Bycatch Assessment of the Estuarine Commercial Gill Net Fishery in NSW

C. A. Gray, D.D. Johnson, D.J. Young and M. K. Broadhurst

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This research would not have been possible without the co-operation of many commercial fishers throughout NSW. We gratefully acknowledge their assistance in all aspects of the study. Members of the Estuary General Management Advisory Committee provided fruitful discussions of various aspects of the gillnet fishery.

Numerous colleagues assisted with sampling; in particular we thank Glen Cuthbert, Michael Wooden, Venessa Gale and Mark Bowland. Tracey McVea formatted the final report and Steve Kennelly and Crispian Ashby provided valuable comments. We also thank our numerous colleagues at NSW Fisheries who provided advice and comments on various aspects of the study.

NON-TECHNICAL SUMMARY

2000/172	Bycatch assessment of the estuarine commercial gill net fishery in NSW

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OBJECTIVE:

(1) Identify and quantify the rates of retained and discarded catches from the different types of gill nets used in the NSW estuarine commercial finfish fishery.

NON TECHNICAL SUMMARY:

OUTCOMES ACHIEVED:

Significant advice to fisheries managers and industry concerning all aspects of this study was provided and several proposed amendments to the regulations concerning the use and configurations of gill (mesh) nets were recommended and incorporated in the Estuary General Fishery Management Strategy and used in the Environmental Assessment of the Estuary General Fishery. In particular, it was recommended that the minimum stretched mesh size permitted in gillnets set overnight be increased from 80 mm to 95 mm. The research findings have also been used to help develop an alternate bottom-set gillnet for use in the dusky flathead gill net fishery.

Knowledge of the retained and discarded catches in a fishery and how they vary spatially, temporally and among different fishing operations is necessary for identifying the potential impacts of fishing on fish stocks and ecosystems, as well as assessing potential interactions among fisheries competing for the same resources (Alverson *et al*., 1994; Kennelly, 1995; Hall, 1999). Fishing can directly and indirectly affect the biomasses and harvested yields of stocks, ecological interactions among species and the productivity and functioning of ecosystems (Fennessy, 1994; Jennings and Kaiser, 1998; Hall, 1999; Kaiser and deGroot, 2000). Discarding in many fisheries is perceived as wasteful and can lead to significant conflict among different users of the resource and if not quantified, can be a major source of uncertainty in fisheries assessments (Chen and Gordon, 1997; Hall, 1999). Information on catch compositions along with data on the selectivity and behaviour of the fishing gears used and the species captured can also greatly assist in determining ways to mitigate bycatches and discarding in fisheries (Chopin and Arimoto, 1995; Hall, 1999; Millar and Fryer, 1999; Broadhurst, 2000). Because of the critical importance of bycatch and discarding issues in many fisheries throughout the world and the need for many fisheries to undergo environmental assessments, there has been much research in recent years to identify and resolve discarding and wastage in fisheries (Alverson *et al*., 1994; Kennelly, 1995; Hall, 1999). Whilst this research has mostly been focused on fisheries that use active fishing gears such as demersal trawls and seines (see Hall, 1999; Broadhurst, 2000; Kaiser and deGroot, 2000), much less emphasis has been placed on fisheries incorporating passive fishing gears, including gillnets (but see Berrow *et al*., 1994; Trippel *et al*., 1996; Gray, 2002; Hutchings and Lamberth, 2002).

Gillnets are the most common gear used by commercial fishers to capture fish in estuaries in New South Wales (NSW), Australia (Pease, 1999). Approximately 770 fishers are permitted to participate in the gillnet fishery which produces around 2500 tonnes of product per annum valued at around $AUD 5 million. Similar to many other coastal fisheries, one of the most contentious issues surrounding the management of the multi-species estuarine fisheries in New South Wales (NSW), Australia, concerns the impacts of discarding of bycatches from commercial fishing practices and the allocation of the fisheries resources among different user groups (primarily recreational versus commercial fisheries). Despite this, little is known about rates of capture of retained and discarded catches and the levels of discards has not been quantified across the different fishing practices used in the fishery. The aim of this study was to redress this current lack of knowledge for the estuarine commercial gillnet fishery in NSW. We achieved our objective by using a stratified observer-based survey where fisheries staff accompanied fishers during normal fishing operations and collected data on the compositions, numbers, weights and lengths of the retained and discarded catches.

The compositions and magnitudes of catches taken in gillnets set for dusky flathead (*Platycephalus fuscus*) in three barrier estuaries (Wallis, Tuggerah and Illawarra lakes) were quantified during 2001. Fishers operating in this fishery are only permitted to retain legal-sized dusky flathead and legal-sized blue swimmer (*Portunus pelagicus*) and mud crab (*Scylla serrata*), and all other organisms must be discarded. Sampling was stratified into two time periods; before and after 1 July 2001 which coincided with the increase in the minimum legal length (MLL) of dusky flathead from 33 to 36 cm total length (TL). A total of 81 fishing trips was sampled, which yielded 38 finfish and 2 portunid crab species. Legal-sized dusky flathead were the most abundant organism captured and accounted for 23-47% by number and 34-54% by weight of the mean observed catch depending on the estuary and survey period, with a mean of 25-59 flathead weighing 13-25 kg being caught per fisher-night. Analyses of similarity identified that the structure (species composition and relative abundance) of catches differed between estuaries, but not between sampling periods. Predominant bycatch species included legal and under-size blue swimmer crab, sea mullet (*Mugil cephalus*), luderick (*Girella tricuspidata*), bream (*Acanthopagrus australis*) and yellowfin leatherjacket (*Meuschenia trachylepis*). These five species accounted for 82% of total bycatch by number and 71% by weight, pooled across the 3 estuaries. More crabs were retained than discarded, with retained legal-size crabs (byproduct) accounting for 16% of total bycatch by number and 13% by weight, with an average of 5-22 crabs weighing 1-6 kg being caught per fisher-night, depending on the estuary. Overall, a total of 7% of dusky flathead captured (number) were below the MLL of 36 cm and discarded, suggesting the nets as currently configured may be relatively selective in catching legal-size flathead. The data show however that 41% of dusky flathead were < 40cm TL, indicating that if the MLL for this species is increased to this length as proposed, new nets will need to be introduced into the fishery.

A scientific observer program was also used throughout 2001 to quantify relationships among the compositions and rates of retained and discarded catches taken in the estuarine commercial multi-species gillnet fishery. Sampling was stratified across 6 estuaries (Richmond, Clarence, Camden Haven and Shoalhaven Rivers and Wallis and Illawarra Lakes) and 3 fishing periods that corresponded with the permitted fishing practices of set and immediate retrieve and overnight set. A total of 265 fishing trips was sampled, which yielded 58 species (53 finfish, 3 invertebrate, 1 bird, 1 tortoise) observed in catches, of which 45 species were retained and 48 species discarded. Sea mullet and luderick accounted for 85% by number of total observed catches, with a further 10% being contributed by bream, dusky flathead and blue swimmer crabs. The remaining 53 species accounted for < 5.5% by number of total observed catches. Multivariate analyses showed that the composition and relative numbers of species caught varied among estuaries and fishing periods. Retained sea mullet and luderick were most characteristic of catches when fishers were permitted only to set and immediately retrieve nets, whereas retained dusky flathead and retained and discarded bream were most important in distinguishing catches when fishers are permitted to set nets overnight. In general, more species and a greater mean number and weight of total individuals were retained than discarded in each fishing period. Average retained catches ranged from 37 to 609 kg per fisher-day and discarded catches from 1 to 10 kg per fisher-day. Throughout the entire survey, 6.2% by number and 3.3% by weight of catches were discarded, with undersized luderick, bream and blue swimmer crab collectively accounting for 69% by number and 49% by weight of all discards observed. Ratios of retained to discarded catches by weight were low (< 1:0.1) but varied according to mesh size and period. Compliance with minimum legal lengths (MLL) accounted for most discarding practices, but for those species with no MLL, discarding was also length-based. The relative selectivity of the nets used in the fishery was quantified for key species. The data show that the proportion of total discards varied with mesh size with fewer total discards occurring in the larger mesh sizes. It is evident that an increase in the minimum mesh size in this fishery from the current 80 mm to at least 89 mm (but preferably 95 mm – see Gray, 2002) would result in fewer total discards. In particular, this would have a significant effect on reducing the discarding of 2 species very important to recreational fishers, bream and luderick (see also Gray, 2002). However, such an increase would impact on retained catches of some other species, particularly sea mullet.

Apart from spatial and temporal fishing closures, solutions to discarding problems in multi-species fisheries elsewhere also include the development of more selective nets and fishing practices that minimise the capture and mortality of non-target species and undersized individuals of the target species. In investigating such options, managers and industry need to set priorities in terms of the importance of minimising the discarding of each species as opposed to maximising the retained catches of those and other species. Apart from developing and testing alternate gillnets with more appropriate configurations for use in these fisheries (e.g. height and material of nets – see Hamley, 1975; Millar and Fryer, 1999; Broadhurst *et al*., 2003; Godoy *et al*., 2003) a further option is to investigate the effects of reducing the permitted maximum setting time (overnight) of nets on catches. Discard levels may be lower and subsequent mortalities of fish may also be reduced because of the reduced soak times (Acosta, 1994; Chopin and Arimoto, 1995), potentially further reducing any potential negative ecological impacts of this fishery.

Keywords: gillnet, bycatch, discard, selectivity, estuarine fish, observer program, Australia.

1. INTRODUCTION

1.1. Background

The issues surrounding bycatch and discarding are amongst the most important facing the management of fisheries throughout the world. Considerable research over the past decade has shown that discarding can affect the yields of fisheries and the functioning of ecosystems (Fennessey 1994; Jennings and Kaiser 1998; Hall 1999; Kaiser and deGroot 2000). Consequently, much emphasis is being placed on reducing discarding in all types of fisheries. In developing strategies to manage discarding, it is fundamental to determine and define the real level of discarding and how it varies in space and time among different fishing operations (Alverson *et al* 1994; Kennelly 1995; Hall 1999). An understanding of the behavior and selectivity of fishing gears and the species captured can help ascertain ways to mitigate discarding (Hall 1999; Broadhurst 2000). Such information has been successfully used to reduce discarding and wastage in some fisheries (see Hall 1999; Broadhurst 2000; Kaiser and deGroot 2000).

One of the most controversial issues in NSW fisheries in recent years surrounds the management of the estuarine fisheries resources. In particular, there is much conflict between different harvest sectors over access and allocation of resources and of the impacts of discarding from commercial fishing on the sustainability of stocks. There is significant belief that the use of commercial fishing gears in estuaries leads to significant bycatch and discarding of undersized and/or unwanted fish and that discarding and mortality of these individuals is reported anecdotally to involve large quantities of recreationally and commercially important species.

Whilst public consternation may be a sufficient reason for fisheries managers and scientists to seek solutions to discarding issues, there are also many biological and economic reasons for doing so. Firstly, there is a clear need to determine the real, as opposed to the perceived, level of the problem and how it varies in space and time among particular fishing operations. If the anecdotal reports of large quantities of fish being discarded prove correct, then there would be obvious large and long-term benefits to all users of the resource if such discarding could be ameliorated. Further, reducing discards from the fishery will improve the efficiencies of the operations and could help improve the quality of the retained product.

1.2. Need

Reduction of wastage in fisheries is a major goal of most fisheries organisations. First however, the magnitude of discarding and how this varies in space and time needs to be quantified. Whilst the composition and magnitude of retained catches can be estimated from reported commercial catch returns, discards only made on boat. Need to assess bycatch for assessment of impacts of fishery on stocks and ecosystems.

1.3. Objective

(1) Identify and quantify the rates of retained and discarded catches from the different types of gill nets used in the NSW estuarine commercial finfish fishery.

1.4. Achievement of objective

Objective 1- achieved. Observer-based surveys were used to identify and quantify the species and length compositions and the magnitudes of the retained and discarded catches from gillnets used in the NSW Estuary General Fishery. We surveyed catches in seven key estuaries: Richmond, Clarence, Camden Haven and Shoalhaven Rivers and Wallis, Tuggerah and Illawarra Lakes throughout 2001.

2. BYCATCH ASSESSMENT OF THE ESTUARINE COMMERCIAL GILLNET FISHERY FOR DUSKY FLATHEAD (*PLATYCEPHALUS FUSCUS*)

2.1. Abstract

We used a scientific observer program to quantify the compositions and magnitudes of catches taken in gillnets set for dusky flathead (*Platycephalus fuscus*) in three barrier estuaries in New South Wales, Australia, during the 2001 fishing season. Fishers operating in this fishery are only permitted to retain legal-sized dusky flathead and legal-sized blue swimmer (*Portunus pelagicus*) and mud crab (*Scylla serrata*), and all other organisms must be discarded. Sampling was stratified into two time periods; before and after 1 July 2001 which coincided with the increase in the minimum legal length (MLL) of dusky flathead from 33 to 36 cm total length (TL). A total of 81 fishing trips was sampled, which yielded 38 finfish and 2 portunid crab species. Legal-sized dusky flathead were the most abundant organism captured and accounted for 23-47% by number and 34-54% by weight of the mean observed catch depending on the estuary and survey period, with a mean of 25-59 flathead weighing 13-25 kg being caught per fisher-night. Analyses of similarity identified that the structure (species composition and relative abundance) of catches differed between estuaries, but not between sampling periods. Predominant bycatch species included legal and under-size blue swimmer crab, sea mullet (*Mugil cephalus*), luderick (*Girella tricuspidata*), bream (*Acanthopagrus australis*) and yellowfin leatherjacket (*Meuschenia trachylepis*). These five species accounted for 82% of total bycatch by number and 71% by weight, pooled across the 3 estuaries. More crabs were retained than discarded, with retained legal-size crabs (byproduct) accounting for 16% of total bycatch by number and 13% by weight, with an average of 5-22 crabs weighing 1-6 kg being caught per fisher-night, depending on the estuary. Overall, a total of 7% of dusky flathead captured (number) were below the MLL of 36 cm and discarded, suggesting the nets as currently configured may be relatively selective in catching legal-size flathead. The data show however that 41% of dusky flathead were < 40cm TL, indicating that if the MLL for this species is increased to this length as proposed, new nets will need to be introduced into the fishery. The data are discussed in terms of making the flathead fishery more sustainable, including alternative management strategies for the fishery.

2.2. Introduction

Significant recreational and commercial fisheries occur for dusky flathead (*Platycephalus fuscus* - Cuvier) in estuarine and coastal waters throughout south-eastern Australia (Kialola *et al.,* 1984; Gray *et al*., 2002). In New South Wales (NSW), up to 200 tonne of dusky flathead (valued at AUD$0.7 million) are reported to be caught by commercial fishers each year (Tanner and Liggins, 1999). Whilst at present there are no equivalent estimates of total recreational (line-only) catches of dusky flathead in NSW, it is acknowledged that recreational catches exceed reported commercial catches in some estuaries (West and Gordon, 1995). Hence there is much dispute among different resource interest groups over the allocation of the flathead resource and the impacts of different fishing gears and sectors on these and other shared fish stocks in the region. Commercial fishers primarily catch dusky flathead in estuaries (99% of total reported commercial landings in NSW) using bottom-set gillnets (> 90% of total landings), with approximately 40% of the reported commercial catch being taken in specially constructed ‘flathead gillnets’. As in many other coastal fisheries, one of the most contentious issues facing the management of the gillnet fishery for dusky flathead concerns the impacts of discarding of bycatches, including under-sized conspecifics. Fundamental to any assessment of the ecological effects of this fishery on stocks is the need to identify and quantify spatial, temporal and gear-related variability in the compositions and magnitudes of both the retained and discarded components of catches (Alverson *et al*., 1994; Kennelly, 1995; Hall, 1999). Such information is also pivotal for developing ways to manage and mitigate bycatch and discarding problems and for determining the most appropriate and ecologically sustainable methods to harvest resources.

The NSW estuarine commercial gillnet fishery for dusky flathead is managed primarily by gear and licence restrictions and temporal and spatial closures. Flathead nets must have a inside mesh size (stretched) between 70 and 80 mm, a maximum depth of 25 meshes and must be constructed in a way that they do not fish more than 0.5 m above the substratum. Minimal or no floatation is used and nets often have a flue and so behave like an entanglement net. The length of any individual net or combination of nets set by a fisher at any one time must not exceed 1500 m. Typically, nets are made of 6 ply strand nylon or 8 strand multi-monofilament netting. Until mid 2002, flathead nets could be set in five estuaries (Wallis, Smiths, Tuggerah, Illawarra Lakes and St Georges Basin) in NSW, where they were permitted to be set overnight between February and November in Wallis and Tuggerah Lakes, but between May and August in the other three estuaries. Typically, nets are set just prior to sunset and retrieved at sunrise. Fishers using flathead nets are not permitted to retain any other catch, except legal-sized blue swimmer crab (*Portunus pelagicus*) and mud crab (*Scylla serrata*) and all other organisms must be discarded.

Discarding is often perceived as very wasteful and it can impact on the productivity and functioning of ecosystems and the biomasses and harvested yields of fish stocks (Jennings and Kaiser, 1998; Hall, 1999; Kaiser and deGroot, 2000). Although gillnets generally are relatively size-selective (Hamley, 1975; Millar and Fryer, 1999), some gillnets used in the estuarine commercial fishery in NSW are known to catch a wide range of sizes of many species, the discards include several species important in other recreational and commercial fisheries (Gray, 2002). There are very few data, however, describing the composition and quantities of the retained and discarded catches taken in the gillnet fishery for dusky flathead. This is particularly concerning given that because of concerns over the status of the stock, the minimum legal length (MLL) of dusky flathead was increased from 33 to 36 cm total length (TL) on 1 July 2001. This increase in MLL could potentially lead to a greater level of discarding of small flathead in the gillnet fishery, potentially negating any positive effects of the MLL increase. Given this and the necessity for all fisheries in NSW to undergo environmental assessments, there was a clear need to assess what is caught, retained and discarded in the estuarine gillnet fishery for dusky flathead. Such information is generally best obtained by placing observers onboard vessels to collect data during normal fishing operations, and ideally, such surveys should be stratified across appropriate spatial and temporal scales that incorporate different fishing operations (see Saila, 1983; Kennelly, 1995).

The aim of the current study was to redress the current lack of knowledge of the composition and quantities of catches (target and non-target species) taken in the estuarine commercial gillnet fishery for dusky flathead in NSW. We used an observer-based program to quantify the species, quantities and length distributions of catches taken during normal fishing operations in the three main estuaries throughout the 2001 fishing season. We discuss the data in terms of managing the fishery and assess the effects of the recent increase in the MLL of dusky flathead on levels of discarding.

2.3. Materials and methods

2.3.1. Observer survey and sampling procedures

The observer survey was done in Wallis Lake (32° 15'S), Tuggerah Lake (33° 18'S) and Lake Illawarra (34° 31'S) (Figure 2.1) throughout the 2001 fishing season. Each of these barrier estuaries supports other commercial and recreational fisheries. The survey was split into two periods: before and after the increase in the MLL of dusky flathead on 1 July 2001. The two survey periods were February to June and July to November in Wallis and Tuggerah Lakes, and May and June, and July and August, in Lake Illawarra.

In each estuary, observers accompanied commercial flathead gill-netters during the early mornings when they retrieved gillnets that had been set overnight, on at least 9 randomly-selected fishing trips (night-sets) in each of the two survey periods. As each net was retrieved into the boat, all organisms were disentangled from the net by the fisher. The observer identified, counted and determined the total weight of all species captured. The total length of dusky flathead and fork lengths (to the nearest cm) of key species were also measured. Non-target organisms were generally processed immediately, so that they could be quickly released to minimize further stress and mortality due to handling, whereas much of the retained catch was processed after the entire net was retrieved. The observers also recorded operational data, including net material, mesh (stretched inside) and ply size, length and depth (number of meshes) of nets, fishing (soak) time and location.

In this study, we define the term 'byproduct' as the total retained crab bycatch, and the term 'total bycatch' refers to the sum of the total crab byproduct and the total discarded bycatch. Mesh size refers to the stretched inside mesh opening.

2.3.2. Data analyses

2.3.2.1. Variations in structures of catches

Non-parametric multivariate analyses were used to delineate spatial and temporal differences in the structure (numbers of each species) of catches. The general procedures used followed those outlined in Clarke (1993) and Clarke and Warwick (2001). Similarity matrices based on the Bray-Curtis similarity measure were generated for the catch abundance data and the inter-relationships among individual catches were displayed graphically in a 2 dimensional multidimensional scaling (MDS) ordination plot. Samples that grouped together in the ordination were most similar and the stress coefficient indicated the goodness-of-fit of the data. One-way analyses of similarity (ANOSIM) were used to test for spatial and temporal differences in the structure of catches. Similarity percentage (SIMPER) analyses were used to identify the species that were most responsible for the similarity of catches within each estuary and survey period. The ratio of similarity/standard deviation is a measure of how consistently each species contributed to the similarity measure within a group, or to the dissimilarity measure between groups. Taxa displaying a high ratio and a high contribution can be considered good discriminating species (Clarke and Warwick, 2001).

