Development of discard-reducing gears and practices in the estuarine prawn and fish haul fisheries of NSW

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TABLE OF CONTENTS

LIST OF TABLES

LIST OF FIGURES

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NON-TECHNICAL SUMMARY

97/207	Developing discard-reducing gears and practices in the estuarine prawn and fish haul fisheries of NSW

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OBJECTIVES:

(1) To identify and quantify the bycatch, discards and landed catches from prawn and fish hauling at a variety of locations throughout NSW using a stratified, randomized observer-based survey; these data will be used to determine key gears, methods and times of discarding that will be addressed in objective 2.

(2) To develop, test and implement modifications to current hauling gears and practices that will decrease the identified problematic discards.

NON TECHNICAL SUMMARY:

OUTCOMES ACHIEVED:

Changes to the regulations concerning the gears and practices used in the prawn and fish haul fisheries in NSW have been implemented as a consequence of this project. Specifically, the method of operating prawn hauls in the Manning River has been changed so that fishers retrieve nets mid-stream as opposed to the riverbank. The maximum permitted size of mesh in the bunts and codends of fish haul nets has been increased from 51 to 57 mm following our experiments and permits have been issued to several haul fishers to use modified hauling gears. Significant advice to fisheries managers and industry concerning all aspects of this study on estuarine haul nets has been made and several amendments to the regulations concerning the use and configurations of haul nets have been made and/or are currently being incorporated in the Estuary General Fishery Management Strategy.

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).

As in many coastal fisheries throughout the world, one of the most contentious issues surrounding the management of the multi-species commercial estuarine fisheries in New South Wales (NSW), Australia, concerns bycatch and discarding. In particular, various resource interest groups have expressed concerns that the estuarine prawn and fish haul fisheries incur high levels of discarding, including species important in other recreational and commercial fisheries. A necessary first step in solving bycatch and discarding issues is to determine the real, as opposed to any perceived, problem and how this varies in space and time.

An observer-based program was used to assess trends in bycatch composition and quantify levels of catches and bycatches from the haul fishery for school prawns (*Metapenaeus macleayi*) in 4 estuaries (Richmond, Manning, Wallamba and Shoalhaven Rivers) in NSW. A total of 46 finfish and 5 invertebrate taxa were identified in bycatches sampled between September 1998 and June 1999. Bycatches were dominated by small fishes (<15 cm TL) of little economic value, including southern herring (*Herklotsichthys castelnaui*), glassy perchlets (*Ambassis* spp.) and cardinal fish (*Siphamia* sp.). Important species such as bream (*Acanthopagrus australis*), sand whiting (*Sillago ciliata*) and tailor (*Pomatomus saltatrix*) were observed in catches, but generally fewer than 15 of each of these species were caught on average per-boat per-day. The composition and structures of bycatches varied between estuaries, demonstrating that bycatch-associated problems were not the same in all locations. Prawn catch:bycatch ratios (by weight) ranged from 1: 0.07 to 1: 0.52 depending on the estuary. These ratios are considerably less than those reported for most other net-based prawn fisheries throughout the world. Estimated total bycatch taken during the fishing season ranged from 1.7 tonnes in the Richmond River to 17.6 tonnes in the Manning River. The data indicate that discarding in this fishery is relatively low compared to other prawn fisheries and probably has little impact on other interacting finfish fisheries in the region.

Bycatch levels in prawn haul nets were greatest in the Manning River where fishers are required to retrieve nets to the shore (riverbank). We showed that a simple change in fishing practice so that nets were retrieved midstream significantly reduced bycatch levels in this fishery. As a direct result of this research, the regulations concerning the way gear is operated in this fishery have been amended and fishers are now required to retrieve prawn haul nets away from the shore.

Observer-based surveys were also used to quantify the composition and quantities of retained and discarded catches in the estuarine fish haul fisheries in Botany Bay, Lake Macquarie, St Georges Basin and the Clarence River in NSW. We estimated that between 38 to 59 % of total fish haul catches by weight and 44 to 77 % by number were discarded, depending on the estuary. Fish haul nets were relatively unselective, capturing a wide range of species of differing morphologies and sizes. The major species discarded included the juveniles of many species important in other recreational and commercial fisheries, including bream (*Acanthopagrus australis*), tarwhine (*Rhabdosargus sarba*), snapper (*Pagrus auratus*), silver trevally (*Pseudocaranx dentex*), silver biddy (*Gerres subfasciatus*) and six-lined trumpeter (*Pelates sexlineatus*) as well as several species of no direct importance to commercial and recreational fishers, including porcupinefish (*Dicotylichthys punctulatus*) and southern herring (*Herklotsichthys castelnaui*). Discarding of several species was very high; we estimated that up to 99% of tarwhine and snapper, 88% of bream, 81% of sand whiting and 33% of silver biddy were discarded from fish hauls.

Discard-associated problems varied among estuaries demonstrating that no one solution will mitigate the identified problems throughout the entire fishery. In terms of fishery-interaction problems, discarding of undersize sand whiting was the major problem observed in northern NSW estuaries, whilst the discarding of undersize tarwhine, snapper and bream were observed to be the major problem in the lagoon-based haul fisheries.

Field-based experiments showed that incorporation of strategically placed transparent netting in the bunts of haul nets significantly reduced the retention of unwanted bycatch, particularly undersized sand whiting (*Sillago ciliata*). Further experiments demonstrated that increasing the maximum mesh size to 57 mm in the bunts of haul nets significantly reduced the meshing and subsequent mortality of undersized sand whiting. Permits have been issued to fishers to modify their fishing gears as a direct result of this research. Work done on haul nets used in coastal lagoons suggest that transparent grids placed in the codends of nets will help facilitate the escape of small bream, tarwhine and snapper from nets prior to sorting. However, all sizes of silver biddy will also escape via such grids and this will have an economic impact on some fishers. We showed, however that short-term survival of discards in the lagoon-based fisheries was relatively high, and suggest that when catches are sorted in a responsible manner (e.g. in adequate water and absence of jellyfish), then discarding from this fishery could have negligible impacts on stock sizes. We encourage industry to adopt a strong protocol for sorting catches, which includes keeping the unsorted catch in adequate water and possibly holding discards in pens prior to release in deeper water away from scavenging birds.

We provided significant advice to fisheries managers and industry concerning all aspects of this study and several amendments to the regulations concerning the use and configurations of haul nets have been made and/or are currently being incorporated in the Estuary General Fishery Management Strategy. These recommendations included changing the method of operating prawn hauls and increasing the mesh size in bunts of fish hauls.

This study was not done to determine Recreational Fishing Havens in NSW.

KEYWORDS: Haul net, seine net, observer survey, bycatch management, discarding, gear development, estuarine fisheries, southeast 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 conflict between commercial prawn and fish haul fisheries in estuaries and other stakeholders, including recreational fishers, other commercial fishers, tourists and the general public. The major issue concerning this method is the belief that the use of haul nets in estuaries leads to significant bycatch and discarding of undersized and/or unwanted fish. The discard and mortality of these individuals is reported anecdotally to involve large quantities of recreationally and commercially important species) and is said to occur in locations where recreational fishers are fishing and/or in places where the public have full view of hauling operations. This has led to widespread outcries over the discard and wastage of these small fish and many calls for the complete banning of hauling as a fishing method. It should be noted that the fish and prawn haul fisheries of NSW are very important and together are valued at approximately $5 million per annum. Consequently any threats to ban the method could have important economic consequences to the small towns in NSW where these fisheries occur.

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

There is a need to identify and quantify what is caught, retained and discarded in estuarine haul nets and assess how this varies among different operations and places to determine the real level of discarding in these fisheries. Such information will assist managers and industry in determining ways to mitigate and manage discarding and bycatch in these fisheries.

1.3. Objectives

(1) To identify and quantify the bycatch, discards and landed catches from prawn and fish hauling at a variety of locations throughout NSW using stratified, randomized observer-based surveys; these data will be used to determine key gears, methods and times of discarding that will be addressed in objective 2.

(2) To develop, test and implement modifications to current hauling gears and practices that will decrease the identified problematic discards.

1.4. Achievement of objectives

Objective 1- achieved. Observer-based surveys were used to quantify the species composition, magnitude and size-composition of discards from the NSW estuarine prawn and fish haul fisheries. The bycatch from prawn hauling was assessed in four key estuaries: the Richmond, Manning, Wallamba and Shoalhaven Rivers. Estimates of discards from the fish haul fisheries were determined for the Clarence River, Botany Bay, Lake Macquarie and St Georges Basin.

Objective 2 - achieved. Experiments in the Manning River demonstrated that retrieving prawn haul nets mid-stream as compared to the shore significantly reduced bycatches in this fishery. Field-based experiments showed that the incorporation of transparent netting in fish haul nets significantly improved the selectivity of nets and reduced unwanted bycatch, particularly the numbers of undersize sand whiting. Further studies on fish haul nets in northern NSW and laboratory experiments at the Cronulla Fisheries Centre showed that increasing the maximum mesh size to 57 mm in the bunt and codend of nets significantly reduced the meshing and subsequent mortality of undersized sand whiting. Transparent grids placed in the codends of haul nets used in coastal lagoons show great potential as a means of facilitating quicker release via the passive escape of discards prior to sorting. Changes to the regulations concerning the gears and practices used in the prawn and fish haul fisheries in NSW have been implemented as a consequence of this project.

2. DISCARDING FROM ESTUARINE PRAWN HAULING

2.1. Introduction

One of the most problematic fishing methods in terms of bycatch and discarding is trawling and, in particular, by-catch from prawn trawling has received considerable attention, with numerous studies having identified and quantified the types and levels of by-catches in several fisheries (see reviews by Andrew and Pepperell 1992; Kennelly 1995). The information obtained in these surveys has aided fisheries managers and scientists to investigate ways to reduce problematic by-catches in some fisheries (see Kennelly 1995; Broadhurst 2000). Although by-catch problems have been identified in prawn-trawl fisheries for several years, far fewer studies have examined by-catches in smaller scale, net-based prawn fisheries, including those that use seine, trammel, cast and stake nets (but see Changchen 1992; Chavez 1992; Andrew *et al*. 1995; Gray 2001).

Several non-trawl methods are used to capture prawns in estuarine waters of New South Wales (NSW), Australia. These include haul, seine, set-pocket and running nets and one of the most contentious issues facing the management of these fisheries involves by-catch. In particular, several resource user groups, including commercial and recreational fishers and conservation groups, claim that most prawning methods incur high levels of wastage because they catch and kill large numbers of juvenile fish. Often these by-catch species are important in other commercial and recreational fisheries leading to fishery-interaction problems (see also Liggins *et al*. 1996). An important first step in dealing with issues concerning by-catch is to quantify the real extent of the perceived problems. Whilst there have been quantitative assessments of by-catches from the estuarine prawn trawl (Gray *et al*. 1990; Liggins and Kennelly 1996; Liggins *et al*. 1996), set-pocket net (Andrew *et al*. 1995), prawn seining (Gray 2001) fisheries in NSW, no such data are available for the prawn haul fisheries.

Several methods have been used to quantify by-catches in prawn fisheries, including logbooks, independent research surveys and onboard observers (see reviews by Andrew and Pepperell 1992; Kennelly 1995). It is generally acknowledged that the most reliable and accurate method to quantify by-catches in commercial fisheries is to place scientific observers onboard vessels, collecting data during normal fishing operations (Saila 1983; Alverson *et al*. 1994; Kennelly 1995). The aims of the current study were to use an observer-based survey to identify and quantify the levels of by-catch in the estuarine prawn haul fisheries in the Richmond, Manning, Wallamba and Shoalhaven Rivers in NSW (Fig. 2.1) throughout the 1998/99 fishing season.

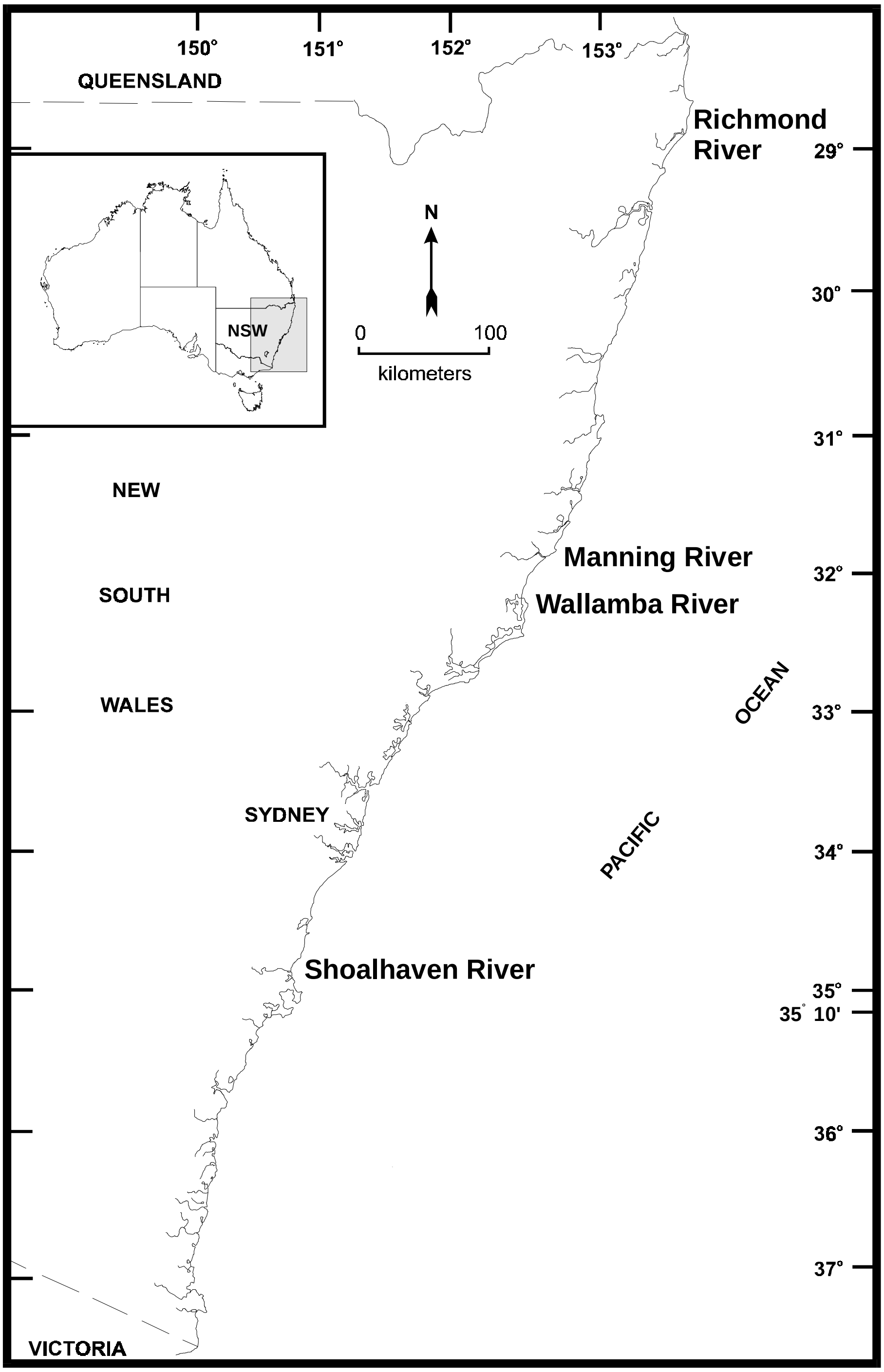

Figure 2.1. Map of NSW showing the four estuaries where the prawn haul fisheries were studied.

2.2. Methods

2.2.1. The NSW prawn haul fishery

Prawn hauling for school prawns (*Metapenaeus macleayi*) is permitted in 10 estuaries in NSW. Approximately 85 fishers operate in the fishery that is valued at about $2 million per annum. Fishers using this gear are not able to retain any species other than prawns so all bycatch must be discarded. The prawn catch is sold for human consumption and for bait.

Typically, prawns are hauled by small vessels (< 6 m) powered primarily by outboard motors, deploying a single net. The total headline length of each haul net must not exceed 40 m and mesh throughout the net and codend must be between 30 and 36 mm. However, the regulations governing the way seines are operated and the length of hauling rope attached to each end of the net varies among estuaries. For example, in some estuaries (e.g. the Richmond and Hasting Rivers) one boat is used to deploy and retrieve the net, which must have an equal length of hauling rope (up to 130 m) on each end (Fig. 2.2a). In other estuaries (e.g. the Wallamba River), two boats are used in the seining operation, one is used as a stationary platform to which the net is hauled, and the other boat is used to deploy and tow the net to the stationary boat (Fig. 2.2b). In this operation, a greater length of rope (up to 220 m) is permitted on the end of the net not being towed, while up to 50 m of rope can be attached to the end of the net that is being towed (Fig. 2.2b). In other estuaries (e.g. the Manning and Shoalhaven Rivers), the nets must be set from and retrieved to the bank of the river (Fig. 2.2c), whereas in the Richmond and Wallamba Rivers, the nets can be set and retrieved mid-stream. The area swept in each hauling operation varies between the way the gear is operated. Winches are also permitted to haul nets in some estuaries (e.g. Richmond and Wallamba Rivers), whereas in other estuaries the nets must be hand-hauled (e.g. Manning River). Most prawn haul crews consist of 2 persons, but in some estuaries (e.g. Richmond River) 1 person is permitted to fish the gear. Prawn hauling is permitted year-round in most estuaries, but it is closed over the winter months of June to August inclusive in some estuaries (e.g. the Manning and Shoalhaven Rivers). Greatest hauling effort and prawn production usually occurs during the warmer months between October and April.

2.2.2. Sampling of catches

In each month between September 1998 and May 1999 scientific observers attempted to accompany commercial prawn haul fishers on four randomly selected fishing trips (fisher-days) in the Richmond, Manning, Wallamba and Shoalhaven Rivers. However, because of the sporadic nature of the fishery and logistical constraints, staffing constraints, bad weather and low fleet effort caused by small prawn catches, it was not possible to achieve complete observer coverage across all estuaries in all months. The number of fisher-days sampled each month varied between locations, and for some months and locations there was no sampling.

On each observed trip, the crew sorted the catch and bycatch from each individual haul (between 1 and 14 hauls per day). The total weights of the retained prawns and the total discarded bycatch in each haul were determined. The observer sorted the bycatch further into individual species and the total weights and numbers of each species were determined. Fish species of economic value were also measured (to the nearest 1 cm), although measurements were not always done for all fish from each individual haul each day. Operational data, including gear configuration and the date, location and time of each haul were also collected.

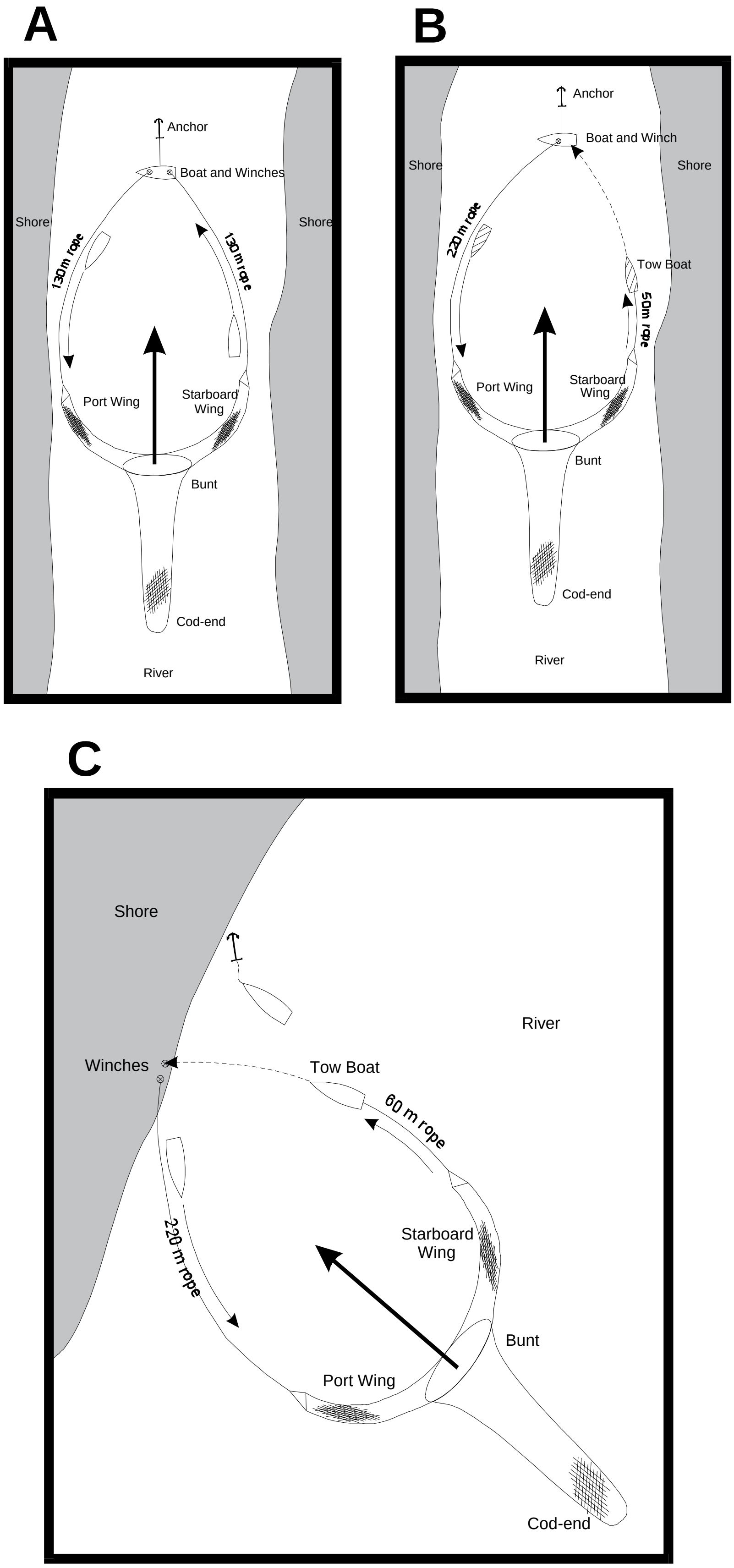

Figure 2.2. Diagrammatic representation of variations in prawn hauling. a. one boat used and net retrieved away from the shore; b. Two boats used and net retrieved away from the shore; c. One or two boats used and net retrieved to the shore.

2.2.3. Data analyses

Non-metric multidimensional scaling (MDS) was used to delineate general patterns in bycatch composition across and within estuaries. The PRIMER program (Clarke and Warwick 1994) was used for these analyses and the general procedures used followed those outlined in Clarke (1993). Total catches per fisher day were used to compare catch composition across estuaries. Data on species abundance for each individual day were 4th root transformed to ensure that each taxonomic grouping contributed evenly to the analysis. Similarity matrices based on the Bray-Curtis similarity measure were generated and the inter-relationships among samples (individual tows) were displayed graphically in a 2 dimensional ordination plot. Samples that grouped together were most similar and the stress coefficient indicated the goodness of fit of the data. A one-way analysis of similarity (ANOSIM) was used to test for spatial differences in bycatches caught between estuaries. Similarity percentage analysis (SIMPER) was used to identify the taxa that were most responsible for the dissimilarity among sample groupings in the MDS plot. The ratio of the mean/se is a measure of how consistently each taxonomic group contributed to the dissimilarity measure between groups. Taxa displaying a high mean/se ratio and a high contribution can be considered good discriminating species (Clarke and Warwick 1994).

Mean daily (catches summed across all hauls) catch rates (+ 1se) of prawns and bycatches were calculated for each estuary. Because of the uneven observer coverage throughout the survey, one-factor analyses of variance, after doing Cochran's test for homogeneity of variances and any necessary transformations, were used to test for differences in the weights and quantities of prawns and bycatches among estuaries (pooled through time) and among months within each estuary. Fisher-days (catches summed across all hauls per day) were used as the unit of replication rather than individual hauls because the latter were not randomly selected in a given month, and therefore were not independent, and in practice, the location of any haul depends on the location and result of the previous haul(s). Student-Newman-Keuls multiple comparisons were used *post hoc* to determine which means differed.

Prawn:by-catch ratios were calculated for all hauls in each estuary. The mean ratio $\hat{R}$ and estimated standard error $S(\hat{R})$ were calculated for each estuary using the following formulae (after Cochran 1963):

$$\hat{R} = \frac{\sum_{i=1}^{n} b_i}{\sum_{i=1}^{n} r_i} \qquad\qquad S(\hat{R}) = \frac{1}{\left(\bar{r}.\sqrt{n}\right)} \cdot \sqrt{\frac{\sum b_i^2 - 2\hat{R}.\sum r_i b_i + \hat{R}^2.\sum r_i^{\,2}}{(n-1)}}$$

where b_i and r_i are the weight (kg) of by-catch and retained prawn catch respectively, for haul *i*, and *n* is the total number of hauls sampled.

Estimates of total prawn catches and total bycatches (+ 1se) by all prawn haul crews in each estuary throughout the 1998/99 fishing season were derived by multiplying the mean daily catch rates per month (CPUE) by the reported number of fisher-days completed by all haul crews in each estuary in month (fishing effort) between September 1998 and June 1999. The total reported fishing effort for each month in each estuary (i.e. total number of fisher-days) was obtained from the mandatory forms that commercial fishers are required to submit to NSW Fisheries. This was done using the standard method for estimating a total (and SE) across multiple randomly sampled strata as outlined in Cochran (1963):

$$\hat{C} = \left(\frac{N'}{N}\right)\sum_{m=1}^{M} N_m.\overline{C}_m$$

$$S(\hat{C}) = \left(\frac{N'}{N}\right)\sqrt{\sum_{m=1}^{M}\frac{N_m^2.S_m^2}{n_m}}$$

in which C is the estimated total catch and S(C) is the associated standard error of all haul crews, and C_m is the mean catch rate per trip, S_m is the standard deviation of sample catch rates, N_m is the total number of trips done by the fleet and n_m is the number of sampled trips in month m of M survey months in the fishing season for a location. N is the total number of trips done by the fleet in all fishing months and N' is the total number of trips done by the fleet in the fishing season including those months that were not survey months. Thus the term N'/N scales the fleet's catch from all survey months to the fleets catch in the fishing season. The implicit assumption here is that the mean catch rates for non-survey months and survey months are the same.

Observed length-frequency distributions of important species were scaled to represent whole fleets using estimated fishing effort. This was done by multiplying the measured length-frequency distributions by the ratio of total fishing effort to sampling effort in each month in each estuary, then adding these to provide an annual distribution, from which a relative length composition was calculated. Since not all individual fish caught were measured in all hauls on all fisher-days, the length-frequencies were scaled up: a) within hauls, to reflect individual fish caught in hauls where some, but not all fish were measured; and b) within months, to account for individuals caught in hauls where no fish were measured at all.

