487	6500	15226
	Northern	903	106	2354	485	0	1328	3892	1517	6894	5574	2001	10033	10854	6167	16348
	Far North	668	81	1660	352	26	818	1416	403	2777	812	196	1726	3248	1545	5005
	Total	**18843**	**10634**	**29153**	**15788**	**10878**	**21408**	**12483**	**7392**	**19232**	**20664**	**13451**	**28576**	**67777**	**53526**	**83237**

Appendix 10. Estimates of mackerel (number of fish ± 90%C.I.) of each species captured by resident boat-based recreational fishers in Queensland between December 1994 and November 1995. All capture estimates are based on catches of diarists and estimates of the number of registered recreational boats that were used to target or capture small mackerel in the 12 months prior to the 1994 telephone and mail survey.

Table 1. Mackerel harvest (caught and kept) (Continued).

		Summer			Autumn			Winter			Spring			Year Total		
Mackerel Species	**Statistical Division**	**No. Fish**	**Lower**	**Upper**	**No. Fish**	**Lower**	**Upper**	**No. Fish**	**Lower**	**Upper**	**No. Fish**	**Lower**	**Upper**	**No. Fish**	**Lower**	**Upper**
Spanish	Brisbane	56	0	191	1593	0	5448	0	0	0	0	0	0	1649	0	5518
	Moreton	208	0	638	88	0	231	0	0	0	67	0	159	363	116	804
	Wide Bay	400	112	854	416	149	890	0	0	0	32	0	102	848	424	1450
	Fitzroy	576	251	1105	485	204	973	97	26	191	156	50	322	1314	817	1994
	Mackay	187	76	351	83	0	276	115	31	228	0	0	0	385	207	644
	Northern	424	172	765	39	0	129	618	168	1335	397	140	798	1477	849	2295
	Far North	131	52	249	289	72	625	242	68	505	645	240	1339	1307	781	2076
	Total	**1982**	**1339**	**2766**	**2993**	**1123**	**6957**	**1071**	**545**	**1804**	**1297**	**763**	**2052**	**7344**	**5154**	**11342**
Shark	Brisbane	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
	Moreton	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
	Wide Bay	0	0	0	28	0	93	0	0	0	32	0	107	60	0	153
	Fitzroy	37	0	124	22	0	72	24	0	83	0	0	0	83	22	189
	Mackay	0	0	0	56	0	133	0	0	0	0	0	0	56	0	133
	Northern	35	0	129	0	0	0	41	0	140	239	0	604	315	75	695
	Far North	119	24	290	105	0	308	81	0	178	116	27	270	421	220	689
	Total	**191**	**69**	**391**	**211**	**81**	**424**	**146**	**54**	**284**	**387**	**132**	**770**	**935**	**585**	**1414**
Unspecified	Brisbane	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
	Moreton	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
	Wide Bay	80	0	215	333	72	829	94	0	329	161	0	527	668	268	1258
	Fitzroy	0	0	0	0	0	0	1162	27	3860	988	97	2903	2150	277	5147
	Mackay	47	0	152	667	0	2105	0	0	0	441	37	1272	1155	214	2749
	Northern	0	0	0	0	0	0	412	91	1043	574	0	1858	986	193	2435
	Far North	0	0	0	0	0	0	162	26	431	120	0	351	282	88	618
	Total	**127**	**25**	**275**	**999**	**218**	**2563**	**1831**	**508**	**4611**	**2284**	**886**	**4581**	**5241**	**2820**	**8575**

Appendix 10. Estimates of mackerel (number of fish ± 90%C.I.) of each species captured by resident boat-based recreational fishers in Queensland between December 1994 and November 1995. All capture estimates are based on catches of diarists and estimates of the number of registered recreational boats that were used to target or capture small mackerel in the 12 months prior to the 1994 telephone and mail survey.

Table 2. Mackerel released (caught and released).