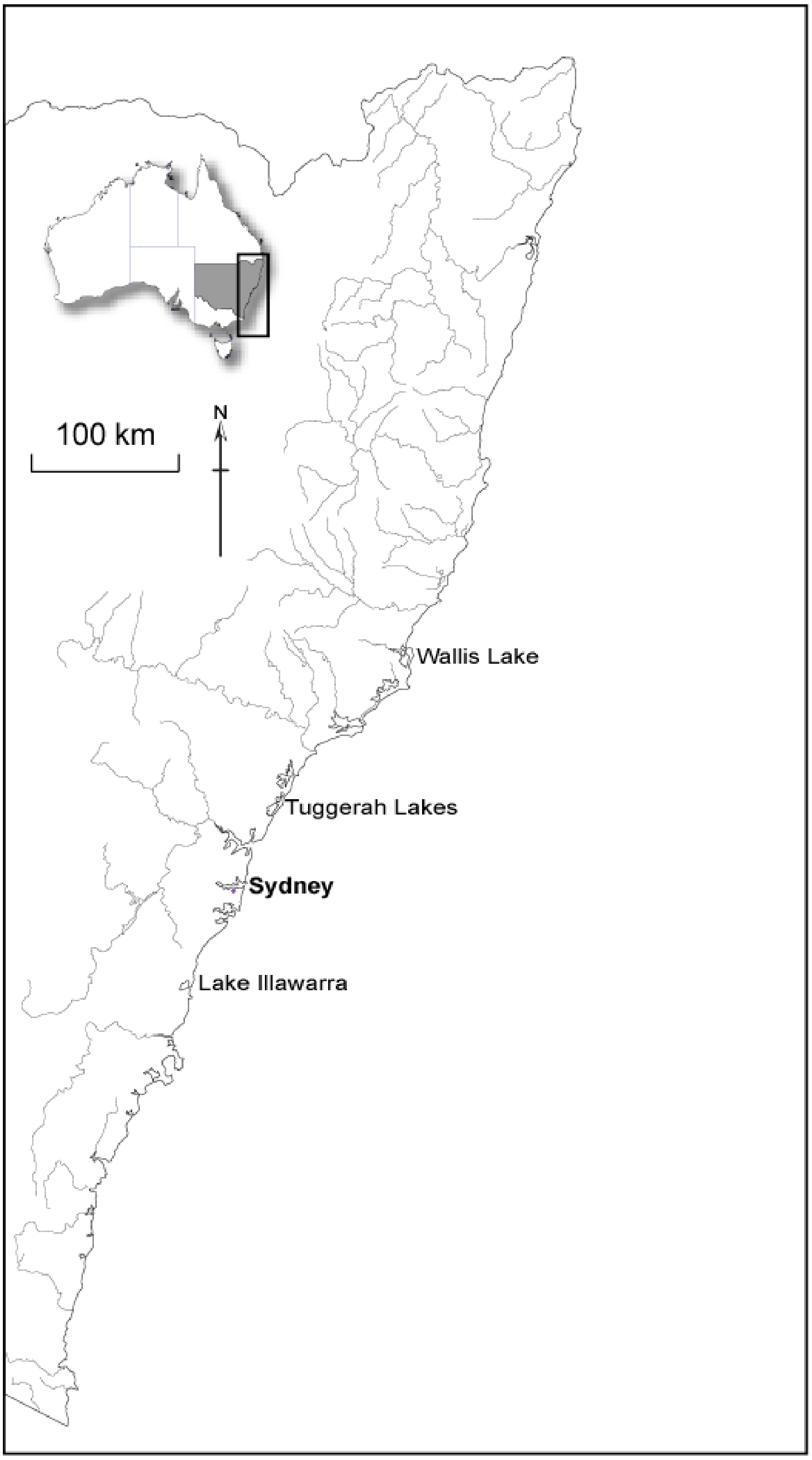

Figure 2.1. Map of NSW showing the three estuaries studied.

2.3.2.2. *Effects of net material on catches*

Multivariate analyses were also used to preliminary assess the effects of net material on catches. One fisher in Wallis Lake simultaneously fished one multi-monofilament net and one nylon net with both nets having similar dimensions and the same mesh size (70 mm). Both nets were 725 m in length, the same height and hanging ratio, but the multi-monofilament net had 0.5 x 8 strand ply and the nylon net had 6 ply. Catches from 6 fisher-nights were compared.

2.3.2.3. *Variations in catch rates*

Two-factor analyses of variance (ANOVA) were used to test for differences in the weights and quantities of catches between the three estuaries and the two survey periods. Analyses were done at two levels: (1) catches per fisher-night and (2) standardised catches per 100 m length of net. The latter analyses were done because commercial fishers used nets of different length and we wished to test for differences in the relative abundances of organisms between estuaries and survey periods. Data were transformed to log (x+1) to stabilize variances (Cochrans test) and Student-Newman-Keuls (SNK) tests were used to determine differences among means following ANOVA. When variances remained heterogeneous following transformation, P was set at 0.01 to reduce Type I errors (Underwood, 1981). The ratio of weight of the retained dusky flathead catch to weight of the total bycatch (all other organisms caught) was calculated for each estuary for each period following the procedures detailed in Cochran (1963).

2.3.2.4. *Estimates of total catches in each estuary*

Estimates of the total catches (+ 1 se) for the entire gillnet fishery for dusky flathead in each estuary were determined for the survey period following the standard method for estimating a total and standard error across multiple randomly sampled strata (Cochran 1963). The observed mean catch rates per-fishing night were multiplied by the reported number of nights fished by all fishers using flathead gillnets in each estuary in each survey period between February and November 2001 (see Gray *et al*., 2001 for details). The total reported fishing effort (i.e. total no. of nights fished using flathead gillnets) was obtained from the forms that commercial fishers are required to submit to NSW Fisheries combined with post-survey interviews with fishers.

2.3.2.5. *Length compositions of catches*

Observed length compositions of catches of dusky flathead, sea mullet (*Mugil cephalus*), bream (*Acanthopagrus australis*), luderick (*Girella tricuspidata*), sand whiting (*Sillago ciliata*) and yellowfin leatherjacket (*Meuschenia trachylepis*) were scaled to represent the total catch by all fishers across all three estuaries. Length composition data were weighted according to the ratio of total fishing effort to sampling effort in each period and estuary and then summed to provide a total distribution across all three estuaries (see Liggins and Kennelly, 1996).

2.4. Results

2.4.1. *Fishing and sampling effort*

A total of 81 gillnet catches, 27 in Wallis Lake, 32 in Tuggerah Lake and 22 in Lake Illawarra, were observed throughout the study, which represented 3.5, 2.8 and 9.6 % of the total reported commercial fishing effort (nightly sets of flathead gillnets) throughout the survey period in each estuary respectively. Total reported fishing effort in 2001 was greatest in Tuggerah Lake and least in Lake Illawarra, with fishing effort being greater in the first half of the year in both Wallis and Tuggerah Lakes. Throughout 2001, 15 fishers reported using flathead nets in Wallis Lake, 17 in Tuggerah Lake and 9 in Lake Illawarra.

Fishers in Wallis and Tuggerah Lakes predominantly used nets with 70 mm mesh whereas in Lake Illawarra fishers predominantly used nets with 76 and 80 mm mesh. Multi-monofilament and nylon nets were used in Wallis and Tuggerah Lakes, whereas only multi-monofilament nets were observed in Lake Illawarra. Nets used in all estuaries typically were 12 to 25 meshes deep and had minimal floats on the headline. Some fishers in Tuggerah Lake used nets with no floats.

2.4.2. *Catch composition*

Legal-sized dusky flathead was the most abundant organism captured accounting for 23 to 47 % of the total mean nightly catch by number and 34 to 53 % by weight, depending on the estuary and survey period (Figure 2.2). A total of 40 species (38 finfish and 2 portunid crabs) were identified in observed bycatches: 18 species in Wallis Lake; 28 species in Tuggerah Lake; and 17 species in Lake Illawarra. Retained legal sized crabs (byproduct) accounted for 3 to 49 % of total bycatch by number and 1 to 12 % by weight, depending on the estuary and period. The mean (± 1se) ratio of weight of retained dusky flathead catch to weight of total bycatch (including byproduct) in each estuary was: 1:1.11 (0.19) in Wallis Lake, 1:2.07 (0.30) in Tuggerah Lake, 1:2.46 (0.92) in Lake Illawarra. There was a significant correlation between the weight of retained dusky flathead catch and total bycatch caught per fisher-night in Tuggerah Lake ($r_{(32)} = 0.408$, $P < 0.05$), but not in Wallis Lake ($r_{(27)} = 0.365$, $P > 0.05$) and Lake Illawarra ($r_{(22)} = 0.268$, $P > 0.05$) (Figure 2.3).

The structure of catches significantly differed between all three estuaries (ANOSIM, Global R = 0.177, $P < 0.001$, pairwise comparisons $P < 0.001$ in all cases; Figure 2.4). However, ANOSIM's did not detect any significant differences ($P > 0.05$) in the structures of catches between the two survey periods within each estuary (R = 0.036, 0.211, 0.073 in Wallis, Tuggerah and Illawarra, respectively). Legal-sized dusky flathead contributed greatest to the similarity measure of catches in all three estuaries (Table 2.1). Other species that were relatively abundant and contributed significantly to the similarity of catches within each estuary were legal and undersize blue swimmer crab, sea mullet, bream and luderick. Estuary catfish (*Cnidoglanis macrocephalus*) were also important in distinguishing catches in Wallis Lake, black sole (*Synaptura nigra*) in Tuggerah and yellowfin leatherjacket in Lake Illawarra (Table 2.1). The SIMPER analysis also showed that the five most important species accounted for 82-94% of the similarity of catches within each estuary.

No significant difference was detected in the structure of catches taken in multi-monofilament versus nylon nets fished simultaneously in Wallis Lake (ANOSIM, R = 0.042, $P > 0.05$). Fifteen species were observed in catches, with legal-sized dusky flathead, legal and under-size blue swimmer crab, sea mullet and bream dominating catches in both nets.

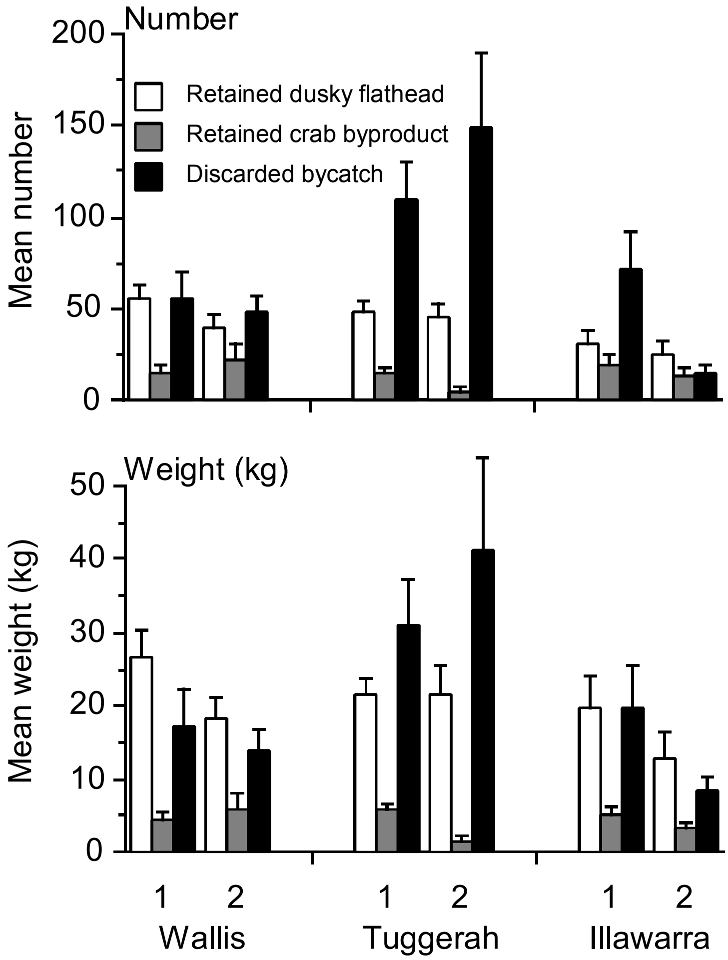

Figure 2.2. Mean (+ 1se) catch rate by number and weight of retained dusky flathead, crab byproduct and discarded bycatch in the two survey periods in each estuary.

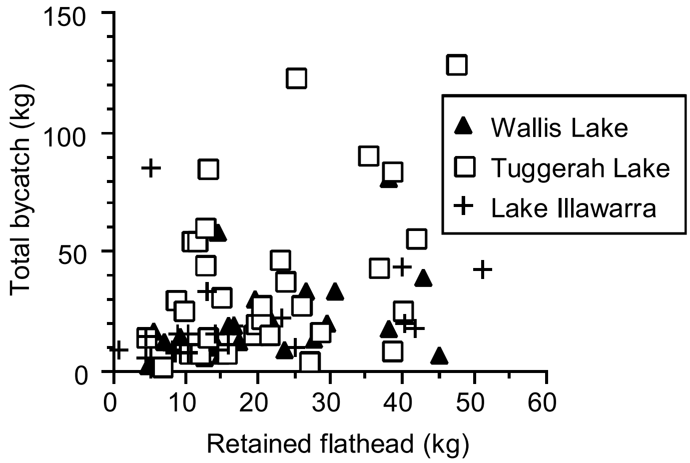

Figure 2.3. Relationships between weight of retained dusky flathead catch and total non-target bycatch in each estuary.

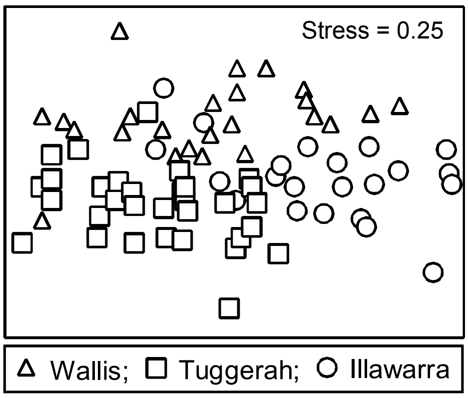

Figure 2.4. MDS ordination plot showing relationships among estuaries in the structure catches taken in flathead gillnets.

Table 2.1. The ten species that contributed greatest to the similarity matrix of catches taken in flathead nets in Wallis Lake, Tuggerah Lake and Lake Illawarra. Analyses based on non-transformed data. Species listed in order of greatest contribution. Mean catch per fisher-night, the ratio of average similarity to standard deviation and the percent contribution of each species to the similarity measure in each estuary are presented.

Species	Mean number caught per-night	Ratio (similarity/ stdev)	Percent contribution	Cumulative contribution
Wallis Lake (average similarity 45.01)				
Dusky flathead (legal-size)	48.15	2.45	62.93	62.93
Blue swimmer crab (legal-size)	17.48	0.72	11.91	74.83
Bream	10.52	0.94	7.43	82.26
Sea mullet	13.52	0.56	5.27	87.53
Blue swimmer crab (under-size)	5.78	0.78	4.70	92.23
Estuary catfish	3.22	0.39	1.73	93.96
Luderick	3.33	0.43	1.12	95.17
Fanbelly leatherjacket	1.59	0.44	1.04	96.21
Sand whiting	1.93	0.40	0.97	97.17
Dusky flathead (under-size)	1.85	0.38	0.89	98.06
Tuggerah Lake (average similarity 41.21)				
Dusky flathead (legal-size)	47.03	2.00	47.00	47.00
Sea mullet	35.91	0.73	14.69	61.70
Luderick	31.72	0.60	7.55	69.25
Blue swimmer crab (legal-size)	10.50	0.67	6.94	76.19
Bream	15.22	0.71	6.48	82.67
Blue swimmer crab (under-size)	11.06	0.58	5.96	88.64
Black sole	5.16	1.02	4.46	93.09
Dusky flathead (under-size)	2.22	0.55	1.33	94.42
Sand whiting	1.84	0.52	0.94	95.36
Yellowfin leatherjacket	3.59	0.44	0.85	96.21
Lake Illawarra (average similarity 41.96)				
Dusky flathead (legal-size)	28.64	1.62	49.32	49.32
Blue swimmer crab (legal-size)	17.00	1.32	28.05	77.37
Blue swimmer crab (under-size)	6.00	0.80	7.01	84.37
Yellowfin leatherjacket	10.91	0.68	6.41	90.78
Luderick	7.68	0.61	3.48	94.26
Sea mullet	17.36	0.32	3.03	97.30
Bream	2.27	0.47	0.87	98.16
Black sole	0.50	0.25	0.35	98.51
Sand whiting	0.41	0.33	0.26	98.77
Silver biddy	0.50	0.30	0.24	99.01

2.4.3. Variations in catch rates

ANOVA detected significant variability in the nightly catches of legal-size and under-size dusky flathead, total bycatch, total retained crab byproduct and total discarded bycatch (Table 2.2). Catches of legal-size dusky flathead varied between periods, with more being caught in Period 1. ANOVA also detected significant differences in the numbers and weights of under-size dusky flathead caught before and after the MLL change, but this varied between estuaries (Tables 2.2 and 2.3). Although SNK tests could not detect which means differed, the data suggest that more under-size flathead were caught in the latter survey period in Wallis Lake. Rates of capture of the retained byproduct, discarded and total bycatch also varied between estuaries or survey periods. The greatest number and weight of total bycatch was taken in Tuggerah Lake (Figure 2.1). A mean of 25 to 59 dusky flathead (weighing 13 to 26 kg) and 28 to 154 total bycatch individuals (weighing 13 to 43 kg) were caught per-fishing night (Figure 2.2). Retained crab byproduct accounted for 5 to 22 (weighing 1 to 6 kg) of the total nightly bycatch (Figure 2.2). Similarly, a mean of 0.1 to 3.4 under-sized dusky flathead were observed to be caught per-night, depending on the estuary and survey period.

Significant spatial and temporal variability was also detected for the standardized catches (per 100 m of net) of the predominant species caught as bycatch (Table 2.3). The mean number of legal-sized dusky flathead caught per 100 m of net per-night varied between 2.59 and 4.85, whilst that of total bycatch varied between 3.44 and 11.72 individuals (Table 2.3). Except for legal and under-size blue swimmer crab, sea mullet, luderick, bream and yellowfin leatherjacket, less than 1 individual of each of the other bycatch species was caught on average per 100 m of net in any estuary (Table 2.3).

2.4.4. Length compositions of catches

The length compositions of important finfish species captured in flathead nets are shown in Figure 2.5. The length compositions of catches of dusky flathead were similar in both periods and in all three estuaries. Dusky flathead smaller than the current MLL of 36 cm TL accounted for 7.2% of all dusky flathead observed in catches throughout the survey. Most (80%) dusky flathead captured were between 36 and 46 cm TL. The majority of bream and luderick captured were below the MLL (22 and 23.5 cm FL respectively), whereas most sea mullet and sand whiting were above the MLL (27.5 and 25 cm FL respectively). Most yellowfin leatherjacket caught were 15-22 cm FL. Sizes of blue swimmer crab were not recorded during the survey.

2.4.5. Estimated total catches and bycatches

Estimates of total catches of dusky flathead and the predominant non-target species by the entire fishery in each estuary are provided in Table 2.4. It was estimated that a total of 46 tonne of dusky flathead and 65 tonne of total bycatch, of which 10 tonne was retained crab byproduct, was caught in flathead nets in the three estuaries throughout the survey. Compared to Wallis and Tuggerah Lakes estimated total catches and bycatches were much less in Lake Illawarra because of the protracted 4 month fishing season in the latter estuary. Apart from legal-size blue swimmer crabs, a greater weight of each species and total bycatch was caught in Tuggerah Lake compared to Wallis Lake. Estimated total bycatches in all estuaries were dominated numerically by blue swimmer crab, sea mullet, luderick, bream and yellowfin leatherjacket.

Table 2.2. Summary of results of two-factor analyses of variance comparing catch per-night fished across the three estuaries and two survey periods.

Estuary and Period were treated as fixed factors. Mean square values and their level of significance are shown. Data transformed to log(x+1) to stabilize variances.
df = degrees of freedom, MS = mean square, * $p < 0.05$, ** $p < 0.01$, ns $p > 0.05$.

Source	df	Dusky flathead legal-size MS	Dusky flathead under-size MS	Total bycatch MS	Retained crab byproduct MS	Discarded bycatch MS
Number caught per-night fished						
Estuary	2	0.153 ns	0.219 ns	0.774 **	0.549 *	1.45 **
Period	1	0.479 *	0.676 **	0.507 *	3.544 **	0.344 ns
Estuary x Period	2	0.099 ns	0.325 *	0.202 ns	0.435 ns	0.578 *
Error	48					
Weight caught per-night fished						
Estuary	2	0.073 ns	0.056 *	0.383 *	0.147 ns	0.74 **
Period	1	0.338 *	0.135 **	0.246 ns	1.446 **	0.044 ns
Estuary x Period	2	0.124 ns	0.051 *	0.058 ns	0.131 ns	0.15 ns
Error	48					

Table 2.3. Mean (+ 1se) catch per 100 m of net set in each estuary of retained legal size dusky flathead, total bycatch, total retained crab byproduct, total discarded bycatch and the fourteen most abundant components of total bycatch species across the three estuaries and two time periods. Significant results of two-factor analyses of variance are also presented. Estuary and period were both treated as fixed factors, data transformed to log (x+1) to stabilize variances, except # where variances remained heterogeneous and the critical P value was set at 0.01. E = estuary, P = survey period, ExP = estuary x period interaction, ns = no significant differences.