The length-frequencies for each species in each estuary were thus generated according to the following formula:

$$Freq_l = \sum_{m=1}^{M}\frac{D_m}{d_m}\left[\frac{N_m}{n_m}\sum_{d=1}^{d_m}\sum_{h=1}^{H_{dm}}\left(\frac{N_{hdm}}{n_{hdm}}.f_{lhdm}\right)\right]$$

where f_{lhdm} is the frequency of length class l for haul h of H hauls, of fisher-day d of d_m sampled days, in month m of M months over the sampled fishing season. N_{hdm} is the number of individual fish measured, N_{hdm} is the total number of individuals caught (including those not measured) in haul h, of fisher-day d and month m. n_m is the number of individual fish caught in hauls where some or all were measured, and N_m is the total number of fish caught in month m, including those in hauls where no fish were measured at all. D_m is the total number of fisher-days by the fleet in month m, and d_m the total number of sampled fisher-days.

The estimated frequency of length l, in the fleet's total catch, $Freq_l$, was converted to a relative length frequency, $RelFreq_l$, for each estuary:

$$RelFreq_l = \frac{Freq_l}{\sum_{l=1}^{L} Freq_l}$$

2.3. Results

2.3.1. Reported fishing effort and observer coverage

Between September 1998 and June 1999, the total reported fishing effort by all crews across all 4 estuaries was 2,141 days (Richmond 589 days; Manning 690 days; Wallamba 463 days; Shoalhaven 399 days). Observers sampled 91 fishing trips (fisher-days), which represented 4.25 % of the total reported fishing effort. The distribution of sampling effort and reported fishing effort in each of the 4 estuaries is displayed in Fig. 2.3. Trends in reported fishing effort varied among estuaries; effort decreased from 158 to 2 fishing days per month throughout the survey in the Richmond River, while in the Manning River it decreased from 120 to 25 days per month between September and January, after which it increased to peak in March (130 days), which was followed by another decline. Reported fishing effort fluctuated around 40 fishing days per month throughout the survey in the Wallamba and Shoalhaven Rivers.

The average number (+ 1se) of observed hauls made per-day by fishers throughout the survey were 8.59 (0.77) in the Richmond River, 6.13 (0.45) in the Shoalhaven River, 5.27 (0.51) in the Wallamba River and 3.17 (0.47) in the Manning River.

2.3.2. Bycatch composition

The majority of bycatch organisms were identified to species, but some organisms (of difficult identification) were assigned to higher taxonomic groupings. A total of 46 finfish and 5 invertebrate taxa, of which 29 taxa were considered commercially/recreationally important, were identified as bycatch throughout the survey (Table 2.1). The bycatch in each estuary was generally dominated by small fish species of little monetary value, including *Herklotsichthys castelnaui*, *Ambassis* spp. and *Siphamia* sp. The majority of individuals of species of recreational/commercial significance, including *Gerres subfasciatus*, *Acanthopagrus australis*, *Sillago ciliata*, *Platycephalus fuscus*, *Pomatomus saltatrix* and *Argyrosomus japonicus*, were juveniles, with most fish captured being < 15 cm in length (Fig. 2.4).

The structure and composition of bycatches varied between estuaries (ANOSIM, R = 0.707, $P < 0.001$), with the Manning and Wallamba Rivers being most similar and the Richmond and Shoalhaven Rivers being most dissimilar (Fig. 2.5). The species that contributed greatest to the dissimilarities in bycatch among estuaries were identified by the SIMPER analyses and are presented in Table 2.2. *Arius graeffei* and *Zebrias scalaris* were caught only in the Richmond River, *Ambassis* spp. were most predominant in the Manning and Wallamba Rivers, whilst *Gerres subfasciatus*, *Acanthopagrus australis* and *Herklotsichthys castelnaui* were predominant in bycatches across most estuaries.

Observed prawn catch to bycatch (weight) ratios ranged from 1:0.07 in the Richmond River to 1:0.52 in the Manning River, with the overall average being 1:0.21 (Fig. 2.6). There was a significant correlation between the weight of prawn catch and weight of total bycatch taken per haul in the Manning River, but not in the other estuaries.

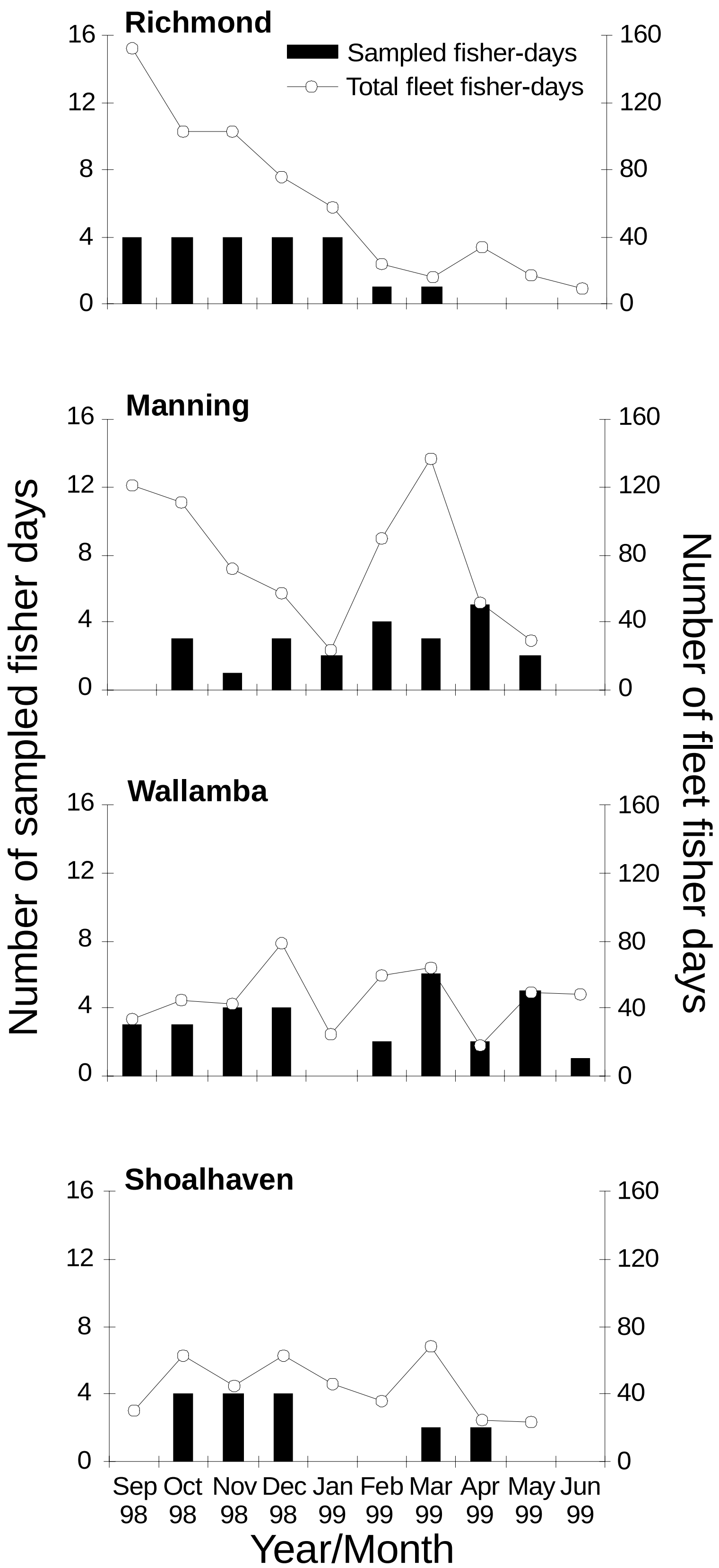

Figure 2.3. Trends in sampling and reported fishing effort in each estuary.

Table 2.1. List of all species of bycatch observed in prawn haul catches in each estuary. # denotes species of commercial/recreational significance, R, M, W, S = Richmond, Manning, Wallamba, Shoalhaven Rivers respectively.

Family	Scientific Name	Common Name	R	M	W	S
Finfish:						
AMBASSIDAE	*Ambassis* spp.	Glass perchlet	*	*	*	*
ANGUILLIDAE	*Anguilla* sp.	Eel #				*
APOGONIDAE	*Siphamia* sp.	Siphon fish	*	*	*	
ARRIPIDAE	*Arripis trutta*	Salmon #			*	
ARRIIDAE	*Arius graeffei*	Fork-tailed catfish #	*			
BOTHIDAE	*Pseudorhombus* spp.	Flounder #	*	*	*	*
CALLIONYMIDAE	*Foetorepus calauropomus*	Stinkfish		*	*	
CARANGIDAE	*Pseudocaranx dentex*	Silver trevally #		*		*
CARCHARHINIDAE	*Carcharhinus* sp.	Whaler shark #	*			
CHAETODONTIDAE	*Selenotoca multifasciata*	Striped butterfish #		*	*	
CLUPEIDAE	*Herklotsichthys castelnaui*	Southern herring	*	*	*	*
	Hyperlophus vittatus	Sandy sprat			*	
	Potamalosa richmondia	Freshwater herring	*	*		
CYNOGLOSSIDAE	*Paraplagusia unicolor*	Lemon tongue sole	*			
CYPRINIDAE	*Cyprinus carpio*	European carp				*
DASYATIDIDAE	*Dasyatis* sp.	Estuary stingray	*	*	*	*
DIODONTIDAE	*Dicotylichthys punctulatus*	Porcupine fish		*		*
GERREIDAE	*Gerres subfasciatus*	Silver biddy #	*	*	*	*
GIRELLIDAE	*Girella tricuspidata*	Luderick #		*	*	*
GOBIIDAE	(mixed spp.)	Goby	*	*	*	*
	Philypnodon grandiceps	Flathead gudgeon	*		*	*
HEMIRAMPHIDAE	*Hyporhamphus regularis*	River garfish #	*		*	
LOBOTIDAE	*Lobotes surinamensis*	Triple-tail	*			
MONACANTHIDAE	*Meuschenia trachylepis*	Yellow-finned leatherjacket #		*		
MONODACTYLIDAE	*Monodactylus argenteus*	Diamond fish	*	*	*	
MUGILIDAE	*Liza argentea*	Flat-tail mullet #		*	*	*
	Mugil cephalus	Sea mullet #		*	*	*
	Myxus elongatus	Sand mullet #				*
PERCICHTHYDAE	*Macquaria novemaculeata*	Australian bass #				*
	Macquaria colonorum	Estuary perch #				*
PLATYCEPHALIDAE	*Platycephalus fuscus*	Dusky flathead #	*	*	*	*
PLOTOSIDAE	*Cnidoglanis macrocephalus*	Estuary catfish#	*	*	*	
	Plotosus lineatus	Striped catfish		*	*	
POMATOMIDAE	*Pomatomus saltatrix*	Tailor #	*	*	*	*
SCIAENIDAE	*Argyrosomus japonicus*	Mulloway #	*	*	*	*
SCORPAENIDAE	*Centropogon australis*	Fortescue	*		*	*
	Notesthes robusta	Bullrout	*	*	*	
SILLAGINIDAE	*Sillago maculata*	Trumpeter whiting #		*		
	Sillago ciliata	Sand whiting #	*	*	*	*
SOLEIDAE	*Synaptura nigra*	Black sole	*	*	*	*
	Zebrias scalaris	Many-banded sole	*			
SPARIDAE	*Acanthopagrus australis*	Yellowfin bream #	*	*	*	*
	Rhabdosargus sarba	Tarwhine #		*	*	*
TERAPONTIDAE	*Pelates* sp.	Six-lined trumpeter		*	*	*
TETRAODONTIDAE	*Tetractenos* sp.	Toadfish	*	*	*	
UROLOPHIDAE	*Trygonoptera testacea*	Stingaree		*		*
Crustaceans:						
PENAIEDAE	*Metapenaeus macleayi*	School prawn #		*		
PORTUNIDAE	*Portunus pelagicus*	Blue-swimmer crab #	*	*		
	Scylla serrata	Mud crab #	*	*	*	
Molluscs:						
OCTOPODIDAE	*Octopus* sp.	Octopus #		*		
TUETHOIDAE	(Unidentified sp.)	Squid #	*	*		

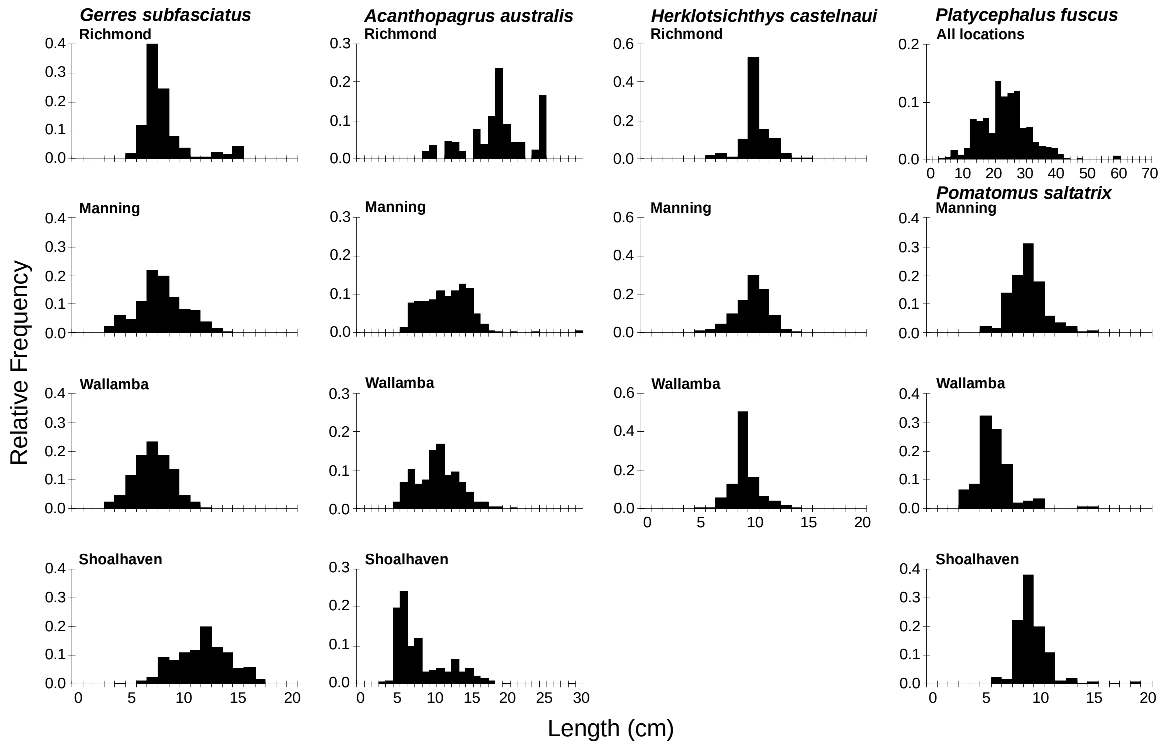

Figure 2.4. Length compositions of five bycatch species in prawn haul nets.

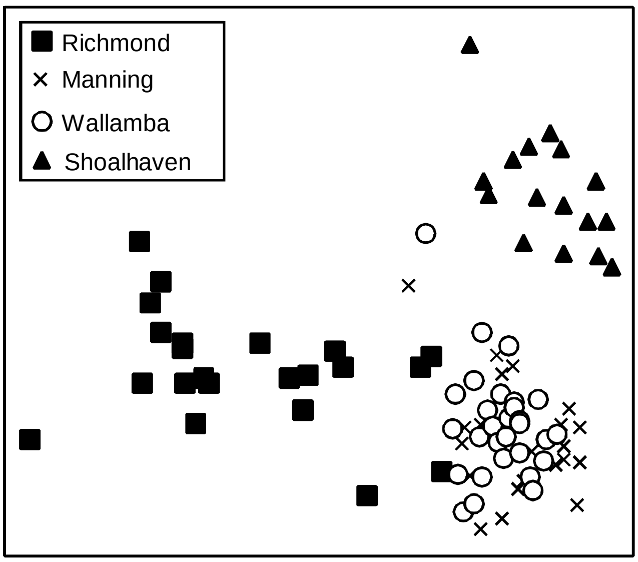

Figure 2.5. MDS ordination showing relationships of structures of bycatch among estuaries.

Table 2.2. Summary of results of SIMPER showing ratio (mean/se) and the percent contribution of the top 5 individual species to similarity of bycatch in each estuary.

	Ratio	% contribution
Richmond River		
Zebrias scalaris	1.81	27.54
Arius graeffei	1.26	20.12
Nototesthes robustus	1.24	13.11
Herklotsichthys castelnaui	0.95	10.66
Acanthopagrus australis	0.95	8.94
Manning River		
Herklotsichthys castelnaui	3.17	24.19
Ambassis spp.	2.3	12.04
Gerres subfasciatus	1.69	11.36
Acanthopagrus australis	3.84	10.11
Cnidoglanis macrocephalus	1.64	8.99
Wallamba River		
Gerres subfasciatus	4.62	21.39
Herklotsichthys castelnaui	2.18	17.94
Ambassis spp.	3.69	16.02
Acanthopagrus australis	1.8	8.91
Platycephalus fuscus	1.82	6.3
Shoalhaven River		
Acanthopagrus australis	4.18	19.35
Gerres subfasciatus	1.76	18.69
Pomatomus saltatrix	2.14	14.86
Sillago ciliata	1.3	8.42
Platycephalus fuscus	0.76	4.92

2.3.3. Catch rates

The mean weights of prawns and total bycatch landed varied among months and estuaries (Fig. 2.7). The mean weight of prawn catch per fisher-day ranged from 5 to 239 kg in November 1998 and February 1999, respectively, in the Wallamba River. The mean weight of bycatch landed per fisher-day ranged from 2 kg in February 1999 in the Richmond River to 105 kg in April 1999 in the Manning River. Mean total bycatch weight was greater in the Manning and Wallamba Rivers than in the Shoalhaven and Richmond Rivers (Fig. 2.7, Table 2.3).

Variations between estuaries in mean catch rates per fisher-day for the major species of bycatch are presented in Table 2.3. Mean daily catch rates of individual taxa varied greatly between estuaries. Bycatches of *Arius graeffei* and *Zebrias scalaris* were only observed in the Richmond River. Mean catch rates per fisher-day of *Herklotsichthys castelnaui*, *Ambassis* spp. and *Siphamia* sp. were greatest in the Manning and Wallamba Rivers. On average, less than 15 individuals of each of *Pomatomus saltatrix*, *Argyrosomus japonicus*, *Sillago ciliata* and *Platycephalus fuscus* were caught per fisher-day in each estuary. This was also true for *Acanthopagrus australis* except in the Wallamba River. Similarly, mean daily catches of *Gerres subfasciatus* were < 40 in each river except the Wallamba River where the average catch per fisher-day was 236 individuals.

2.3.4. Estimates of total catches and bycatches

Estimates of the total prawn catches and bycatches of the major taxa by all haul crews in each estuary throughout the 1998/99 fishing season are presented in Table 2.4. Estimated total prawn catches ranged from 7.9 to 42.4 tonnes in the Shoalhaven and Manning Rivers respectively, whereas in the same estuaries the estimated total bycatches ranged from 1.7 to 17.6 tonnes respectively. *Herklotsichthys castelnaui* accounted for 37, 60 and 34 % of the estimated total bycatch in the Richmond, Manning and Wallamba Rivers respectively. Other major contributors to the estimated total bycatches in each estuary were *Arius graeffei* (20%) and *Zebrias scalaris* (20%) in the Richmond River and *Gerres subfasciatus* (44%) in the Wallamba River. *Gerres subfasciatus* (24%), *Pomatomus saltatrix* (26%) and *Acanthopagrus australis* (15%) contributed greatest to estimated total bycatches in the Shoalhaven River. Overall, in catching an estimated 131 tonnes of prawns, these four ports combined caught approximately 27 tonnes of bycatch (a prawn to bycatch weight ratio of 1:0.21).

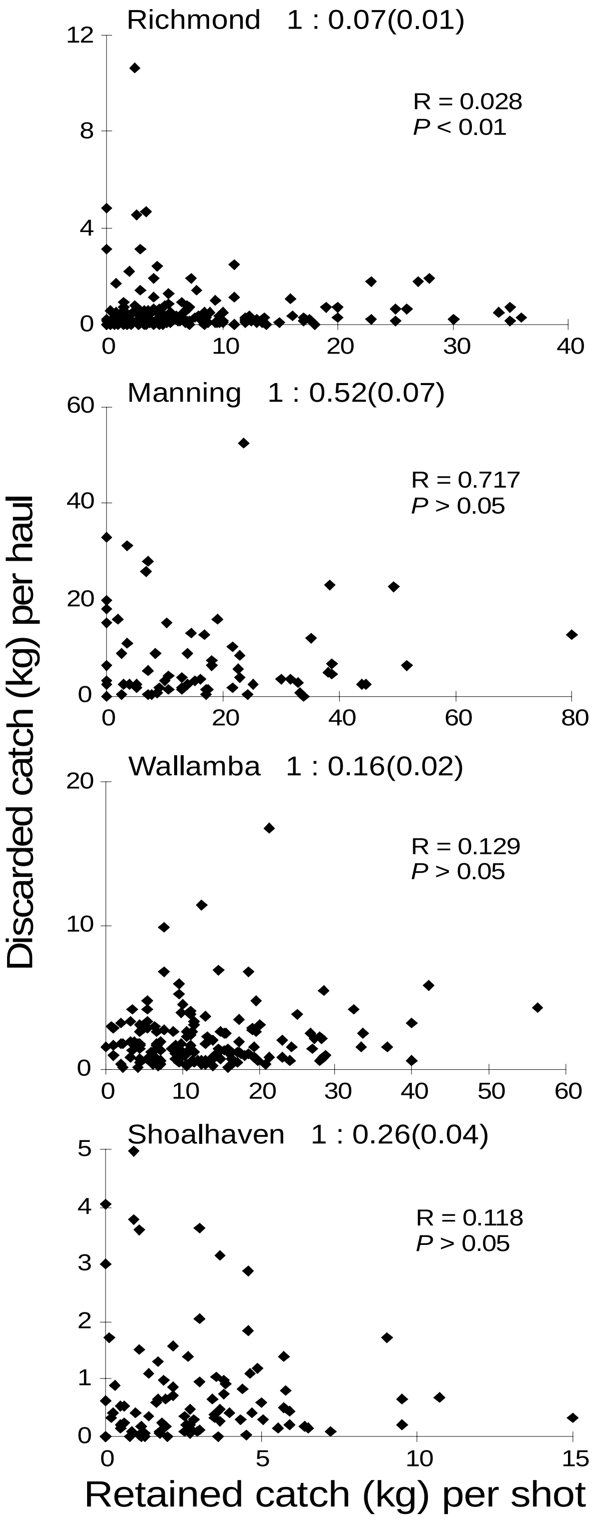

Figure 2.6. Relationships between the weight of prawn catch and weight of total bycatch in each estuary. Prawn to bycatch ratios by weight and the correlation coefficient (R) and its significance are given for each estuary.

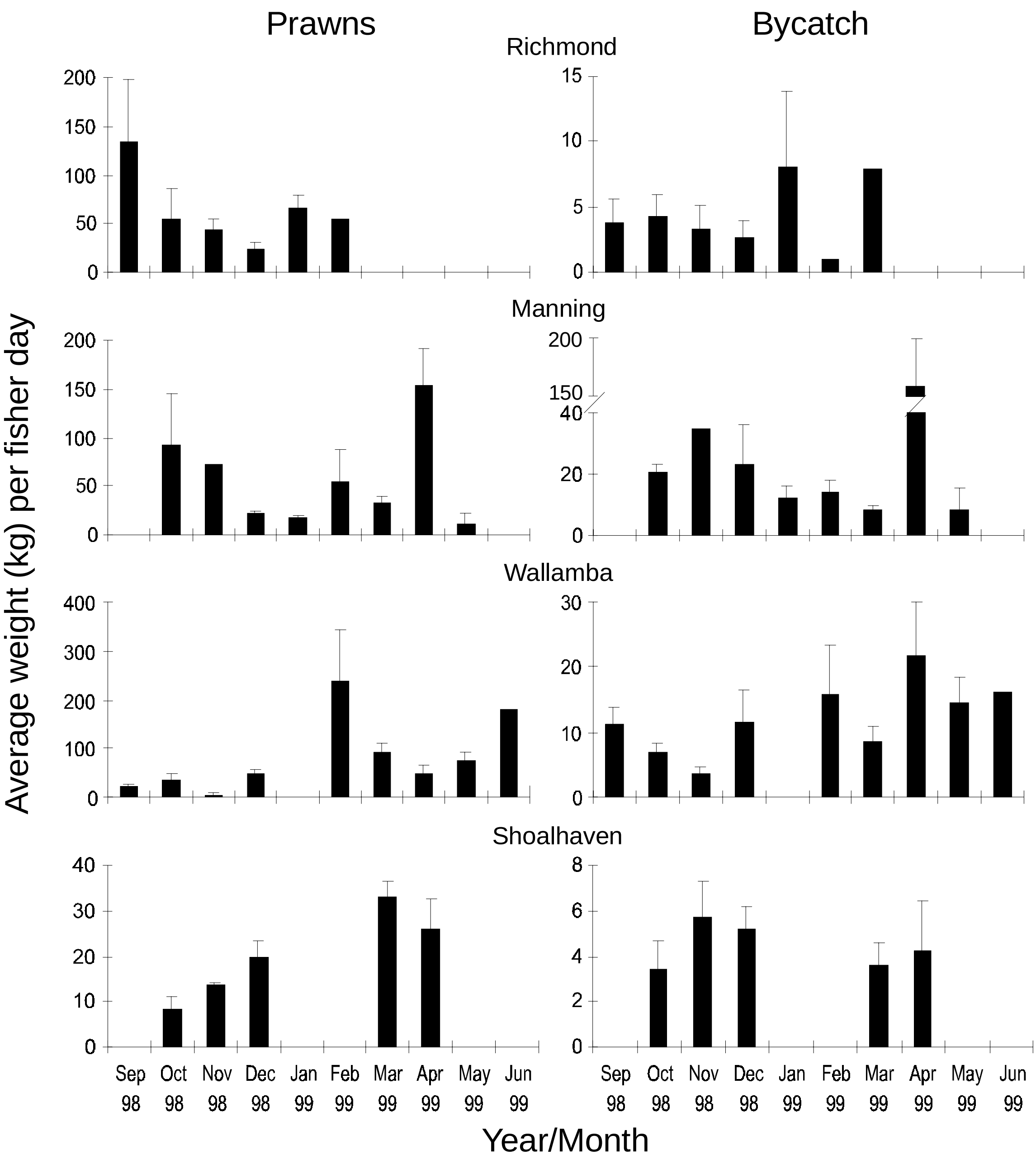

Figure 2.7. Catch rates of prawns and total bycatch weight in each estuary throughout the survey.

Table 2.3. Mean (+ 1 se) catches per fisher-day (trip) in the Richmond, Manning, Wallamba and Shoalhaven Rivers pooled across all sample months and summaries of results of one-way analyses of variance comparing catches across the 4 estuaries pooled across all sample months. Data transformed to log (x + 1), degrees of freedom = 3, 87 in each test.