		Summer			Autumn			Winter			Spring			Year Total		
Mackerel Species	**Statistical Division**	**No. Fish**	**Lower**	**Upper**	**No. Fish**	**Lower**	**Upper**	**No. Fish**	**Lower**	**Upper**	**No. Fish**	**Lower**	**Upper**	**No. Fish**	**Lower**	**Upper**
Spotted	Brisbane	451	0	1466	59	0	197	88	0	277	0	0	0	598	63	1684
	Moreton	23	0	76	29	0	101	62	0	208	0	0	0	114	24	274
	Wide Bay	801	169	1715	83	0	225	91	0	309	128	0	438	1103	438	2064
	Fitzroy	167	61	338	142	21	382	1017	279	2404	260	82	541	1586	785	2948
	Mackay	443	24	1066	139	27	345	1364	280	2969	593	158	1448	2540	1238	4325
	Northern	71	0	237	0	0	0	288	0	713	96	0	315	455	135	928
	Far North	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
	Total	**1956**	**991**	**3401**	**452**	**209**	**786**	**2910**	**1507**	**4885**	**1077**	**541**	**1978**	**6395**	**4396**	**8821**
School	Brisbane	169	0	575	177	52	382	434	83	1111	0	0	0	780	306	1507
	Moreton	0	0	0	354	0	1085	154	0	456	67	0	227	575	137	1391
	Wide Bay	667	175	1741	1095	347	2361	1128	141	3140	129	30	292	3019	1517	5403
	Fitzroy	56	0	150	1147	487	2163	2494	465	6594	832	366	1574	4529	2245	8520
	Mackay	537	111	1360	4610	263	14182	5139	0	16608	1545	0	4814	11830	2730	26463
	Northern	106	0	284	156	0	531	741	85	1735	0	0	0	1003	333	2080
	Far North	162	0	518	26	0	87	0	0	0	0	0	0	189	0	570
	Total	**1697**	**866**	**2954**	**7566**	**2824**	**17429**	**10091**	**3536**	**22892**	**2573**	**927**	**5846**	**21926**	**12586**	**36875**
Grey	Brisbane	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
	Moreton	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
	Wide Bay	80	0	262	0	0	0	0	0	0	0	0	0	80	0	262
	Fitzroy	0	0	0	22	0	75	48	0	161	0	0	0	70	0	189
	Mackay	47	0	149	778	0	2566	473	0	1589	694	0	2241	1990	561	4280
	Northern	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
	Far North	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
	Total	**127**	**0**	**325**	**800**	**0**	**2574**	**521**	**0**	**1668**	**694**	**0**	**2241**	**2141**	**706**	**4457**
All Small	Brisbane	611	0	1732	240	50	481	696	104	1424	0	0	0	1547	568	2945
	Moreton	23	0	73	388	0	1096	221	0	551	66	0	219	698	133	1554
	Wide Bay	1643	560	3017	2210	982	3790	1174	99	3352	258	31	590	5285	3181	8366
	Fitzroy	227	54	433	2617	723	5375	5241	1586	11592	2425	898	4676	10510	5541	17099
	Mackay	1034	88	2214	5454	197	16814	7097	222	19193	2961	395	7612	16546	4147	34942
	Northern	214	34	443	157	0	481	1479	454	2700	394	0	888	2244	1078	3577
	Far North	169	0	515	86	0	229	106	0	309	28	0	90	389	77	823
	Total	**3921**	**2120**	**6123**	**11152**	**4177**	**23521**	**16015**	**6430**	**30241**	**6132**	**2636**	**11087**	**37219**	**23039**	**56452**

Appendix 10. Estimates of mackerel (number of fish ± 90%C.I.) of each species captured by resident boat-based recreational fishers in Queensland between December 1994 and November 1995. All capture estimates are based on catches of diarists and estimates of the number of registered recreational boats that were used to target or capture small mackerel in the 12 months prior to the 1994 telephone and mail survey.

Table 2. Mackerel released (caught and released) (Continued).

		Summer			Autumn			Winter			Spring			Year Total		
Mackerel Species	**Statistical Division**	**No. Fish**	**Lower**	**Upper**	**No. Fish**	**Lower**	**Upper**	**No. Fish**	**Lower**	**Upper**	**No. Fish**	**Lower**	**Upper**	**No. Fish**	**Lower**	**Upper**
Spanish	Brisbane	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
	Moreton	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
	Wide Bay	27	0	87	138	0	358	0	0	0	0	0	0	165	28	396
	Fitzroy	56	0	190	507	153	1111	121	28	254	78	23	165	762	363	1367
	Mackay	210	48	472	1750	113	5206	1211	0	3689	504	40	1458	3675	1169	7795
	Northern	0	0	0	78	0	261	82	0	278	48	0	159	208	47	469
	Far North	54	0	134	0	0	0	162	0	430	306	0	898	523	166	1135
	Total	**347**	**147**	**629**	**2473**	**711**	**5982**	**1577**	**361**	**4032**	**937**	**328**	**1971**	**5333**	**2779**	**9398**
Shark	Brisbane	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
	Moreton	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
	Wide Bay	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
	Fitzroy	0	0	0	0	0		0	0	0	0	0	0	0	0	0
	Mackay	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
	Northern	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
	Far North	0	0	0	60	0	203	80	0	256	28	0	92	168	29	390
	Total	**0**	**0**	**0**	**60**	**0**	**203**	**80**	**0**	**256**	**28**	**0**	**92**	**168**	**29**	**390**
Unspecified	Brisbane	0	0	0	0	0	0	176	0	575	0	0	0	176	0	575
	Moreton	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
	Wide Bay	107	0	311	1032	356	2045	31	0	107	0	0	0	1170	479	2164
	Fitzroy	0	0	0	1279	0	4007	1719	443	3758	1300	173	3523	4298	1855	7809
	Mackay	0	0	0	0	0	0	0	0	0	221	0	720	221	0	720
	Northern	35	0	118	0	0	0	453	84	1216	287	0	787	775	270	1548
	Far North	0	0	0	0	0	0	27	0	93	0	0	0	27	0	93
	Total	**142**	**29**	**352**	**2311**	**817**	**5078**	**2407**	**1024**	**4595**	**1808**	**547**	**4005**	**6668**	**3983**	**10446**