	Wallis Lake				Tuggerah Lake				Lake Illawarra				ANOVA
	Period 1		Period 2		Period 1		Period 2		Period 1		Period 2		
Number													
Dusky flathead retained (legal)	4.78	(0.51)	4.60	(0.92)	3.14	(0.32)	2.59	(0.44)	4.08	(1.17)	2.76	(0.50)	ns
Total bycatch	6.16	(1.24)	7.81	(0.97)	8.73	(1.63)	9.37	(2.42)	11.72	(2.32)	3.44	(0.80)	ns
Retained crab byproduct	1.17	(0.30)	1.87	(0.54)	1.06	(0.23)	0.30	(0.14)	2.82	(1.01)	1.82	(0.49)	E, P
Discarded bycatch	4.99	(1.29)	5.94	(1.11)	7.66	(1.57)	9.07	(2.42)	8.90	(1.83)	1.63	(0.37)	E, ExP
Sea mullet	1.58	(0.84)	0.98	(0.39)	2.66	(0.71)	2.08	(0.78)	3.16	(1.41)	0.05	(0.02)	ns
Blue swimmer crab (legal)	1.07	(0.31)	1.82	(0.53)	0.95	(0.23)	0.29	(0.14)	2.82	(1.01)	1.82	(0.49)	E, P
Luderick	0.36	(0.15)	0.35	(0.17)	1.36	(0.78)	3.18	(1.14)	1.96	(0.95)	0.10	(0.05)	ns
Bream	1.07	(0.36)	1.17	(0.50)	0.94	(0.30)	1.27	(0.46)	0.40	(0.17)	0.08	(0.03)	E
Blue swimmer crab (under-size)	0.42	(0.13)	0.72	(0.24)	1.00	(0.20)	0.19	(0.10)	1.10	(0.29)	0.49	(0.24)	ns
Yellowfin leatherjacket	0.43	(0.33)	0.09	(0.05)	0.29	(0.17)	0.14	(0.05)	1.60	(0.63)	0.36	(0.13)	E, P #
Estuary catfish	0.30	(0.11)	0.50	(0.23)	0.09	(0.07)	0.16	(0.07)	0.00	(0.00)	0.00	(0.00)	E #
Sand whiting	0.21	(0.08)	0.29	(0.24)	0.09	(0.03)	0.20	(0.05)	0.09	(0.04)	0.03	(0.02)	ns #
Dusky flathead (under-size)	0.04	(0.03)	0.46	(0.13)	0.16	(0.04)	0.14	(0.05)	0.04	(0.02)	0.05	(0.03)	E, ExP #
Black sole	0.09	(0.04)	0.01	(0.01)	0.39	(0.07)	0.24	(0.07)	0.04	(0.02)	0.10	(0.05)	E #
Flat-tail mullet	0.12	(0.08)	0.03	(0.03)	0.00	(0.00)	0.57	(0.29)	0.13	(0.13)	0.00	(0.00)	ExP #
Tarwhine	0.03	(0.03)	0.55	(0.28)	0.03	(0.02)	0.00	(0.00)	0.04	(0.02)	0.00	(0.00)	E, ExP #
Tailor	0.03	(0.03)	0.32	(0.14)	0.09	(0.04)	0.08	(0.03)	0.08	(0.06)	0.00	(0.00)	ExP #
Fanbelly leatherjacket	0.07	(0.04)	0.30	(0.07)	0.04	(0.02)	0.04	(0.01)	0.00	(0.00)	0.00	(0.00)	E, P, ExP #

Table 2.3. Continued

	Wallis Lake				Tuggerah Lake				Lake Illawarra				ANOVA
	Period 1		Period 2		Period 1		Period 2		Period 1		Period 2		
Weight (kg)													
Dusky flathead retained (legal)	2.29	(0.32)	2.15	(0.45)	1.42	(0.14)	1.25	(0.22)	2.64	(0.75)	1.37	(0.27)	ns #
Total bycatch	1.93	(0.49)	2.09	(0.27)	2.60	(0.47)	2.61	(0.71)	3.12	(0.69)	1.37	(0.19)	ns
Retained crab byproduct	0.36	(0.08)	0.50	(0.15)	0.39	(0.08)	0.09	(0.04)	0.72	(0.25)	0.43	(0.11)	E, P
Discarded bycatch	1.57	(0.47)	1.59	(0.28)	2.20	(0.46)	2.52	(0.71)	2.39	(0.57)	0.94	(0.16)	ns
Sea mullet	0.69	(0.40)	0.37	(0.16)	0.92	(0.23)	0.74	(0.28)	1.14	(0.51)	0.02	(0.01)	ns
Blue swimmer crab (legal)	0.27	(0.08)	0.44	(0.13)	0.25	(0.06)	0.07	(0.03)	0.72	(0.25)	0.43	(0.11)	E, P #
Luderick	0.08	(0.04)	0.10	(0.05)	0.35	(0.19)	0.70	(0.25)	0.48	(0.24)	0.03	(0.01)	ns
Bream	0.18	(0.06)	0.19	(0.07)	0.13	(0.04)	0.17	(0.06)	0.07	(0.03)	0.01	(0.01)	ns
Blue swimmer crab (under-size)	0.05	(0.02)	0.09	(0.03)	0.15	(0.04)	0.02	(0.01)	0.21	(0.07)	0.09	(0.03)	ns #
Yellowfin leatherjacket	0.05	(0.04)	0.01	(0.00)	0.04	(0.02)	0.02	(0.00)	0.23	(0.11)	0.04	(0.01)	E #
Estuary catfish	0.15	(0.06)	0.27	(0.13)	0.07	(0.05)	0.19	(0.08)	0.00	(0.00)	0.00	(0.00)	ns #
Sand whiting	0.06	(0.03)	0.07	(0.06)	0.03	(0.01)	0.06	(0.01)	0.03	(0.01)	0.01	(0.01)	ns #
Dusky flathead (under-size)	0.01	(0.00)	0.10	(0.03)	0.04	(0.01)	0.04	(0.01)	0.01	(0.01)	0.01	(0.01)	P, ExP #
Black sole	0.01	(0.00)	0.00	(0.00)	0.05	(0.01)	0.04	(0.01)	0.00	(0.00)	0.01	(0.01)	E #
Flat-tail mullet	0.03	(0.02)	0.01	(0.01)	0.00	(0.00)	0.15	(0.08)	0.02	(0.02)	0.00	(0.00)	E, ExP #
Tarwhine	0.00	(0.00)	0.07	(0.04)	0.00	(0.00)	0.00	(0.00)	0.01	(0.00)	0.00	(0.00)	E, ExP #
Tailor	0.02	(0.02)	0.14	(0.06)	0.04	(0.02)	0.04	(0.01)	0.01	(0.01)	0.00	(0.00)	ns #
Fanbelly leatherjacket	0.01	(0.01)	0.04	(0.01)	0.01	(0.00)	0.01	(0.00)	0.00	(0.00)	0.00	(0.00)	E, ExP #

Table 2.4. Estimated total catch by number and weight (kg) of legal-sized dusky flathead, total bycatch, retained crab byproduct, discarded bycatch and the 15 most common bycatch species by all fishers using flathead nets in Wallis, Tuggerah and Illawarra Lakes during 2001. Note that the permitted fishing season in Wallis and Tuggerah Lakes is between February and November, whereas in Lake Illawarra it is between May and August.

	Wallis Lake		Tuggerah Lake		Lake Illawarra		Wallis Lake		Tuggerah Lake		Lake Illawarra	
	Catch (no.)	s.e.	Catch (no.)	s.e.	Catch (no.)	s.e.	Catch (kg)	s.e.	Catch (kg)	s.e.	Catch (kg)	s.e.
Dusky flathead (retained)	37,507	(3,851)	54,509	(5,548)	6,529	(1,116)	17,524	(1,963)	24,890	(2,380)	3,847	(689)
Total bycatch	54,732	(6,879)	155,487	(23,147)	14,944	(3,081)	16,041	(2,577)	44,831	(6,740)	4,408	(890)
Retained crab bycatch	14,195	(3,538)	13,546	(2,294)	3,876	(735)	3,977	(967)	4,994	(854)	981	(180)
Discarded bycatch	40,537	(6,464)	141,941	(23,215)	11,068	(2,956)	12,064	(2,381)	39,837	(6,803)	3,427	(876)
Individual bycatch species												
Sea mullet	10,531	(4,008)	41,615	(9,324)	3,959	(2,307)	4,515	(1,896)	14,487	(3,057)	1,480	(829)
Luderick	2,597	(805)	36,762	(11,861)	1,751	(878)	627	(195)	8,684	(2,749)	433	(226)
Blue swimmer crab (legal size)	13,618	(3,515)	12,170	(2,163)	3,876	(735)	3,374	(886)	3,205	(583)	981	(180)
Bream	8,194	(2,173)	17,639	(3,840)	518	(298)	1,348	(364)	2,361	(524)	97	(56)
Blue swimmer crab (undersize)	4,501	(992)	12,821	(2,785)	1,368	(291)	568	(140)	1,806	(417)	254	(56)
Yellowfin leatherjacket	2,106	(1,492)	4,165	(1,864)	2,487	(958)	241	(179)	528	(211)	324	(126)
Black sole	462	(201)	5,976	(974)	114	(42)	48	(21)	848	(146)	12	(5)
Estuary catfish	2,510	(676)	1,992	(765)	0	(0)	1,365	(376)	1,992	(718)	0	(0)
Dusky flathead (undersize)	1,443	(462)	2,572	(512)	83	(32)	291	(91)	635	(133)	17	(7)
Flattail mullet	548	(355)	3,405	(1,792)	52	(42)	156	(93)	954	(508)	11	(8)
Sand whiting	1,500	(572)	2,137	(457)	93	(29)	382	(154)	648	(127)	29	(10)
Tailor	1,154	(500)	1,485	(457)	62	(43)	539	(221)	711	(229)	15	(8)
Porcupine fish	0	(0)	2,680	(832)	21	(14)	0	(0)	723	(241)	5	(4)
Tarwhine	1,933	(855)	254	(135)	41	(19)	274	(113)	34	(17)	6	(3)
Mud crab (legal size)	577	(174)	1,376	(327)	0	(0)	603	(220)	1,788	(425)	0	(0)

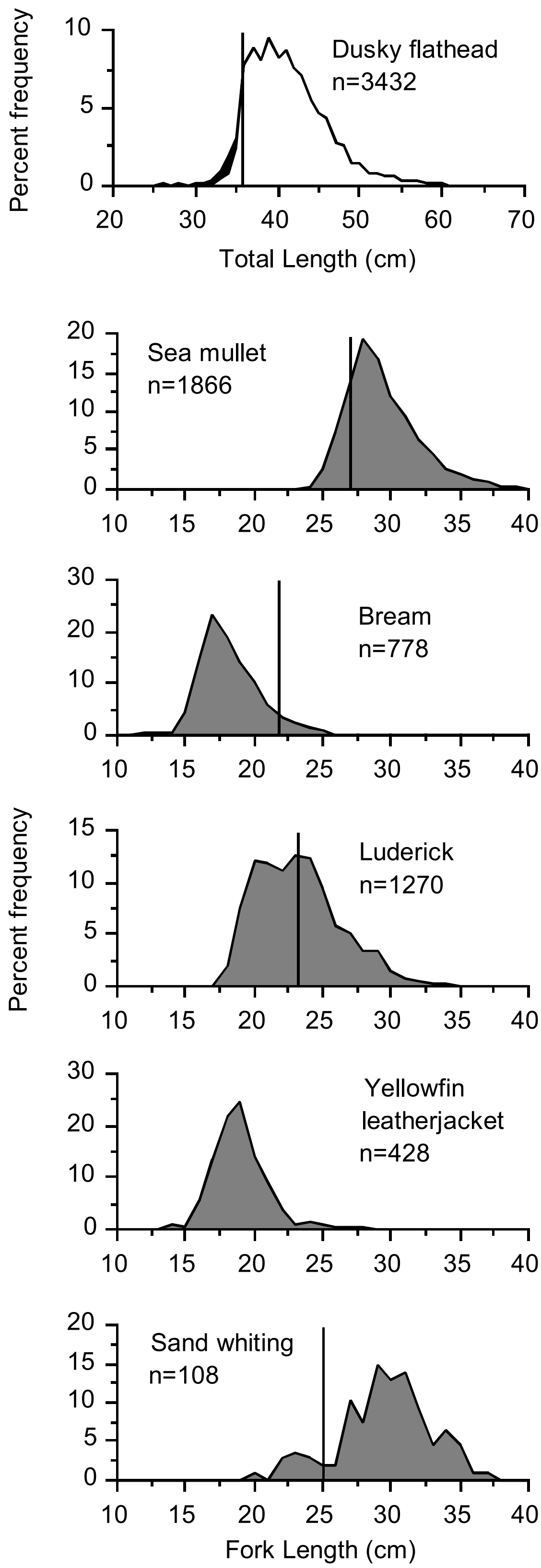

Figure 2.5. Observed length-frequency distributions of dusky flathead, sea mullet, bream, luderick, yellowfin leatherjacket and sand whiting taken in flathead nets pooled across the three estuaries throughout the survey. The vertical line represents the MLL for each species in NSW. There is no MLL set for yellowfin leatherjacket.

2.5. Discussion

2.5.1. Composition and quantities of retained and discarded catches

Dusky flathead were the most abundant species in catches throughout the survey numerically accounting for 31% of observed total catches, pooled across the three estuaries. The increase in the MLL of dusky flathead to 36 cm TL appeared to have little impact on the discarding rates of under-sized flathead, except in Wallis Lake where there was a slight trend for more under-sized flathead to be discarded after the MLL increase. Overall, relatively few (7% by number) dusky flathead below the current MLL were observed in catches and the levels of discarding of these fish (approximately 1 tonne across all 3 estuaries) were low, suggesting that the currently configured flathead nets may be relatively selective at catching legal-sized flathead. Independent experimental studies on the selectivity of flathead gillnets in NSW (Broadhurst *et al*. 2003) confirm this conclusion. For example, 6.9 % of dusky flathead caught in experimental gillnets with 70 mm mesh and 2.4 % in nets with 80 mm mesh were less than 36 cm TL (Broadhurst *et al*., 2003). We acknowledge, however, that the selectivity of nets depends on several interacting factors including the abundance, availability and catchability of different sized fish as well as the efficiency of the fishing gear. Despite these findings, we acknowledge that levels of discarding of under-sized dusky flathead in this fishery could vary greatly between years. For example, Liggins *et al*. (1996) reported a threefold change between years in the levels of discarding of small snapper in a coastal embayment prawn trawl fishery.

Our data show that commercial fishers operating in the gillnet fishery for dusky flathead caught, on average, between 13-25 kg of dusky flathead predominantly between 36-46 cm TL per-night and supplemented their income by retaining an average of 1-6 kg of crab byproduct per night. These catch rates are very similar to those observed for legal-sized dusky flathead and blue swimmer crabs caught in larger-meshed (> 80 mm) gillnets that are permitted to be set overnight during winter in estuaries in NSW (average observed catches of legal-sized dusky flathead and blue swimmer crab ranged between 2-23 and 0-7 kg per night among estuaries, respectively – Gray 2002). However, fishers in the latter fishery are only permitted to set 725 m of net as opposed to the 1500 m permitted in the flathead fishery. The weight of retained dusky flathead to total bycatch ratios in the dusky flathead fishery (1:1.1 to 1:2.1) were greater than that determined for the winter overnight set gillnet fishery (< 1:1.07) where fishers are able to retain legal-size individuals of many different species of fish and crustaceans.

Much research has shown that bycatch and discarding problems can be area and gear specific, and so management of discarding in many fisheries can be complex. This has been shown to be true for the estuarine beach-seine (Gray and Kennelly, 2003) and prawn seine (Gray *et al*., in press) fisheries in NSW and there is also evidence of this in the gillnet fishery for dusky flathead. The multivariate analyses showed that the assemblages of organisms and the relative abundance of several individual species captured in flathead nets varied among estuaries in both sampling periods. For example, sea mullet and luderick were much more abundant in catches in Tuggerah Lake than in the other estuaries. Similar inter-estuary variation in catch rates was evident in the overnight set gillnet fishery (Gray, 2002). Despite these findings, in general, the principal species caught and the patterns of discarding observed in the flathead fishery were similar in all three estuaries. Bycatches were dominated by a small number of species, notably blue swimmer crab, sea mullet, bream, and luderick, which are important in other recreational and commercial fisheries. These species accounted for up to 83% of the total observed bycatch (pooled across all three estuaries) in this fishery, and except for sea mullet, these same species were also observed to be the main discards in the overnight-set gillnet fishery (Gray, 2002). In the latter fishery, discards of these and most other species mostly comprised individuals below a MLL, whereas in the flathead gillnet fishery the discards comprised individuals of all sizes (even above a MLL) as fishers are not able to retain any finfish product other than flathead. Most other bycatch species observed in flathead nets were captured in very low numbers and the estimated total levels of discarding of these other species were relatively small (< 2,000 individuals per annum for many species).

The estimated total retained and discarded catches taken in flathead nets varied greatly among estuaries and this generally reflected differences in the total reported fishing effort and the length of the fishing season as well as differences in the relative abundances of different organisms. Reported fishing effort in Wallis and Tuggerah Lakes was far greater (> 3x) than in Lake Illawarra due to the extended fishing season. Estimated total catches of dusky flathead and bycatches therefore were significantly (4-6x) greater in the former estuaries than in Lake Illawarra. Greater catches of sea mullet and luderick contributed to the 3.3x total discarded bycatch in Tuggerah Lake (40 tonne) compared to Wallis Lake (12 tonne) over the 10 month fishing season. Estimated total discarded catches for the 3 month overnight-set gillnet fishery ranged from <1 to approximately 21 tonne depending on the estuary (Gray, 2002). These estimated total catch levels from the flathead and overnight-set gillnet fisheries are far less than those for estuarine beach-seining in NSW (Gray *et al*. 2001; Gray and Kennelly 2003), which is the other main commercial method of catching finfish in estuaries in NSW. The assumptions and factors affecting the accuracy of our estimated total catches from this observer-based program are the same as those discussed in detail for the overnight set gillnet fishery by Gray (2002). Briefly, these assumptions were: (1) the observer days made in each estuary were unbiased and were representative of all fishing crews and trips; (2) there were no systematic measurement errors made by observers; (3) the presence of an observer did not influence normal fishing operations and sorting practices; (4) the reported fishing effort per fisher in terms of numbers of days fished per period were accurate; and (5) the estimates of discarded catches assumed that individuals were not captured on a multiple basis. We believe the main factor affecting the accuracy of our estimated total catches concerns the reporting of fishing effort, as we do not know whether fishers over or under-estimated their true effort. We note, however, that many fishers were interviewed after the survey to help ascertain their real levels of fishing effort.

Although discarding levels of under-sized dusky flathead observed in the current study were relatively negligible, this could change dramatically if the MLL for the species is increased to 40 cm TL as currently proposed. We found that 41% of all dusky flathead captured in the present study were smaller than 40 cm TL and this potential level of discarding would be considered highly wasteful if mortalities were high. If the proposed increase in the MLL of dusky flathead to 40 cm TL is implemented, then an alternative management strategy may need to be implemented into the fishery.

The discarding of some species from flathead nets could potentially be a concern, particularly since many were juveniles of important species including bream, luderick and sea mullet. Although we did not quantify whether discards were alive or dead when retrieved from nets, it is known that not all fish are dead upon retrieval of gillnets set overnight in estuaries. Gray (2002) reported species-specific survival rates of fish captured in the winter fishery, with most of the key bycatch species, including luderick, bream and sea mullet showing high rates of survival (> 82 % alive upon discarding). However, several important species such as tailor and mulloway displayed low rates of survival (< 58%). We note however, that survival rates may vary between periods of warm and cold water and this needs to be investigated.

2.5.2. *Management and reduction of discards*

It may be possible to reduce some bycatches and subsequent discarding in this fishery, especially for some of the important finfish species. Data presented in Gray (2002) and Broadhurst *et al*. (2003) indicate that increasing the minimum permitted mesh size to 95 mm would virtually eliminate bycatches of sea mullet and sand whiting and significantly decrease bycatches of under-size bream and luderick. Given that legal-size individuals of these species are not currently allowed to be retained in this fishery, this would reduce potential wastage. However, the impacts of any change in mesh size on retained dusky flathead and crab catches would need to be considered. If fishers were regulated to use a larger mesh, it may be possible to allow them to retain other legal-size by-product to offset any potential losses (potential reduced flathead catches) in income associated with using the larger mesh. This may also negate potential wastage in the fishery, but could lead fishers using these nets to target other species, potentially increasing effort and changing the fishery to a multi-species one. Many resource user groups would consider this undesirable, and the current policy that prohibits the retention of legal-size finfish other than dusky flathead is specifically designed to stop this. If possible, it would be preferable to modify existing fishing gears and practices to minimize the capture of non-target organisms in this fishery.

Reduction of bycatches, but not retained catches, in this flathead fishery may be possible by altering the configurations and dimensions of gillnets independent of mesh size. Previous studies have shown technical factors such as net material, hanging ratio, ply size, colour, height of net and soak time significantly affect catches in gillnets (Hamely, 1975; Acosta, 1994; Acosta and Appeldoorn, 1995; Samaranayaka *et al*., 1997). Because of potential confounding effects, it was not possible to test for these sorts of variations in the configurations of gear in the current observer-based program (except for the preliminary test between net types). We suggest, however, that industry, managers and scientists experimentally test the usefulness of alternative net designs and fishing arrangements as a way of reducing bycatches and potential wastage in this fishery.