Variable	Richmond River		Manning River		Wallamba River		Shoalhaven River		ANOVA	
	Mean	se	Mean	se	Mean	se	Mean	se	F-ratio	Significance
Prawn weight (kg)	61.1	14.38	67.92	15.3	68.47	12.85	17.73	2.4	2.65	ns
Bycatch weight (kg)	4.43	1.15	35.44	10.58	11.04	1.39	4.58	0.59	19.69	<0.001
No. of bycatch species	8.36	0.9	12.91	0.98	12.33	0.65	11.06	0.86	5.29	<0.001
Herklotsichthys castelnaui	41.88	27.91	427.92	77.45	224.6	70.38	0.69	0.36	53.02	<0.001
Gerres subfasciatus	6.82	4.62	35.97	10.31	235.55	56.83	16.63	3.48	43.49	<0.001
Ambassis spp.	3.65	1.48	45.8	10.79	63.58	13.11	1.06	0.38	44.08	<0.001
Siphamia sp.	0.45	0.32	114.45	44.16	12.47	5.35	0	0	13.11	<0.001
Acanthopagrus australis	2.77	0.6	10.47	2.66	24.62	6.05	9.88	2.18	7.69	<0.001
Cnidoglanis macrocephalus	7.09	4.9	25.74	6.98	11.43	2.7	0	0	16.22	<0.001
Arius graeffei	32.44	9.14	0	0	0	0	0	0	49.02	<0.001
Zebrias scalaris	30.68	7.45	0	0	0	0	0	0	107.99	<0.001
Selenotoca multifasciatus	0	0	22.77	13.97	1.89	1.03	0	0	5.97	<0.001
Monodactylus argenteus	0.05	0.05	6.03	2.96	11.51	3.93	0	0	9.14	<0.001
Pomatomus saltatrix	0.05	0.05	8.91	3.23	2.63	1.18	11.44	4.18	13.82	<0.001
Platycephalus fuscus	2.97	1.18	9.28	1.98	2.75	0.47	1.44	0.35	7.41	<0.001
Philypnodon grandiceps	0.05	0.05	0	0	5	2.66	1.31	0.73	13.14	<0.001
Liza argentea	0	0	4.26	2.91	1.14	0.6	1.31	0.91	2.09	ns
Pseudorhombus spp.	0.14	0.1	4.96	1.85	0.27	0.14	0.31	0.12	10.12	<0.001
Sillago ciliata	0.27	0.12	0.17	0.08	2	0.71	1.81	0.55	8.26	<0.001
Synaptura nigra	1	0.51	0.3	0.16	0.67	0.23	2.88	1.45	2.69	ns
Foetorepus calauropomus	0	0	3.09	1.54	0.8	0.27	0	0	7.01	<0.001
Tetraodontidae	1.18	0.75	0.13	0.07	2.13	0.47	0	0	11.36	<0.001
Potamalosa richmondia	3.82	1.8	0.3	0.26	0	0	0	0	7.67	<0.001
Notesthes robusta	2.77	0.5	0.78	0.29	0.27	0.11	0	0	21.2	<0.001
Rhabdosargus sarba	0	0	1.25	0.54	0.23	0.15	2.25	0.78	6.59	<0.001
Argyrosomus japonicus	0.68	0.59	0.78	0.23	0.17	0.08	1.38	0.43	4.49	<0.05
Girella tricuspidata	0	0	0.13	0.07	0.23	0.11	1.69	0.71	10.78	<0.001
Macquaria novemaculeata	0	0	0	0	0	0	2.06	1.15	7.33	<0.001
Total other species combined	2.55	1.32	3.57	0.9	2.39	0.36	6.31	1.42	5.12	<0.05
Total all species	141.31	33.39	727.06	103.27	606.33	106.06	62.44	6.27	40.23	<0.001

Table 2.4. The total reported fishing effort and the estimated total catch and bycatch (+ 1 SE) by the entire prawn haul fleet in each estuary between September 1998 and August 1999. [Note that the Manning and Shoalhaven Rivers are closed to fishing between June and August inclusive. Numbers are given except where noted].

	Richmond River		Manning River		Wallamba River		Shoalhaven River	
	Catch	SE	Catch	SE	Catch	SE	Catch	SE
Total reported effort (days)	589		690		463		399	
Prawn weight (kg)	39,345	10,249	42,360	8,207	41,688	6,810	7,949	599
Bycatch weight (kg)	2,394	506	17,602	2,408	5,409	695	1,744	224
Numbers								
Herklotsichthys castelnaui	31,922	25,937	314,988	43,386	104,802	30,133	228	118
Gerres subfasciatus	4,045	2,860	29,226	9,098	133,163	26,558	6,444	1,356
Ambassis sp.	2,141	886	38,065	8,631	29,725	4,364	364	109
Siphamia sp.	225	126	80,894	26,874	5,149	1,668	0	0
Acanthopagrus australis	1,469	276	6,372	1,000	12,698	2,352	4,087	445
Cnidoglanis macrocephalus	3,432	1,788	15,570	3,188	3,991	615	0	0
Arius graeffei	17,100	4,936	0	0	0	0	0	0
Zebrias scalaris	16,942	3,935	0	0	0	0	0	0
Selenotoca multifasciata	0	0	7,462	3,581	744	202	0	0
Monodactylus argentus	21	21	3,970	2,575	5,323	1,108	0	0
Pomatomus saltatrix	16	16	8,140	798	1,227	497	6,810	1,573
Platycephalus fuscus	1,627	604	5,761	832	1,476	189	629	133
Philidron grandiceps	42	42	0	0	2,047	837	548	310
Liza argentea	0	0	2,500	1,810	397	172	486	316
Pseudorhombus spp.	50	32	3,553	600	83	44	105	41
Sillago ciliata	187	80	107	63	961	489	686	182
Synaptura nigra	825	358	120	54	361	163	920	382
Foetorepus calauropomus	0	0	2,260	1,360	364	121	0	0
Tetradontidae	758	485	146	47	1,067	276	0	0
Potamalosa richmondia	2,400	1,054	282	270	0	0	0	0
Notesthes robusta	1,717	306	516	199	128	28	0	0
Rhabdosargus sarba	0	0	992	571	247	126	1,177	203
Argyrosomus japonicus	315	49	339	50	77	41	560	173
Girella tricuspidata	0	0	81	52	119	35	640	292
Macquaria australiensis	0	0	0	0	0	0	647	381
Total other species	1,369	769	1,835	247	1,099	159	2,079	398
Total all species	86,603	31,011	523,179	46,189	305,248	53,732	26,409	2,689

2.4. Discussion

2.4.1. Composition and magnitude of bycatches

As in many other prawn fisheries throughout the world (see Saila 1983; Andrew and Pepperell 1992; Kennelly et al. 1998), the observed bycatches in the estuarine prawn haul fishery in NSW were dominated by small finfish (< 15 cm TL). This is also consistent with data from the other estuarine net-based prawn fisheries in NSW that use trawls, snigging, pocket and running nets (Andrew et al. 1995; Liggins et al. 1996, Gray 2001; Hewitt and Gray unpublished data). Most bycatch species in the prawn haul fishery were of little economic value (e.g. *Ambassis* spp., *Siphamia* sp. and *Herklotsichthys castelnaui*). The juveniles of several economically important species (e.g. *Platycephalus fuscus* and *Acanthopagrus australis*) were also represented in catches, but the majority of these taxa were caught in very low numbers (< 15 per-day per-crew), the exception being *Gerres subfasciatus*. Few crustaceans were observed in bycatches. These findings contrast with those obtained for a lagoon-based prawn-seine fishery in NSW, where juveniles of important fish and crustacean species (e.g. sparids, sillaginids and monocanthids) dominated bycatches (Gray 2001). In the latter fishery, a modified form of seining using a larger net (140 m headline length) is used, with seining often taking place over and adjacent to seagrasses where small fish are often abundant (see Gray 2001).

The types and quantities of bycatches in other prawn fisheries have been shown to vary over a range of spatial and temporal scales (Gray *et al*. 1990; Ramm et al. 1990; Liggins *et al*. 1996; Kennelly *et al*. 1998; Gray 2001). The multivariate analyses performed here identified differences in the structure and composition of bycatches among estuaries, suggesting there are latitudinal variations in the bycatches from prawn hauling among estuaries. The most notable patterns were the high abundances of *Arius graeffei* and *Zebrias scalaris* in the northern most river (Richmond River) and their absence in southern rivers, and the predominance of *Herklotsichthys castelnaui*, *Ambassis* sp. and *Siphamia* sp. in the Manning and Wallamba Rivers compared to the Richmond and Shoalhaven Rivers. The structure and composition of bycatches in the oceanic prawn trawl fishery off NSW have been reported to change with latitude (Kennelly et al., 1998) and, combined with these results presented here suggest that bycatch associated problems are not always uniform within a fishery, as they can be area-specific. This is further exemplified by the observed between-estuary variability in the relative abundances of most species observed in the bycatches. For example, mean catches of *Gerres subfasciatus* were more than 5 fold greater in the Wallamba River than elsewhere. It is also known that bycatches within a fishery can vary greatly on a year-to-year basis (e.g. Liggins et al. 1996) so both spatial and temporal variability in bycatches needs to be considered in determining management options to mitigate discarding.

Estimated prawn catch:bycatch ratios (by weight) in the prawn haul fisheries studied here were less than 1:0.5 in all estuaries. Variability in these ratios and the lack of significant correlations between catches and bycatches shows that prawn catch is not a good indicator of bycatch weight in this fishery. Bycatch ratios are clearly fishery- and gear-specific and can also vary temporally. The greatest ratio determined in the current study was for the Manning River where fishers are required by law to retrieve their nets to the river bank. This suggests that this method of prawn hauling may entrap many small fish in shallow water precluding their escape compared to elsewhere where nets are retrieved mid-stream (see Chapter 5). The bycatch ratios determined in this study were far less than those reported for prawn-trawl fisheries in other parts of the world (usually > 1:5, see Andrew and Pepperell 1992), including the estuarine (1:1.5 to 1:3.5 - see Liggins and Kennelly 1996; Liggins et al. 1996) and oceanic (1:3.5 to 1:16.0 - see Kennelly et al. 1998) prawn-trawl fisheries in NSW. Our prawn haul bycatch ratios were also considerably less than those reported for prawn seining in coastal lagoons (1:0.9 – Gray 2001), but of a similar magnitude to that reported for estuarine pocket nets used in NSW (1:0.38 - Andrew et al. 1995).

The estimated total prawn harvests in each estuary for the whole season ranged from 8 to 42 tonnes, whereas estimated total bycatches ranged from 2 to 18 tonnes (Table 2.4). Reported estimated total bycatches in other estuarine prawn fisheries in NSW include: prawn seining-20 tonnes in Tuggerah Lake (Gray 2001), prawn trawling- 66 –177 tonnes in the Clarence River (Liggins et al. 1996), 34-42 tonnes in Port Jackson and 120-165 tonnes in Botany Bay (Liggins and Kennelly 1996). In comparing these estimates, it is noted that the species composition and capture rates of bycatches as well as the reported fishing effort varied greatly between fisheries. Factors affecting the accuracy and precision of our estimated total catches and bycatches in each estuary need also to be considered. In deriving these estimates we assumed that: (1) the observer days made in each estuary were unbiased and were representative of all crews; (2) there were no systematic measurement errors made by observers; (3) the presence of an observer did not influence normal hauling operations and sorting practices; (4) the average catches of the months not surveyed were equal to those of the months surveyed; (5) the reported fishing effort per crew in terms of numbers of days fished per month were accurate;, and (6) the estimates of total bycatches assumed that individuals were not captured on a multiple basis. We believe that assumption 1, 2 and 3 are valid, as the observed fishers and days fished were done haphazardly, and the performance of fishers and their gears was monitored. We do not believe that the presence of an observer affected the sorting practices of fishers, as most fish captured were small and of no economic value. In regard to assumption 5, it is not known whether, on average, fishers over- or under-estimated monthly fishing effort, however it was impractical to monitor effort by all crews throughout the survey. We have no information concerning whether individual bycatch species were caught more than once in this fishery.

Although not quantified in this study, anecdotal observations indicated that most discarded species including *Acanthopagrus australis*, *Sillago ciliata* and *Platycephalus fuscus* were in good condition when returned to the water. In contrast, other species including *Herklotsichthys castelnaui*, *Pomatomus saltatrix*, *Gerres subfasciatus* and *Ambassis* spp, were often in poor condition or dead when discarded. These latter species were less hardy and more susceptible to scale loss than the former species. Similar species-specific condition patterns of discards have been observed in the pocket net and prawn seine fisheries in NSW (Andrew et al. 1995; Gray 2001). We note that; unlike trawling, the entire operation of setting, retrieving and sorting catches from prawn hauling generally takes less than 15 minutes to complete and thus bycatch in this fishery is generally less susceptible to damage than trawling. We also observed that catches were mostly sorted on trays or in fish tubs, and suggest that survival of bycatch may be enhanced if catches are sorted in water. Despite these observations and our quantification of the composition and levels of discarding reported here, additional information is required to determine the ecological impacts of discarding from this haul fishery (see Andrew and Pepperell 1992; Hall 1999; Kaiser and deGroot 2000).

2.4.2. Bycatch reduction

Although bycatch levels in the estuarine haul fishery were amongst the lowest reported for any prawn fishery in NSW and other parts of the world, there may be ways to decrease the small quantities of bycatch landed and thus reduce any potential negative ecological impacts of discarding in this fishery. Greatest bycatch levels were observed in the Manning River. A simple change in fishing practice from retrieving nets to the bank and replacing this with retrieving nets mid-stream (as done in other estuaries) will reduce greatly bycatch in this fishery (see Chapter 5). Further, bycatch reduction devices (BRDs) including sorting panels, grids and square-mesh panels and codends have been successfully used to reduce bycatch in other prawn fisheries (for review see Broadhurst 2000). Codends made entirely of square-mesh may reduce the capture of small fish species such as *Ambassis* spp. and *Siphamia* sp., whilst sorting panels, such as the Nordmore grid, may help reduce bycatches of larger species including *Acanthopagrus australis*, *Herklotsichthys castelnaui* and *Gerres subfasciatus* in this fishery. However, given the low speed of net retrieval of the gear, these BRDs may not be as effective in haul nets as in trawls.

3. DISCARDING FROM ESTUARINE FISH HAULING

3.1. Introduction

The impacts of fishing on coastal and estuarine fisheries resources and habitats have received significant attention in recent years, with much research being focused on resolving bycatch and discarding concerns (Alverson et al. 1994; Kennelly 1995; Hall 1999). Discarding can impact on the biomasses and yields of fisheries, ecological interactions among species and consequently the functioning of ecosystems (Fennessy 1994; Jennings and Kaiser 1998; Hall 1999; Kaiser and deGroot 2000). The issue of discarding therefore often leads to much conflict among different resource interest groups, and because of the large volumes of wastage often associated with discarding in some fisheries, much emphasis has been placed on reducing discarding in fisheries.

Fundamental to any assessment of the ecological effects of fishing is the need to identify the compositions (species, quantities, length/age distributions) of retained and discarded catches and how these vary spatially and temporally among different fishing operations within any given fishery (Alverson et al. 1994; Kennelly 1995; Hall 1999). In developing strategies to mitigate and manage discarding in a fishery it is also important to have an understanding of the behavior and selectivity of the fishing gears and the species captured (Chopin and Arimoto 1995; Hall 1999; Millar and Fryer 1999; Broadhurst 2000). Such information has been used to successfully reduce discarding and wastage in several large-scale demersal trawl fisheries (see Hall 1999; Broadhurst 2000; Kaiser and deGroot 2000). Whilst bycatch and discarding problems have been examined for a variety of trawl fisheries, there has been much less focus on reducing and managing discarding in smaller-scale coastal fisheries, including those that use haul nets (but see Lamberth et al. 1994, 1995; Gray et al. 2000, 2001; Kennelly and Gray 2001).

Commercial fish hauling is permitted in most estuaries in New South Wales (NSW), Australia, where it forms the basis of a valuable fishery that annually lands approximately 2,000 tonnes of finfish valued at approximately $AUD 5 million. Although this fishery is one of the oldest in Australia, it is also one of the most contentious because many other interest groups, including recreational anglers, conservationists, local councils, tourism operators and the general public claim that many juveniles of recreationally and commercially important species are caught, killed and discarded in this fishery. Consequently, many interest groups have proposed that commercial hauling be banned in NSW estuaries. Despite the economic importance and perceived negative impacts of this fishery, no scientific studies have described the catch composition or quantified the levels of discarding in this fishery. This is a necessary first step in implementing solutions to manage this and other interacting commercial fisheries and to reduce conflict among the various interest groups.

3.2. Methods

The methods and results for this study are provided in great detail in Gray et al. (2001) and Gray and Kennelly (ms) provided in appendices 3 and 4 respectively. A brief overview detailing the major aspects of the study is provided here.

3.2.1. Fish hauling

The estuarine fish haul fisheries in NSW are managed by input controls, including spatial and temporal closures and gear restrictions like minimum and maximum mesh sizes and lengths of nets. The regulations concerning the configuration of haul nets vary among estuaries. Nets are permitted to have a maximum headline length of 375 m in rivers and 1000 m in lagoons, with the same amount of hauling rope permitted on either end of the net. In the coastal lagoons, up to 2000 m of hauling rope is permitted in the winter months of June to August. The length of the bunt must not exceed a third of the total length of the net and it must include a center cod-end. Mesh size in the cod-end must be between 30 and 50 mm, whilst the mesh in the rest of the bunt must not exceed 57 mm and mesh in the wings must not be less than 80 mm.

Haul nets are generally set from a small (< 6 m) boat in a semi-circular configuration and are hauled by small winches back towards the shore (see Gray et al. 2000). Fish are generally herded in front of the net during hauling and do not enter the codend until just prior to the cessation of hauling when the nets are landed in shallow water (see Gray et al. 2000). Because jellyfish and detached seaweed can affect hauling operations and the condition and mortality of the fish captured, the codend is often left open during most of the hauling operation so that jellyfish and detached vegetation pass through and do not accumulate in the net. Where this practice is used, the codend is thus tied closed just prior to landing the net This particularly occurs in the lagoons and Botany Bay, but it was not observed in the coastal rivers where hauls are of shorter duration. Nets are generally landed in shallow water at the shore edge or against a backing net in about 1 m water depth and approximately 10-50 m offshore. Catches are generally sorted in ankle to waist deep water, with the discards sometimes being allowed to swim out of the net whilst the retained product is collected and placed in an adjacent boat.

3.2.2. Sampling of catches

Observer-based surveys were used to quantify the species composition and estimate the quantities and length compositions of the retained and discarded catches taken in the commercial haul fisheries in the Clarence River, Botany Bay, Lake Macquarie and St Georges Basin. Scientific observers accompanied commercial fishers in each estuary between February 1998 and 1999. Except for the Clarence River where no reliable reported effort data was available, catches were extrapolated to estimate total retained and discarded catches for the 3 remaining estuaries for the period February 1998/99.

3.3. Results

A list of all species observed in catches is given in Table 3.1. A total of 120 taxa were observed in catches; 52 taxa in retained catches and 101 in discarded catches. The juveniles of several important species, including bream (*Acanthopagrus australis*), tarwhine (*Rhabdosargus sarba*), snapper (*Pagrus auratus*), sand whiting (*Sillago ciliata*) and luderick (*Girella tricuspidata*) were predominant in discarded catches. Discarded catches also included several species of little direct importance to commercial or recreational fishers, including porcupinefish (*Dicotylichthys punctulatus*), boxfish (*Anoplocapros inermis*) and toads (family Tetradontidae).

Retained and discarded catches of the predominant species varied greatly among time periods in each estuary as well as between estuaries. For example, in the Clarence River, retained and discarded catches of sand whiting were greatest in spring/summer, but for bream in autumn/winter (Fig 3.1). These patterns reflected seasonal changes in the target species and the configuration of gear used.

Table 3.1. List of all taxa retained and discarded in observed fish haul catches in each estuary examined. R = retained, D = discarded.

Family	Scientific name	Common name	Botany Bay		Lake Macquarie		St Georges Basin		Clarence River	
Finfish										
AMBASSIDAE	*Ambassis* spp.	Glassy Perchlet								D
ANGUILLIDAE	*Anguilla reinhardtii*	Longfinned Eel			R	D	R	D		
ANTENNARIIDAE	*Antennarius striatus*	Striped Anglerfish				D				
APOGONIDAE	*Apogon fasciatus*	Striped Cardinalfish								D
ARACANTHIDAE	*Anoplocapros inermis*	Eastern boxfish		D						
ARIIDAE	*Arius graeffei*	Fork-tailed Catfish							R	
ARRIPIDAE	*Arripis truttaceus*	Eastern Australian Salmon						D		
ATHERINIDAE	*Atherinomorus ogilbyi*	Ogilby's hardyhead		D		D		D		
BELONIDAE	*Strongylura leiura*	Slender Longtom			R	D			R	D
BRACHAELURIDAE	*Brachaelurus waddi*	Blind Shark				D				
BOTHIDAE	*Pseudorhombus arsius*	Large-toothed flounder	R	D	R	D	R	D		D
	Pseudorhombus jenynsii	Small-toothed flounder	R	D	R	D	R	D		D
CALLIONYMIDAE	*Repomucenus calcaratus*	Spotted sand-dragonet		D						
CARANGIDAE	*Caranx melampygus*	Bluefin Trevally								D
	Caranx papuensis	Brassy Trevally								D
	Caranx sexfasciatus	Bigeye Trevally							R	
	Decapterus muroadsi	Southern mackerel scad		D						
	Pseudocaranx dentex	Silver trevally	R	D	R	D	R	D		
	Seriola lalandi	Kingfish	R	D						
	Trachurus spp.	Yellowtail & Jack mackerel	R	D	R	D	R	D		D
CARCHARHINIDAE	*Carcharhinus leucas*	Bull Shark							R	
	Carcharhinus spp	Whaler Sharks							R	
CHAETODONTIDAE	*Scatophagus argus*	Spotted scat			R	D				D
	Selenotoca multifasciata	Striped Butterfish			R	D			R	D
CHEILODACTYLIDAE	Unidentified spp.	Morwong		D						
CLUPEIDAE	*Herklotsichthys castelnaui*	Southern herring		D		D		D		D
DACTYLOPTERIDAE	*Dactyloptena orientalis*	Flying gurnard		D						D
DASYATIDIDAE	*Dasyatis thetidis*	Estuary stingray		D		D		D		D
DINOLESTIDAE	*Dinolestes lewini*	Long-finned seapike		D		D				
DIODONTIDAE	*Dicotylichthys punctulatus*	Three-bar porcupinefish		D		D		D		D
ENOPLOSIDAE	*Enoplosus armatus*	Old wife		D						

Table 3.1. continued

Family	Scientific name	Common name	Botany Bay		Lake Macquarie		St Georges Basin		Clarence River	
GERREIDAE	*Gerres subfasciatus*	Silver biddy	R	D	R	D	R	D	R	D
GIRELLIDAE	*Girella tricuspidata*	Luderick	R	D	R	D	R	D	R	D
HEMIRAMPHIDAE	*Arrhamphus sclerolepis*	Snub-nosed garfish							R	D
	Hyporhamphus australis	Eastern garfish	R			D			R	
	Hyporhamphus regularis	River garfish	R		R	D		D	R	D
HETERODONTIDAE	*Heterodontus* sp.	Port Jackson sharks		D						
LABRIDAE	Unidentified spp.	Wrasse		D						
	Achoerodus viridis	Eastern Blue Groper						D		
LATRIDIDAE	*Latris lineata*	Striped trumpeter		D						
LEIGONATHIDAE	*Leigonathus* sp.	Ponyfish				D				
LUTJANIDAE	*Lutjanus russelli*	Moses Perch								D
	(mixed spp.)									D
MONACANTHIDAE	*Brachaluteres jacksonianus*	Pigmy leatherjacket		D						
	Eubalichthys mosaicus	Mosaic leatherjacket		D						
	Meuschenia freycineti	Six-spined leatherjacket	R	D		D	R	D		
	Meuschenia trachylepis	Yellow-finned leatherjacket	R	D	R	D	R	D	R	D
	Monacanthus chinensis	Fanbelly leatherjacket	R	D	R	D	R	D		D
	Nelusetta ayraudi	Chinaman leatherjacket	R	D						
	Scobinichthys granulatus	Rough leatherjacket	R	D		D		D		
MONODACTYLIDAE	*Schuettea scalaripinnis*	Ladder-finned pomfret		D		D				
	Monodactylus argenteus	Diamond fish				D		D		D
MUGILIDAE	*Liza argentea*	Flat-tail mullet	R	D	R	D	R	D	R	D
	Mugil cephalus	Sea mullet	R	D	R	D	R	D	R	D
	Mugil georgii	Fantail Mullet				D			R	D
	Myxus elongatus	Sand mullet	R	D	R	D	R	D	R	D
	Myxus petardi	Pink eye mullet							R	D
MULLIDAE	*Parupeneus signnatus*	Black-Spot goatfish								D
	Upeneichthys lineatus	Blue-striped goatfish	R	D						
	Upeneus tragula	Bar Tailed Goatfish				D				
MYLIOBATIDAE	*Myliobatis australis*	Eagle Ray				D				D
ORECTOLOBIDAE	*Orectolobus* sp.	Wobbegong shark		D						

Table 3.1. continued

Family	Scientific name	Common name	Botany Bay		Lake Macquarie		St Georges Basin		Clarence River	
OSTRACIIDAE	*Lactoria cornuta*	Longhorn cowfish		D						D
	Tetrosomus concatenatus	Turretfish		D						
PLATYCEPHALIDAE	*Neoplatycephalus richardsoni*	Tiger flathead	R							
	Platycephalus arenarius	Northern sand flathead								D
	Platycephalus caeruleopunctatus	Eastern blue-spotted flathead	R	D						
	Platycephalus endrachtensis	Bar-tailed flathead								D
	Platycephalus fuscus	Dusky flathead	R	D	R	D	R	D	R	D
	Suggrundus jugosus	Mud flathead		D						
PLEURONECTIDAE	*Ammotretis rostratus*	Long snouted flounder	R	D						
PLOTOSIDAE	*Cnidoglanis macrocephalus*	Estuary catfish		D		D	R	D	R	D
	Plotosus lineatus	Striped catfish				D			R	D
POMATOMIDAE	*Pomatomus saltatrix*	Tailor	R	D	R	D	R	D	R	D
PRIACANTHIDAE	*Priacanthus macracanthus*	Red Bigeye			R	D				
RACHYCENTRIDAE	*Rachycentron canadus*	Cobia			R					
RHINOBATIDAE	*Aptychotrema rostrata*	Shovelnose ray		D	R	D				
	Trygonorhina fasciata	Banjo ray		D						
SCIAENIDAE	*Argyrosomus japonicus*	Mulloway	R	D	R					D
SCOMBRIDAE	*Scomber australasicus*	Slimy mackerel		D						
SCORPAENIDAE	*Centropogon australis*	Fortescue		D						
SCORPIDIDAE	*Scorpis lineolatus*	Silver sweep		D						
SIGANIDAE	*Siganus* sp.	Black trevally (spinefoot)	R	D		D				D
SILLAGINIDAE	*Sillago maculata*	Trumpeter whiting	R	D	R	D	R	D		
	Sillago ciliata	Sand whiting	R	D	R	D	R	D	R	D
SOLEIDAE	*Synaptura nigra*	Black sole		D	R	D	R	D		
	Zebrias scalaris	Many-banded sole		D						
SPARIDAE	*Acanthopagrus australis*	Yellowfin bream	R	D	R	D	R	D	R	D
	Pagrus auratus	Snapper	R	D	R	D	R	D		
	Rhabdosargus sarba	Tarwhine	R	D	R	D	R	D	R	D
SPHYRNIDAE	*Sphyrna zygaena*	Smooth Hammerhead			R					
SPHYRAENIDAE	*Sphyraena novaehollandiae*	Snook				D				
SYNGNATHIDAE	*Hippocampus whitei*	Seahorse								D

Table 3.1. continued

Family	Scientific name	Common name	Botany Bay		Lake Macquarie		St Georges Basin		Clarence River	
SYNODONTIDAE	*Trachinocephalus myops*	Painted Grinner				D				
TERAPONTIDAE	*Pelates quadrilineatus*	Six-lined trumpeter		D	R	D	R	D		D
TETRAODONTIDAE	*Contusus brevicaudus*	Rough toadfish		D						
	Arothron hispidus	Stars & stripes toadfish		D		D				D
	Tetractenos glaber	Smooth toad								D
	Tetractenos hamiltoni	Common toadfish		D		D		D		D
	Marilyna pleurosticta	Banded toad		D		D				D
	Torquigner pleurogramma	Weeping toado		D		D				D
	Torquigner squamicauda	Brush-tail toadfish		D						
TORPEDINIDAE	*Hypnos monopterygium*	Numbfish		D						
TRICANTHIDAE	*Trixiphichthys weberi*	Black tip tripod fish								D
TRIGLIDAE	*Chelidonichthys kumu*	Red gurnard	R	D	R		R	D		
	Pterygotrigla polyommata	Latchet					R	D		
	Unidentified spp.	Gurnard		D			R	D		
UROLOPHODAE	*Trygonoptera testacea*	Common stingaree		D		D				
Crustaceans										
GRAPSIDAE	*Sessarma* sp.	Mangrove crab								D
PENAEIDAE	*Penaeus esculentus*	Tiger prawn								D
	Penaeus plebejus	King prawn	R	D	R	D				
PORTUNIDAE	*Ovalipes* sp.	Two-spot sand crab		D						D
	Portunus pelagicus	Blue-swimmer crab	R	D	R	D	R	D	R	D
	Thalamita sp.	Swimmer crab		D						
	Scylla serrata	Mud crab			R					D
	Unidentified spp.	Crab other		D	R	D				
Molluscs										
LOLIGINIDAE	*Sepioteuthis australis*	Southern calamari	R	D	R	D				
OCTOPODIDAE	*Octopus* sp.	Octopus	R	D	R	D				
SEPIIDAE	*Sepia* spp.	Giant cuttlefish	R	D	R	D				
TUETHOIDAE	*Nototodarus gouldi*	Arrow squid	R		R	D				
	Unidentified spp.	Squid other	R	D	R	D				

Spatial and temporal variations in retained and discarded catch rates of several important species in Lake Macquarie and St Georges Basin are shown in Figure 3.2. More bream, tarwhine and snapper were discarded than retained in each season in both lagoons. This was also evident for tailor (*Pomatomus saltatrix*) in Lake Macquarie and sand whiting and fanbelly leatherjacket (*Monacanthus chinensis*) in St Georges Basin. No clear discarding patterns were evident for the other important species shown, with more of one species being discarded in a particular season but more retained in another season. For example, in St Georges Basin, more silver trevally (*Pseudocaranx dentex*) were discarded than retained in autumn and winter, whereas the opposite occurred in summer. Relationships between retained and discarded catch rates of most species also varied between seasons and lagoons. For example, rates of discarding of trumpeter whiting (*Sillago maculata*) in Lake Macquarie were similar across seasons, whereas retained catch rates were greater in autumn and winter compared to spring and summer.