3. BYCATCH ASSESSMENT OF THE ESTUARINE MULTI-SPECIES GILLNET FISHERY

3.1. Abstract

A scientific observer program was used to quantify relationships among the compositions and rates of retained and discarded catches taken in the estuarine commercial gillnet fishery in New South Wales, Australia. Sampling was stratified across 6 estuaries and 3 fishing periods that corresponded to different permitted setting practices throughout 2001. A total of 265 fishing trips was sampled, yielding 58 species (53 finfish, 3 invertebrate, 1 bird, 1 tortoise), of which 45 and 48 species were retained and discarded, respectively. *Mugil cephalus* and *Girella tricuspidata* accounted for 85% by number of total observed catches, with a further 10% being contributed by *Acanthopagrus australis*, *Platycephalus fuscus* and *Portunus pelagicus*. The remaining 53 species accounted for < 5.5% by number of total observed catches. Multivariate analyses showed that the composition and relative numbers of species caught varied among estuaries and fishing periods. Retained *M. cephalus* and *G. tricuspidata* were most characteristic of catches when fishers were permitted only to set and immediately retrieval nets, whereas retained *P. fuscus* and retained and discarded *A. australis* were most important in distinguishing catches when fishers were permitted to set nets overnight. In general, more species and a greater mean number and weight of total individuals were retained than discarded during each fishing period. Average retained catches ranged from 37 to 609 kg fisher-day-1 and discarded catches from 1 to 10 kg fisher-day-1. Throughout the entire survey, 6.2% by number and 3.3% by weight of catches were discarded, with undersized *G. tricuspidata*, *A. australis* and *P. pelagicus* collectively accounting for 69% by number and 49% by weight of all discards observed. Ratios of retained-to-discarded catches by weight were low (< 1:0.1) but varied according to mesh size and period. Compliance with minimum legal lengths (MLL) accounted for most discarding practices, but for those retained species with no MLL, discarding was also length-based. The general selectivity of the nets used in the fishery was quantified for key species and implications of the data are discussed and recommendations concerning management of discarding in the fishery presented.

3.2. Introduction

Knowledge of the retained and discarded catches in a fishery and how these vary spatially, temporally and among different fishing operations is necessary for identifying the potential impacts of fishing on stocks and ecosystems, as well as assessing potential interactions among fisheries competing for the same resources (Alverson *et al*., 1994; Kennelly, 1995; Hall, 1999). Fishing can directly and indirectly affect the biomasses and harvested yields of stocks, ecological interactions among species and the productivity and functioning of ecosystems (Fennessy, 1994; Jennings and Kaiser, 1998; Hall, 1999; Kaiser and deGroot, 2000). Discarding in many fisheries is perceived as wasteful and can lead to significant conflict among different users of the resource and if not quantified, can be a major source of uncertainty in fisheries assessments (Chen and Gordon, 1997; Hall, 1999). Information on retained and discarded catch compositions along with data on the selectivity of the fishing gears used and behaviour of the species captured can greatly assist in determining ways to mitigate bycatches and discarding in fisheries (Chopin and Arimoto, 1995; Hall, 1999; Millar and Fryer, 1999; Broadhurst, 2000). Because of the critical importance of bycatch and discarding issues in many fisheries throughout the world and the need for environmental assessments of fisheries, there has been much research in recent years to identify and resolve discarding and wastage (Alverson *et al*., 1994; Kennelly, 1995; Hall, 1999; Broadhurst, 2000). This research has mostly been focused on fisheries that use towed fishing gears such as demersal trawls and seines (see Hall, 1999; Broadhurst, 2000; Kaiser and deGroot, 2000). Much less emphasis has been placed on fisheries incorporating static fishing gears, including gillnets and trammel nets (but see Berrow, 1994; Trippel *et al*., 1996; Akiyama, 1997; Trent *et al*., 1997; Erzini *et al*., 2002; Gray, 2002; Hutchings and Lamberth, 2002; 2003; Godoy *et al*., 2003).

Gillnets are used to harvest many different types and species of fish and form the basis of many commercial fisheries throughout the world (Berrow, 1994; Petrakis and Stergiou, 1996; Hickford *et al*., 1997; Lamberth *et al*., 1997; Madsen *et al*., 1997; Trent *et al*., 1997; Hutchings and Lamberth, 2002; Stergiou *et al*., 2002). Significant controversy surrounds many coastal and oceanic gillnet fisheries, particularly those that interact with, and include, marine mammals, turtles and sea birds as bycatches (Trippel *et al*., 1996; Cox *et al*., 1998; Quinn, 1998; Julian and Beeson, 1998; D'agrosa *et al*., 2000; Oesterblom *et al*., 2002). Consequently, in such fisheries much research is being done to reduce the bycatch of such organisms (Trippel *et al*., 1999; Melvin *et al*., 1999). Controversy in gillnet fisheries is not restricted to high profile and large-scale fisheries. For example, in several small-scale gillnet fisheries, such as those based in coastal and estuarine waters in southern Africa and Australia, there is considerable conflict among different resource interest groups over the use of gillnets and their potential impacts on the sustainability of stocks as well as general concerns among different fishing sectors over access and allocation to the resource (Lamberth *et al*., 1997; Gray, 2002; Hutchings and Lamberth, 2003). Much of this conflict stems from the fact that the primary species targeted and many of the discards in these gillnet fisheries are important in other regional commercial and recreational fisheries (Bronte and Johnson, 1983; Gray, 2002; Hutchings and Lamberth, 2002). Consequently, there is much pressure to mitigate discarding and reduce effort in these fisheries.

Gillnets are the most common gear used by commercial fishers to capture fish in estuaries in New South Wales (NSW), Australia (Pease, 1999). Whilst port sampling and fishers logbooks supply some information on the species, size compositions and quantities of retained catches (e.g. Gray *et al*., 2002), very little is known about the discarded catches in this fishery. Gray (2002) previously assessed discarding in a sector of the fishery that is permitted to set gillnets overnight, but interactions between retained and discarded catches and how they vary according to seasons and fishing gears and practices have not been examined. The aims of the current study were to address this lack of knowledge in the estuarine commercial gillnet fishery in NSW. We achieved this by using a stratified observer-based survey to quantify the species and length compositions of the retained and discarded catches taken in 6 estuaries spanning more than 1500 km of coast. We specifically examined relationships between the retained and discarded components of catches by assessing the effects of fishing season, setting practice and mesh size.

3.3. Materials and Methods

3.3.1. NSW estuarine commercial gillnet fishery

Approximately 770 fishers are endorsed to participate in the estuarine commercial gillnet fishery across 100 estuaries in NSW. The fishery annually lands approximately 2,500 tonnes of finfish and crabs valued at around $AUD 5 million per annum. Reported total landed gillnet catches include over 70 species, however *Mugil cephalus* (sea mullet) and *Girella tricuspidata* (luderick) account for approximately 70-75% by weight of the reported total gillnet landings throughout the state.

Gillnets are used year-round and although different regulations govern the use, mesh sizes and lengths of gillnets among estuaries and months of the year, there are 3 basic methods of operation: (i) set and immediate retrieval, (ii) 3-hour set and (iii) overnight set. In general, the method of set and immediate retrieval and nocturnal 3-hour set is permitted year-round, whereas diurnal 3-hour set and the overnight (sunset to sunrise) setting of nets is permitted only during winter (May to August). The method of set and immediate retrieval can occur at anytime and often involves deploying the net around a school of fish or a submerged structure, after which the fishers often disturb the water (e.g. using oars or outboard motor), scare the fish into the meshes, and then retrieve the net. The extended overnight setting of gillnets is permitted during winter due to the belief that, the cold water reduces the mortality of unwanted fish and thus the majority of discards are alive when released (see Gray, 2002). Further, the condition of the retained fish is good for marketing, as opposed to summer, when warmer water causes the fish to deteriorate quickly. There is also a separate, but limited, estuarine gillnet fishery for *Platycephalus fuscus* (dusky flathead) permitted in 4 estuaries, but this is dealt with in Chapter 2 (see also Gray *et al*., in press).

The minimum legal stretched mesh opening in gillnets used in the general fishery must not be < 80 mm (except for specific bottom-set gillnets for dusky flathead – see Chapter 2 and Gray *et al*., in press), while the length of any individual, or combination, of nets must not exceed 725 m (except in 5 estuaries including Lake Wooloweyah and the Broadwater in the Clarence River where nets can be 1450 m in length). A range of mesh sizes from 80-250 mm is used in the fishery to target a wide variety of species of different morphologies and sizes, including sparids, platycephalids, mugilids, monocanthids and carcharinids (Pease, 1999; Gray, 2002). Nets are constructed of a variety of materials, the most common being multi-monofilament and nylon, and are typically red, green, grey or black, 20 to 66 meshes deep of 0.41-0.62 mm (210/4 to 210/6 strand nylon and 0.5*8 strand multi-monofilament) twine thickness and hung at a ratio of 0.5. Gillnets are generally staked or anchored at each end and are mostly bottom set (except when targeting schools of sea mullet - *Mugil cephalus*). Nets used in shallow areas, may fish the entire water column.

3.3.2. Sampling of retained and discarded catches

Commercial gillnet catches were sampled between January and December 2001 from 6 estuaries (Richmond, Clarence, Camden Haven and Shoalhaven Rivers and Wallis and Illawarra Lakes) spanning approximately 1,500 km of coast (Figure 3.1). In this study, the Clarence River included Lake Woolooweyah and the Broadwater, whilst the Camden Haven River included Queens and Watson Taylors Lakes.

For each sample, scientific observers accompanied commercial fishers during one full-days fishing activity (including night-time). For nets set overnight, observers accompanied fishers during the morning when they retrieved their nets. As each net was retrieved into the boat, each organism was disentangled from the net by the fisher, who then decided whether it would be retained or discarded. The observer identified, counted and determined the total weight of all retained and discarded species. The lengths (fork length – FL - for fish with forked or emarginate caudal fin, total length – TL - for fish with truncated or rounded caudal fin) to the nearest 1-cm of key species were also measured. Discarded fish that were alive were generally processed immediately, so that they could be released quickly back into the water to minimise further stress and mortality. In contrast, much of the retained dead catch was processed after the entire net was retrieved. The observers also recorded operational data, including mesh and twine thickness, length, depth and hanging ratio of nets, fishing time and location.

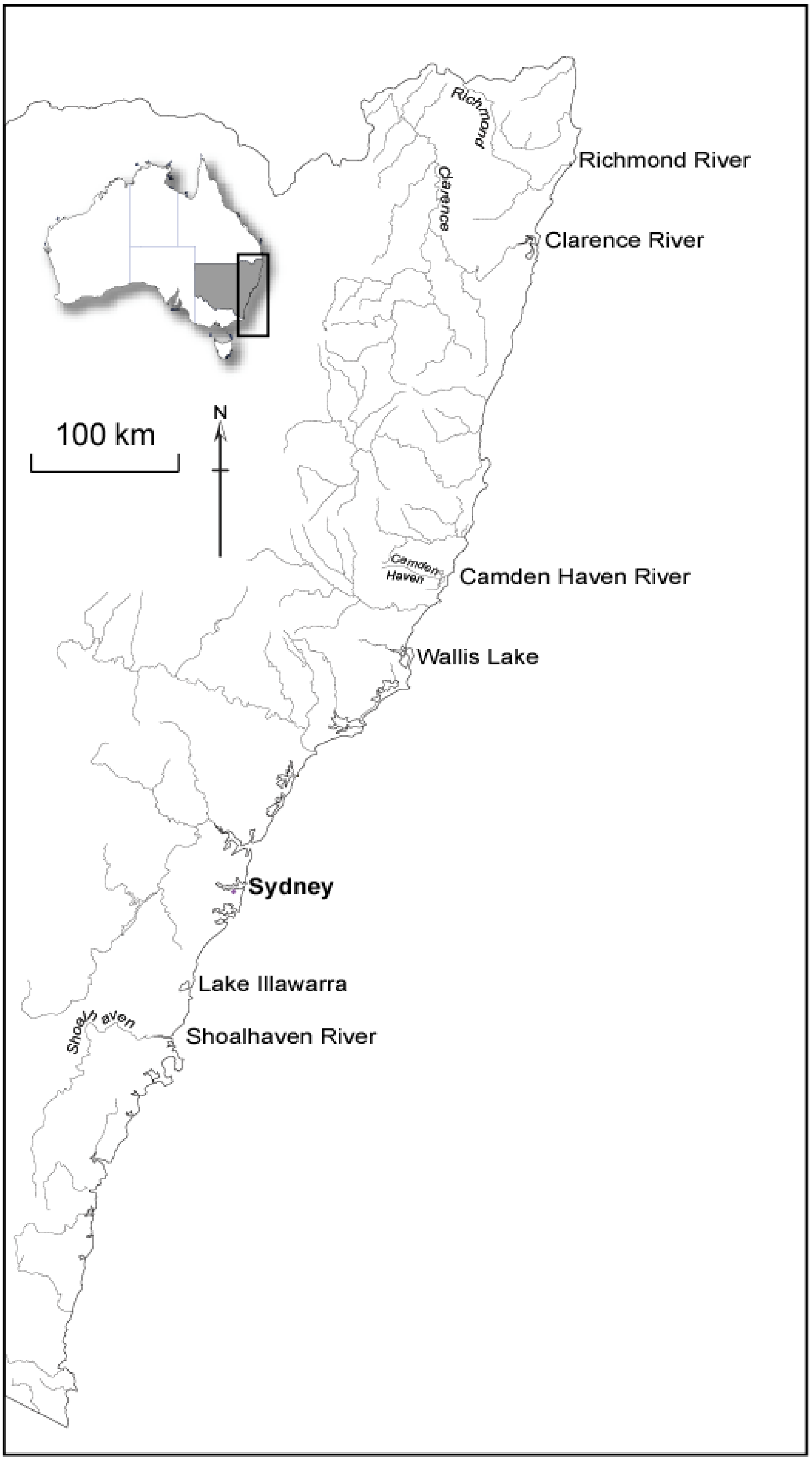

Figure 3.1. Map of New South Wales showing the 6 study estuaries.

3.3.3. Data analyses

To assess seasonality influences and the effects of the different fishing practices of set, splash and retrieval versus overnight setting on retained and discarded catches, the data were divided into 3 fishing periods to coincide with permitted fishing practice – Period 1 (January to April) and Period 3 (September to December) coincided with the continuous fishing practice of set and immediate retrieval, whereas Period 2 (May to August) corresponded when nets were set overnight.

3.3.4. Variations in structures of catches

Non-parametric multivariate analyses were used to delineate spatial, temporal and gear-related differences in the structures (composition and relative numbers of each retained and discarded species) of catches. The general procedures used followed those outlined in Clarke (1993) and Clarke and Warwick (2001). Similarity matrices based on the Bray-Curtis similarity measure were generated using non-transformed catch data and the inter-relationships among individual catches were displayed graphically in 2 dimensional multidimensional scaling (MDS) ordination plots. Samples that grouped together in each ordination were most similar and the stress coefficient indicated the goodness of fit of the data. A stress coefficient of < 0.15 indicates that the ordination is a relatively good representation of underlying data. One-way analyses of similarity (ANOSIM) were used to test for spatial, temporal and gear-related differences in the structures of catches. Similarity percentage (SIMPER) analyses were used to identify the species that were most responsible for the similarity of catches within each estuary and fishing period, and to identify which species contributed greatest to the dissimilarity of catches taken in nets of different mesh size. The ratio of similarity (dissimilarity)/standard deviation is a measure of how consistently each species contributed to the similarity measure within a group, or to the dissimilarity measure between groups. Taxa displaying a high ratio and a high contribution can be considered good discriminating species (Clarke and Warwick, 2001).

3.3.5. Variations in retained and discarded catch rates

Mean ± 1 standard error (se) catch rates per fishing trip and per 100 m of net were calculated for each estuary and each fishing period. Analyses of variance (ANOVA) were used to test for differences in the weights and quantities of retained and discarded catches between estuaries and fishing periods. Analyses were done at two levels: (1) catches per fisher-night and (2) standardised catches per 100 m length of net. The latter analyses were done because commercial fishers used nets of different length and we wished to test for differences in the relative numbers of organisms caught between estuaries and fishing periods. Data were transformed to log (x+1) to stabilize variances (Cochran's test) and Student-Newman-Keuls (SNK) tests were used to determine differences among means following ANOVA.

The ratio of retained to discarded catch by weight was determined for each estuary in each fishing period. The ratio of weight of the retained catch to weight of discarded catch was calculated for each estuary for each fishing period following the procedures detailed in Cochran (1963).

3.3.6. Length compositions of catches and relative selectivity of gillnets

Observed length compositions of retained and discarded catches of several key species - *M. cephalus*, *G. tricuspidata*, *P. fuscus* and *Acanthopagrus australis* (bream), *Sillago ciliata* (sand whiting) were plotted for each mesh size used. Data for each mesh size were pooled across all study estuaries and when sample sizes were small, data were also pooled across specific mesh sizes. These data were used to assess the relative selectivity of nets used in the fishery for these key species. We did not attempt to fit selectivity curves to these data because assumptions critical to the models were contravened. Specifically, true fishing effort could not be standardised even though we knew the setting time and number and length of nets observed, because different nets were constructed of different materials, twine thickness, hanging ratios and heights and we could not standardise for these. Further, different fish populations were most likely fished throughout the survey and in different sections of each estuary as well as in the different estuaries and so the probability of all fish encountering nets of all mesh sizes would not have been equal. We did attempt to select subsets of the data where nets of similar construction but different mesh sizes were fished simultaneously. However, generally very few replicate observations of only 2 mesh sizes were obtained and this was considered insufficient to model the data and generate realistic selectivity curves (Millar and Fryer, 1999). Thus we described the general trends in the lengths of fish caught in nets of different mesh sizes and used this to assess the relative selectivity of nets used in the fishery.

3.4. Results

3.4.1. Observer coverage

A total of 265 gillnet catches were observed throughout the study; 18 in the Richmond River, 60 in the Clarence River, 50 in the Camden Haven River, 53 in Wallis Lake, 41 in Lake Illawarra and 43 in the Shoalhaven River. A total of 195 observations for set and immediate retrieval (99 in Period 1, 11 in Period 2 and 85 in Period 3), 3 for 3-hour sets and 67 for overnight sets (all in Period 2) were made during the study. The number of catches observed for each mesh size was: 80 mm (133 catches), 100 mm (70 catches), 95 mm (29 catches), 89 mm (22 catches), 83 mm (10 catches), 150 mm (1 catch). The majority of nets observed were constructed of multi-monofilament (429 nets), compared to nylon (31 nets). Few catches were observed in Period 1 and none in Period 2 in the Richmond River as this estuary was closed to fishing between February and September 2001 following a large flood event that caused massive fish kills (for details, see Kennelly and McVea, 2002).

3.4.2. Retained and discarded catch composition

A total of 58 species comprising 53 teleosts, 3 invertebrate, 1 bird and 1 tortoise was identified in observed commercial catches throughout the study (Table 3.1). Fishers retained a total of 43 species, whilst 46 species were discarded, with 14 of these latter species always discarded. Eleven species were solely retained, but these were captured in low numbers. Overall, *M. cephalus* and *G. tricuspidata*, accounted for 85% by number and 89% by weight of the observed total catch and 89% by number and weight of the total retained catch, pooled across all estuaries and time periods (Table 3.2). *A. australis*, *Portunus pelagicus* and *P. fuscus*, were the next most numerous species caught and collectively contributed 9% by number and 7% by weight towards the observed total catch and 7% by number and weight to the total retained catch. The remaining 53 species attributed for < 5.5% by number of the total observed catch (Table 3.2).

Discards comprised the undersized individuals of several target species, including *A. australis*, *G. tricuspidata*, *P. pelagicus*, other species of recreational and commercial importance, including *Pomatomus saltatrix*, *Macquaria novemaculeata*, *M. colonorum* and *Argyrosomus japonicus*, as well as several species of little commercial or recreational value, including *Notesthes robusta*, *Selenotoca multifasciata*, *Dasyatis thetidis* and *Dicotylichthys punctulatus* (Table 3.1). These latter species were generally caught in low numbers. Overall, 6.2% by number and 3.3% by weight of the total observed catch was discarded (Table 3.2). Discards made a significant contribution to the total catch of some of the primary species, including *A. australis* (36% by number), *P. pelagicus* (39%) and *A. japonicus* (67%) (Table 3.2). Minimum legal lengths (MLL's) accounted for most of the observed discarding. *A. australis*, *G. tricuspidata*, *M. cephalus*, *Sillago ciliata* and *P. fuscus* were both retained and discarded, with fish below the MLL's mostly discarded. Discarding of species with no MLL (e.g. *Cnidoglanis macrocephalus* and *Liza argentea*) was also length based with the smallest individuals mostly being discarded because of their low market value, however this varied among fishers. Overall, undersized *G. tricuspidata*, *A. australis* and *P. pelagicus* collectively accounted for 69% by number and 49% by weight of all discards observed in the study (Table 3.2). The large stingray, *D. thetidis* accounted for 18% of the weight of the total observed discarded catch.

3.4.3. Seasonal and spatial variations in retained and discarded catches

MDS and ANOSIM tests showed that the structure of catches varied spatially and temporally (Figures 3.2 and 3.3, Tables 3.3 and 3.4). Specifically, the MDS separated total catches (individual observed trips pooled within each fishing season) based on estuary and fishing period (Figure 3.2). Several species, including *Arius graeffei*, *Mugil georgii*, and *Myxus petardi* were only caught in the 2 most northern estuaries and *M. novemaculeata* and *M. colonorum* were caught only in the riverine estuaries (Richmond, Clarence and Shoalhaven Rivers). Despite the graphical separation of catches, it was not possible to test for significant differences in catch structure between estuaries by ANOSIM due to the small sample sizes caused by the pooling of data.

Individual catches varied among fishing periods within each estuary, except between Periods 1 and 3 in the Camden Haven and Shoalhaven Rivers and Wallis Lake and also between Periods 1 and 2 in the Shoalhaven River (Table 3.3). The SIMPER analyses identified the species that contributed greatest to the similarity of catches within each estuary in each fishing period (Table 3.4). Notably, in Periods 1 and 3 when fishers are permitted only to set and immediately retrieve nets, retained *M. cephalus* contributed greatest to the similarity of catches in each estuary, except in the Shoalhaven River and the Richmond River in Period 3 where retained *G. tricuspidata* contributed greatest to the similarity measure (Table 3.4). During the overnight setting period (Period 2), retained *P. fuscus* contributed greatest to the similarity of catches in the Camden Haven and Wallis Lake, whilst retained *A. australis* provided the greatest contribution in the Clarence River. Other components of catches that were generally important in distinguishing catches during all fishing periods were retained and discarded *A. australis*, retained *S. ciliata* in the Clarence and Camden Haven Rivers and Wallis Lake, and retained and discarded *P. pelagicus* in Lake Illawarra (Table 3.4).

Except for the Richmond River and Lake Illawarra in Period 1 and the Clarence River in Period 3, a greater mean total number of species was retained than discarded in each estuary and fishing period (Figure 3.4, Table 3.5). Further, a greater mean total weight and mean total number of individuals was retained than discarded in each estuary in each fishing period (Figure 3.4, Table 3.5). Observed mean total weight of retained catches varied between 37 kg per fisher-day (Lake Illawarra in Period 2) to 609 kg per fisher-day (Richmond River in Period 1), whilst observed mean total weight of discards per fisher-day ranged from 1 kg (Wallis Lake in Period 1) to 10 kg (Richmond River in Period 1) (Figure 3.4).

Variations between estuaries in mean retained and discarded catches for the major species are shown in Figs. 5 and 6. Fewer *M. cephalus*, *G. tricuspidata* and *P. fuscus* were discarded than retained in all estuaries. This was also true for *S. ciliata*, except in Lake Illawarra in Period 1. No clear pattern was evident for *A. australis* and *P. pelagicus*. For example, more *A. australis* were retained than discarded in Wallis Lake and the Shoalhaven River, but the opposite was evident in the Camden Haven River (Figure 3.5).

ANOVAS detected significant differences between estuaries and periods in the mean retained and discarded catches for most species (Table 3.5). Rankings of retained and discarded catches between estuaries were species specific and varied among time periods. Despite this, retained catches of *M. cephalus* generally tended to be greatest in Periods 1 and 3, whilst retained and discarded catches of *P. fuscus* were greatest in Period 2, except in the Richmond and Shoalhaven

Rivers. Retained and discarded catches of *P. pelagicus* were greater in Lake Illawarra than elsewhere, but no clear spatial or temporal trends were evident for *G. tricuspidata* and *A. australis*.

Observed ratios (+1se) of the total weights of retained to discarded catches varied significantly according to estuary and period (ANOVA, df = 16, 247, MS = 0.104, p< 0.01) but were low in all estuaries and periods, ranging from 1:0.010 (0.004) in Wallis Lake Period 1 to 1:0.099 (0.006) in Lake Illawarra Period 2. There was no significant correlation between the weight of retained catch to discarded catch per fishing day in any estuary or period (Table 3.6). Except for the Clarence River, the ratio of catch discarded was greatest in each estuary in Period 2 (Table 3.6), but this was also dependent on mesh size (see below).

Table 3.1. List of all species observed in commercial gillnet catches and the numbers retained and discarded in each estuary throughout the study.

Family	Scientific Name	Common Name	Retained							Discarded						
			RR	CR	CH	WL	LI	SR	Total	RR	CR	CH	WL	LI	SR	Total
Teleosts:																
Anguillidae	*Anguilla spp.*	River eel		9					9				2			2
Ariidae	*Arius graeffei*	Fork-tail catfish	3	151					154	27	6					33
Arripidae	*Arripis trutta*	Salmon		8				1	9							
Belonidae	*Strongylura leiura*	Longtom			2	5			7			1				1
Bothidae	*Pseudorhombus arsius*	Large-tooth flounder		1	1	4	1		7	1	7	1		1	3	13
Bothidae	*Pseudorhombus jenynsii*	Small-tooth flounder						6	6			3			1	4
Carangidae	*Caranx ignobilis*	Giant trevally		1					1							
Carangidae	*Caranx sexfasciatus*	Bigeye trevally			5				5							
Carangidae	*Pseudocaranx dentex*	Silver trevally	2				1	17	20					1		1
Carangidae	*Trachurus spp.*	Yellowtail												1		1
Carcharhinidae	*Carcharhinus melanopterus*	Black-tip shark		1					1							
Carcharhinidae	*Carcharhinus spp.*	Whaler shark	3	4					7							
Chaetodontidae	*Selenotoca multifasciata*	Striped butterfish		26					26	6	3	6	11	2		28
Clupeidae	*Herklotsichthys castelnaui*	Southern herring		2					2	3	35					38
Cyprinidae	*Cyprinus carpio*	Carp						4	4							
Dasyatididae	*Dasyatis thetidis*	Black stingray									1					1
Dasyatididae	*Dasyatis brevicaudatus*	Estuary stingray			12	9			21	9	103	11	14	9	6	152
Diodontidae	*Dicotylichthys punctulatus*	Three-bar porcupinefish								2	3	2	5	2	12	26
Elopidae	*Megalops cyprinoides*	Oxeye herring		1					1	2						2
Enoplosidae	*Enoplosus armatus*	Old wife		64	10	8			82		8					8
Gerreidae	*Gerres subfasciatus*	Silver biddy					6		6	4	8	1		7	2	22
Girellidae	*Girella tricuspidata*	Luderick	2657	643	1285	1531	2904	3031	12051	83	37	315	11	468	112	1026
Hemiramphidae	*Hyporhamphus regularis*	River garfish		1					1							
Hemiramphidae	*Arrhamphus sclerolepis*	Snub-nose garfish										1				1
Monacanthidae	*Monacanthus chinensis*	Fanbelly leatherjacket			10	32			42					2		2
Monacanthidae	*Meuschenia freycineti*	Six-spine leatherjacket					1		1							

Table 3.1. Continued.

Family	Scientific Name	Common Name	Retained							Discarded						
			RR	CR	CH	WL	LI	SR	Total	RR	CR	CH	WL	LI	SR	Total
Monacanthidae	*Meuschenia trachylepis*	Yellowfin leatherjacket			10	1	71	11	93		1	10		7	1	19
Monacanthidae	*Scobinichthys granulatus*	Rough leatherjacket				3			3							
Mugilidae	*Mugil cephalus*	Sea mullet	6741	9970	4891	3215	14912	620	40349	7	43	1	1	11	3	66
Mugilidae	*Mugil georgii*	Fantail mullet		18	1				19	2	64					66
Mugilidae	*Liza argentea*	Flat-tail mullet	2	421	55	39	18	29	564	7	18	3	19		3	50
Mugilidae	*Myxus petardi*	Pink eye mullet		152				11	163	85	53		1			139
Mugilidae	*Myxus elongatus*	Sand mullet			3		1		4							
Myliobatidae	*Myliobatis australis*	Eagle ray									1					1
Percichthyidae	*Macquaria novemaculeata*	Bass								12	34				27	73
Percichthyidae	*Macquaria colonorum*	Estuary perch													22	22
Platycephalidae	*Platycephalus fuscus*	Dusky flathead	15	281	576	209	168	44	1293	2	29	27	6	2		66
Plotosidae	*Cnidoglanis macrocephalus*	Estuary catfish			6	176		2	184			1	16		3	20
Plotosidae	*Plotosus lineatus*	Striped catfish										1				1
Pomatomidae	*Pomatomus saltatrix*	Tailor	3	10	6	19	18	6	62		18	9	3	39	10	79
Rhinobatidae	*Aptychotrema rostrata*	Shovelnose ray	1						1							
Sciaenidae	*Argyrosomus japonicus*	Mulloway		52		3		3	58	3	98	9	1	7		118
Scorpaenidae	*Notesthes robusta*	Bullrout									6	3			11	20
Scorpaenidae	*Centropogon australis*	Fortescue									2					2
Siganidae	*Siganus fuscescens*	Black spinefoot										1				1
Sillaginidae	*Sillago ciliata*	Sand whiting	16	158	233	46	22	20	495	2	14	11	2	13	3	45
Soleidae	*Synaptura nigra*	Black sole			3		1		4		2	2		3	3	10
Sparidae	*Acanthopagrus australis*	Yellowfin bream	4	1022	50	370	360	149	1955	65	398	247	63	274	41	1088
Sparidae	*Pagrus auratus*	Snapper												8		8
Sparidae	*Rhabdosargus sarba*	Tarwhine					6		6				1	5		6
Triglidae	*Chelidonichthys kumu*	Red gurnard				1	1		2					2	1	3
Urolophidae	*Trygonoptera testacea*	Stingaree common													4	4

Table 3.1. Continued.

Family	Scientific Name	Common Name	Retained							Discarded						
			RR	CR	CH	WL	LI	SR	Total	RR	CR	CH	WL	LI	SR	Total
Crustaceans:																
Portunidae	*Portunus sanguinolentus*	Three-spot crab					2		2							
Portunidae	*Scylla serrata*	Mud crab	2	26	12	18	1		59	3	32	14				49
Portunidae	*Portunus pelagicus*	Blue-swimmer crab			10	64	798		872		20	14	42	478		554
Other:																
Chelidae	*Emydura macquarii*	Short-neck tortoise									1					1
Phalacrocoracidae	*Phalacrocorax spp.*	Cormorant												1		1
Total species			12	23	20	19	19	15	43	20	28	24	16	21	19	46

Table 3.2. Summary of observed top 10 species caught by number and weight in gillnets pooled across all estuaries and periods and their contribution to total catch, the proportion retained and contribution to the total retained and discarded catch.

Species	Total caught	% total catch	% retained	% total retained catch	% total discarded catch
a) Number					
Mugil cephalus	40415	64.6	99.8	68.8	1.7
Girella tricuspidata	13077	20.9	92.2	20.5	26.5
Acanthopagrus australis	3043	4.9	64.2	3.3	28.1
Portunus pelagicus	1426	2.3	61.2	1.5	14.3
Platycephalus fuscus	1359	2.2	95.1	2.2	1.7
Liza argentea	614	1.0	91.9	1.0	1.3
Sillago ciliata	540	0.9	91.7	0.8	1.2
Myxus petardi	302	0.5	54.0	0.3	3.6
Cnidoglanis macrocephalus	204	0.3	90.2	0.3	0.5
Argyrosomus japonicus	176	0.3	33.0	0.1	3.0
All other species	1367	2.2	48.8	1.1	18.1
Total	62523		93.8	100.0	100.0
b) Weight (kg)					
Mugil cephalus	22206.6	70.2	99.9	71.4	1.6
Girella tricuspidata	5811.8	18.4	96.1	18.0	21.3
Acanthopagrus australis	1046.8	3.3	78.1	2.6	21.8
Platycephalus fuscus	880.6	2.8	98.6	2.8	1.2
Dasyatis thetidis	282.0	0.9	32.8	0.3	18.0
Arius graeffi	266.6	0.8	99.7	0.9	0.1
Portunus pelagicus	244.6	0.8	74.7	0.6	5.9
Cnidoglanis macrocephalus	202.8	0.6	89.8	0.6	2.0
Myxus petardi	198.1	0.6	59.7	0.4	7.6
Liza argentea	196.4	0.6	93.0	0.6	1.3
All other species	753.0	2.4	73.2	1.9	19.2
Total	31628.1		96.7	100.0	100.0

Table 3.3. Summary of results of 1 way analyses of similarity comparing the structure of catches across periods within each estuary. 5000 permutations were done for each analysis on non-transformed data.

Estuary	P1 v P2		P1 v P3		P2 v P3	
	R	significance	R	significance	R	significance
Richmond River	-	-	0.475	0.2%	-	-
Clarence River	0.165	0.6%	0.080	2.8%	0.231	0.3%
Camden Haven River	0.398	0.1%	-0.075	96.4%	0.386	0.1%
Wallis Lake	0.372	0.1%	0.086	15.0%	0.139	3.4%
Lake Illawarra	0.648	0.1%	0.210	1.5%	0.360	0.3%
Shoalhaven River	0.021	25.6%	0.030	20.9%	0.152	4.3%

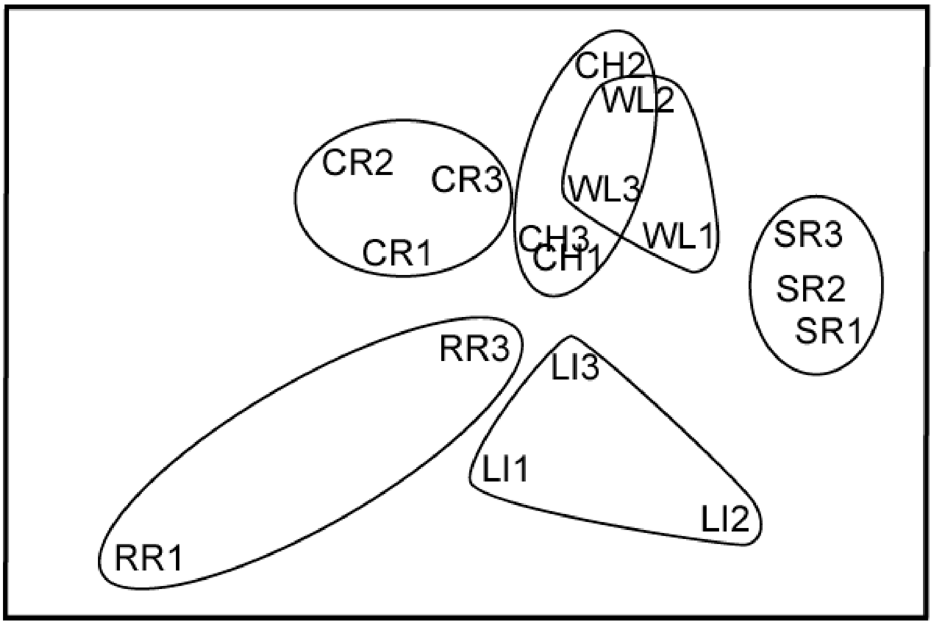

Figure 3.2. MDS ordinations showing differences in total catches between estuaries and fishing periods. RR = Richmond River, CR = Clarence River, CH = Camden Haven, WL = Wallis Lake, LI = Lake Illawarra, SR = Shoalhaven River; Number refers to period.

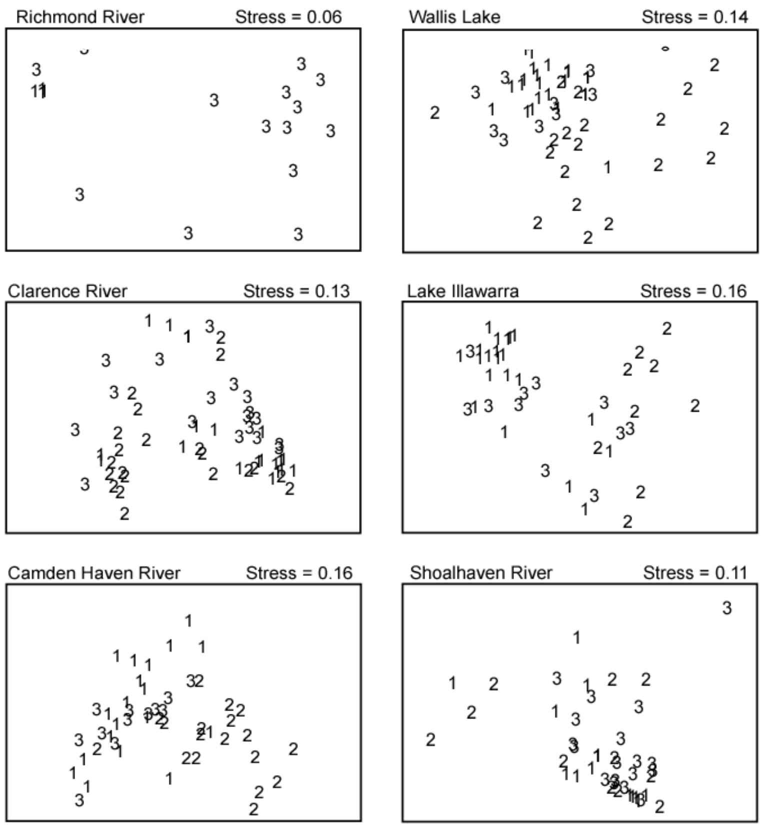

Figure 3.3. MDS ordinations showing differences in catches between fishing periods in each estuary. Number refers to period.

Table 3.4. Summary of SIMPER analyses listing the 5 species that contributed greatest to the percent contribution of similarity measure of total catches in each sampling period in each estuary. r,d denote retained and discarded respectively. No data were collected during Period 2 in the Richmond River. Analyses done on non-transformed data.

Period 1 Species	%	**Period 2** Species	%	**Period 3** Species	%
Richmond River					
Mugil cephalus (r)	98.8			*Girella tricuspidata* (r)	79.2
Myxus petardi (d)	0.5			*Mugil cephalus* (r)	17.6
Arius graeffei (d)	0.4			*Girella tricuspidata* (d)	1.2
Macquaria novemaculeata (d)	0.2			*Acanthopagrus australis* (d)	1.0
Carcharhinus spp. (r)	0.1			*Platycephalus fuscus* (r)	0.5
Clarence River					
Mugil cephalus (r)	89.7	*Acanthopagrus australis* (r)	45.7	*Mugil cephalus* (r)	74.9
Acanthopagrus australis (r)	4.1	*Mugil cephalus* (r)	23.0	*Girella tricuspidata* (r)	10.0
Platycephalus fuscus (r)	2.1	*Platycephalus fuscus* (r)	10.6	*Acanthopagrus australis* (d)	6.7
Acanthopagrus australis (d)	1.5	*Acanthopagrus australis* (d)	9.1	*Platycephalus fuscus* (r)	2.7
Girella tricuspidata (r)	1.4	*Dasyatis thetidis* (d)	4.3	*Sillago ciliata* (r)	1.6
Camden Haven River					
Mugil cephalus (r)	70.5	*Platycephalus fuscus* (r)	55.0	*Mugil cephalus* (r)	70.9
Girella tricuspidata (r)	22.1	*Mugil cephalus* (r)	18.0	*Girella tricuspidata* (r)	18.1
Girella tricuspidata (d)	1.9	*Girella tricuspidata* (r)	9.1	*Platycephalus fuscus* (r)	3.9
Acanthopagrus australis (d)	1.8	*Sillago ciliata* (r)	8.0	*Girella tricuspidata* (d)	3.7
Platycephalus fuscus (r)	1.5	*Acanthopagrus australis* (d)	5.2	*Sillago ciliata* (r)	1.5
Wallis Lake					
Mugil cephalus (r)	48.8	*Platycephalus fuscus* (r)	31.7	*Mugil cephalus* (r)	67.9
Girella tricuspidata (r)	45.4	*Mugil cephalus* (r)	30.2	*Girella tricuspidata* (r)	21.8
Acanthopagrus australis (r)	5.1	*Girella tricuspidata* (r)	15.5	*Acanthopagrus australis* (r)	7.5
Platycephalus fuscus (r)	0.2	*Acanthopagrus australis* (r)	11.2	*Acanthopagrus australis* (d)	1.4
Acanthopagrus australis (d)	0.2	*Cnidoglanis macrocephalus* (r)	3.1	*Sillago ciliata* (r)	0.6
Lake Illawarra					
Mugil cephalus (r)	83.2	*Girella tricuspidata* (r)	29.2	*Mugil cephalus* (r)	56.6
Girella tricuspidata (r)	7.8	*Portunus pelagicus* (d)	13.5	*Girella tricuspidata* (r)	17.2
Portunus pelagicus (d)	1.9	*Platycephalus fuscus* (r)	12.6	*Portunus pelagicus* (r)	11.6
Girella tricuspidata (d)	1.8	*Portunus pelagicus* (r)	10.8	*Acanthopagrus australis* (r)	5.1
Acanthopagrus australis (d)	1.8	*Acanthopagrus australis* (r)	10.3	*Acanthopagrus australis* (d)	4.3
Shoalhaven River					
Girella tricuspidata (r)	87.0	*Girella tricuspidata* (r)	88.1	*Girella tricuspidata* (r)	82.3
Acanthopagrus australis (r)	5.3	*Mugil cephalus* (r)	4.6	*Mugil cephalus* (r)	13.6
Mugil cephalus (r)	4.3	*Acanthopagrus australis* (r)	2.5	*Acanthopagrus australis* (r)	2.7
Acanthopagrus australis (d)	1.5	*Sillago ciliata* (r)	1.1	*Girella tricuspidata* (d)	0.9
Pomatomus saltatrix (d)	0.6	*Girella tricuspidata* (d)	0.8	*Acanthopagrus australis* (d)	0.2

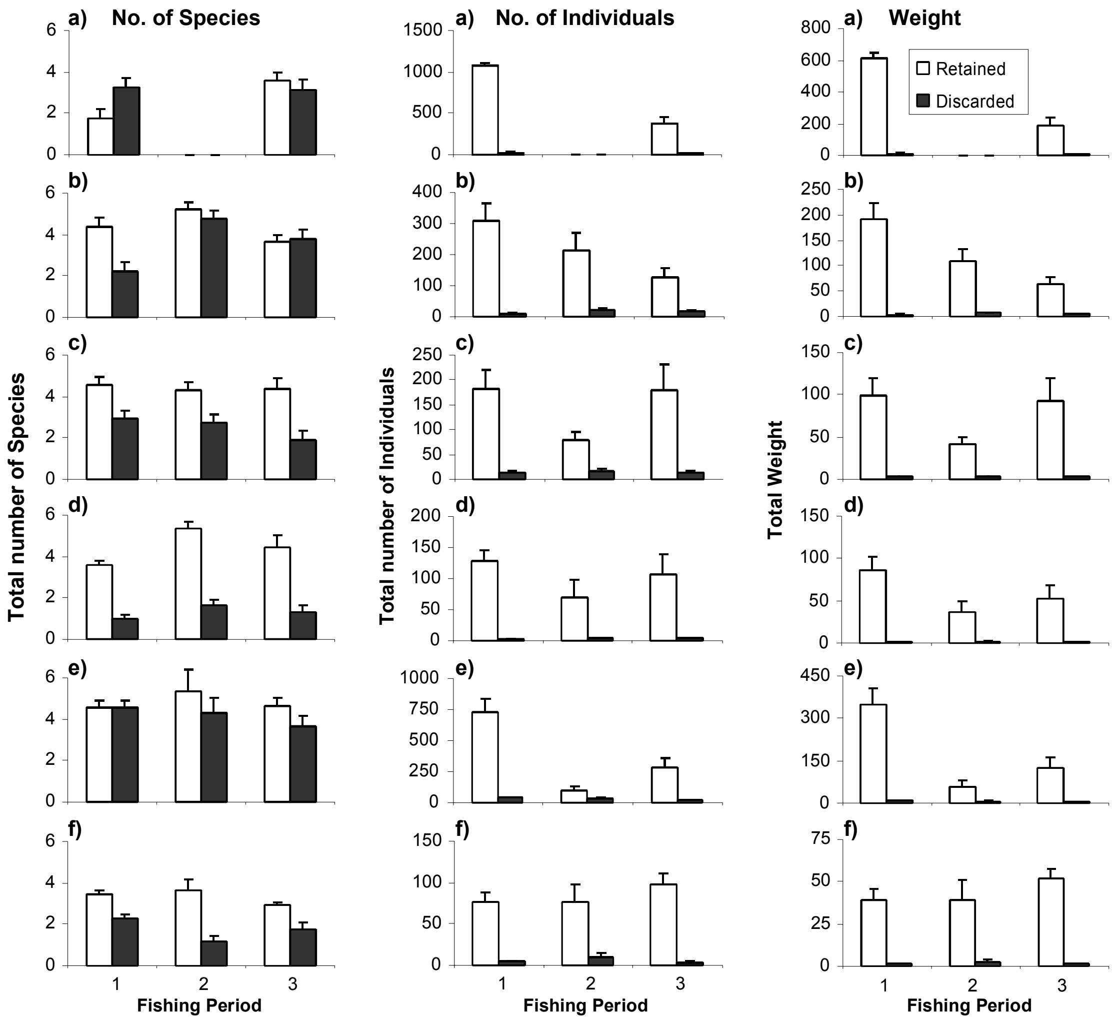

Figure 3.4. Mean daily (+ 1 se) weight and number of total retained and discarded catches in each studied estuary during the survey. a) Richmond River, b) Clarence River, c) Camden Haven, d) Wallis Lake, e) Lake Illawarra, f) Shoalhaven River.