Figures 3.3 to 3.5 show the length compositions of several important species caught in haul nets. These figures show that the nets used in this fishery are relatively non-selective with many small fish being captured. The existence of a minimum legal length (MLL) accounted for the separation of discarded and retained individuals for many species: fish below the MLL were discarded. Individuals of species that do not have a MLL, including silver trevally, silver biddy (*Gerres subfasciatus*), rough and yellow-finned leatherjackets (*Scobinichthys granulatus* and *Meuschenia trachylepis*, respectively), were discarded, with most of the larger individuals being retained.

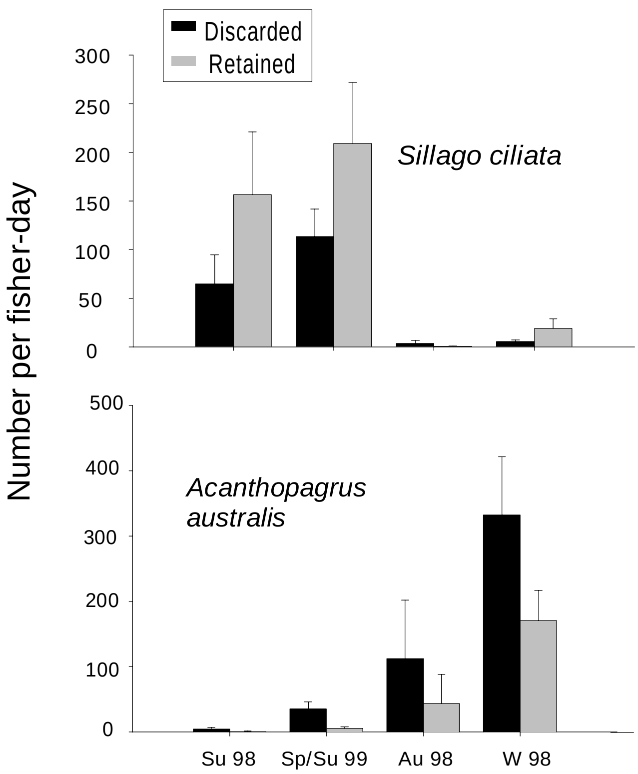

Figure 3.1. Mean (+1se) numbers of retained and discarded catches of sand whiting and bream in each season in the Clarence River.

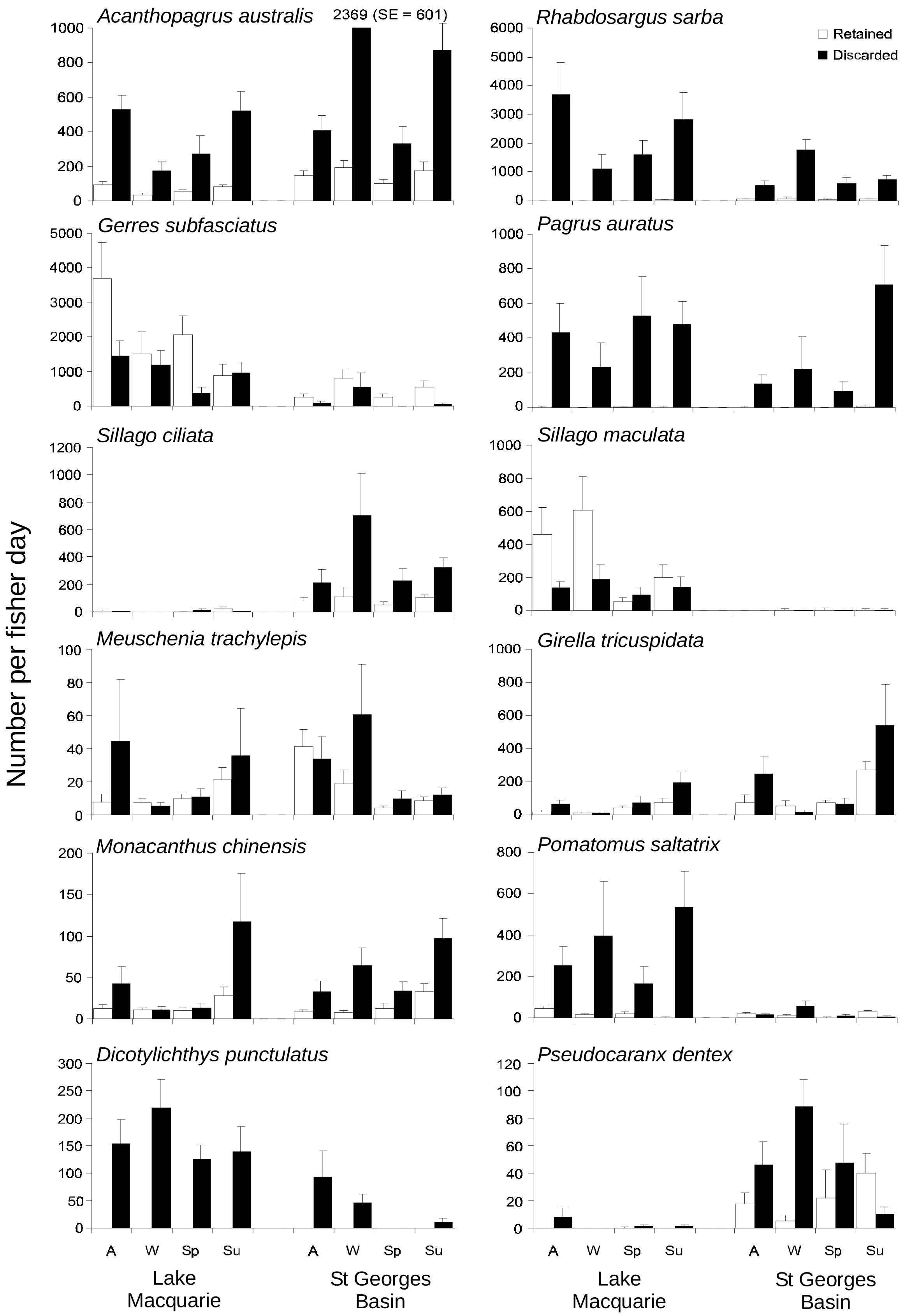

Figure 3.2. Mean (+1se) numbers of retained and discarded catches of individual species in each season in Lake Macquarie and St Georges Basin.

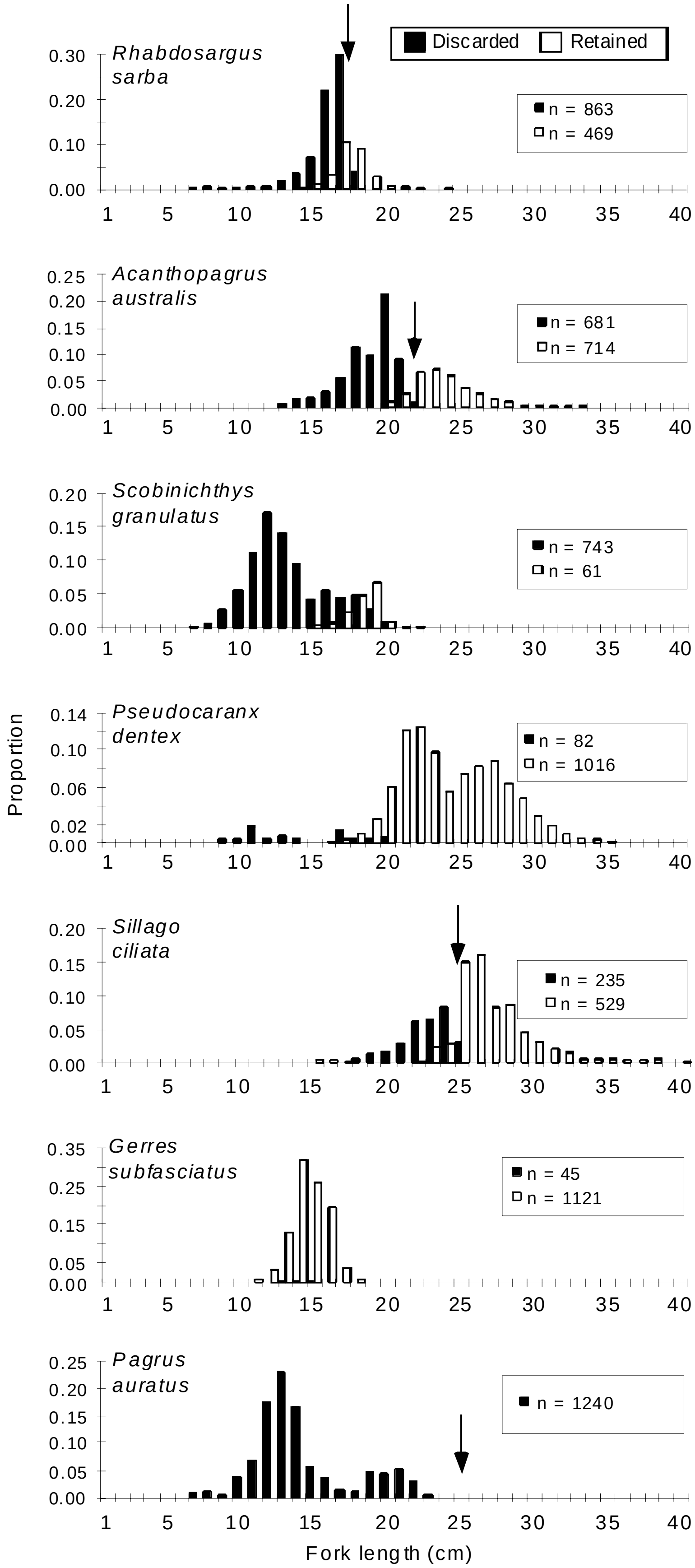

Figure 3.3. Length compositions of retained and discarded components of haul catches of important species in Botany Bay. Arrows indicate minimum legal length.

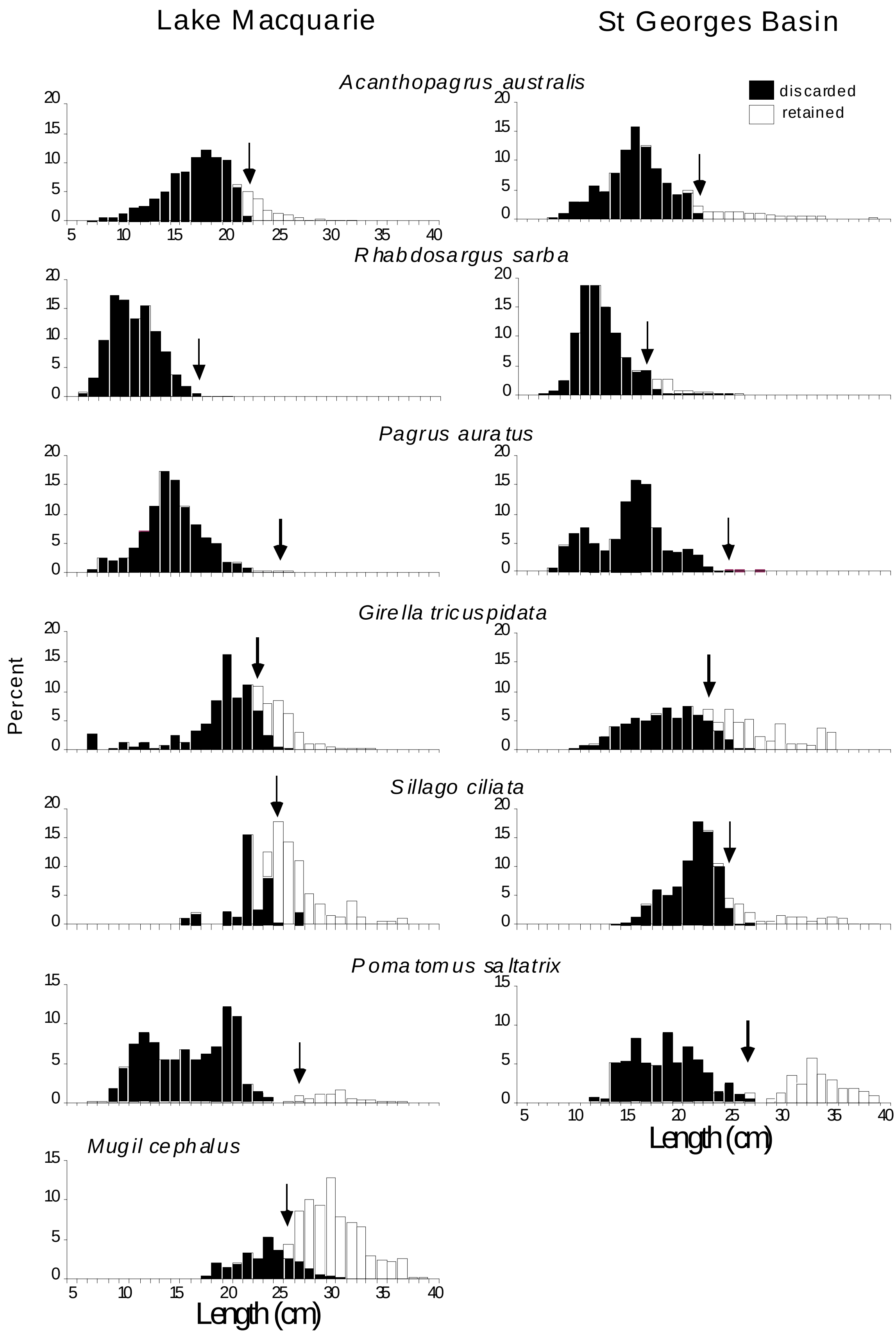

Figure 3.4. Length compositions of retained and discarded components of haul catches of important species in Lake Macquarie and St Georges Basin. Arrows indicate minimum legal length.

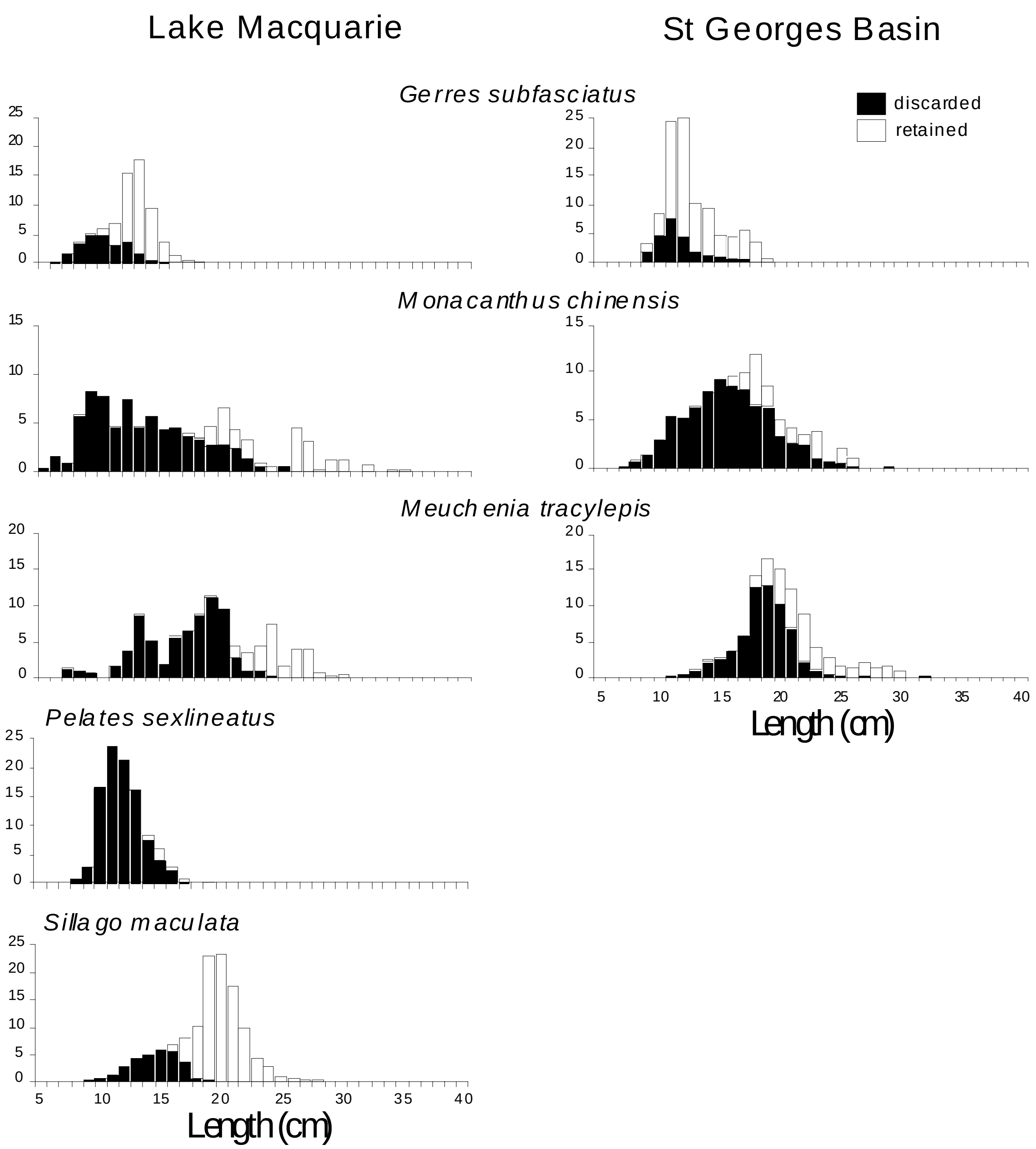

Figure 3.5. Length compositions of retained and discarded components of haul catches of important species in Lake Macquarie and St Georges Basin. Species shown do not have a minimum legal length.

Table 3.2. Estimated total retained and discarded catches of the 25 most numerically abundant species caught in the haul fishery in Botany Bay between February 1998 and January 1999.

Species	Common name	Retained Number	SE	Discarded Number	SE	Discarded %	Retained Weight (kg)	SE	Discarded Weight (kg)	SE	Discarded %
Total individuals		729,409	244,655	581,472	180,988	44	152,018	44,986	92,844	22,920	38
Gerres subfasciatus	Silver biddy	346,825	161,346	2,932	2,434	1	30,087	14,526	207	163	1
Pseudocaranx dentex	Silver trevelly	241,899	101,224	18,361	14,678	7	80,750	34,031	1,718	1,195	2
Rhabdosargus sarba	Tarwhine	34,568	11,404	148,892	90,438	81	5,663	1,908	17,485	11,665	76
Pagrus auratus	Snapper	38	38	142,261	87,647	100	12	12	11,956	6,816	100
Acanthopagrus australis	Bream	28,079	7,304	63,064	38,297	69	10,701	2,886	11,603	7,724	52
Dicotylichthys punctulatus	Porcupinefish	0	0	32,301	6,643	100	0	0	25,614	6,857	100
Scobinichthys granulatus	leatherjacket	4,184	3,378	51,797	6,067	93	506	421	3,243	418	87
Sillago ciliata	Sand whiting	15,142	4,839	6,987	3,708	32	3,802	1,250	859	435	18
Meuschenia freycineti	leatherjacket	440	371	21,942	8,011	98	42	35	1,070	420	96
Trachurus spp.	Scad	988	543	13,854	7,043	93	164	115	734	389	82
Sepia spp.	Cuttlefish	2,832	1,115	14,772	3,154	84	379	154	990	248	72
Portunus pelagicus	Blue swimmer crab	7,197	2,904	6,282	2,693	47	2,149	823	790	417	27
Sepioteuthis australis	Squid	10,988	5,054	807	807	7	2,429	1,191	40	40	2
Nelusetta ayraudi	leatherjacket	6,426	3,240	5,748	3,170	47	544	279	376	235	41
Trygonorhina fasciata	Estuary ray	0	0	3,564	1,464	100	0	0	6,801	3,123	100
Heterodontus portusjacksoni	Port jackson shark	0	0	7,131	5,114	100	0	0	1,322	906	100
Sillago maculata	Trumpeter whiting	5,527	4,097	1,509	1,407	21	590	383	55	49	8
Anoplocapros inermis	Boxfish	0	0	6,106	2,837	100	0	0	2,442	1,048	100
Squid - other	Squid	6,275	3,539	18	18	0	1,731	856	2	2	0
Meuschenia trachylepis	leatherjacket	172	155	7,203	1,875	98	15	12	278	56	95
Seriola lalandi	Kingfish	1,195	1,086	266	241	18	2,484	2,336	335	288	12
Siganus fuscescens	Black trevelly	1,949	1,404	1,488	1,440	43	385	267	402	396	51
Platycephalus fuscus	Dusky flathead	3,018	795	852	597	22	1,388	364	190	136	12
Mugil cephalus	Sea mullet	2,193	1,030	838	808	28	1,223	657	165	162	12
Pomatomus saltatrix	Tailor	1,460	768	1,386	430	49	867	494	235	78	21

Table 3.3. Estimated total retained and discarded catches of the 25 most numerically abundant species caught in the haul fishery in Lake Macquarie between February 1998 and January 1999.

Species	Common name	Retained Number	SE	Discarded Number	SE	Discarded %	Retained Weight (kg)	SE	Discarded Weight (kg)	SE	Discarded %
Total individuals		2095466	278981	3929144	431761	65.2	199023	19560	269229	20032	57
Gerres subfasciatus	Silver biddy	1439162	259044	728787	132588	33.6	74285	14293	18883	3931	20.3
Rhabdosargus sarba	Tarwhine	5887	1729	1594651	288761	99.6	1000	342	63135	11270	98.4
Sillago maculata	Trumpeter whiting	253718	55522	100065	24006	28.3	23896	5241	3880	933	14
Acanthopagrus australis	Bream	45501	4305	256172	28699	84.9	15443	1725	33119	3607	68.2
Pagrus auratus	Snapper	1408	504	274905	56941	99.5	476	156	27309	5153	98.3
Pomatomus saltatrix	Tailor	14101	3617	236322	63492	94.4	5570	1533	15763	6003	73.9
Pelates sexlineatus	Trumpeter six-lined	9842	5704	231225	38333	95.9	638	349	7002	1211	91.7
Dicotylichthys punctulatus	Porcupinefish	0	0	113422	15762	100	0	0	61437	8660	100
Sepioteuthis australis	Southern calamari	87497	13725	20897	8788	19.3	7678	1003	615	277	7.4
Mugil cephalus	Sea mullet	73867	15104	30385	9371	29.1	30501	6144	5757	1449	15.9
Liza argentea	Flat-tail mullet	45822	27275	35190	19046	43.4	12297	6981	5290	2140	30.1
Girella tricuspidata	Luderick	22890	5897	55188	12347	70.7	7704	1922	9441	2253	55.1
Leiognathus sp.	Ponyfish	0	0	77885	29338	100	0	0	764	320	100
Herklotsichthys castelnaui	Southern herring	0	0	50317	14229	100	0	0	1246	305	100
Monacanthus chinensis	Fanbelly leatherjacket	10176	2201	30436	9861	74.9	2414	499	2367	776	49.5
Meuschenia trachylepus	Yellow-finned leatherjacket	7521	1633	16730	8472	69	1891	399	1690	904	47.2
Nototodarus gouldi	Arrow squid	16001	12004	74	52	0.5	1051	789	3	2	0.3
Sepia sp.	Cuttlefish	8831	3018	3231	983	26.8	1067	329	436	197	29
Portunus pelagicus	Blue swimmer crab	7416	1769	3931	1369	34.6	2316	523	568	187	19.7
Hyporhamphus regularis	River garfish	9708	2248	1517	890	13.5	700	153	105	51	13
Tetractenos hamiltoni	Toadfish	0	0	10647	3229	100	0	0	428	141	100
Selenotoca multifasciata	Striped butterfish	2632	1473	7436	3811	73.9	652	358	786	327	54.6
Sillago ciliata	Sand whiting	6030	2495	3354	1042	35.7	1593	664	428	146	21.2
Trachurus novaezelandi	Yellowtail	2303	1394	5131	1922	69	216	139	418	255	65.9
Trygonoptera testacea	Stingaree	0	0	7192	1769	100	0	0	3976	1123	100
All other 45 species		25151		34054		57.5	7633		4383		36.5

Table 3.4. Estimated total retained and discarded catches of the 25 most numerically abundant species caught in the haul fishery in St Georges Basin between February 1998 and January 1999.

Species	Common name	Retained Number	SE	Discarded Number	SE	Discarded %	Retained Weight (kg)	SE	Discarded Weight (kg)	SE	Discarded %
Total individuals		283243	35182	955166	135837	77.1	57919	4509	84794	10190	59.4
Acanthopagrus australis	Bream	36527	4581	276242	7239	88.3	13022	12	31382	734	70.7
Rhabdosargus sarba	Tarwhine	15347	3758	241779	4853	94	3559	7	13246	233	78.8
Gerres subfasciatus	Silver biddy	145407	32831	43342	3221	23	10583	21	1633	109	13.4
Pelates sexlineatus	Six-lined trumpeter	2468	2468	121882	4139	98	207	2	4543	135	95.6
Sillago ciliatia	Sand whiting	20682	5143	89331	2766	81.2	5928	9	10366	296	63.6
Girella tricuspidata	Luderick	27519	5148	50791	2124	64.9	10856	16	8559	403	44.1
Pagrus auratus	Snapper	648	292	69187	2466	99.1	292	1	6619	231	95.8
Monacanthus chinensis	Fanbelly leatherjacket	3437	803	13806	302	80.1	892	2	1396	42	61
Pseudocaranx dentex	Silver trevally	4866	1459	11764	302	70.7	989	2	850	22	46.2
Meuschenia trachylepus	Yellow-finned leatherjacket	4276	913	7001	271	62.1	927	2	765	27	45.2
Pomatomus saltatrix	Tailor	3424	645	6180	246	64.3	1525	2	648	27	29.8
Platycephalus fuscus	Dusky flathead	6803	1235	2772	61	28.9	5822	9	608	15	9.5
Dicotylichthys punctulatus	Porcupinefish	0	0	9498	415	100	0	0	2389	132	100
Trachurus novaezelandi	Yellowtail	3610	1926	4638	221	56.2	351	1	378	18	51.8
Sillago maculata	Trumpeter whiting	1338	663	920	41	40.8	248	1	101	4	29
Myxus elongatus	Sand mullet	1421	832	668	80	32	472	2	198	25	29.6
Liza argentea	Flat-tail mullet	1771	1250	41	4	2.3	848	4	10	1	1.2
Synaptura nigra	Black sole	105	84	1171	45	91.7	33	0	187	7	84.9
Mugil cephalus	Sea mullet	933	613	59	8	6	568	3	15	2	2.5
Chelidonichthys kumu	Red gurnard	416	373	479	27	53.5	94	1	79	4	45.6
Meuschenia freycineti	Six-spined leatherjacket	420	182	287	14	40.6	85	0	34	2	28.3
Anguilla sp.	River eel	493	347	145	11	22.7	247	1	80	6	24.4
Herklotsichthys castelnaui	Southern harring	0	0	637	35	100	0	0	40	3	100
Cnidoglanis macrocephalus	Estuary catfish	0	0	588	42	100	0	0	363	25	100
Pseudorhombus arsius	Large-toothed flounder	38	38	344	44	90	8	0	53	7	87.4

We estimated that between 38 to 59% of total haul catches by weight and between 44 to 77% by number were discarded (Tables 3.2-3.4). These estimates were derived by multiplying observed catch rates by the reported fishing effort in each estuary. This could not be done for the Clarence River because of a lack of reliable effort data. Estimated total discards included hundreds of thousands of juveniles of important species, including bream, tarwhine, snapper and sand whiting. The proportion of catches of important species that were discarded varied among species and estuaries (Table 3.2–3.4). For example, we estimated that 69, 85 and 88% of all bream caught were discarded in Botany Bay, Lake Macquarie and St Georges Basin respectively. Overall, estimated total discards were greater in Lake Macquarie than in the other estuaries examined.

3.4. Discussion

Recreational and other commercial fishers in estuarine and coastal waters in NSW target many of the species caught in estuarine fish haul nets. As in several other multi-species fisheries, the discarded catches observed in this study contained the juveniles of several target species (e.g. bream, sand whiting) and other species important in other commercial and recreational fisheries (e.g. silver trevally, tailor) as well as several species of little direct importance to commercial and recreational fishers (porcupinefish, boxfish and toads). Commercial fishers primarily are the only group that catches silver biddy and sea mullet. In terms of issues of conflict between commercial and recreational fishers, the main concerns over discarding identified in this study therefore involves juvenile bream, tarwhine, snapper and sand whiting.

Haul nets are relatively non-selective because they catch a wide variety of fish taxa of differing morphologies and sizes. Discarding in this fishery of most of the important species (e.g. bream, sand whiting) was primarily due to enforcement of a minimum legal length (MLL), because it is illegal to retain fish below a MLL. For species with no MLL (e.g. silver trevally, silver biddy), usually only the larger fish were retained and it is most likely that market and economic forces probably drive this grading.

Catch rates of individual species varied spatially and temporally and thus there are no simple ways to reduce discarding in this fishery via spatio-temporal closures to fishing. We estimated large quantities of retained and discarded catches were involved in the haul fisheries in each estuary (in excess of 100 tonnes per annum). More species and total individuals were generally discarded than retained, although the proportion of fish discarded was dependent on the species and estuary. Given the large quantities of discarding and the species involved, it is not surprising that there is much public pressure to ban this method of fishing in NSW estuaries. We note here, that the NSW government has announced that Lake Macquarie, Botany Bay and St. Georges Basin are being made recreational fishing areas and commercial fishing will be terminated in these estuaries in 2002.

We know that not all fish die after discarding. Fish have previously been tagged and released following capture in haul nets and many fish have been recaptured several years after release (West 1993). Further, our own short-term survival experiments showed that survival of most important species (except silver biddy) was greater than 90% (see Chapter 4). Thus, discarding from the fish haul fishery may not severely affect fish stock sizes of these species. Despite this, the actual impacts of discarding from this fishery can not be determined in this study as much more additional information is required, including rates of natural mortality and stock sizes (see Andrew and Pepperell 1992; Hall 1999). However, given the quantities and species discarded in this fishery, it is recommended that industry adopts and further investigates ways to mitigate discarding in this fishery.

4. DISCARD-REDUCING HAULING GEARS AND PRACTICES

4.1. Introduction

In developing strategies to manage and mitigate discarding, it is fundamental to determine and define the real level of discarding and how it varies in space and time and among different fishing operations (Alverson et al. 1994; Kennelly 1995; Hall 1999). Secondly, an understanding of the behavior and selectivity of fishing gears and the species captured can help determine ways to solve discarding problems (Hall 1999; Millar and Fryer 1999; Broadhurst 2000). Such information has been used successfully to reduce discarding and wastage in some fisheries (see Hall 1999; Broadhurst 2000; Kaiser and deGroot 2000).

The observer-based surveys reported in the previous chapters and in Gray (2000) and Gray et al. (2001) (see Appendices 3,4,5) identified bycatch and discarding problems in the estuarine prawn and fish haul fisheries of NSW. Problems were gear- and area-specific, and thus there was no one solution to reduce discarding in these fisheries. Because of this, we executed a variety of studies in this project to develop discard-reducing gears and practices in several of the more problematic fisheries and methods identified in the observer work. An overview of this work is described for each fishery below.

4.2. Prawn hauling

Negligible levels of bycatch were observed in the Richmond River so no work on discard-reduction was done in this fishery. It is recommended, in fact, that the methods used in the Richmond River be considered as a excellent low bycatch method for application elsewhere in NSW. In contrast to the Richmond River, greatest levels of bycatches from prawn hauling were observed in the Manning River where fishers are regulated to retrieve their nets to the riverbank. It is well documented that many small fishes are highly abundant along the littoral fringes of estuaries, particularly in vegetated areas (Potter et al. 1990; Ruiz et al. 1993; Gray et al. 1996). We hypothesized that the incidental capture of small fish would be reduced if nets were landed away from the shore, i.e. in midstream. In most other estuaries, prawn haul nets are retrieved to boats anchored away from the shore (i.e. midstream). We therefore tested whether retrieving nets mid-stream reduced levels of bycatch in the Manning River fishery.

4.2.1. Comparison of fishing methods

We chartered a commercial prawn haul crew to do a series of paired hauls, one to shore and another to mid-stream, at several locations normally used by commercial prawn haul fishers within the Manning River. A total of 24 paired hauls were done across 7 locations between 1-3 June 1999, immediately following the seasonal winter closure of the fishery. We did this experiment during the closure to avoid competing with other haul crews for locations doing their normal fishing activities. The order of hauls (shore v midstream) at each location was determined by flipping a coin. All organisms captured in each haul were identified, counted, weighed and measured.

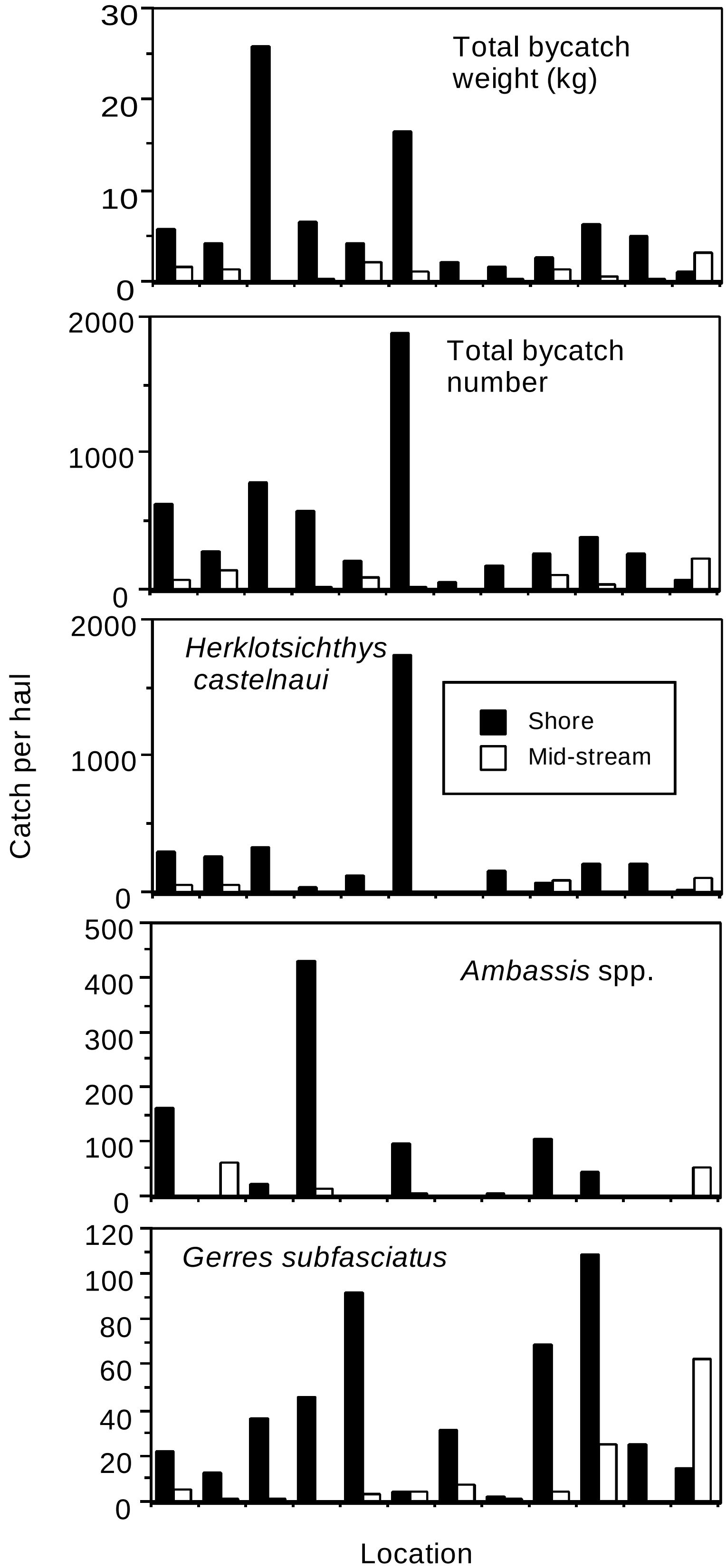

Figure 4.1. Comparisons of bycatches from prawn hauls retrieved to shore versus mid-stream.

4.2.2. Results

Very few prawns were caught during this study and the effects of the different fishing practices on the retained product could not be determined. Bycatches were significantly reduced when nets were retrieved mid-stream (Fig. 4.1). This was primarily due to fewer *Gerres subfasciatus* (silver biddy), *Ambassis* spp. (perchlet) and *Herklotsichthys castelnaui* (southern herring) being captured in midstream hauls.

4.2.3. Discussion

This small study showed that a simple change in fishing practice of retrieving nets mid-stream compared to the shore could lead to a dramatic reduction in bycatch in this fishery. The littoral fringes of estuaries are home to many species of small fishes and we suggest that these fishes were unable to escape capture from nets as they were hauled to the shore. Further, retrieving nets midstream may negate other potential negative impacts of this fishery on the environment. In particular, fishers will not have to trample about the shore and so reduce any impacts of this activity on littoral vegetation and fauna in sediments. Further, less hauling of nets over seagrass and other littoral vegetation will occur, potentially reducing the physical impacts of hauling over vegetation.

As a direct result of this research, the regulations concerning the way fishers operate prawn haul nets in the Manning River is being modified. Fishers have been issued permits in 2001 to trial the alternative method of retrieving nets midstream. Following this trial period, other modifications may be made to the fishing practice and the regulation governing this fishery will be changed as part of the Estuary General Fishery Management Plan.

4.3. Fish hauling

The observer surveys identified that discarding problems associated with fish hauling differed between estuaries. In northern NSW estuaries, a major discarding issue concerned undersized sand whiting (particularly during spring/summer), whereas in the large coastal lagoons, the main discarding problem involved undersize bream, tarwhine and snapper. Two experiments addressed the problem of mitigating the capture and subsequent discarding of undersize sand whiting and two other experiments addressed the issue of discarding in lagoons. The research methodologies, results and discussions of these experiments are reported in Gray et al. (2000), Kennelly and Gray (2000) (Appendices 6 and 7 respectively). A brief overview of these studies is provided here. All experiments were done in consultation with, and included active participation by, commercial haul fishers.

4.3.1. Experiment 1 – use of transparent netting in haul nets

In our first experiment we compared catches in haul nets with and without panels of transparent netting using a covered net experiment (Gray et al. 2000 – see Appendix 6). This experiment was done in the Bellinger River and documented that incorporation of transparent netting strategically placed in the bunts of nets significantly improved the size selection of sand whiting (*Sillago ciliata*) and reduced the bycatch of other species. We showed that the mid-selection point of sand whiting in conventional nets was much less than the current minimum legal length of approximately 25 cm fork length. Insertion of the transparent panels in the haul net was particularly effective in allowing the escapement of undersize sand whiting. The effectiveness of the transparent panels on allowing fish to escape varied among species, probably due to differing escape responses to visual cues. The transparent panels show great potential as a means of improving the selectivity of haul nets.

4.3.2. Experiment 2 – effects of increasing the maximum mesh size in haul nets

In our second experiment (Kennelly and Gray 2000 – see Appendix 7), we determined the effects of altering the mesh size in the bunt and codend of haul nets on the meshing and discarding of undersize sand whiting (Sillago ciliata). We examined four mesh sizes: 45, 50, 57 and 64 mm, in an alternate-haul experiment in the Clarence River. A laboratory experiment was done to determine the mortality of sand whiting after becoming meshed in haul nets. We showed that the maximum mesh size (50 mm) permitted in the bunts and codends of nets at the time of the study caught a large proportion of undersize sand whiting that became meshed in the netting and were subsequently discarded. The laboratory experiment showed that up to 40% of these fish may die within 10 days whereas no unmeshed fish died. The 57 mm mesh size meshed few undersize sand whiting yet retained almost the same number of legal-sized fish as the 50 mm mesh. We therefore recommended that the maximum mesh size allowed in the bunts of nets used in this and similar fisheries be raised to 57 mm to allow the escape of large numbers of undersize sand whiting that are being caught, meshed and discarded in a condition that leads to significant mortality.

This recommendation was discussed with industry and managers and the regulations concerning the maximum permitted mesh sizes in haul nets is in the process of being amended to allow fishers to use up to 57 mm meshing. Fishers are currently being issued permits to use 57 mm mesh in their haul nets until the regulation is changed.

4.3.3. Experiment 3 – survival of discards

In this study we assessed the short-term survival of several common species of fish discarded from the lagoon-based haul fisheries. We tested for differences in fishes that were hauled versus those that were hauled and sorted. Discarded fish were held in floating pens (3 x 2.5 x 2 m) in St Georges Basin for a period of 10 days in two replicated time periods in late summer and in winter 2000. Each pen was checked twice daily and all dead fish were removed, identified counted, weighed and measured. Fish held in the pens were not fed during the experiment. At the end of each experiment all remaining fish in each pen were removed, counted, weighed and released.

Survival of discarded undersize tarwhine (*Rhabdosargus sarba*), snapper (*Pagrus auratus*), bream (*Acanthopagrus australis*) and sand whiting (*Sillago ciliata*) was relatively high (> 80%) for fish that were hauled and for those that were hauled and sorted in both time periods (Table 4.1). Discarded silver biddy (*Gerres subfasciatus*) displayed the lowest rates of survival in the experiment, with survival being least for fish hauled and sorted. Mortality of silver biddy was also greatest in winter. Many silver biddies died in the first 3 days with most showing significant scale loss. These fish are therefore easily damaged in the hauling and subsequent sorting operations. The greater mortality of these fish following sorting suggests that the extra length of time they were in the nets caused more stress and damage. Most fish held in the pens schooled together and swam in circles. Some species showed different behaviors, including bream, which were observed to nudge the netting walls of the pens continually. This may have contributed to some mortality in this species as several fish that died had open wounds on the top of their head where they had been rubbing the nets. Nevertheless, survival over 10 days was relatively high showing that, under good fishing conditions and sorting practices, discarding may be having little impact on subsequent stocks of these species. The data obtained in this work can be used to help assess the impacts of discarding in the haul fishery and can also be incorporated into stock assessments of key estuarine fish species.

We recommend industry adopts a code of conduct in this fishery that incorporates sorting be done in water without landing the catch on the shore or in a boat. To further aid survival of discards released into the wild, we suggest that where scavenging birds (pelicans and cormorants) are abundant, discards be held in pens and released in deeper water away from birds some time after they have orientated and recovered following the hauling and sorting operation.

Table 4.1. Summary of survival rates of discards of main species held for 10 days in pens in St Georges Basin in summer and winter 2000 after they were hauled and sorted as per normal fishing practices.

a. Summer

	Experiment 1		Experiment 2	
Species	Initial No.	% Survived	Initial No.	% Survived
Silver biddy	347	37	562	92
Bream	272	91	176	100
Snapper	74	100	41	98
Tarwhine	1328	100	2157	100
Luderick	172	100	84	100
Sand whiting	98	100	85	100
Trumpeter	17	100	9	100

b. Winter

	Experiment 3		Experiment 4	
Species	Initial No.	% Survived	Initial No.	% Survived
Silver biddy	2656	7	100	10
Bream	22	86	161	80
Snapper	N/A	N/A	116	97
Tarwhine	244	99	1777	98
Luderick	19	100	98	100
Sand whiting	1	100	5	100
Trumpeter	2334	100	33	100

4.3.4. *Experiment 4 – use of grids in lagoon-based fisheries*

In this work we examined the potential use of grids placed in the codends of haul nets to help particular species to escape prior to the sorting of catches. Because of the multi-species nature of the lagoon-based fisheries targeting many species of differing morphologies and sizes, a simple increase in mesh size would not be effective in reducing the capture of most discards without the subsequent loss of many legal sized fish (such as high value sand whiting, *Sillago ciliata*). Further, given the large quantities of fish often caught in each haul and the relatively high survival rates of the main discarded species, we did not think it appropriate to force all the catch through rigid sorting grids (as used in some fish trawls) as they entered the codend. Rather, we wanted to facilitate the passive escape of fish from the codend between the time the haul is completed and prior to the sorting operation.

We constructed several small pens of netting with grids of different bar space and horizontal/vertical placement. Grids constructed of metal (as used in prawn trawls) and of Perspex (which was clear) were tested. Large quantities of discards from commercial haul net catches were placed in the pens immediately following sorting and the reactions of fish to the grids were examined using video. The video examination showed that many fish, including undersize snapper

(*Pagrus auratus*), tarwhine (*Rhabdosargus sarba*) and bream (*Acanthopagrus australis*) and silver biddy (*Gerres subfasciatus*) of all sizes, reacted to the grids and swam through grids placed vertically and horizontally. Fish too large to fit through the grids were seen to nudge the grids continually trying to escape. Fish were observed to react more positively to grids that were clear (made from Perspex – see Fig 4.2) compared to the metal grids. We believe this is associated with visual cues, similar to that observed with the transparent netting tested in our first experiment.

We suggest that grids strategically placed along the codends of haul nets show strong potential as a means of facilitating the passive escape of small fishes from catches after they have entered the codend. Use of such grids could potentially reduce the sorting time of catches and could lead to improvement in the quality of the retained product. Catches would still require sorting however, as not all fish would escape via such grids (e.g. porcupinefish, *Dicotylichthys punctulatus*). However, survival of some fish (e.g. silver biddy, *Gerres subfasciatus*) may be enhanced if they can escape nets prior to sorting. The use of such grids would impact on retained catches, as species such as silver biddy would effectively be lost from catches and this would have a negative economic impact on many fishers who retain this species. Nevertheless, we recommend that industry further investigate the utility of grids in codends in this fishery as a means of reducing the necessity of sorting many small fishes.

Figure 4.2. Photo of a grid made of Perspex.

4.4. Conclusions

Our research on modifications to gears and fishing practices in prawn and fish hauls clearly showed that bycatch and discarding-associated problems could be reduced in these fisheries. The work on prawn hauls documented that a simple change in fishing practice can lead to a significant reduction in bycatch in this fishery. Likewise, a simple increase in the maximum mesh size permitted in fish haul nets significantly reduced the capture and subsequent mortality of undersize sand whiting. As a result of this research, the regulations concerning the operation of prawn haul gears and the configuration of fish haul gears are being amended. We conclude by recommending that industry be proactive and further develop ways to mitigate bycatch and discarding problems identified in these fisheries.

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6. IMPLICATIONS

6.1. Benefits

This study has provided quantitative data on the spatial and temporal variations in the compositions and levels of bycatches and discards in the estuarine prawn and fish haul fisheries in NSW. It has also tested and recommended several ways to reduce discarding in these fisheries. Subsequent changes to regulations concerning fishing gear and practices have been made. This will benefit all resource user groups of the estuarine fisheries resources in NSW. This study has also provided invaluable data for inclusion in the Estuary General Fishery Management Strategy and associated Environmental Impact Statement.

6.2. Further developments

Similar research to that outlined here needs to be done on specific haul nets, namely the garfish and trumpeter whiting haul nets used in NSW estuaries.

6.3. Planned outcomes

We achieved our planned outcomes by quantifying the composition and quantities of bycatch and discards taken in the estuarine prawn and fish haul fisheries in NSW. We developed and modified gears to reduce the identified problematic discards. The results have been presented to managers and industry and have been incorporated in the Estuary General Fishery Management Strategy.

6.4. Conclusions

This study was successful in quantifying the bycatches and discarding practices in the estuarine commercial prawn and fish haul fisheries in NSW. This information was obtained using observer-based surveys stratified across the major estuaries throughout the fishery. Bycatch levels in the prawn haul fishery were relatively low and were mostly comprised of small species of fish of little economic value. It was concluded that bycatch and discarding in this fishery probably has little impact on other interacting finfish fisheries in NSW. In contrast, discarding in the fish haul fishery was relatively high, with discards accounting for more than 44% by number of total catches. Current fish haul nets are relatively unselective, capturing a wide range of species of differing morphologies and sizes. Discard-associated problems varied among estuaries demonstrating that no one solution will mitigate the identified problems throughout the entire fishery. In terms of fishery-interaction problems, discarding of undersize sand whiting was the major problem observed in northern NSW estuaries, whilst the discarding of undersize tarwhine, snapper and bream were observed to be the major problem in the lagoon-based haul fisheries.

Bycatch levels in prawn haul nets were greatest in the Manning River where fishers are required to retrieve nets to the shore (riverbank). We showed that a simple change in fishing practice so that nets were retrieved midstream significantly reduced bycatch levels in this fishery. As a direct result of this research, the regulations concerning the way gear is operated in this fishery have been amended and fishers are now required to retrieve prawn haul nets away from the shore.

Field-based experiments showed that incorporation of strategically placed transparent netting in the bunts of haul nets significantly reduced the retention of unwanted bycatch, particularly undersized sand whiting (*Sillago ciliata*). Further experiments demonstrated that increasing the maximum mesh size to 57 mm in the bunts of haul nets significantly reduced the meshing and subsequent mortality of undersized sand whiting. Permits have been issued to fishers to modify their fishing gears as a direct result of this research. Work done on haul nets used in coastal lagoons suggest that transparent grids placed in the codends of nets will help facilitate the escape of small bream, tarwhine and snapper from nets prior to sorting. However, all sizes of silver biddy will also escape via such grids and this will have an economic impact on some fishers. We showed, however that short-term survival of discards in the lagoon-based fisheries was relatively high, and suggest that when catches are sorted in a responsible manner (e.g. in adequate water and absence of jellyfish), then discarding from this fishery could have negligible impacts on stock sizes. We encourage industry to adopt a strong protocol for sorting catches, which includes keeping the unsorted catch in adequate water and possibly holding discards in pens prior to release in deeper water away from scavenging birds.

We conclude by recommending that industry be proactive and further develop ways to mitigate bycatch and discarding problems identified in these haul 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 the environmental, commercial and recreational fishing interest groups in NSW. The intellectual property owned by FRDC as specified in the agreed contract is 60.1%.

Appendix 2.

Staff

Staff directly employed on this project with FRDC funds were:

Dr Charles Gray
Mr Crispian Ashby
Mr Darryl Sullings
Ms Fiona Staines
Ms Kate Hodgson
Ms Venessa Gale
Mr Max Beatson
Mr Damian Young

Appendix 3 to 11

Please note that Appendices 3 to 11 (as listed below) are available from the authors.

Appendix 3. 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.