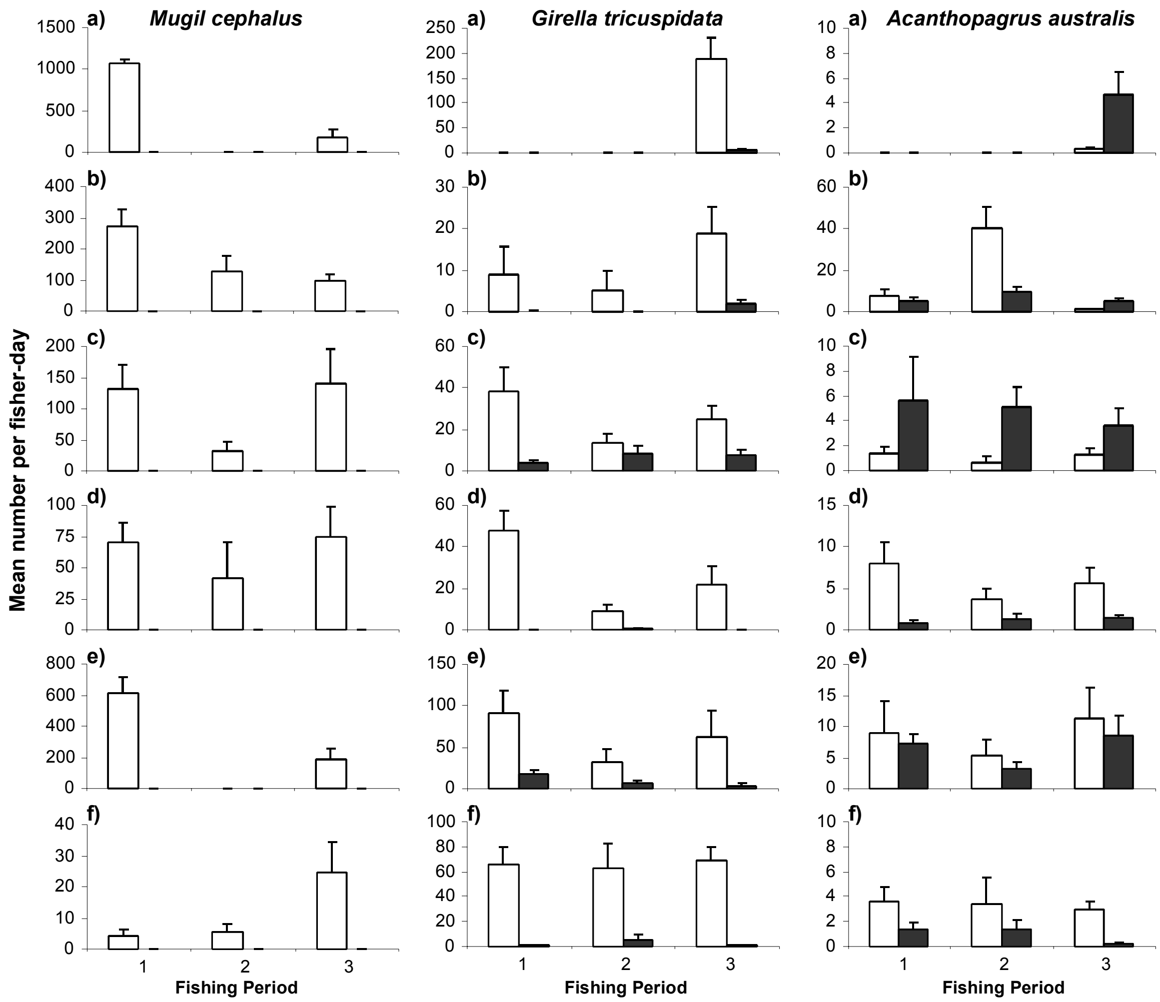

Figure 3.5. Mean daily (+ 1 se) number of retained and discarded catches of *Mugil cephalus*, *Girella tricuspidata* and *Acanthopagrus australis* in each studied estuary during the survey. a) Richmond River, b) Clarence River, c) Camden Haven, d) Wallis Lake, e) Lake Illawarra, f) Shoalhaven River.

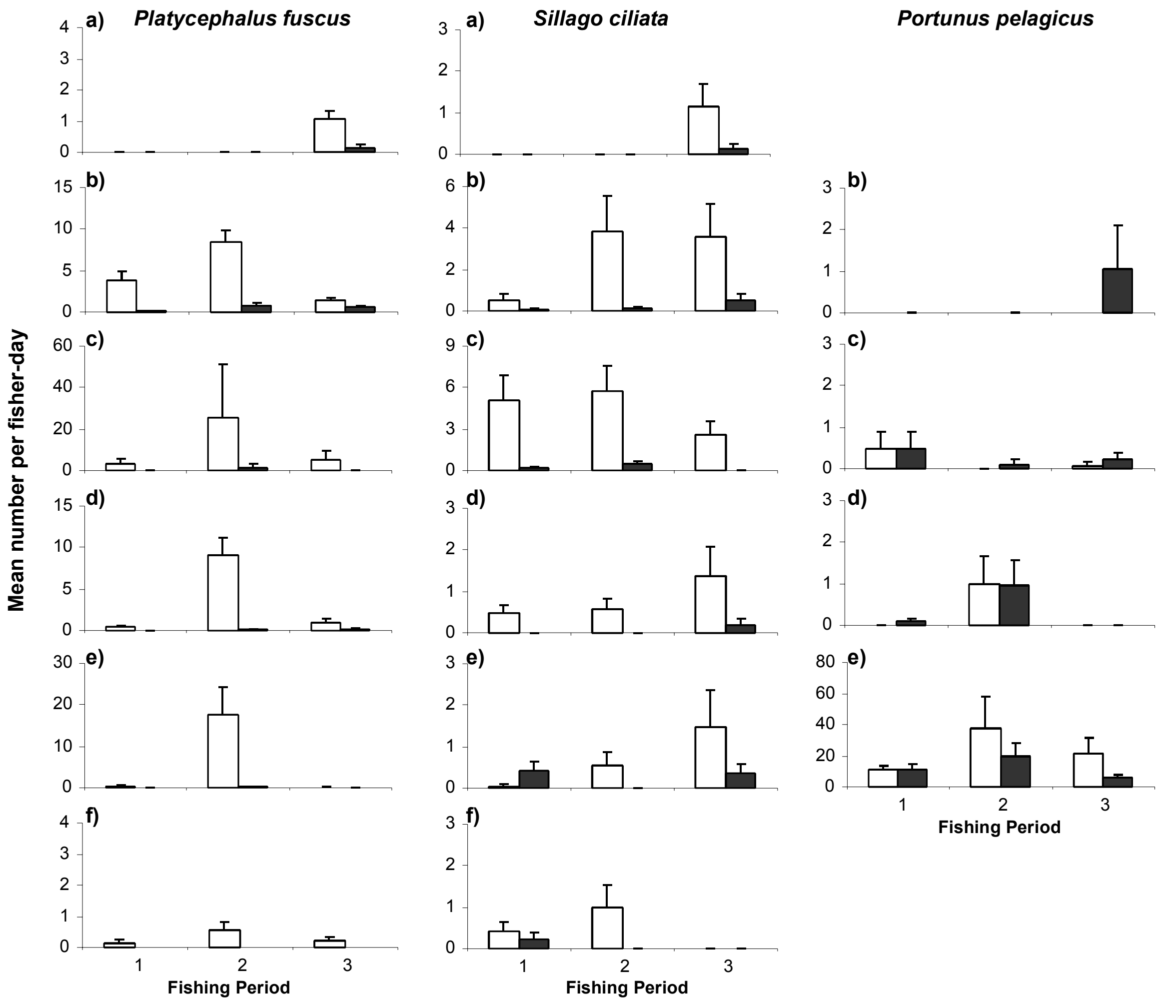

Figure 3.6. Mean daily (+ 1 se) number of retained and discarded catches of *Platycephalus fuscus*, *Sillago ciliata* and *Portunus pelagicus* in each studied estuary during the survey. a) Richmond River, b) Clarence River, c) Camden Haven, d) Wallis Lake, e) Lake Illawarra, f) Shoalhaven River.

Table 3.5. Summaries of mean square values from two-factor analyses of variance comparing retained and discarded catches across 5 estuaries (Clarence, Camden Haven, Wallis, Illawarra and Shoalhaven) and the three fishing periods for total species, individuals and weight and the common species presented in Fig 5. Data transformed to log (x+1). Degrees of freedom = 4 for Estuary and 2 for Period. Significance; **p < 0.01, *p < 0.05, ns p > 0.05.

	Retained catch				Discarded catch			
	Estuary (E)	Period (P)	ExP	Residual	Estuary (E)	Period (P)	ExP	Residual
No. of Species	0.06*	0.05ns	0.02ns	0.02	0.57**	0.10ns	0.06ns	0.04
No. of Individuals	1.59**	3.32**	0.60**	0.13	3.12**	0.49ns	0.23ns	0.17
Weight (kg)	1.35**	2.94**	0.61**	0.16	0.92**	0.15ns	0.08ns	0.11
M. cephalus	5.92**	18.51**	2.43**	0.33	1.03**	0.45ns	1.50**	0.19
A. australis	1.03**	0.45ns	1.50**	0.19	2.17**	0.05ns	0.15ns	0.15
P. fuscus	2.03**	5.48**	0.31**	0.13	0.02ns	0.13**	0.02ns	0.01
G. tricuspidata	5.27**	2.57**	0.50ns	0.42	1.87**	0.01ns	0.42**	0.16
S. ciliata	0.78**	0.24ns	0.16ns	0.12	0.01ns	0.00ns	0.02ns	0.01
P. pelagicus	3.55**	0.01ns	0.10ns	0.12	2.85**	0.02ns	0.11ns	0.12

Table 3.6. Summary of mean ratio by weight of retained-to-discarded catch, associated standard error (se) and r value and significance of correlation.

	n	ratio	se	r^2	significance
Richmond River P1	4	1:0.016	0.007	0.117	ns
Richmond River P3	14	1:0.026	0.012	-0.335	ns
Clarence River P1	20	1:0.017	0.004	0.640	ns
Clarence River P2	21	1:0.069	0.024	-0.052	ns
Clarence River P3	19	1:0.082	0.022	0.030	ns
Camden Haven P1	19	1:0.036	0.011	0.045	ns
Camden Haven P2	18	1:0.093	0.024	0.654	ns
Camden Haven P3	13	1:0.027	0.008	0.424	ns
Wallis Lake P1	23	1:0.010	0.004	0.212	ns
Wallis Lake P2	19	1:0.053	0.031	-0.205	ns
Wallis Lake P3	11	1:0.019	0.004	0.865	ns
Lake Illawarra P1	21	1:0.022	0.004	0.317	ns
Lake Illawarra P2	9	1:0.099	0.058	-0.048	ns
Lake Illawarra P3	11	1:0.031	0.011	0.344	ns
Shoalhaven River P1	14	1:0.038	0.009	-0.248	ns
Shoalhaven River P2	11	1:0.071	0.038	-0.064	ns
Shoalhaven River P3	18	1:0.030	0.008	0.481	ns

3.4.4. *Effects of mesh size on retained and discarded catches and relative net selectivity*

Adequate data were available so that multivariate analyses could be done to assess the effects of different mesh sizes on the structure of catches in each period in the Clarence River and Wallis Lake. ANOSIM showed that catches differed between 80 and 100 mm mesh in each period in the Clarence River. In Wallis Lake few direct comparisons could be made, but catches differed between 80 and 100 mm mesh during Period 2 and 83 and 100 mm mesh during Periods 2 and 3 (Table 3.7). The species that contributed greatest to the dissimilarity in the structure of catches taken in the different mesh sizes are shown in Table 8. *M. cephalus*, which was primarily captured in greater numbers in 80 and 83 mm mesh compared to 100 mm mesh contributed greatest (up to 85% in Clarence River and 60% in Wallis Lake) to dissimilarities. *P. fuscus* made a significant contribution to the dissimilarity of catches in Period 2 in Wallis Lake and *G. tricuspidata* and *A. australis* were also important in distinguishing catches in both estuaries (Table 3.8).

The length compositions of the primary fish species caught in each major mesh size observed are shown in Figure 3.7. In general, the mean size of each primary species caught increased with increasing mesh size. Nets of all mesh sizes were relatively efficient and selective for harvesting *M. cephalus* and *P. fuscus*, with more than 99% (by number) of *M. cephalus* and 94% of *P. fuscus* retained in all observed mesh sizes (80 to 100 mm). In contrast, up to 76% of *A. australis* caught in 80 mm mesh were discarded, but this observation was reversed in nets having 89 mm mesh and greater. Up to 11% of *G. tricuspidata* captured in 80 and 83 mm mesh were discarded, but this decreased to $< 4\%$ in nets with 89 mm mesh or larger. *S. ciliata* were predominantly caught in gillnets with 80 mm mesh, of which 95% were retained.

Although the proportion of each of the primary species retained generally increased with increasing mesh size (Figure 3.7), there was no such trend for total numbers and weights of all species combined as the proportions retained varied according to mesh size and period (Table 3.9). The ratio of retained to discarded catch by weight also varied with mesh size and period (ANOVA, $df = 10, 244$, $MS = 0.150$, $p< 0.01$). The mean number and weight of the retained and discarded catch in each period was greatest in the 80 mm mesh (ANOVA's, $p < 0.001$; Table 3.9). A greater number and weight of discards was caught during Period 2 compared to Periods 1 and 3 in the 80, 95 and 100 mm mesh. Further, for the 80 and 95 mm mesh, the proportion of catch retained was least during Period 2 compared to Periods 1 and 3, but this was not evident in 100 mm mesh. In 80 mm mesh fewer fish were retained during Period 2 than in Periods 1 and 3, when during the latter periods fishers were generally targeting schools of sea mullet and luderick.

Table 3.7. Summary of results of 1-way analyses of similarity comparing structure of catches across different mesh sizes in each Period in the Clarence River and Wallis Lake. Analyses done on non-transformed data standardized to number per 100 m of netting.

	R value	Significance (%)	Permutations
Clarence River			
Period 1			
80 v 95	0.195	16.4	220
80 v 100	0.708	0.1	999
95 v 100	0.132	24.2	165
Period 2			
80 v 95	0.978	0.1	999
80 v 100	0.754	1.8	56
95 v 100	0.29	11.5	364
Period 3			
80 v 100	0.765	0.3	999
Wallis Lake			
Period 1			
80 v 89	-0.066	57.3	999
80 v 100	0.593	10.0	10
89 v 100	-0.006	41.8	999
Period 2			
80 v 83	0.136	22.6	84
80 v 100	0.937	0.2	462
83 v 100	0.818	1.2	84
Period 3			
80 v 83	0.143	38.9	36
80 v 100	0.0	100.0	3
83 v 100	0.929	2.8	36

Table 3.8. Summary of SIMPER analyses showing the 5 species that contributed greatest to the dissimilarity between structure of catches taken in different mesh sizes. Results shown for those comparisons significant according to ANOSIM presented in Table 7. Mean number caught per 100 m of net taken in each mesh size, DV = dissimilarity value, DV/SD = dissimilarity value/standard deviation, % = percentage contribution to dissimilarity value, Cum % = cumulative percent contribution to dissimilarity value.

Clarence River

Species	80 mm	100 mm	DV	DV/SD	%	Cum.%
Period 1, Average dissimilarity = 88.73						
M. cephalus (r)	63.04	3.20	76.13	4.07	85.80	85.80
M. petardi (r)	1.24	0.00	2.82	0.56	3.18	88.98
G. tricuspidata (r)	0.12	1.16	1.75	0.53	1.97	90.95
A. australis (r)	0.26	0.95	1.73	0.84	1.95	92.90
A. australis (d)	0.87	0.06	1.68	1.24	1.90	94.80
Period 2, Average dissimilarity = 83.18						
M. cephalus (r)	85.91	8.84	54.86	2.20	65.96	65.96
A. australis (r)	0.82	9.26	5.90	1.37	7.10	73.05
L. argentea (r)	8.18	0.33	5.68	0.56	6.83	79.89
A. australis (d)	3.47	0.87	3.39	0.62	4.07	83.96
S. ciliata (r)	2.69	0.00	2.91	0.73	3.50	87.46
Period 3, Average dissimilarity = 90.06						
M. cephalus (r)	13.08	0.28	50.55	2.29	56.13	56.13
G. tricuspidata (r)	2.47	0.82	11.42	0.92	12.69	68.82
A. japonicus (d)	0.06	0.55	3.87	0.59	4.29	73.11
A. australis (d)	0.61	0.17	3.70	0.67	4.11	77.22
S. ciliata (r)	0.50	0.05	3.66	0.45	4.06	81.28

Wallis Lake

Species	80 mm	100 mm	DV	DV/SD	%	Cum.%
Period 2, Average dissimilarity = 85.65						
M. cephalus (r)	2.81	0.02	20.72	1.94	24.19	24.19
P. fuscus (r)	2.75	0.41	16.79	2.17	19.60	43.79
G. tricuspidata (r)	1.53	0.37	10.22	0.98	11.93	55.72
A. australis (r)	0.13	1.10	8.10	1.61	9.46	65.18
C. macrocephalus (r)	0.00	1.08	7.82	1.26	9.13	74.30
Species	83 mm	100 mm	DV	DV/SD	%	Cum.%
Period 2, Average dissimilarity 85.78						
P. fuscus (r)	2.56	0.41	18.79	2.76	21.90	21.90
M. cephalus (r)	2.28	0.02	16.95	1.36	19.76	41.66
A. australis (r)	0.15	1.10	10.09	1.59	11.76	53.43
C. macrocephalus (r)	0.00	1.08	9.71	1.23	11.32	64.75
G. tricuspidata (r)	0.51	0.37	5.18	1.43	6.04	70.79
Period 3, Average dissimilarity = 82.75						
M. cephalus (r)	9.44	0.33	49.66	2.37	60.02	60.02
G. tricuspidata (r)	1.96	3.97	20.11	1.48	24.31	84.33
A. australis (r)	0.45	1.41	6.72	1.95	8.12	92.45
L. argentea (d)	0.15	0.00	1.36	0.37	1.64	94.10
L. argentea (r)	0.13	0.00	0.87	0.50	1.05	95.14
A. australis (d)	0.12	0.07	0.80	1.19	0.97	96.11

Table 3.9. The average number and weight of retained and discarded catches and the proportion retained in each mesh size in each period where n ≥ 5 observations. Data pooled across all species and estuaries. n = number of observations.

Mesh Size	Period	n	Number			Weight (kg)		
			R	D	R%	R	D	R%
80 mm	1	46	29.8	0.5	97.1	56.1	2.2	94.2
80 mm	2	39	12.3	0.7	89.7	27.0	2.7	82.9
80 mm	3	48	14.9	0.5	94.6	30.3	1.9	90.4
83 mm	3	9	7.6	0.2	97.9	14.4	0.6	96.0
89 mm	1	20	16.7	0.2	98.7	25.1	0.5	97.8
95 mm	1	5	7.7	0.3	94.5	12.1	1.1	88.4
95 mm	2	14	8.4	0.5	91.8	13.4	2.0	81.6
95 mm	3	10	6.8	0.3	96.8	13.9	0.5	96.3
100 mm	1	28	8.7	0.3	94.3	15.0	0.9	91.4
100 mm	2	20	7.6	0.9	89.5	11.7	1.5	88.5
100 mm	3	13	6.5	0.3	84.3	11.6	0.9	81.6

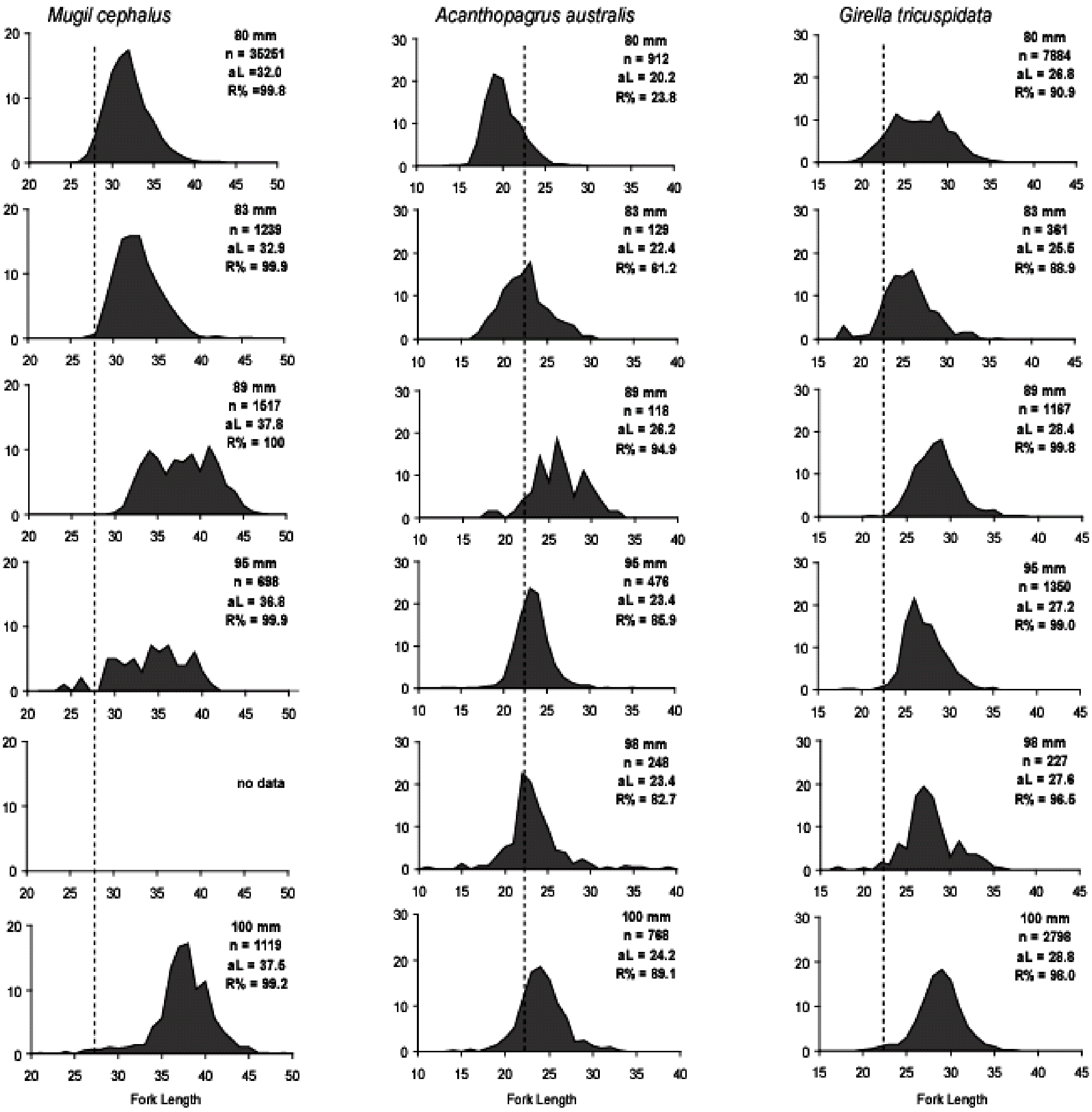

Figure 3.7. Length-frequency distributions of retained and discarded catches of *Mugil cephalus, Girella tricuspidata, Acanthopagrus australis*, *Sillago ciliata* and *Platycephalus fuscus* in each mesh size. Note data pooled across all estuaries and fishing periods. n denotes number of fish measured, aL = mean length of fish sampled, %R = proportion of fish retained. Vertical line denotes the minimum legal length (MLL) of the species.

3.5. Discussion

In any study designed to quantify retained and discarded catches in a fishery, several inherent assumptions are usually required. In this study, the specific assumptions underlying the accuracy of our results included that the actual days, nets and fishers selected for sampling were unbiased and representative of the entire fishery, the presence of an observer did not influence normal fishing operations and sorting practices and there were no systematic measurement errors made by the observers. Our attempts to select the fishers and days fished at random helped meet these assumptions and in the case of nets set overnight, our observers often approached fishers after they had set their nets and so they could not affect where the netting took place. Our observers also reported that netting generally occurred around other commercial fishers, but we acknowledge that the presence of an observer may have affected some sorting practices. Observers were also extensively trained and supervising observers did some sampling in each estuary during each fishing period. Despite our assumptions, the data presented here and in Gray (2002) reveal several general conclusions concerning the spatial and temporal variabilities in the retained and discarded catches and the relative selectivity of gillnets used by commercial fishers throughout estuaries in NSW. These data provide quantitative information on which future discussions concerning the management of the fishery and the potential impacts of discarding on stocks and their possible mitigation can be based.

The data provided here and along with that reported in Gray (2002) show that many species are retained and discarded in this gillnet fishery, highlighting how this fishery interacts with other fisheries in the region and how it may potentially impact on stocks and ecosystems. We stress however, that we were unable to ascertain the direct ecological impacts of this fishery, including that of discarding, as other data not currently available are required. Nevertheless, our data demonstrate the main reasons why there is much conflict among different harvest sectors concerning this fishery. The primary species retained (e.g. *M. cephalus*, *A. australis*, *G. tricuspidata*, *P. fuscus*) in this gillnet fishery are species that are targeted by other commercial fishing sectors (e.g. beach-seine, traps, handlines) and except for *M. cephalus*, by recreational fishers (line only) in estuarine and inshore waters. Similarly, the discarded catches were dominated numerically by undersize conspecifics (below the MLL) of some of the primary target species (notably *A. australis*, *G. tricuspidata*, and *P. pelagicus*), as well as juveniles of other species of recreational and commercial significance (e.g. *M. novaemaculeata*, *P. saltatrix* and A. *japonicus*). Hence, the assessment and management of these species and the interacting fisheries in which they are taken can be very complex (see also Hutchings and Lamberth, 2002; 2003).

Our analyses revealed considerable variation in the structure of catches among estuaries, time periods and fishing practices. The multivariate analyses suggested that catch structures were relatively distinct among estuaries; the strongest between the most northern and southern estuaries surveyed. A similar pattern was reported in Gray (2002), suggesting there may be some geographical gradient in the structure of retained and discarded catches taken in the gillnet fishery throughout NSW. Similar species-specific latitudinal gradients in the bycatches from the estuarine prawn seine (Gray *et al*., in press) and coastal prawn trawl (Kennelly *et al*., 1998) fisheries in NSW have been reported. Similarly, Pease (1999) showed that the composition of the reported retained commercial catches from all estuarine fishing methods varied along the coast and these data were used to classify the estuarine commercial fisheries in NSW according to latitudinal zones. Although we acknowledge that the observed inter-estuary differences in the structure of gillnet catches may reflect different targeting practices of fishers between estuaries, we suggest that these differences most likely reflect actual differences in the ichthyofaunal assemblages in the different estuaries throughout NSW. Such differences are probably caused by a suite of abiotic and biotic factors such as estuarine geomorphology and hydrography (Roy *et al*., 2001), recruitment fluctuations and rates of immigration and emigration of individual species among estuaries and the geographic and habitat-associated distributions of individual species (Blaber, 2000). These combined findings suggest that fishing-induced impacts on species and estuarine ecosystems could vary considerably between different estuaries and geographic regions. This could potentially force any solutions to ameliorate such impacts, including fishing closures and changes to fishing practices, to be developed on a regional, estuary type or estuary-specific basis (see also Gray and Kennelly, 2003; Gray *et al*., in press). As an example, discards of *M. novemaculeata* and *M. colonorum* were greatest in riverine type estuaries (Richmond, Clarence, Shoalhaven Rivers) whereas discards of *P. pelagicus* were greatest in the barrier estuaries (Illawarra and Wallis Lake).

Despite the observed differences in the overall structure of gillnet catches between estuaries, the principal species caught and the patterns of discarding were, in general, similar in each estuary. In particular, seasonal changes in the prevalence and catch rates of specific species were evident and these generally reflected changes in legal fishing practice (i.e. set and immediate retrieval versus overnight set). Retained *M. cephalus* and *G. tricuspidata* dominated total catches in all estuaries during Periods 1 and 3 when fishers were permitted only to set and immediately retrieval nets. During these fishing periods, fishers actively search and target schools of these 2 species. Fishers typically encircle nets around schools or structures and then disturb the water by splashing oars, rattling chains or revving outboard motors to scare fish into the nets. During this type of operation, bycatches are usually very low, particularly when targeting *M. cephalus*, which during summer is surface dwelling. During summer, fishers often use surface floating nets that usually have minimal contact with the substratum as they actively search for schools of *M. cephalus*, which are highly visible. Fishers use negatively buoyant nets to target *G. tricuspidata*, which is a benthic species often associated with submerged structures and vegetated (seagrass) habitats. Consequently, more discards are generally taken when targeting this species compared to *M. cephalus*. Catches of *M. cephalus* and *G. tricuspidata* collectively accounted for 85% by number of the total observed catches throughout the entire survey, with retained catch rates generally greatest during Periods 1 and 3 when these 2 species contributed > 90% towards the similarity of total catches within each estuary. In winter (when nets can legally be set overnight), fishers tend to indiscriminately target a wider range of species using bottom set nets, with retained *P. fuscus* and *S. ciliata* and retained and discarded *A. australis* more prevalent in catches. Bottom-set nets are effective at catching *M. cephalus* in winter and so they are still very important in catches. This fishing practice involves fishers setting nets in areas where fish travel between tides and/or day and night and relies more on the movements of fish compared to the practice of set and immediate retrieval. Rates of discarding were generally higher with this fishing practice, with undersized *A. australis*, *G. tricuspidata* and *P. pelagicus* dominating discarded catches. Bycatches of turtles and seabirds were extremely low (only 1 observed occurrence of each throughout the survey) and although dolphins do occur, and were observed, in estuaries during the study, no captures were recorded in nets, indicating that the estuarine gillnet fishery does not pose a direct threat to populations of these species.

Observed retained-to-discard catch ratios (by weight) in the gillnet fishery were < 1:0.1 (1%) in all estuaries and periods and were lower than that reported by Gray (2002) for gillnets set overnight in 1999 (up to 1:0.6)(6%). The reasons for this observed difference between the two studies is not clear, but it documents how rates of discarding, and relationships with retained catches can vary considerably in time and space within a given fishery (see also Gray *et al*., 2001). This highlights how the use of generalised ratios of retained-to-discarded catches can be misleading and need to be interpreted with caution (see also Gray *et al*., in press; Ye, 2002). Despite this, there are few reports of discard ratios for other commercial gillnet fisheries, but low discard ratios have been reported for pelagic gillnet fisheries (Alverson *et al*., 1994). Assessments of potential impacts of discarding require estimates of total levels of discarding in a fishery. Unfortunately, it was not possible to estimate the magnitude of total discards taken in this fishery during this study due to the lack of specific reporting of fishing effort in terms of the number of days that fishers actually deployed different net types. Despite this, our data are very useful in identifying the suitability of different nets and fishing practices and provide information to assess potential mechanisms that might mitigate discarding in this fishery.

Although we could not model the selectivity of nets used in this gillnet fishery, the data presented here and in Gray (2002) show the relative selectivity of the different mesh sizes of gillnets used in the fishery for the major species. As expected, the mean lengths of the primary fish species captured increased with increasing mesh size, although we note that the selectivity of gillnets is not only a function of mesh size and fish size and morphology (Hamley, 1975; Millar and Fryer, 1999). Overall, discard rates were very low (<1%) in all mesh sizes for *M. cephalus* documenting that there was virtually no wastage in the harvesting of this species. In contrast, *A. australis* displayed high (up to 76%) discard rates in the smaller (80-83mm) mesh sizes, indicating that the harvesting of this species was relatively inefficient, and depending on rates of mortality, potentially very wasteful. A similar, but less alarming, pattern was evident for *G. tricuspidata* (see also Gray, 2002). The data presented also showed that the proportion of total discards was negatively correlated with increasing mesh size. It is therefore evident that an increase in the minimum mesh size in this fishery from the current 80 mm to at least 89 mm (but preferably 95 mm – see Gray, 2002) would result in fewer total discards. In particular, this would have a significant effect on reducing the discarding of 2 species very important to recreational fishers, *A. australis* (from 76% to 15%) and *G. tricuspidata* (12 % to 3%) (see Figure 3.7 and also Gray, 2002). A change in mesh size may have little effect in reducing the discarding of portunid crabs, which probably become entangled in nets of all mesh sizes.

Because of the multi-species nature of the fishery, any increase in minimum mesh size however, may not be suitable during all periods and for all fishing practices as it would greatly impact on the retention rates of *M. cephalus*; the most abundant and valuable (as determined by total landings) species taken in the fishery. An option would be to allow fishers to use surface floating nets of small (80 mm) mesh to target this species during summer. However such a decision needs to consider the broader management of this species as it is also harvested primarily for its roe in an adjacent coastal beach-seine fishery (Smith and Deguara, 2002). The most appropriate size and life history stage to harvest *M. cephalus* needs to be determined and a suitable mesh size be enforced. Discarding levels were, however, generally greatest in winter when fishers do not actively set nets to target *M. cephalus*, and so any increase in mesh size during this period would probably not greatly impact on retained catches of this species, but it would greatly reduce discards of other species.

Apart from spatial and temporal fishing closures, solutions to discarding problems in multi-species fisheries elsewhere also include the development of more selective nets and fishing practices that minimise the capture and mortality of non-target species and undersized individuals of the target species. In investigating such options for multi-species fisheries, managers and industry need to set priorities in terms of the importance of minimising the discarding of each species as opposed to maximising the retained catches of those and other species. Apart from developing and testing alternate gillnets with more appropriate configurations (e.g. height and material of nets – see Hamley, 1975; Millar and Fryer, 1999; Broadhurst *et al*., 2003; Godoy *et al*., 2003) a further option is to investigate the effects of reducing the permitted maximum setting time (overnight) of nets during winter on catches. Discard levels may be lower and subsequent mortalities of fish may also be reduced because of the reduced soak times (Acosta, 1994; Chopin and Arimoto, 1995), potentially further reducing any potential negative ecological impacts of this fishery.

4. GENERAL CONCLUSIONS

The data presented display the variability in the compositions and the magnitudes of the retained and discarded catches taken in the estuarine commercial gillnet fishery in NSW.

In the gillnet fishery for dusky flathead, legal-sized dusky flathead were the most abundant organism captured and accounted for up to 47% by number and 54% by weight of the mean observed catch depending on the estuary. Predominant bycatch species taken in the fishery included legal and under-size blue swimmer crab, sea mullet, luderick, bream and yellowfin leatherjacket. These five species accounted for 82% of total bycatch by number and 71% by weight. More crabs were retained than discarded, with retained legal-size crabs (byproduct) accounting for 16% of total bycatch by number and 13% by weight. Overall, a total of 7% of dusky flathead captured (by number) were below the MLL of 36 cm and discarded, suggesting the nets as currently configured may be relatively selective in catching legal-size flathead. The data show however, that 41% of dusky flathead were < 40cm TL, indicating that if the MLL for this species is increased to this length as proposed, new nets will need to be introduced into the fishery.

Sea mullet and luderick accounted for 85% by number of total observed catches in the multi-species fishery, with a further 10% being contributed by bream, dusky flathead and blue swimmer crabs. Retained sea mullet and luderick were most characteristic of catches when fishers were permitted only to set and immediately retrieve nets, whereas retained dusky flathead and retained and discarded bream were most important in distinguishing catches when fishers are permitted to set nets overnight. In general, more species and a greater mean number and weight of total individuals were retained than discarded in the fishery. Throughout the entire survey, 6.2% by number and 3.3% by weight of catches were discarded, with undersized luderick, bream and blue swimmer crab collectively accounting for 69% by number and 49% by weight of all discards observed. The data show that the proportion of total discards varied with mesh size with fewer total discards occurring in the larger mesh sizes. It is evident that an increase in the minimum mesh size in this fishery from the current 80 mm to at least 89 mm (but preferably 95 mm – see Gray, 2002) would result in fewer total discards. In particular, this would have a significant effect on reducing the discarding of 2 species very important to recreational fishers, bream and luderick (see also Gray, 2002), but would impact on retained catches of sea mullet.

Apart from spatial and temporal fishing closures, solutions to discarding problems in multi-species fisheries elsewhere also include the development of more selective nets and fishing practices that minimise the capture and mortality of non-target species and undersized individuals of the target species. In investigating such options, managers and industry need to set priorities in terms of the importance of minimising the discarding of each species as opposed to maximising the retained catches of those and other species. Apart from developing and testing alternate gillnets with more appropriate configurations for use in these fisheries (e.g. height and material of nets – see Hamley, 1975; Millar and Fryer, 1999; Broadhurst *et al*., 2003; Godoy *et al*., 2003) a further option is to investigate the effects of reducing the permitted maximum setting time (overnight) of nets on catches. Discard levels may be lower and subsequent mortalities of fish may also be reduced because of the reduced soak times (Acosta, 1994; Chopin and Arimoto, 1995), potentially further reducing any potential negative ecological impacts of this fishery. We conclude by recommending that industry be proactive and further develop ways to mitigate discarding in these gillnet fisheries.

5. LITERATURE CITED

Acosta, A.R., (1994) Soak time and net length effects on catch rates of entangling nets in coral reef areas. *Fisheries Research* 19, 105-119.

Acosta, A.R & Appeldoorn, R.S., (1995) Catching efficiency and selectivity of gillnets and trammel nets in coral reefs from southwestern Puerto Rico. *Fisheries Research* 22, 175-196.

Akiyama, S., (1997) Discarded catch of set-net fisheries in Tateyama Bay. *Journal of Tokyo University of Fisheries* 84, 53-64.

Alverson, D.L., Freeberg, M.H., Murawski, S.A & Pope, J.G., (1994) A global assessment of fisheries bycatch and discards. *FAO Fisheries Technical Paper* 339, 233 pp.

Berrow, S.D., (1994) Incidental capture of elasmobranchs in the bottom-set gill-net fishery off the south coast of Ireland. *Journal Marine Biological Association United Kingdom* 74, 837-847.

Blaber, S.J.M., (2000) Tropical Estuarine Fishes – Ecology, Exploitation & Conservation. *Fisheries Biology and Aquatic Resources Series 7*. Blackwell Science. Oxford. 384 pp.

Broadhurst, M.K., (2000) Modifications to reduce bycatch in prawn trawls: A review and framework for development. *Reviews in Fish Biology and Fisheries* 10, 27-60.

Broadhurst, M.K., Gray, C.A., Young, D.J. & Johnson, D.D., (2003) Relative efficiency and size selectivity of bottom-set gillnets for dusky flathead, *Platycephalus fuscus* and other species in New South Wales, Australia. *Archive of Fishery and Marine Research* 50.

Bronte, C.R. & Johnson, D.W., (1983) Occurrence of sport fish in a commercial net fishery in Kentucky. *North American Journal of Fisheries Management* 3, 239-242.

Chen, Y. & Gordon, G.N.G., (1997) Assessing discarding at sea using a length-structured yield-per-recruit model. *Fisheries Research* 30, 43-55.

Chopin, F.S. & Arimoto, T., (1995) The condition of fish escaping from fishing gears – a review. *Fisheries Research* 21, 315-327.

Clarke, K.R., (1993) Non-parametric multivariate analyses of changes in community structure. *Australian Journal of Ecology* 18, 117-143.

Clarke, K.R. & Warwick, R.M., (2001) Change in marine communities: an approach to statistical analysis and interpretation. 2nd edition. pp 144. (Natural Environmental Research Council, UK.)

Cochran, W.G., (1963) Sampling Techniques. 2nd edition. Wiley, New York. 413 pp.