Appendix 4. Gray, C.A., Kennelly, S.J. (submitted manuscript). Catch characteristics of the commercial beach-seine fisheries in two Australian estuaries. Manuscript to be submitted to *Fisheries Research*.

Appendix 5. Gray, C.A. (2001) Spatial variation in by-catch from a prawn seine-net fishery in a south-east Australian coastal lagoon. *Marine and Freshwater Research* 52, 987-993.

Appendix 6. Gray, C.A., Larson, R.B., Kennelly, S.J. (2000) Use of transparent netting to improve size selectivity and reduce bycatch in fish seine nets. *Fisheries Research* 45, 155-166.

Appendix 7. Kennelly, S.J., Gray, C.A. (2000) Reducing the mortality of discarded undersize sand whiting *Sillago ciliata* in an estuarine seine fishery. *Marine and Freshwater Research* 51, 749-753.

Appendix 8. Gray, C.A., Kennelly, S.J. (1999) Reducing by-catch of estuary hauling nets. *Fisheries NSW, Spring 1999, 10.*

Appendix 9. Kennelly, S.J., Gray, C.A. (2001) Effects of increasing mesh size in bunts of estuarine haul nets when targeting sand whiting. *Fisheries NSW, Spring 2000/Summer 2001, 28-29.*

Appendix 10. Gray, C.A. Research update – estuary general. *Fisheries NSW, Summer 2000,34.*

Appendix 11. Gray, C.A., Kennelly, S.J. (2000) Use of transparent material to aid management of bycatch issues in the beach-seine fisheries in New South Wales, Australia. Abstract of presentation given at the 3rd World Fisheries Congress, China, October 2000.

Appendix 3

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.

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Retained and discarded catches from commercial beach-seining in Botany Bay, Australia

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Abstract

Observer-based estimates of the quantities and size compositions of discarded and retained catches from the commercial beach-seine fishery in Botany Bay, NSW, Australia are presented. A total of 71 finfish and 10 invertebrate taxa were identified in catches sampled between February 1998 and February 1999, with 39 taxa being retained by fishers and 77 taxa discarded. *Gerres subfasciatus*, *Pseudocaranx dentex*, *Sillago ciliata*, *Acanthopagrus australis* and *Rhabdosargus sarba* dominated retained catches. Discards included small individuals of many retained species that are also important in other commercial and recreational fisheries, including *S. ciliata*, *A. australis*, *R. sarba*, *Pagrus auratus*, *Meuschenia freycineti* and *Scobinichthys granulatus*, as well as some non-monetary valued species such as *Dicotylichthys punctulatus*, *Anoplocapros inermis* and several tetraodontids. The estimated monthly ratio of retained to discarded catch (kg) ranged from 1:0.26 to 1:2.48. An estimated 44% of total individuals and 38% of the total weight of catches were discarded. It was estimated that this fishery annually discarded 93 t of fish and invertebrates, which included hundreds of, thousands of commercially and recreationally important species. The results are discussed in terms of their consequences for interactions with other fisheries.

Keywords: Seine-net; Commercial catches; By-catch; Discards; Estuarine fisheries; Observer program

1. Introduction

In recent decades there has been significant concern throughout the world over the effects of the incidental capture and subsequent discarding of non-target organisms as part of normal commercial fishing operations (for reviews see Saila, 1983; Andrew and Pepperell, 1992; Alverson et al., 1994; Kennelly, 1995). In multi-species finfish fisheries using otter trawls and Danish seines, discards often include smaller individuals of the target species and fish that at larger sizes are important in other commercial and recreational fisheries, potentially affecting the yields of these other fisheries (e.g. Howell and Langan, 1987; Fennessy, 1994). Such discarding often leads to conflict among various resource interest groups (particularly commercial and recreational fishers), and has important consequences for stock assessments and the subsequent management and utilization of fish stocks.

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Considerable research has documented the composition and levels of discarding in demersal otter trawl and Danish seine fisheries for fish and prawns (see above reviews for references). There is far less information, however, on the levels of discarding in other smaller-scale coastal fisheries, including those using beach-seines. Beach-seine-nets are used to capture fish, crustaceans and molluscs commercially throughout the world (Lamberth et al., 1994; Evans et al., 1995), but these fisheries often occur in areas where the general public can scrutinize catches, leading to significant controversy surrounding the issue of their discarding practices (e.g. Lamberth et al., 1994; Gray et al., 2000).

Commercial beach-seining for finfish (locally termed as 'fish hauling') is permitted in most estuaries in NSW, Australia, where it forms the basis of a valuable fishery that annually lands approximately 2000 t of finfish valued at approximately $AUD 5 million. Although this fishery is one of the oldest in Australia, it is also one of the most contentious with many other interest groups, including recreational anglers, conservationists, local councils, tourism operators and the general public claiming that many juveniles of recreationally and commercially important species are caught and killed in the fishery. Further, there are disputes among angling groups over the allocation and quantities of finfish retained by this commercial fishery. Because of these two factors, like other beach-seine fisheries throughout the world (e.g. South Africa, Lamberth et al., 1994), many groups have proposed that commercial beach-seining be banned in NSW estuaries. Despite the economic importance and perceived negative impacts of this fishery, no studies have described the catch composition or quantified the levels of discarding in this fishery. This is a necessary first step in implementing solutions to manage this and other interacting commercial fisheries and to reduce conflict among the various interest groups.

In this study we conduct an observer-based survey, in which catch data were collected during normal commercial fishing operations, to quantify the species composition and estimate the quantities and size compositions of the retained and discarded catches taken in the commercial beach-seine fishery in Botany Bay, one of the largest and most productive commercial estuarine fisheries in NSW. This information was used to assess potential interactions of this fishery with other commercial and recreational fisheries in the region.

2. Materials and methods

2.1. *The commercial beach-seine fishery in Botany Bay*

Botany Bay (34°00′; 151°14′) is a shallow (mean depth 5 m) semi-enclosed, temperate, marine-dominated embayment approximately 8 km across having a surface water area of approximately 49 km^2 (Fig. 1). The bay experiences semi-diurnal tides with freshwater input from the Georges and Cooks Rivers. The northern and western shores surrounding the bay are urbanized, including large industrial areas, whereas the southern shores include the Towra Point Aquatic Reserve. Botany Bay supports several commercial fisheries in addition to beach-seining (gill-netting, trapping and prawn trawling) and a large recreational fishery.

Commercial beach-seine fisheries in NSW are managed by input controls that include spatial and temporal closures and gear restrictions. Seining is permitted along most shores in Botany Bay, the main exceptions being the Cooks River, above the Woronora Bridge in the Georges River, Sylvania Waters, the Towra Point Aquatic Reserve, between the Sydney Airport runways and within the Port Botany shipping terminal on the northern shore (Fig. 1). The fishery is closed on weekends and public holidays. The nets used in the Botany Bay fishery have a maximum headline length of 375 m with a further 1200 m of hauling rope allowed on either end of the net. The length of the bunt (center of net) must not exceed 90 m, which must include a centerpiece (cod-end) of mesh 30–50 mm, whilst the remainder of the bunt must be made of mesh greater than 57 mm. The mesh in the wings of the net must not be lesser than 80 mm. The rope and net are set from a small boat in a semicircle starting and ending at the shoreline (see Gray et al., 2000) with most crews hauling the nets using small petrol-powered winches. Seining generally occurs during high or low tides, when water flow is minimal. Catches are usually sorted in shallow water adjacent to the shoreline, but occasionally some catches are sorted on board a boat or on land. Because

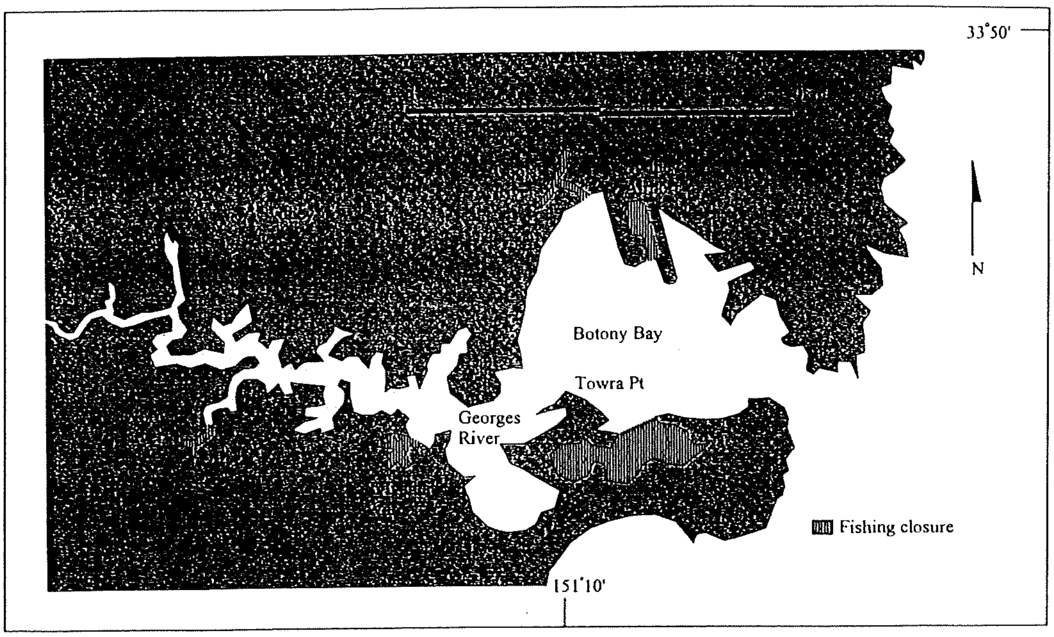

Fig. 1. Map of Botany Bay showing where beach-seining is permitted.

jellyfish often occur within the bay and affect seining operations, most crews leave the cod-end open as nets are retrieved until the net gets close to shore, when the cod-end is tied closed. Jellyfish, therefore, pass through the net, but because of the herding effect of the net the fish remain in front of the net until it nears the shore (see Gray et al., 2000). Some nets also have escape gaps through which jellyfish are released before the nets approach the shore. Beach-seine crews usually consist of two or three persons, with up to eight crews working in Botany Bay.

2.2. Observer survey

Scientific observers accompanied commercial beach-seine crews on four randomly selected fishing trips in each month between February 1998 and February 1999, except in May–July 1998 when there was little fishing effort. For each observed haul, the total catch was sorted into the retained and discarded components by the commercial fishers. The total weights and numbers of each individual species retained were recorded, as were the lengths (to the nearest cm) of key commercially and recreationally important species. The discarded catch was then sorted by the observer into species, and the total weights and numbers of each discarded species were determined. Fish species of commercial and recreational importance were also measured (to the nearest cm). When discarded catches were too large to sample entirely, the discarded catch was subsampled and the data were scaled accordingly. Between September 1998 and February 1999, sagittal otoliths were collected from four discarded species (*Acanthopagrus australis*, *Pagrus auratus*, *Rhabdosargus sarba* and *Sillago ciliata*) to determine age compositions of these discards.

2.3. Data analyses

2.3.1. Temporal variation in rates of retained and discarded catches

Mean catch rates (±1 S.E.) per haul were calculated for each observer month. One-factor analyses of variance were used to test for differences among months in weights and quantities of retained and discarded catches. Prior to analysis, data were checked for homogeneity of variances using Cochran's test, and transformed if necessary.

The ratio of discarded to retained catch $\hat{R}$, and $S(\hat{R})$ the estimated standard error of $\hat{R}$, were calculated for each month and for the entire survey period using the following formulae (Cochran, 1963):

$$\hat{R} = \frac{\sum_{i=1}^{n} d_i}{\sum_{i=1}^{n} r_i},$$

$$S(\hat{R}) = \frac{1}{\bar{r}\sqrt{n}}\sqrt{\frac{\sum d_i^2 - 2\hat{R}\sum r_i d_i + \hat{R}^2 \sum r_i^2}{n-1}}$$

where d_i and r_i are the weight (kg) or number of the discarded and retained catches, respectively, for haul i, and n is the total number of hauls sampled.

2.3.2. *Estimates of retained and discarded catches by the entire fleet*

Estimates of retained and discarded catches (±1 S.E.) by the entire beach-seine fishery in Botany Bay were derived by multiplying the observed monthly mean catch per haul (CPUE) by the reported number of hauls completed by all seine crews in Botany Bay each month between February 1998 and January 1999. This was done using the standard method for estimating a total and standard error across multiple randomly sampled strata (Cochran, 1963)

$$\hat{C} = \frac{N'}{N}\sum_{m=1}^{M} N_m \overline{C}_m, \qquad S(\hat{C}) = \frac{N'}{N}\sqrt{\sum_{m=1}^{M}\frac{N_m^2 S_m^2}{n_m}}$$

in which $\hat{C}$ is the estimated annual catch, $S(\hat{C})$ the associated standard error, $\overline{C}_m$ the mean catch per haul, S_m the standard deviation of sample catch rates, N_m the total number of hauls done by all crews and n_m the number of sampled hauls in month m of M survey months. N is the total number of hauls done by all crews during the survey months and N' the total number of hauls done by all crews throughout the entire year, including those months that were not surveyed. Thus the term N'/N scales the fleets catch from all survey months to the fleets catch for the entire year. These calculations assumed that the mean catch rates for the months not surveyed were the same as the months surveyed. The total fishing effort for each month (i.e. total number of hauls) was obtained from the mandatory forms that commercial fishers are legally required to submit to NSW Fisheries each month.

2.3.3. *Size compositions of retained and discarded catches*

Observed size–frequencies of the retained and discarded catches of each commercial species were scaled to represent the whole fleet using estimated fishing effort. This was done by multiplying measured size–frequencies by the ratio of total fishing effort to sampling effort in each month, then summing these to provide an annual distribution, from which a relative size composition was calculated (see Liggins and Kennelly, 1996).

2.3.4. *Age compositions of discards*

Ages were determined for a total of 349 fish from four species using the following procedures. One sagittal otolith from each fish was embedded in clear resin and sectioned (approximately 25–30 μm) in a transverse plane through the focus using a low speed saw fitted with two diamond blades. The resulting section was polished and mounted on a glass slide and viewed under a binocular microscope with reflected light against a black background. Otolith sections of the species examined display narrow opaque and broad translucent zones, which equate to annual growth zones (based on tag/recapture studies, see Ferrell, 2000). Assignment of age was based on counts of completed opaque zones (i.e. number of opaque rings from the focus to the outer edge). Two readers independently assigned ages to each sectioned otolith. An age–length key was determined for each species, which was applied to each estimated annual discarded length composition to obtain the estimated age compositions of discards.

3. Results

3.1. *Distribution of sampling and fishing effort*

Fig. 2 shows the distribution of sampling effort and the reported fishing effort in number of hauls and fisher-days throughout the survey period. Reported fishing effort was greatest between December and May (summer/autumn), and least in July and October.

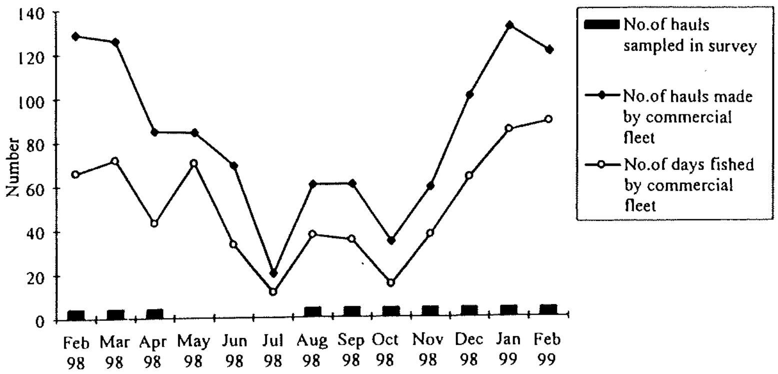

Fig. 2. The distribution of sampling effort (number of hauls) and reported fishing effort (number of fisher-days and hauls) between February 1998 and February 1999.

3.2. Catch composition

A total of 71 finfish and 10 invertebrate taxa (species or higher taxonomic groups) were identified in catches throughout the observer survey (Table 1). A total of 39 taxa were retained by fishers, and 77 taxa were discarded; only the two species of hemiramphids, an unidentified carangid and *Nototodarus gouldi* were solely retained. Thirty nine finfish taxa were solely discarded, and another 29 finfish taxa were retained and discarded.

Taxa were assigned to a relative index of abundance according to their mean retained and discarded catch rates per haul (Table 1). Retained catch rates of *Pseudocaranx dentex* and *Gerres subfasciatus* were estimated to be greater than 100 individuals per haul, while *S. ciliata*, *A. australis* and *R. sarba* had estimated retained catch rates greater than 10 individuals per haul. Two sparids, *P. auratus* and *R. sarba* had estimated discarded catch rates greater than 100 individuals per haul, while a further seven taxa had estimated discarded catch rates greater than 10 individuals per haul. Forty-seven finfish taxa had estimated discarded catch rates of less than 1 individual per haul.

3.3. Temporal variation in rates of capture of retained and discarded species

A greater number of species was discarded than retained in each survey month (Fig. 3). The discarded catch contained fewer total individuals and weighed less than the retained catch in each survey month except April 1998 and January 1999. Although ANOVAs revealed no significant temporal differences in the total numbers and weights of the retained and discarded catches in each month (Table 2), more than 1000 individuals were retained per haul in March, September and October 1998 and in February 1999, which was primarily attributed to *G. subfasciatus*. More than 1000 individuals, primarily *A. australis* and *R. sarba*, were discarded per haul in March 1998 and January 1999.

Variations in rates of retained and discarded catches for the major species are shown in Fig. 4. Most species were caught in each month surveyed, but large (albeit mostly non-significant) fluctuations in retained and discarded catches were prevalent. Analyses of variance revealed few significant temporal differences in retained and discarded catches (Table 2), probably due to the inherent variability and low statistical power of the tests. Despite this, the data clearly showed that large numbers of *A. australis* were discarded in September, October and January, *R. sarba* in October and January, *S. ciliata* in September and October, *P. auratus*, *Trachurus* spp., *Scobinichthys granulatus* and *Meuschenia freycineti* in March. *Portunus pelagicus*, *A. australis*, *R. sarba*, *P. dentex*, *S. ciliata* and *G. subfasciatus* were retained in most months surveyed.

Ratios of the total weights retained to discarded ranged from 1:0.26 (±0.09) in February 1999 to

Table 1
Taxonomic composition of retained and discarded commercial beach-seine catches. Relative abundance index (mean number per haul): +>0, ++>1, +++>10, ++++>100

Family	Scientific name	Common name	Retained	Discarded
Finfish				
Aracanthidae	*Anoplocapros inermis*	Eastern boxfish		++
Atherinidae	*Atherinomorus ogilbyi*	Ogilby's hardyhead		+
Bothidae	*Pseudorhombus arsius*	Large-toothed flounder	+	+
	Pseudorhombus jenynsii	Small-toothed flounder	+	+
Callionymidae	*Foetorepus calauropomus*	Stinkfish		+
Carangidae	*Decapterus muroadsi*	Southern mackerel scad		+
	Pseudocaranx dentex	Silver trevally	++++	+++
	Seriola lalandi	Kingfish	+	+
	Trachurus spp.	Yellowtail & Jack mackerel	+	++
	(Unidentified spp.)	Trevally	+	
Cheilodactylidae	(Unidentified mixed spp.)	Morwong		+
Clupeidae	*Herklotsichthys castelnaui*	Southern herring		++
Dactylopteridae	*Dactyloptena orientalis*	Flying gurnard		+
Dasyatididae	*Dasyatis thetidis*	Estuary stingray		+
Dinolestidae	*Dinolestes lewini*	Long-finned seapike		+
Diodontidae	*Dicotylichthys punctulatus*	Three-bar porcupinefish		+++
Enoplosidae	*Enoplosus armatus*	Old wife		+
Gerreidae	*Gerres subfasciatus*	Silver biddy	++++	++
Girellidae	*Girella tricuspidata*	Lunderick	++	+
Hemiramphidae	*Hyporhamphus australis*	Eastern garfish	+	
	Hyporhamphus regularis	River garfish	+	
Heterodontidae	*Heterodontus portusjacksoni*	Port Jackson shark		+
Labridae	(Unidentified mixed spp.)	Wrasse		+
Latrididae	*Latris lineata*	Striped trumpeter		+
Monacanthidae	*Brachaluteres jacksonianus*	Pigmy leatherjacket		+
	Eubalichthys mosaicus	Mosaic leatherjacket		+
	Meuschenia freycineti	Six-spined leatherjacket	+	+++
	Meuschenia trachylepis	Yellow-finned leatherjacket	+	++
	Monacanthus chinensis	Fanbelly leatherjacket	+	+
	Nelusetta ayraudi	Chinaman leatherjacket	++	++
	Scobinichthys granulatus	Rough leatherjacket	++	+++
	(Unidentified mixed spp.)	Leatherjacket	+	+
Monodactylidae	*Monodactylus argentus*	Diamond fish		+
Mugilidae	*Liza argentea*	Flat-tail mullet	++	+
	Mugil cephalus	Sea mullet	++	+
	Myxus elongatus	Sand mullet	+	+
Mullidae	*Upeneichthys lineatus*	Blue-striped goatfish	+	+
Orectolobidae	*Orectolobus* spp.	Wobbegong shark		+
Ostracidae	*Lactoria cornuta*	Longhorn cowfish		+
	Tetrosomus concatenatus	Turretfish		+
Platycephalidae	*Platycephalus caeruleopunctatus*	Eastern blue-spotted flathead	+	+
	Platycephalus fuscus	Dusky flathead	++	+
	Suggrundus jugosus	Mud flathead		+
Pleuronectidae	*Ammotretis rostratus*	Long snouted flounder	+	+
Plotosidae	*Cnidoglanis macrocephalus*	Estuary catfish		+
Pomatomidae	*Pomatomus saltatrix*	Tailor	++	++
Rhinobatidae	*Aptychotrema rostrata*	Shovelnose ray		+
	Trygonorhina fasciata	Banjo ray		++
Sciaenidae	*Argyrosomus japonicus*	Mulloway	++	+
Scombridae	*Scomber australasicus*	Slimy mackerel		+
Scorpaenidae	*Centropogon australis*	Fortescue		+

Table 1 (*Continued*)

Family	Scientific name	Common name	Retained	Discarded
Scorpididae	*Scorpis lineolatus*	Silver sweep		+
Siganidae	*Siganus fuscescens*	Black trevally	++	+
Sillaginidae	*Sillago maculata*	Trumpeter whiting	++	++
	Sillago ciliata	Sand whiting	+++	+++
Soleidae	*Synaptura nigra*	Black sole		+
	Zebrias scalaris	Many-banded sole		+
Sparidae	*Acanthopagrus australis*	Yellowfin bream	+++	+++
	Pagrus auratus	Snapper	+	++++
	Rhabdosargus sarba	Tarwhine	+++	++++
Teraponidae	*Pelates sexlineatus*	Six-lined trumpeter		+
Tetraodontidae	*Arothron hispidus*	Stars & stripes toadfish		+
	Marilyna pleurosticta	Banded toadfish		+
	Tetractenos glaber	Smooth toadfish		+
	Tetractenos hamiltoni	Common toadfish		++
	Torquigner pleurogramma	Weeping toadfish		+
	Torquigner squamicauda	Brush-tail toadfish		+
Torpedinidae	*Hypnos monopterygium*	Numbfish		+
Triglidae	*Chelidonichthys kumu*	Red gurnard	+	+
	(Unidentified mixed spp.)	Gurnard		+
Urolophodae	*Trygonoptera testacea*	Common stingaree		++
Crustaceans				
Penaeidae	(Mixed spp.)	Prawn	+	+
Portunidae	*Ovalipes* sp.	Two-spot sand crab		+
	Portunus pelagicus	Blue-swimmer crab	++	++
	Thalamita sp.	Swimmer crab		+
	(Unidentified crab spp.)	Crab		++
Molluscs				
Loliginidae	*Sepioteuthis australis*	Southern calamari	++	+
Octopodidae	*Octopus* sp.	Octopus	+	+
Sepiidae	*Sepia* spp.	Cuttlefish	++	+++
Tuethoidae	*Nototodarus gouldi*	Arrow squid	+	
	(Mixed cephalopod spp.)	Squid other	++	+

1:2.48 (±2.11) in January 1999, with the overall ratio for the survey being 1:0.51 (±0.14) (Table 3). For 8 of the 10 months sampled, the ratio of retained to discarded catch (kg) was less than 1:0.49. The large ratio in January 1999 was due to the exceptionally large numbers of discarded *R. sarba* and *A. australis*.

3.4. Estimates of annual retained and discarded catches by the entire fleet

Estimates of the total annual retained and discarded catches (±1 S.E.) for the major species by the entire seine fishery in Botany Bay are presented in Table 4. Note, however, that the precision of these estimates varies among species. An estimated annual total retained catch of 152±45 t and discarded catch of 93±23 t was taken in the fishery between February 1998 and January 1999. Discards made a major contribution to the total catch of many target species, including *A. australis* and *R. sarba* (Table 4).

3.5. Size compositions of retained and discarded catches

Fig. 5 provides summaries of the sizes of important fish species retained and discarded by the fleet.

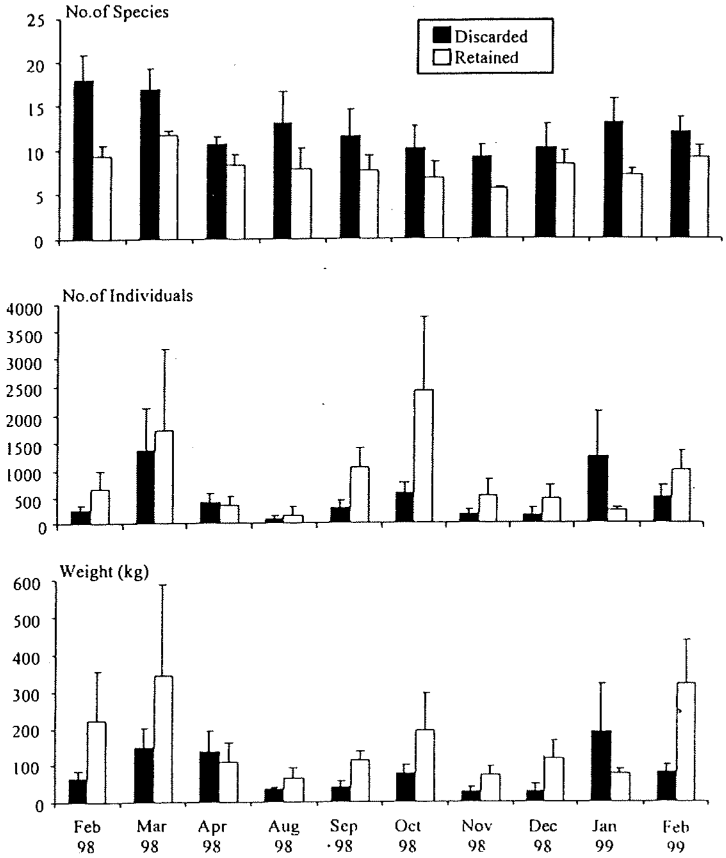

Fig. 3. Mean (±1 S.E.) weight and number of total retained and discarded catches during the survey.

A. australis, *R. sarba* and *S. ciliata* were both retained and discarded, with fish below the minimum legal length (MLL) mostly being discarded. Although there is no MLL on *P. dentex* and *S. granulatus*, these species were either retained or discarded according to length. *P. dentex* were predominantly retained with only the smallest individuals discarded, whereas *S. granulatus* were predominantly discarded with only the larger individuals retained. All sizes of *G. subfasciatus* captured were retained, with discarding occurring only when catches comprised a few individuals. In contrast, all sizes of *P. auratus*, *M. freycineti* and *Trachurus* spp. were discarded because of the small sizes of fish caught.

3.6. *Age compositions of discards*

Discarded *P. auratus* were predominantly 0+ and 1+ years of age, whereas discarded *R. sarba* and *S. ciliata* were primarily 1+ and 2+ years and *A. australis* 2+ and 3+ years (Table 5).

4. Discussion

Descriptions of the retained and discarded catches from an estuarine beach-seine fishery in NSW have not been reported previously. The above results from our direct observation and quantification of the mag-

Table 2
Results of one-way analyses of variance testing for differences among months in retained and discarded beach-seine catches

Species/grouping	Discarded				Retained			
	C^a	Transform	F-ratio	P	C	Transform	F-ratio	P
Totals								
No. of species	0.18	–	1.53	ns[b]	0.3	ln(x + 1)	1.28	ns
No. of individuals	0.19	ln(x + 1)	1.31	ns	0.35	ln(x + 1)	0.99	ns
Weight (kg)	0.31	ln(x + 1)	1.74	ns	0.31	ln(x + 1)	0.66	ns
No. of individuals of each species								
Pagrus auratus	0.20	ln(x + 1)	0.69	ns				
Rhabdosargus sarba	0.17	ln(x + 1)	2.47	<0.05	0.4	ln(x + 1)	–	
Acanthopagrus australis	0.30	ln(x + 1)	1.68	ns	0.21	ln(x + 1)	1.9	ns
Scobinichthys granulatus	0.35	–	2.05	ns	0.93	ln(x + 1)[c]	1.69	ns
Dicotylichthys punctulatus	0.26	ln(x + 1)	0.68	ns				
Meuschenia freycineti	0.40	ln(x + 1)[c]	–					
Trachurus spp.	0.32	ln(x + 1)	0.97	ns				
Pseudocaranx dentex	0.37	ln(x + 1)[c]	0.7	ns	0.25	ln(x + 1)	4.14	<0.01
Sepia spp.	0.31	ln(x + 1)	4.16	<0.01	0.48	ln(x + 1)	1.51	ns
Sillago ciliata	0.29	ln(x + 1)	3.71	<0.01	0.26	ln(x + 1)	3.09	<0.01
Heterodantus portusjacksoni	0.43	ln(x + 1)[c]	0.88	ns				
Meuschenia trachylepsis	0.36	–	0.91	ns				
Portunus pelagicus	0.27	ln(x + 1)	1.01	ns				
Gerres subfasciatus	0.35	ln(x + 1)	0.63	ns	0.34	ln(x + 1)	2.6	<0.05
Nelusetta ayraudi	0.41	ln(x + 1)[c]	2.19	ns	0.56	ln(x + 1)[c]	1.22	ns
Sillago maculata	0.66	ln(x + 1)[c]	0.75	ns	0.66	ln(x + 1)[c]	0.87	ns
Pomatomus saltatrix	0.29	ln(x + 1)	3.5	<0.001	0.39	ln(x + 1)	1.4	ns

[a] C denotes Cochran's value.
[b] ns: Not significant at P>0.05.
[c] Variances heterogeneous after transformation.

nitudes and size-distributions of catches in the Botany Bay beach-seine fishery provide the first robust estimates of how this fishery may interact with other commercial and recreational fisheries in this region.

Table 3
Ratios of retained to discarded catches in each survey month and for the overall survey

Month	Number (±1 S.E.)	Weight (±1 S.E.)
February 1998	1:0.44 (0.18)	1:0.29 (0.18)
March 1998	1:0.79 (0.23)	1:0.44 (0.21)
April 1998	1:1.17 (0.61)	1:1.25 (0.37)
August 1998	1:0.53 (0.36)	1:0.49 (0.20)
September 1998	1:0.30 (0.05)	1:0.35 (0.07)
October 1998	1:0.24 (0.08)	1:0.41 (0.17)
November 1998	1:0.39 (0.25)	1:0.43 (0.17)
December 1998	1:0.36 (0.37)	1:0.26 (0.21)
January 1999	1:5.06 (3.95)	1:2.48 (2.11)
February 1999	1:0.49 (0.09)	1:0.26 (0.09)
Overall survey	1:0.60 (0.16)	1:0.51 (0.14)

4.1. Composition and magnitude of retained and discarded catches

The fish and invertebrate species caught in the Botany Bay beach-seine fishery were typical of those that inhabit estuaries and coastal embayments in NSW. Sparids, sillaginids, carangids, gerreids and monacanthids dominated finfish catches, whereas several cephalopods and portunid crabs dominated invertebrate catches. As in other multi-species finfish fisheries, the discarded catches contained juveniles of the main target species (e.g. *A. australis*, *R. sarba*, *S. ciliata*, *P. dentex* and several monacanthid species) in addition to several species of little commercial or recreational value (e.g. *Dicotylichthys punctulatus*, *Anoplocapros inermis* and various tetraodontid species). Except for *D. punctulatus*, these latter species were caught in relatively low numbers. The existence of an MLL was the principal reason for the discarding of most species; individuals below the MLL were too

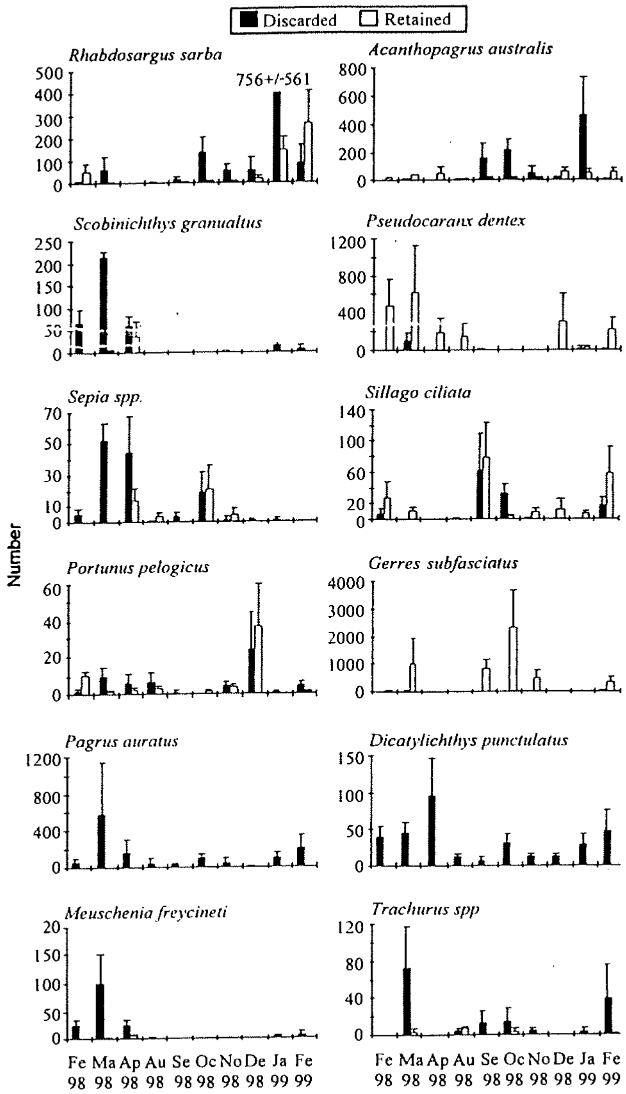

Fig. 4. Mean (±1 S.E.) number of retained and discarded catches of the main species during the survey.

small to sell. The discarding of species with no MLL (e.g. *P. dentex* and *S. granulatus*) was also size-based (and probably market driven) with only the larger individuals being retained for sale. Notably, all sizes of *G. subfasciatus* were retained.

Retained and discarded catch rates varied throughout the survey and such variation was species-specific. Estimated retained to discarded ratios (by weight) in the fishery were less than 1:0.49 in all but two survey months, with the survey average being 1:0.51. Similar

Table 4
Estimated annual retained and discarded catches by the entire beach-seine fleet in Botany Bay between February 1998 and January 1999

	Discarded		Retained		Discarded %	Discarded		Retained		Discarded %
	Number	1 S.E.	Number	1 S.E.		Weight	1 S.E.	Weight	1 S.E.	
All species	581472	180988	729409	244655	44	92844	22920	152018	44986	38
Rhabdosargus sarba	148892	90438	34568	11404	81	17485	11665	5663	1908	76
Pagrus auratus	142261	87647	38	38	100	11956	6816	12	12	100
Acanthopagrus australis	63064	38297	28079	7304	69	11603	7724	10701	2886	52
Scobinichthys granulatus	51797	6067	4184	3378	93	3243	418	506	421	87
Dicotylichthys punctulatus	32301	6643	0	0	100	25614	6857	0	0	100
Meuschenia freycineti	21942	8011	440	371	98	1070	420	42	35	96
Pseudocaranx dentex	18361	14678	241899	101224	7	1718	1195	80750	34031	2
Sepia spp.	14772	3154	2832	1115	84	990	248	379	154	72
Trachurus spp.	13854	7043	988	543	93	734	389	164	115	82
Meuschenia trachylepis	7203	1875	172	155	98	278	56	15	12	95
Heterodontus portusjacksoni	7131	5114	0	0	100	1322	906	0	0	100
Sillago ciliata	6987	3708	15142	4839	32	859	435	3802	1250	18
Crabs — mixed spp.	6772	2433	0	0	100	442	161	0	0	100
Portunus pelagicus	6282	2693	7197	2904	47	790	417	2149	823	27
Anoplocapros inermis	6106	2837	0	0	100	2442	1048	0	0	100
Nelusetta ayraudi	5748	3170	6426	3240	47	376	235	544	279	41
Trygonorhina fasciata	3564	1464	0	0	100	6801	3123	0	0	100
Gerres subfasciatus	2932	2434	346825	161346	1	207	163	30087	14526	1
Trygonoptera testacea	1663	1006	0	0	100	823	494	0	0	100
Sillago maculata	1509	1407	5527	4097	21	55	49	590	383	8
Siganus fuscescens	1488	1440	1949	1404	43	402	396	385	267	51
Tetractenos hamiltoni	1477	286	0	0	100	85	18	0	0	100
Pomatomus saltatrix	1386	430	1460	768	49	235	78	867	494	21
Tetrosomus concatenatus	1383	631	0	0	100	64	29	0	0	100
Monacanthus chinensis	947	351	270	106	78	79	32	108	45	42
Pseudorhombus jenynsii	919	407	305	305	75	108	41	56	56	66
Platycephalus fuscus	852	597	3018	795	22	190	136	1388	364	12
Mugil cephalus	838	808	2193	1030	28	165	162	1223	657	12
Sepioteuthis australis	807	807	10988	5054	7	40	40	2429	1191	2
Dinolestes lewini	749	453	0	0	100	118	73	0	0	100
Pelates sexlineatus	639	469	0	0	100	20	12	0	0	100
Girella tricuspidata	494	250	1381	463	26	84	49	858	273	9
Aptychotrema rostrata	483	473	0	0	100	483	480	0	0	100
Brachaluteres jacksonianus	462	295	0	0	100	7	4	0	0	100
Latris lineata	457	213	0	0	100	32	17	0	0	100
Orectolobus spp.	377	178	0	0	100	190	108	0	0	100
Dactyloptena orientalis	324	324	0	0	100	11	11	0	0	100
Decapterus muroadsi	288	288	0	0	100	12	12	0	0	100
Seriola lalandi	266	241	1195	1086	18	335	288	2484	2336	12
Eubalichthys mosaicus	236	236	0	0	100	12	12	0	0	100
Centropogon australis	235	154	0	0	100	10	6	0	0	100
Cnidoglanis macrocephalus	220	220	0	0	100	439	439	0	0	100
Torquigner squamicauda	207	144	0	0	100	14	8	0	0	100
Upeneichthys lineatus	194	140	52	52	79	10	8	5	5	66
Tetractenos glaber	183	183	0	0	100	9	9	0	0	100
Atherinomorus ogilbyi	157	157	0	0	100	5	5	0	0	100
Synaptura nigra	140	100	0	0	100	49	35	0	0	100
Herklotsichthys castelnaui	136	98	0	0	100	5	4	0	0	100
Liza argentea	135	72	1828	1350	7	27	14	515	382	5

Table 4 (*Continued*)

	Discarded		Retained		Discarded %	Discarded		Retained		Discarded %
	Number	1 S.E.	Number	1 S.E.		Weight	1 S.E.	Weight	1 S.E.	
Pseudorhombus arsius	77	77	38	38	67	15	15	15	15	50
Octopus sp.	40	40	1422	594	3	4	4	1052	473	0
Argyrosomus japonicus	27	27	113	70	20	19	19	513	342	4
Squid — mixed spp.	18	18	6275	3539	0	2	2	1731	856	0
Nototodarus gouldi	0	0	674	674	0	0	0	259	259	0
Hyporhamphus regularis	0	0	869	686	0	0	0	102	84	0
Hyporhamphus australis	0	0	37	37	0	0	0	4	4	0

discard ratios have been reported for other multi-species fisheries, including coastal beach-seining (Lamberth et al., 1994), demersal fish trawling and Danish seining (see Alverson et al., 1994).

It is useful to compare the results obtained in this study with those obtained from a study in 1990–1992 of another controversial fishery in Botany Bay — the estuarine prawn-trawl fishery (Liggins et al., 1996). The retained to discarded ratios observed in the current study were generally less than that observed for prawn trawling (1:1.5–3.5), and the magnitude of the estimated annual total discarded catch of 93 t from beach-seining was also less than the estimated 120–165 t for the prawn-trawl fleet (Liggins et al., 1996). Similarly, the estimated total numbers of discards for the prawn-trawl fishery was greater than for the beach-seine fishery. In comparing discarded catches between the beach-seine and prawn-trawl fisheries in Botany Bay, it should be noted that (1) prawn trawlers are prohibited from landing fish that have an MLL, and consequently they discard fish above the MLL, and (2) the prawn-trawl fishery operates only between November and March during which the effort (fisher-days) is considerably greater than that in the seine fishery. The magnitude of discarding in the beach-seine fishery was large for some species (e.g. estimated total discards of important species such as *R. sarba*, *P. auratus*, and *A. australis* being greater than 10 t). The estimated total numbers of discards of some key species in the seine fishery was less than that estimated for the prawn-trawl fishery (e.g. *P. pelagicus* and *Platycephalus fuscus*), but for others the opposite was evident (e.g. *A. australis* and *S. ciliata*). Notably, the estimated 142 000 *P. auratus* discarded in the beach-seine fishery during our survey was greater than the estimated 112 000 discards of this species in the prawn-trawl fishery in 1990/1991, but it was considerably less than the estimated 720 000 prawn-trawl discards in 1991/1992 (Liggins et al., 1996). This highlights the importance of considering inter-annual variability in catches when assessing impacts of discarding on stocks.

Table 5
The estimated relative percent age composition of discarded fish

Species	Age (years)					*n*
	0+	1+	2+	3+	4+	
P. auratus	44	38	18	0	0	134
R. sarba	9	32	59	0	0	83
A. australis	0	6	39	51	4	65
S. ciliata	0	53	43	4	0	67

The precision of the estimated retained and discarded catches by the entire beach-seine fleet needs to be considered. In making these estimates we assumed that: (1) the four observer days each month were unbiased and represented the hauls of all crews, (2) there were no systematic measurement errors made by our observers, (3) the presence of an observer did not influence normal seining operations and sorting practices, (4) the average catches of the months not surveyed were equal to those of the months surveyed, (5) the reported fishing effort in terms of the numbers of hauls per month made by each crew was accurate, (6) the estimates of total discarded catches assumes that individuals were not captured on a multiple basis. We believe that assumptions (1)–(3) are valid, because the observed fishers and days fished were determined randomly, and the performance of fishers and their gears were carefully monitored. Most often, observers

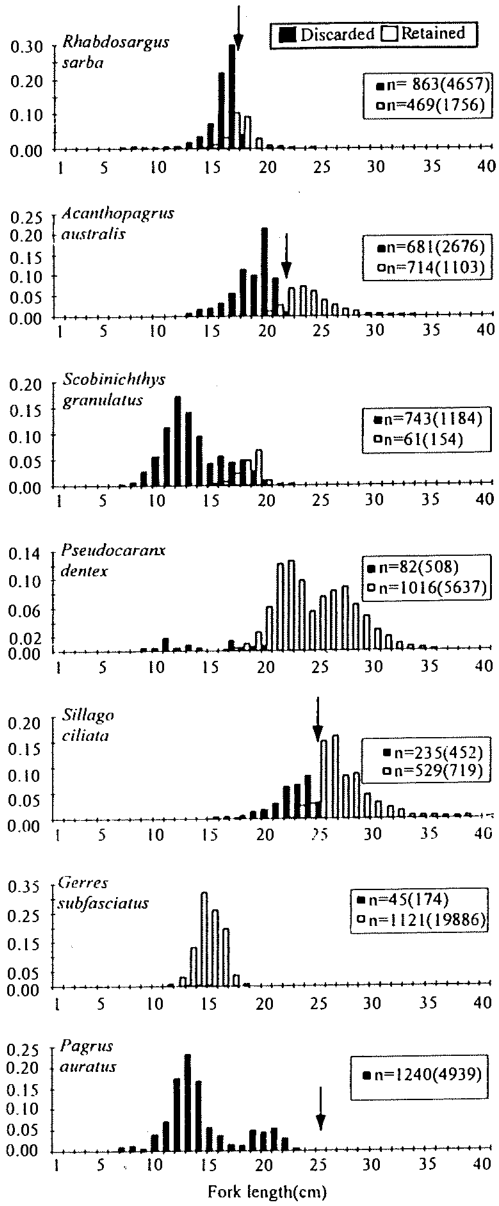

Fig. 5. Length-frequency distributions of retained and discarded catches of the main species. *n* denotes number of fish measured (total estimated number). The arrows denote the MLL of the species.

approached each beach-seine crew after the seining operation had started, so they could not affect where or when seining took place. We acknowledge, however, that the presence of an observer may have affected some sorting practices. In regard to assumption (5), it is not known whether on an average, fishers in this fleet over- or under-estimated monthly fishing effort. It has been estimated that the Botany Bay prawn-trawl fleet underestimated their actual effort by an average of 45% in 1990/1991 (Liggins et al., 1996). Whilst the validity of this last assumption for the beach-seine fishery is not known, it was impractical to monitor effort by all crews during the survey. Although we did not quantify assumption (6), several small fish were observed to have notches on their heads where they had previously been meshed in a net (either gill or seine) indicating that they had previously been captured in a net-based fishery. Hence, some discarded fish in this fishery may have been captured more than once. Nonetheless, large numbers of several species (particularly *P. auratus* and *R. sarba*, see Table 4) were discarded, and ways to minimize this need to be addressed.

4.2. Fisheries interactions and management implications

Several species caught in the beach-seine fishery, including *A. australis*, *R. sarba*, *P. auratus*, *S. ciliata*, *P. saltatrix* and several monacanthid species are targeted by recreational fishers and by other commercial fishers in estuarine gill-netting and trapping fisheries and in coastal beach-seining, trapping, trawling and handline fisheries in NSW and adjoining states (Kailola et al., 1993). Total catches and discarding of these species alone were highly variable in time in this fishery, thus making it difficult to minimize the discarding of these species via simple temporal closures. Moreover, year-to-year variations in catches need to be considered before generalizations can be made regarding the most appropriate times for temporal closures. Winter closures introduced in the coastal beach-seine fishery in False Bay, South Africa did not have the desired effect, primarily because they occurred in the wrong season to minimize catches of important species (Lamberth et al., 1995b). Greatest fishing effort in the Botany Bay beach-seine fishery occurs in the warmer months when other users of the waterway are also most active. However, a weekend and public holiday closure is already in place to help in minimizing conflict among the different user groups.

Discarding at the levels described here can have a range of impacts on interacting fisheries and stock assessments, but it is overly simplistic to assume that discarding is having a major impact on fish stocks. The direct effects of discarding are not known because they depend on several interacting factors, including the mortality of individuals following discarding, the proportion of the stock represented by discards, and the natural mortality that individuals would have experienced had they not been captured (Andrew and Pepperell, 1992; Pitcher and Chuenpagdee, 1994; Kennelly, 1995). Because many stock assessments rely on the reconstructions of age compositions of exploited populations (Megrey, 1989), inclusion of discard data can significantly alter assessments concerning the status of stocks (Alverson et al., 1994). Depending on the mortalities of discards, the age compositions of discards from all fisheries may need to be considered in stock assessments and included in models of the stock dynamics of these species. It is known, however, that not all fish die following discarding from beach-seining. West (1993) tagged and released fish (e.g. *A. australis*, *P. auratus* and *S. ciliata*) captured in commercial beach-seine-nets to determine their movement patterns and many of these fish survived several years prior to their subsequent recapture. Whilst the lack of much of the above information prevents us from estimating the effects of discarding on stocks of these species, the quantities of discards involved in this fishery (and presumably in similar estuarine beach-seine fisheries throughout NSW), indicate that it would be advisable for industry, managers and scientists to seek ways to reduce any negative effects of discarding on the fisheries resources and to reduce conflict among user groups.

Solutions to discarding problems in multi-species fisheries elsewhere include the development of more selective fishing gears and practices that minimize the capture of non-target species and undersized individuals of the target species. Discards accounted for a major proportion of the total catch of some of the target species, including *A. australis* and *S. ciliata* (Table 4), indicating that the relative selectivity of current beach-seine-nets requires attention (see also beach-seine-nets used in South African fisheries, e.g. Lamberth et al., 1994, 1995a). Although it is possible that by simply increasing the mesh size in these nets may decrease discards, more undersize fish may become gilled in the bunt of nets, increasing the mortality of discards (Kennelly and Gray, 2000). Discards may be less stressed and damaged in nets having finer meshed bunts and cod-ends than if larger mesh sizes were prescribed, particularly if fishers implement sorting practices that take place in water (and not on land or on boats). Further, an increase in mesh size may affect the retention of some species (e.g. *G. subfasciatus*) for which all sizes can be retained by fishers. Whilst transparent panels placed in the bunts of similar estuarine beach-seine-nets have proved successful in reducing the quantity of undersized sand whiting captured in nets (Gray et al., 2000), in this particular multi-species fishery in Botany Bay, many species of different morphologies are targeted, making it difficult to develop more selective gears. Despite such problems, fishers and scientists must work towards solutions. Most importantly, the mortality of discards in this fishery needs to be assessed in order to determine the actual impacts of discarding on targeted stocks and other fisheries.

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Appendix 4

Gray, C.A., Kennelly, S.J. (submitted manuscript). Catch characteristics of the commercial beach-seine fisheries in two Australian estuaries. Manuscript to be submitted to *Fisheries Research*.

Catch characteristics of the commercial beach-seine fisheries in two Australian estuaries

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Abstract

Scientific observers sampled the retained and discarded catches taken in two of the largest commercial beach-seine fisheries (Lake Macquarie and St Georges Basin) in New South Wales, Australia. Catches were sampled in each water body in each of four seasons throughout 1998/99 and the data were used to estimate the quantities and length compositions of species caught in these fisheries and to assess potential interactions with other fisheries. A total of 118 catches were sampled which yielded 72 finfish and 10 invertebrate species. Multivariate analyses showed that the structures of catches varied between estuaries, with 70 species (41 of which were retained) captured in Lake Macquarie and 37 species (26 retained) in St Georges Basin. Despite differences in the structure of catches between estuaries, the predominant species taken and patterns of discarding were similar in each fishery. The sparids *Rhabdosargus sarba*, *Acanthopagrus australis* and the gerreid *Gerres subfasciatus* were three of the four most abundant species caught in each estuary, with 99%, 88% and 34% of these species discarded, respectively. Compliance with minimum legal lengths (MLL) accounted for most discarding practices, but for those species with no MLL, discarding was generally market-driven and size-based. An estimated 65% by number and 57% by weight of the catch in Lake Macquarie and 77% by number and 59% by weight of the catch in St Georges Basin was discarded. We further estimated that a total of 468 t (269 t discarded) was caught in Lake Macquarie and 143 t (85 t discarded) was caught in St Georges Basin throughout the one year survey. We discuss our findings in relation to interactions with other regional fisheries and future management strategies.

Keywords: Discarding, Bycatch, Seine net, Estuarine fish assemblages, Australia

1. Introduction

The impacts of fishing on coastal fisheries resources and habitats have received a great deal of attention in recent years. In particular, there has been significant research to identify and resolve bycatch, discarding and wastage in many fisheries (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 a very wasteful practice and can lead to significant conflict among different resource interest groups. Discarding is therefore one of the foremost management concerns facing fisheries organizations throughout the world. Discards are often a major source of uncertainty in many fisheries assessments and it is well recognized that accurate and robust stock assessments need quantitative information concerning both the retained and discarded components of catches (Chen and Gordon, 1997; Hall, 1999).

Fundamental to any assessment of the ecological effects of any fishery is the need to identify and quantify the composition (species, quantities, length/age distributions) of the retained and discarded components of catches and how these vary spatially and temporally among different fishing operations (Alverson et al., 1994; Kennelly, 1995; Hall, 1999). In developing strategies to ameliorate and manage discarding, it is important to understand the selectivity of the fishing gears and the behaviors of the species captured (Chopin and Arimoto, 1995; Hall, 1999; Millar and Fryer, 1999; Broadhurst, 2000). Such information has been used successfully to reduce discarding and wastage in several demersal trawl fisheries (see Hall, 1999; Broadhurst, 2000; Kaiser and deGroot, 2000). There has been much less focus, however, on obtaining information on discarding and on managing its impacts in smaller-scale coastal fisheries, including those that use beach-seines (but see Lamberth et al., 1994, 1995a,b; Gray et al., 2000; Gray et al., 2001; Kennelly and Gray, 2000).

In New South Wales (NSW), Australia, commercial beach-seining (known locally as "fish hauling") is permitted in many estuaries, where it forms the basis of a regionally-based fishery that annually lands approximately 2,000 tonnes of finfish valued at approximately $AUD 5 million. As with coastal beach-seine fisheries in other parts of the world (e.g. South Africa - Lamberth et al., 1997) that take place in areas adjacent to populated centers and consequently attract significant public scrutiny and conflict, controversy surrounds the NSW fishery with several resource user groups recommending the method be banned (see Gray et al., 2001). The reasons for this are threefold: (1) disputes over resource allocation among interacting fisheries, (2) concerns over the sustainability of the shared resource and (3) environmental impacts of beach-seines on benthic habitats and discarded species. Most concerns stem from the fact that the primary species targeted and many of the discards in these fisheries are often important in other regional commercial and recreational fisheries (Lamberth et al., 1994; Gray et al., 2001). Whilst the composition of catches in coastal and embayment beach-seine fisheries in southern Africa and southeastern Australia have been documented, there is very limited data available for similar fisheries that occur in estuaries.