Cox, T.M., Read, A.J., Barco, S., Evans, J., Gannon, D.P., Koopman, H.N., McLellan, W.A., Murray, K., Nicolas, J., Pabst, D.A., Potter, C.W., Swingle, W.M., Thayer, V.G., Touhey, K.M. & Westgate, A.J. (1998) Documenting the bycatch of harbor porpoises, *Phocoena phocoena*, in coastal gillnet fisheries from stranded carcasses. *Fishery Bulletin* 96, 727-734.

D'agrosa, C., Lennert-Cody, E.C. & Vidal, O., (2000) Vaquita bycatch in Mexico's artisanal gillnet fisheries: driving a small population to extinction. *Conservation Biology* 14, 1110-1119.

Erzini, K., Costa, M.E., Bentes, L. & Borges, T.C., (2002) A comparative study of the species composition of discards from five fisheries from the Algarve (southern Portugal). *Fisheries Management and Ecology* 9, 31-40.

Fennessy, F.T., (1994) The impact of commercial prawn trawlers on linefish off the north coast of Natal, South Africa. *South African Journal of Marine Science* 14, 263-279.

Godoy, H., Furevik, D., Lokkeborg, S., (2003) Reduced bycatch of red king crab (*Paralithodes camtschaticus*) in the gillnet fishery for cod (*Gadus morhua*) in northern Norway. *Fisheries Research* 62, 377-384.

Gray, C.A., (2002) Management implications of discarding in an estuarine multi-species gill net fishery. *Fisheries Research* 56, 177-192.

Gray, C.A., Gale, V.J., Stringfellow, S.L. & Raines, L.P., (2002) Variations in sex, length and age compositions of commercial catches of *Platycephalus fuscus* (Pisces: Platycephalidae) in New South Wales, Australia. *Marine and Freshwater Research* 53, 1091-1100.

Gray, C.A., Johnson, D.D., Young, D.J. & Broadhurst, M.K., (in press). Discards from the commercial gillnet fishery for dusky flathead (*Platycephalus fuscus*) in New South Wales, Australia: spatial variability and initial effects of change in minimum legal length of target species. *Fisheries Management and Ecology*

Gray, C.A. & Kennelly, S.J., (2003) Catch characteristics of the commercial beach-seine fisheries in two Australian barrier estuaries. *Fisheries Research* 63, 405-422.

Gray C.A., Kennelly, S.J. & Hodgson, K.E., (in press) Low levels of bycatch from estuarine prawn seining in New South Wales, Australia. *Fisheries Research*.

Gray, C.A., Kennelly S.J., Hodgson, K.E., Ashby, C.T.J. & Beatson, M.L., (2001) Retained and discarded catches from commercial beach-seining in Botany Bay, Australia. *Fisheries Research* 50, 205-219.

Hall, S.J., (1999) The Effects of Fishing on Marine Ecosystems and Communities. Fish Biology and Aquatic Resources Series 1. Blackwell Science. Oxford. 274 pp.

Hamley, J.M., (1975) Review of gillnet selectivity. *Journal of the Fisheries Research Board of Canada* 32, 1943-1969.

Hickford, M.J.H., Schiel, D.R. & Jones, J.B., (1997) Catch characteristics of commercial gill-nets in a nearshore fishery in central New Zealand. *New Zealand Journal of Marine and Freshwater Research* 31, 249-259.

Hutchings, K. & Lamberth, S.J., (2002) Bycatch in the gillnet and beach-seine fisheries in the Western Cape, South Africa, with implications for management. *South African Journal of Marine Science 24*, 227-241.

Hutchings, K. & Lamberth, S.J., (2003) Likely impacts of an eastward expansion of the inshore gill-net fishery in the Western Cape, South Africa: implications for management. *Marine and Freshwater Research* 54, 39-56

Jennings, S. & Kaiser, M.J., (1998) The effects of fishing on marine ecosystems. *Advances in Marine Biology* 34, 201-352.

Juliam, F., Beeson, M., (1998) Estimates of marine mammal, turtle, and seabird mortality for two California gillnet fisheries: 1990-1995. *Fishery Bulletin* 96, 271-284.

Kailola, P.J., Williams, M.J., Stewart, P.C., Reichelt, R.E., McNee, A. & Grieve, C. (1993) Australian Fisheries Resources. Bureau of Resource Sciences, Department of Primary Industry and Energy, Fisheries Research and Development Corporation, Canberra Australia.

Kaiser, M.J. & de Groot, S.J., (2000) Effects of fishing on non-target species and habitats. Blackwell Science. Oxford.

Kennelly, S.J., (1995) The issue of bycatch in Australia's demersal trawl fisheries. *Reviews in Fish Biology and Fisheries* 5, 213-234.

Kennelly, S.J., Liggins, G.W. & Broadhurst, M.K., (1998) Retained and discarded by-catch from oceanic prawn trawling in New South Wales, Australia. *Fisheries Research* 36, 217-236.

Kennelly, S.J. & McVea, T., (2002) Scientific reports on the recovery of the Richmond and Macleay Rivers following fish kills in February and March 2001. NSW Fisheries Final Report Series, No. 39. ISSN 1440-3544.

Lamberth, S.J., Sauer, W.H.H., Mann, B.Q., Brouwer, S.L., Clark, B.M. & Erasmus, C., (1997) The status of the South African beach-seine and gill-net fisheries. *South African Journal of Marine Science* 18, 195-202.

Liggins, G.L. & Kennelly, S.J., (1996) Bycatch from prawn trawling in the Clarence River estuary, New South Wales, Australia. *Fisheries Research* 25, 347-367.

Madsen, N., Holst, R., Wileman, D. & Moth-Poulsen, T., (1999) Size selectivity of sole gill nets fished in the North Sea. *Fisheries Research* 44, 59-73.

Marais, J.F.K., (1985) Some factors influencing the size of fishes caught in gillnets in eastern cape estuaries. *Fisheries Research* 3, 251-261.

Melvin, E.F., Parrish, J.K. & Conquest, L.L., (1999) Novel Tools to Reduce Seabird Bycatch in Coastal Gillnet Fisheries. *Conservation Biology* 13, 1386-1397.

Millar R.B. & Fryer R.J., (1999) Estimating the size-selection curves of towed gears, traps, nets and hooks. *Reviews in Fish Biology and Fisheries* 9, 89-116.

Oesterblom, H., Fransson, T. & Olsson, O., (2002) Bycatches of common guillemot (*Uria aalge*) in the Baltic Sea gillnet fishery. *Biological Conservation* 105, 309-319.

Pease, B.C., (1999) A spatially orientated analysis of estuaries and their associated commercial fisheries in New South Wales, Australia. *Fisheries Research* 42, 67-86.

Petrakis, G. & Stergiou, K.I., (1996) Gill net selectivity for four fish species (*Mullus barbatus, Pagellus erythrinus, Pagellus acarne* and *Spicara flexuosa*) in Greek waters. *Fisheries Research* 27, 17-27.

Quinn, S.P., (1988) Effectiveness of restricted areas in reducing incidental catches of game fish in a gillnet fishery. *North American Journal of Fisheries Management* 8, 2245-230.

Roy, P.S., Williams, R.J., Jones, A.R., Yassini, I., Gibbs, P.J., Coates, B., West, R.J., Scanes, P.R., Hudson, J.P. & Nichol, S., (2001) Structure and function of south-east Australian estuaries. *Estuarine, Coastal and Shelf Science* 53, 351-384.

Saila, S.B., (1983) Importance and assessment of discards in commercial fisheries. *FAO Fisheries Circular* 765, 62pp. FAO, Rome.

Samaranayaka, A., Engas, A. & Jorgensen, T., (1997) Effects of hanging ratio and fishing depth on the catch rates of drifting tuna gillnets in Sri Lankan waters. *Fisheries Research* 29, 1-12.

Smith, K., Deguara, K., (2002) Review of biological information and stock assessment for the NSW sea mullet resource. NSW Fisheries Fishery resource Assessment Series 12. ISSN 1440-057X.

Stergiou, K.I., Moutopoulos, D.K. & Erzini, K., (2002) Gill net and longline fisheries in Cyclades waters (Aegean Sea): species composition and gear competition. *Fisheries Research* 57, 25-37.

Tanner, M. & Liggins, G.L., (1999) New South Wales Commercial Fisheries statistics 1993/94 to 1997/98. NSW Fisheries Research Institute. Cronulla, Australia.

Trent, L., Parshley, D.E. & Carlson, J.K., (1997) Catch and bycatch in the shark drift gillnet fishery off Georgia and East Florida. *Marine Fisheries Reviews* 59, 19-28.

Trippel, E.A., Strong, M.B., Terhune, J.M., Conway, J.D., (1999) Mitigation of harbour porpoise (*Phocoena phocoena*) by-catch in the gill-net fishery in the lower Bay of Fundy. *Canadian Journal of Fisheries and Aquatic Science* 56, 113-123.

Trippel, E.A., Wang, J.Y., Strong, M.B., Carter, L.S. & Conway, J.D., (1996) Incidental mortality of harbour porpoise (*Phocoena phocoena*) by the gill-net fishery in the lower Bay of Fundy. *Canadian Journal of Fisheries and Aquatic Science* 53, 1294-1300.

Underwood, A.J., (1981) Techniques of analysis of variance in experimental marine biology and ecology. *Oceanography and Marine Biology: an Annual Review* 19, 513-605.

West, R.J. & Gordon, G.N.G., (1995) The commercial and recreational harvest of fish from two Australian coastal rivers. *Australian Journal of Marine and Freshwater Research* 45, 1259-1279.

Ye, Y., (2002) Bias in estimating bycatch-to-shrimp ratios. *Aquatic Living Resources* 15, 149-154.

6. IMPLICATIONS

6.1. Benefits and adoption

This study has provided quantitative data on the spatial and temporal variations in the compositions and levels of retained and discarded catches taken in the estuarine gillnet fisheries in NSW. It has also tested the selectivity of some nets used in the fishery. This study has provided invaluable data for inclusion in the Estuary General Fishery Management Strategy and the associated Environmental Impact Statement.

6.2. Further developments

Research into the effects of modifying the configurations of gillnets and altering permitted fishing practices could assist in developing ways to minimize discarding in these multi-species fisheries. Industry should be proactive in developing discard-reducing fishing gears.

6.3. Planned outcomes

We achieved our planned outcomes by quantifying the composition and quantities of bycatch and discards taken in the estuarine gillnet fisheries in NSW. The results have been presented to managers and industry and have been incorporated in the Estuary General Fishery Management Strategy. The data are thus being used to help formulate future management strategies for the fishery.

6.4. Conclusions

This study was successful in quantifying the catches and discarding practices in the estuarine commercial gillnet fisheries in NSW. This information was obtained using observer-based surveys stratified across the major estuaries throughout the fishery during 2001.

In the gillnet fishery for dusky flathead, legal-sized dusky flathead were the most abundant organism captured and accounted for up to 47% by number and 54% by weight of the mean observed catch depending on the estuary. Predominant bycatch species taken in the fishery included legal and under-size blue swimmer crab, sea mullet, luderick, bream and yellowfin leatherjacket. These five species accounted for 82% of total bycatch by number and 71% by weight. More crabs were retained than discarded, with retained legal-size crabs (byproduct) accounting for 16% of total bycatch by number and 13% by weight. Overall, a total of 7% of dusky flathead captured (by number) were below the MLL of 36 cm and discarded, suggesting the nets as currently configured may be relatively selective in catching legal-size flathead. The data show however, that 41% of dusky flathead were < 40cm TL, indicating that if the MLL for this species is increased to this length as proposed, new nets will need to be introduced into the fishery.

Sea mullet and luderick accounted for 85% by number of total observed catches in the multi-species fishery, with a further 10% being contributed by bream, dusky flathead and blue swimmer crabs. Retained sea mullet and luderick were most characteristic of catches when fishers were permitted only to set and immediately retrieve nets, whereas retained dusky flathead and retained and discarded bream were most important in distinguishing catches when fishers are permitted to set nets overnight. In general, more species and a greater mean number and weight of total individuals were retained than discarded in the fishery. Throughout the entire survey, 6.2% by number and 3.3% by weight of catches were discarded, with undersized luderick, bream and blue swimmer crab collectively accounting for 69% by number and 49% by weight of all discards observed. The data show that the proportion of total discards varied according to targeting practices and with mesh size with fewer total discards occurring in the larger mesh sizes. It is evident that an increase in the minimum mesh size in this fishery from the current 80 mm to at least 89 mm (but preferably 95 mm – see Gray, 2002) would result in fewer total discards. In particular, this would have a significant effect on reducing the discarding of 2 species very important to recreational fishers, bream and luderick (see also Gray, 2002), but would impact on retained catches of sea mullet.

Apart from spatial and temporal fishing closures, solutions to discarding problems in multi-species fisheries elsewhere also include the development of more selective nets and fishing practices that minimise the capture and mortality of non-target species and undersized individuals of the target species. In investigating such options, managers and industry need to set priorities in terms of the importance of minimising the discarding of each species as opposed to maximising the retained catches of those and other species. Apart from developing and testing alternate gillnets with more appropriate configurations for use in these fisheries (e.g. height and material of nets – see Hamley, 1975; Millar and Fryer, 1999; Broadhurst *et al*., 2003; Godoy *et al*., 2003) a further option is to investigate the effects of reducing the permitted maximum setting time (overnight) of nets on catches. Discard levels may be lower and subsequent mortalities of fish may also be reduced because of the reduced soak times (Acosta, 1994; Chopin and Arimoto, 1995), potentially further reducing any potential negative ecological impacts of this fishery. We conclude by recommending that industry be proactive and further develop ways to mitigate discarding in these gillnet fisheries.

APPENDICES

Appendix 1.

Intellectual property

No specific commercial value came from this research in terms of patents or copyrights, however the information is extremely relevant to fishery managers and scientists and to environmental, commercial and recreational fishing interest groups in NSW. The intellectual property owned by FRDC as specified in the agreed contract is 54.68 %.

Appendix 2.

Staff

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Other titles in this series:

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No. 1 Andrew, N.L., Graham, K.J., Hodgson, K.E. and Gordon, G.N.G., 1998. Changes after 20 years in relative abundance and size composition of commercial fishes caught during fishery independent surveys on SEF trawl grounds. Final Report to Fisheries Research and Development Corporation. Project No. 96/139.

No. 2 Virgona, J.L., Deguara, K.L., Sullings, D.J., Halliday, I. and Kelly, K., 1998. Assessment of the stocks of sea mullet in New South Wales and Queensland waters. Final Report to Fisheries Research and Development Corporation. Project No. 94/024.

No. 3 Stewart, J., Ferrell, D.J. and Andrew, N.L., 1998. Ageing Yellowtail (*Trachurus novaezelandiae*) and Blue Mackerel (*Scomber australasicus*) in New South Wales. Final Report to Fisheries Research and Development Corporation. Project No. 95/151.

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No. 6 Allan, G.L. and Rowland, S.J., 1998. Fish meal replacement in aquaculture feeds for silver perch. Final Report to Fisheries Research and Development Corporation. Project No. 93/120-03. 237pp + appendices.

No. 7 Allan, G.L., 1998. Fish meal replacement in aquaculture feeds: subprogram administration. Final Report to Fisheries Research and Development Corporation. Project No. 93/120. 54pp + appendices.

No. 8 Heasman, M.P., O'Connor, W.A. and O'Connor, S.J., 1998. Enhancement and farming of scallops in NSW using hatchery produced seedstock. Final Report to Fisheries Research and Development Corporation. Project No. 94/083. 146pp.

No. 9 Nell, J.A., McMahon, G.A. and Hand, R.E., 1998. Tetraploidy induction in Sydney rock oysters. Final Report to Cooperative Research Centre for Aquaculture. Project No. D.4.2. 25pp.

No. 10 Nell, J.A. and Maguire, G.B., 1998. Commercialisation of triploid Sydney rock and Pacific oysters. Part 1: Sydney rock oysters. Final Report to Fisheries Research and Development Corporation. Project No. 93/151. 122pp.

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No. 15 Otway, N.M. and Macbeth, W.G., 1999. The physical effects of hauling on seagrass beds. Final Report to Fisheries Research and Development Corporation. Project No. 95/149 and 96/286. 86pp.

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No. 18 Gray, C.A., Pease, B.C., Stringfellow, S.L., Raines, L.P. and Walford, T.R., 2000. Sampling estuarine fish species for stock assessment. Includes appendices by D.J. Ferrell, B.C. Pease, T.R. Walford, G.N.G. Gordon, C.A. Gray and G.W. Liggins. Final Report to Fisheries Research and Development Corporation. Project No. 94/042. 194pp.

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No. 23 Survey Development Working Group, 2000. Development of the National Recreational and Indigenous Fishing Survey. Final Report to Fisheries Research and Development Corporation. Project No. 98/169. (Volume 1 – 36pp + Volume 2 – attachments).

No.24 Rowling, K.R and Raines, L.P., 2000. Description of the biology and an assessment of the fishery of Silver Trevally *Pseudocaranx dentex* off New South Wales. Final Report to Fisheries Research and Development Corporation. Project No. 97/125. 69pp.

No. 25 Allan, G.L., Jantrarotai, W., Rowland, S., Kosuturak, P. and Booth, M., 2000. Replacing fishmeal in aquaculture diets. Final Report to the Australian Centre for International Agricultural Research. Project No. 9207. 13pp.

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No. 29 Heasman, M.P., Goard, L., Diemar, J. and Callinan, R., 2000. Improved Early Survival of Molluscs: Sydney Rock Oyster (*Saccostrea glomerata*). Final report to the Aquaculture Cooperative Research Centre. Project No. A.2.1. 63pp.

No. 30 Allan, G.L., Dignam, A and Fielder, S., 2001. Developing Commercial Inland Saline Aquaculture in Australia: Part 1. R&D Plan. Final Report to Fisheries Research and Development Corporation. Project No. 1998/335.

No. 31 Allan, G.L., Banens, B. and Fielder, S., 2001. Developing Commercial Inland Saline Aquaculture in Australia: Part 2. Resource Inventory and Assessment. Final report to Fisheries Research and Development Corporation. Project No. 1998/335. 33pp.

No. 32 Bruce, A., Growns, I. and Gehrke, P., 2001. Woronora River Macquarie Perch Survey. Final report to Sydney Catchment Authority, April 2001. 116pp.

No. 33 Morris, S.A., Pollard, D.A., Gehrke, P.C. and Pogonoski, J.J., 2001. Threatened and Potentially Threatened Freshwater Fishes of Coastal New South Wales and the Murray-Darling Basin. Report to Fisheries Action Program and World Wide Fund for Nature. Project No. AA 0959.98. 177pp.

No. 34 Heasman, M.P., Sushames, T.M., Diemar, J.A., O'Connor, W.A. and Foulkes, L.A., 2001. Production of Micro-algal Concentrates for Aquaculture Part 2: Development and Evaluation of Harvesting, Preservation, Storage and Feeding Technology. Final Report to Fisheries Research and Development Corporation. Project No. 1993/123 and 1996/342. 150pp + appendices.

No. 35 Stewart, J. and Ferrell, D.J., 2001. Mesh selectivity in the NSW demersal trap fishery. Final Report to Fisheries Research and Development Corporation. Project No. 1998/138. 86pp.

No. 36 Stewart, J., Ferrell, D.J., van der Walt, B., Johnson, D. and Lowry, M., 2001. Assessment of length and age composition of commercial kingfish landings. Final Report to Fisheries Research and Development Corporation. Project No. 1997/126. 49pp.

No. 37 Gray, C.A. and Kennelly, S.J., 2001. Development of discard-reducing gears and practices in the estuarine prawn and fish haul fisheries of NSW. Final Report to Fisheries Research and Development Corporation. Project No. 1997/207. 151pp.

No. 38 Murphy, J.J., Lowry, M.B., Henry, G.W. and Chapman, D., 2002. The Gamefish Tournament Monitoring Program – 1993 to 2000. Final report to Australian Fisheries Management Authority. 93pp.

No. 39 Kennelly, S.J. and McVea, T.A. (Ed), 2002. Scientific reports on the recovery of the Richmond and Macleay Rivers following fish kills in February and March 2001. 325pp.

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No. 41 Pollard, D.A. and Pethebridge, R.L., 2002. Report on Port Kembla Introduced Marine Pest Species Survey. Final Report to Port Kembla Port Corporation. 72pp.

No. 42 O'Connor, W.A, Lawler, N.F. and Heasman, M.P., 2003. Trial farming the akoya pearl oyster, *Pinctada imbricata*, in Port Stephens, NSW. Final Report to Australian Radiata Pty. Ltd. 170pp.

No. 43 Fielder, D.S. and Allan, G.L., 2003. Improving fingerling production and evaluating inland saline water culture of snapper, *Pagrus auratus*. Final Report to the Aquaculture Cooperative Research Centre. Project No. C4.2. 62pp.

No. 44 Astles, K.L., Winstanley, R.K., Harris, J.H. and Gehrke, P.C., 2003. Experimental study of the effects of cold water pollution on native fish. A Final Report for the Regulated Rivers and Fisheries Restoration Project. 55pp.

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No. 48 Henry, G.W. and Lyle, J.M. (Ed), 2003. The National Recreational and Indigenous Fishing Survey. Final Report to Fisheries Research and Development Corporation. Project No. 1999/158. 188 pp.

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No. 54 Growns, I., Gehrke, P. and Astles, A., 2003. Spatial and temporal variation in composition of riverine fish communities. Final Report to Water Management Fund. Project No. SW1 part 2. 24pp.

No. 55 Gray, C. A., Johnson, D.D., Young, D.J. and Broadhurst, M. K., 2003. Bycatch Assessment of the Estuarine Commercial Gill Net Fishery in NSW. Final Report to Fisheries Research and Development Corporation. Project No. 2000/172. 58pp.