The aims of the current study were to redress the current lack of knowledge of the composition and quantities of the retained and discarded components of catches for the estuary-based beach-seine fisheries in NSW. We used an observer-based survey to quantify the species, quantities and length distributions of catches taken in two of the largest barrier estuaries in NSW, Lake Macquarie and St Georges Basin. We present a comparison of the catch characteristics among these estuaries and across four seasons in 1998/99. The data presented can be used to help develop ways to ameliorate discarding and to aid the development of management plans for these and similar fisheries.

2. Materials and methods

2.1. Study estuaries

Lake Macquarie (151°36′ E, 33°06′ S) and St Georges Basin (150°36′ E, 35°08′ S) are shallow (mean depth 25 and 15m, respectively), temperate, barrier estuaries (*sensu* Roy, 1984; Roy et al., 2001) (Fig. 1). Lake Macquarie has a surface water area of 125 km^2 and a catchment area of 700 km^2; St Georges Basin has a surface water area of 44 km^2 and a catchment area of 390 km^2 (Bell and Edwards, 1980). There is minimal riverine input into either estuary and because of their constricted entrances to the sea, wave currents dominate these estuaries. Except for the entrance channels, tidal flow is of the order of 10 cm/day, along a coast that typically experiences a 2 m rise and fall. Much of the land surrounding Lake Macquarie is urbanized, particularly the northern and western shores. In contrast, St Georges Basin is surrounded by more vegetated habitat, particularly along the eastern and southern shores. Both estuaries support commercial (beach-seine, gill net, crab trap and prawn seine) and recreational (line only) fisheries.

2.2. Commercial beach-seine fisheries

The estuarine beach-seine fisheries in NSW are managed by input controls, including spatial and temporal closures and gear restrictions including minimum and maximum mesh sizes and lengths of nets. Minimum legal length (MLL) restrictions are enforced for several species of fish. Beach-seine nets used in both estuaries are permitted to have a maximum headline length of 1000 m with a further 1000 m of hauling rope on each end which can be increased up to 2000 m of rope during the winter months of June to AuguSt The length of the bunt must not exceed a third of the total length of the net and it must include a center cod-end. Mesh sizes in the cod-end must be between 30 and 50 mm, whilst the mesh in the rest of the bunt must not exceed 57 mm and the mesh in the wings must not be less than 80 mm (Fig. 2).

Beach-seine nets are generally set in a semi-circular configuration from small (< 6 m) boats and are hauled back towards the shore by small winches (see Gray et al., 2000). Usually, fish are herded in front of the net during hauling and do not enter the codend until just prior to the cessation of seining when the net is landed in shallow water (see Gray et al., 2000). Because jellyfish and detached seagrass can affect hauling operations and the condition and mortality of fish captured, the codends in this fishery are often left open during most of the seining operation so that unwanted material passes through and does not accumulate in the codend. Thus, the codend is often tied closed just prior to landing the net. In each estuary, nets are generally landed against a backing net in about 1-m water depth and approximately 10-50 m offshore. Catches are generally sorted in waist-deep water, with the discards being allowed to swim out of the net whilst the fish to be retained are collected and placed in an adjacent boat. Generally, each crew in each estuary does one seine per day with the operation usually beginning around sunrise and taking between 1-3 hours to land the net. Depending on catch levels, however, sorting of the catch can often take several hours after the net is landed. Most seine crews consist of 3-4 persons and generally 2 or 3 boats are used in each operation.

Beach-seining is permitted in the southern half of Lake Macquarie and along all shores of St Georges Basin, except in Jewfish Bay, which is only open to seining in winter. Seining is not permitted in Lake Macquarie on weekends and public holidays to minimize potential conflicts with other users of the waterway. In St Georges Basin, fishers voluntarily agreed not to fish on weekends and public holidays.

2.3. Observer survey and sampling procedures

Scientific observers attempted to accompany commercial beach-seine crews on 16 randomly selected fishing trips (days) in each season between March 1998 and February 1999. Complete observer coverage was not achieved due to logistic constraints, so the minimum number of trips observed in any season was 12 (Table 1). For each observed haul, between 3 to 6 random samples of the total catch were obtained prior to it being sorted by the fishers. These samples were sorted into the retained and discarded components by a crewmember and the observer and the total numbers and weights of each individual species retained and discarded were recorded, as were the lengths (to the nearest 1-cm) of some key species. The total weights of each retained catch and of each individual species retained were obtained when fishers deposited and weighed each catch at the local fishers' cooperative. A ratio of sampled to total retained catch was determined for each sample and this ratio was used in estimating the total weight and number of the discarded catch. The weights and numbers of discards determined in each sample were multiplied by the appropriate ratio to obtain estimates of the total weight and number of discarded catch in each observed trip.

2.4. Data analyses

2.4.1. Variations in structures of catches

Non-parametric multivariate analyses were used to identify spatial and temporal differences in the structures (relative abundance of each species) of catches. The general procedures used followed those outlined in Clarke (1993) and Clarke and Warwick (1994). Data on the abundance of each individual species in each catch were 4th root transformed to ensure that each taxonomic grouping contributed fairly evenly to each analysis. Similarity matrices based on the Bray-Curtis similarity measure were generated 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 seasonal differences in the structures of catches. Similarity percentage analyses (SIMPER) were used to identify those species that were most responsible for the similarity of catches within each season, in addition to the overall dissimilarity among catches in Lake Macquarie and St Georges Basin. The ratio of mean/se 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, 1994).

2.4.2. Variations in rates of retained and discarded catches

Mean (± 1se) seasonal catch rates per haul were calculated for each estuary. Two-factor analyses of variance (ANOVA) were used to test for differences in weights and quantities of retained and discarded catches between the two estuaries and the four seasons. Prior to analyses, data were tested for homogeneity of variances using Cochran's test, and transformed to log (x+1) if necessary. SNK tests were used to determine differences among means following ANOVA. The ratios of weight of discarded catch to weight of retained catch were calculated for each estuary for the entire survey period following the procedures detailed in Cochran (1963).

2.4.3. Estimates of annual total retained and discarded catches in each estuary

Estimates of the total annual retained and discarded catches (± 1 se) by all beach-seine crews in each estuary were determined for the survey period. This was done by multiplying the observed seasonal mean catch rates per haul and the reported number of hauls completed by all seine crews in each estuary in each season between March 1998 and February 1999 (see Gray et al., 2001 for details). The latter fishing effort for each month (i.e. total number of hauls) was obtained from the forms that commercial fishers are required to submit to NSW Fisheries.

2.4.4. Length compositions of retained and discarded catches

Observed length compositions of the retained and discarded catches of each commercial species were scaled to represent the annual catch by all crews in each estuary. Length composition data were weighted according to the ratio of total fishing effort to sampling effort in each season and then summed to provide an annual distribution, from which a relative annual length compositions were calculated (see Liggins and Kennelly, 1996).

3. Results

3.1. Fishing and sampling effort

Total reported beach-seine fishing effort in the number of fisher-days (1 day = 1 haul) was greater in Lake Macquarie than in St Georges Basin in each season throughout the 1 year survey (Table 1). Fishing effort was greatest in autumn and winter in Lake Macquarie, but was greatest in spring in St Georges Basin. Throughout the survey period, 5 crews reported fishing in Lake Macquarie whereas 3 crews reported fishing in St Georges Basin. A total of 58 fisher days in Lake Macquarie and 60 days in St Georges Basin were sampled throughout the survey which represented 8.4% and 24.2% of the total reported fishing days in each estuary respectively.

3.2. Retained and discarded catch composition

A total of 72 finfish and 10 invertebrate species were identified in catches throughout the survey; 70 species in Lake Macquarie and 37 species in St Georges Basin. The structure of catches differed between estuaries (ANOSIM, $R = 0.704$, $p < 0.001$; Fig. 3) and the SIMPER analysis identified the 25 species that accounted for 75% of the observed dissimilarities (Table 2). Inter-estuary differences were mostly attributable to greater abundances of *Sillago maculata*, *Gerres subfasciatus*, *Sepiothetus australis* and *Pagrus australis* in Lake Macquarie, whereas abundances of *Sillago ciliata*, *Pelates sexlineatus*, *Pseudocaranx dentex* and *Acanthopagrus australis* were greatest in St Georges Basin. The structure of catches also varied among seasons within each estuary (ANOSIM, Table 3) and the species most responsible for the similarities in catch structure within each season are given in Table 4. Several species, including *G. subfasciatus* and *Rhabdosargus sarba,* were dominant in all seasons in both estuaries.

Fishers retained a total of 41 species in Lake Macquarie and 26 species in St Georges Basin, whilst individuals of 64 species were discarded in Lake Macquarie and individuals of all 37 species were discarded in St Georges Basin. Twenty-nine species were solely discarded in Lake Macquarie and 11 species in St Georges Basin. In total, 65% by number and 57% by weight of the catch in Lake Macquarie was discarded, whilst 77% by number and 59% by weight of the catch in St Georges Basin was discarded (Tables 5 and 6).

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Acanthopagrus australis, *R. sarba* and *G. subfasciatus* were among the four most numerically abundant species caught in both estuaries, with significant numbers contributing to both the retained and discarded components of catches (Tables 5 and 6). Up to 99% of *R. sarba*, 88% of *A. australis* and 34% of *G. subfasciatus* were discarded. Other numerically dominant species observed in catches in both estuaries included *P. sexlineatus*, *P. auratus*, *Girella tricuspidata* and *Pomatomus saltatrix*, with > 60% of each species being discarded. Cephalopods, *S. maculata* and *Mugil cephalus* were numerically abundant in catches in Lake Macquarie but not in St Georges Basin, whereas the opposite was observed for *Pseudocaranx dentex* and *S. ciliata*. In both estuaries, species that were only discarded were dominated numerically by *Dicotylichthys punctulatus*, whilst in Lake Macquarie, *Leiognathus* sp. and *Herklotsichthys castelnaui* were also only discarded in numerically large numbers. The six species that were solely retained in Lake Macquarie (*Argyrosomus japonicus*, *Sphyrna* sp., *Rachycentron canadum*, *Scylla serrata*, *Octopus* sp., *Chelidonichthys kumu*) were relatively rare and occurred in very low abundances (estimated < 100 individuals of each species caught per year).

3.3. Variation in rates of capture of retained and discarded species

A greater mean number of species and total individuals were discarded than retained in each season in both estuaries (Fig. 4). This pattern was also evident for mean weights of catches in all seasons in Lake Macquarie, and in winter and summer in St Georges Basin. A greater number of retained and discarded species were captured in Lake Macquarie than in St Georges Basin in each season (ANOVA, Table 7).

Seasonal trends in retained and discarded catches varied between estuaries (Fig. 4, Table 7). A greater number of species were retained in summer in St Georges Basin, but no such trend was evident in Lake Macquarie. No seasonal trend was evident in the number of species discarded in St Georges Basin, whereas fewer species were discarded in spring in Lake Macquarie. Overall, discarding (by weight and number) was greatest in autumn and summer in Lake Macquarie, but in winter and summer in St Georges Basin. Conversely, retained catches (by weight and number) were greatest in autumn in Lake Macquarie, but in summer (weight) and winter (number) in St Georges Basin.

Spatial and temporal variations in retained and discarded catch rates of several important species are shown in Fig. 5. More *A. australis*, *R. sarba* and *P. auratus* were discarded than retained in each season in both estuaries. This was also evident for *P. saltatrix* in Lake Macquarie and *S. ciliata* and *M. chinensis* in St Georges Basin. No clear discarding patterns were evident for the other important species shown, with more of one species being discarded in a particular season but more retained in another season. For example, in St Georges Basin, more *P. dentex* were discarded than retained in autumn and winter, whereas the opposite occurred in summer. Relationships between retained and discarded catch rates of most species also varied between seasons and estuaries. For example, rates of discarding of *S. maculata* in Lake Macquarie were similar across seasons, whereas retained catch rates were greater in autumn and winter compared to spring and summer.

Although most species shown were caught in each season in both estuaries, species-specific spatial and temporal fluctuations in retained and discarded catches were evident. Overall, retained and discarded catch rates of *S. maculata* and *G. subfasciatus* and discarded catch rates of *P. saltatrix* were greater in Lake Macquarie than in St Georges Basin. Conversely, retained and discarded catch rates of *S. ciliata* and *P. dentex* were greater in St Georges Basin.

Trends in seasonal retained and discarded catch rates often varied between estuaries and were also species-specific. For example, discarded catch rates of *A. australis* and *R. sarba* were least in winter in Lake Macquarie, but were greatest in winter in St Georges Basin. Further, retained catch rates of *G. subfasciatus* were greatest in autumn in Lake Macquarie, but in winter in St Georges Basin.

3.4. Estimates of annual retained and discarded catches

Estimates of total annual retained and discarded catches for the predominant species by the entire beach-seine fishery in each estuary are provided in Tables 5 and 6. It was estimated that a total of 468 tonnes (approx. 6,025,000 individuals) was caught in Lake Macquarie and 143 tonnes (approx. 1,234,000 individuals) in St Georges Basin throughout the one-year survey. Estimated total retained catches were greater in Lake Macquarie (by a factor of 4.9 by number and 3.3 by weight) than in St Georges Basin. A similar trend was also evident for several important species, including *A. australis*, *R. sarba*, *P. auratus*, *S. maculata* and cephalopods which were captured in significantly greater numbers in Lake Macquarie. Estimated total discards

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in both estuaries were dominated numerically by *G. subfasciatus* and *R. sarba* in Lake Macquarie and *R. sarba* and *A. australis* in St Georges Basin.

Total retained to discarded catch ratios by weight (pooled over the entire survey) were 1: 1.35 and 1:1.46 for Lake Macquarie and St Georges Basin, respectively.

3.5. Length compositions of retained and discarded catches

The length compositions of important fish species retained and discarded are shown in Fig. 6. The existence of minimum legal lengths (MLL) explained the length-based discarding of most species, including high value species such as *A. australis, R. sarba, P. auratus, S. ciliata*. Although there is no MLL on *S. maculata, G. subfasciatus, M. trachylepis* and *M. chinensis*, generally only the larger individuals were retained. The length composition of catches of most species was similar in each estuary.

Discussion

In any study designed to quantify retained and discarded catches, several inherent assumptions are usually required. In this study, the specific assumptions underlying the accuracy of our estimates are: (1) the actual days and hauls randomly selected for sampling were representative of hauls done by all fishers; (2) there were no systematic measurement errors made by the observers; (3) the presence of an observer did not influence normal fishing operations and sorting practices; (4) the reported fishing effort in terms of the numbers of days fished by each crew was accurate; and (5) the estimates of total discarded catches assumed that individual fish were not captured more than once. Our attempts to select the days fished and the actual fishers at random supports assumptions 1, 2 and 3 but we acknowledge that the presence of an observer may have affected some sorting practices and, unfortunately, it was beyond the scope of this project to examine the validity of assumptions 4 and 5. Nevertheless, the data presented here and in Gray et al. (2000; 2001) have revealed several general conclusions concerning the spatial and temporal variabilities in catches and the relative non-selectivity of the fishing gears used in estuarine beach-seine fisheries in NSW.

The multivariate analyses (Table 2 and Fig. 3) showed two distinctly different estuarine fisheries, i.e. the compositions and relative abundances of catches differed between estuaries in all seasons. In particular, nearly double the number of species was observed in catches in Lake Macquarie compared to St Georges Basin and several species were relatively abundant in one estuary but virtually absent in the other (e.g. *S. maculata* was common only in Lake Macquarie, whereas the opposite was evident for *S. ciliata*). Observed catch rates of several species were also consistently greater in one estuary; e.g. the mean seasonal catch rates of *G. subfasciatus, D. punctulatus and P. saltatrix* in Lake Macquarie were more than double those in St Georges Basin.

We can infer from these results the somewhat obvious conclusion that the catch characteristics of estuarine beach-seine fisheries probably differ due to basic differences in the faunal assemblages in the estuaries throughout the year which are, in turn, caused by a suite of abiotic and biotic factors such as the effects of estuarine geomorphology on hydrographic conditions and water circulation, rates of immigration and emigration of individual species and recruitment fluctuations. An important implication of this conclusion is that fishing-induced impacts on species and the estuarine systems in which they occur will vary substantially among estuaries, forcing any solutions to ameliorate such impacts to be done on an estuary-specific basis. Spatio-temporal interactions such as these are not uncommon in estuarine and coastal ichthyofaunal assemblages and their associated fisheries, making the management of these types of fisheries (and their very significant discarding problems) among the most complex of any fishery-type in the world.

Despite the observed overall differences in beach-seine catches between estuaries, the principal species caught and their patterns of discarding in each fishery were, in general, similar, with sparids, sillaginids and a gerreid numerically dominating catches; R. *sarba*, *A. australis* and *G. subfasciatus* were among the 4 most commonly abundant species captured in each estuary. The predominant species caught (retained and discarded) in these estuarine fisheries was also similar to those observed in the nearby coastal embayment beach-seine fishery in Botany Bay (Gray et al., 2001) except that in Botany Bay, more marine-dominated species (e.g. *Anoplocapros inermis*, *Scobinichthys granulatus*, *P. dentex*) were observed in catches.

Although most species were caught throughout the year, trends in retained and discarded catch rates were species-specific and varied between estuaries and seasons. That is, temporal (seasonal) changes in the capture of individual species and of the total retained and discarded catches were not the same in both water bodies. For example, the total catches (by number and weight) were greatest in winter in St Georges Basin, but in autumn and summer in Lake Macquarie.

The estimated total catch of the fishery in Lake Macquarie was greater by a factor of 4.9 by weight and 3.3 by number than that in St Georges Basin and was partly related to the greater reported fishing effort (x 2.8) in the former. Similarly, the estimated total retained and discarded catches of several of the predominant species, including *A. australis*, *R. sarba* and *G. subfasciatus*, were significantly greater in Lake Macquarie than in St Georges Basin. The total catch in the Botany Bay beach-seine fishery was estimated by Gray et al. (2001) to be 245 t which falls between the 468 tonnes for Lake Maquarie and the 143 tonnes for St Georges Basin. In all 3 fisheries, discards were dominated by large numbers of several important species including *A. australis* and *R. sarba*. In the Botany Bay fishery, the overall discard ratio by weight (38%) was less than that observed in the fisheries described here (57-59%). This was also evident for several individual species; e.g. an estimated 85-88% of *A. australis* were discarded in the estuarine fisheries compared to 69% in Botany Bay. Such a trend probably reflects the relative role played by barrier estuaries in providing a nursery function to small fish compared to coastal embayments and nearshore environments like Botany Bay.

The data in this paper have shown that, in general, the beach-seine nets as currently configured and used in the estuarine fisheries of NSW are relatively non-selective in that they catch a wide range of species of differing morphologies and sizes. This is typical of other coastal beach-seine fisheries throughout the world (Jones, 1982; Lamberth et al., 1995a) and is the underlying cause of many debates concerning the potential ecological impacts of these types of fisheries.

The observed patterns of discarding in Lake Macquarie and St Georges Basin were basically the same and comparable to those observed in the Botany Bay beach-seine fishery (Gray et al., 2001) with the enforcement of minimum legal lengths being the principal reason for discarding of many species. The discarding of commercial species with no MLL (e.g. *G. subfasciatus*, *M. trachylepis*) was subjective but generally length-based, with mostly larger individuals being retained for sale to satisfy a particular market. This selection varied slightly between crews and hauls depending on the quantity and composition of the total catch and the willingness to sort these species by size on any given day. Overall, more species were discarded than retained in Lake Macquarie and St Georges Basin with all individuals of many species being discarded regardless of size because they were of little commercial or recreational value.

As in other multi-species fisheries, including other beach-seine fisheries in Australia (Gray et al., 2001) and South Africa (Lamberth et al., 1984, 1985a,b), the discards sampled in the present study contained juveniles of most of the primary target species. For some of these, the discarded component exceeded the retained catches. For example, up to 88% of the total catches of *A. australis* and 99% of *R. sarba* and *P. auratus* (a total of more than 10 t) were discarded. These same trends were evident in the Botany Bay fishery (Gray et al., 2001) and highlight how these nets are not effective in catching these targeted species selectively. With the exception of *G. subfasciatus*, most of the primary species captured in these beach-seine fisheries are also targeted in other commercial and recreational fisheries in southeastern Australia, causing significant conflict with other users and the concerns over wastage mentioned earlier.

Whilst we observed quite high levels of discarding, this study has not determined the actual impacts of this discarding on stocks. Nevertheless, our observers found that not all fish die following discarding from these estuarine beach-seine fisheries. A field-based study done in St Georges Basin showed that when catches were sorted in water and handled appropriately, it was possible to achieve less than 5% mortality for discarded *R. sarba*, *P. auratus* and *A. australis* (Gray et al., in prep.). Several tagging studies done in NSW on fish discarded after normal commercial beach-seining operations have had fish recaptured several years after release, further illustrating the significant survival of beach-seined fish (West, 1993). It is therefore unrealistic to assume that all (or even most) fish die as a result of discarding - such an assumption would seriously overestimate the potential impacts of discarding in these fisheries. Further, the estimated magnitude of discarding in these fisheries may not be as great as that indicated, because fish may be caught more than once and so our estimates of discards may not represent real losses to populations (see Assumption 5 above). For some species, however, it is known that post-release mortality is relatively high (e.g. 65% for *G. subfasciatus*) and the presence of jellyfish (e.g *Catostylus mosaicus*) in catches can increase the mortality of individual fish if they are stung while crowded in bunts and codends. There is, therefore, the potential that the capture and subsequent discarding of some species in this fishery may have significant impacts at certain times and any such impacts would be species-specific.

Given the species compositions and quantities of discards involved in the estuarine beach-seine fisheries described here and in Gray et al. (2001), the low survival rates observed for some species and the community-based concerns over discarding in these fisheries, it is clear that industry, managers and scientists need to seek ways to alleviate any potential negative effects of discarding in this fishery. Most discarding problems in fisheries are ameliorated using two categories of management strategies: (i) spatial and temporal closures to fishing or (ii) the implementation of more selective fishing gears and practices. Given the large spatial and temporal fluctuations in retained and discarded catches identified in the present study, it would be difficult to manage these issues via fixed spatial and temporal closures without significant impacts on the levels of retained landings. It may be possible, however, to reduce discarding problems and still maintain acceptable levels of retained catches via flexible spatial and temporal closures that are identified by continuing, large-scale observer programmes but such a strategy would cost a significant proportion of the value of most of these small-scale fisheries.

Mesh size restrictions are often used to regulate the sizes of fish caught in net-based fisheries and research has shown that the inclusion of transparent panels and increasing the minimum mesh size in the bunts of beach-seine nets can reduce the capture and subsequent discarding of some sizes of some species (Gray et al., 2000; Kennelly and Gray, 2001). However, given the wide size range, diversity and morphologies of fishes involved in these fisheries, it is clear that no single mesh size or simple gear modification would allow the harvest all desired sizes of all targeted species whilst minimizing the discarding of most of the undesired individuals. However, pre-requisite to determining the most appropriate gear configurations to use in these fisheries, industry and managers must assign relative priorities in terms of minimizing the discarding of each species compared to maximizing the retention and/or conservation of those and other species.

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Figure captions

Figure 1. Map of southeastern Australia showing Lake Macquarie and St Georges Basin.

Figure 2. Diagram of a beach-seine net.

Figure 3. MDS ordination showing differences in the structure of catches between estuaries.

Figure 4. Mean (+1se) numbers of retained and discarded species, total weights and total numbers of individuals taken in each season in each estuary.

Figure 5. Mean (+1se) numbers of retained and discarded catches of individual species.

Figure 6. Size compositions of retained and discarded catches.

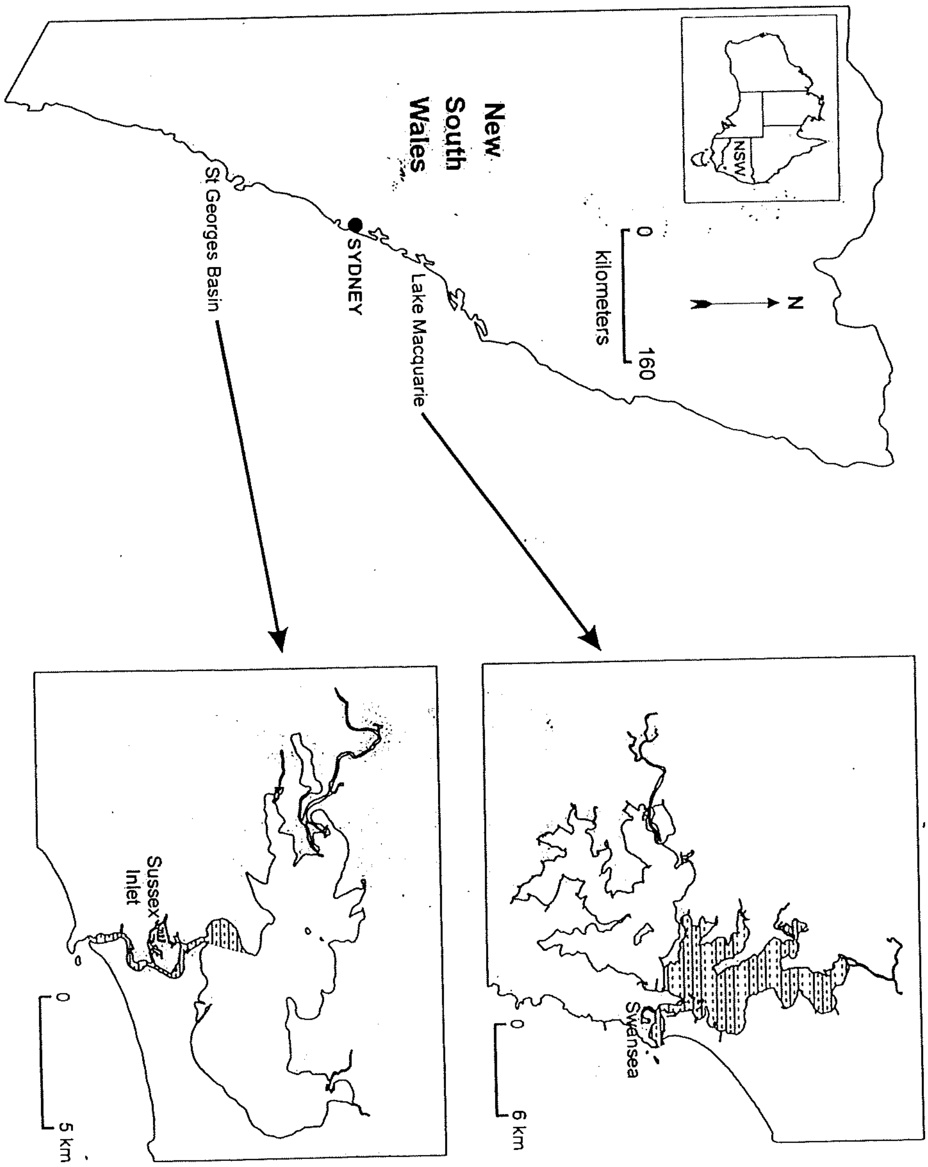
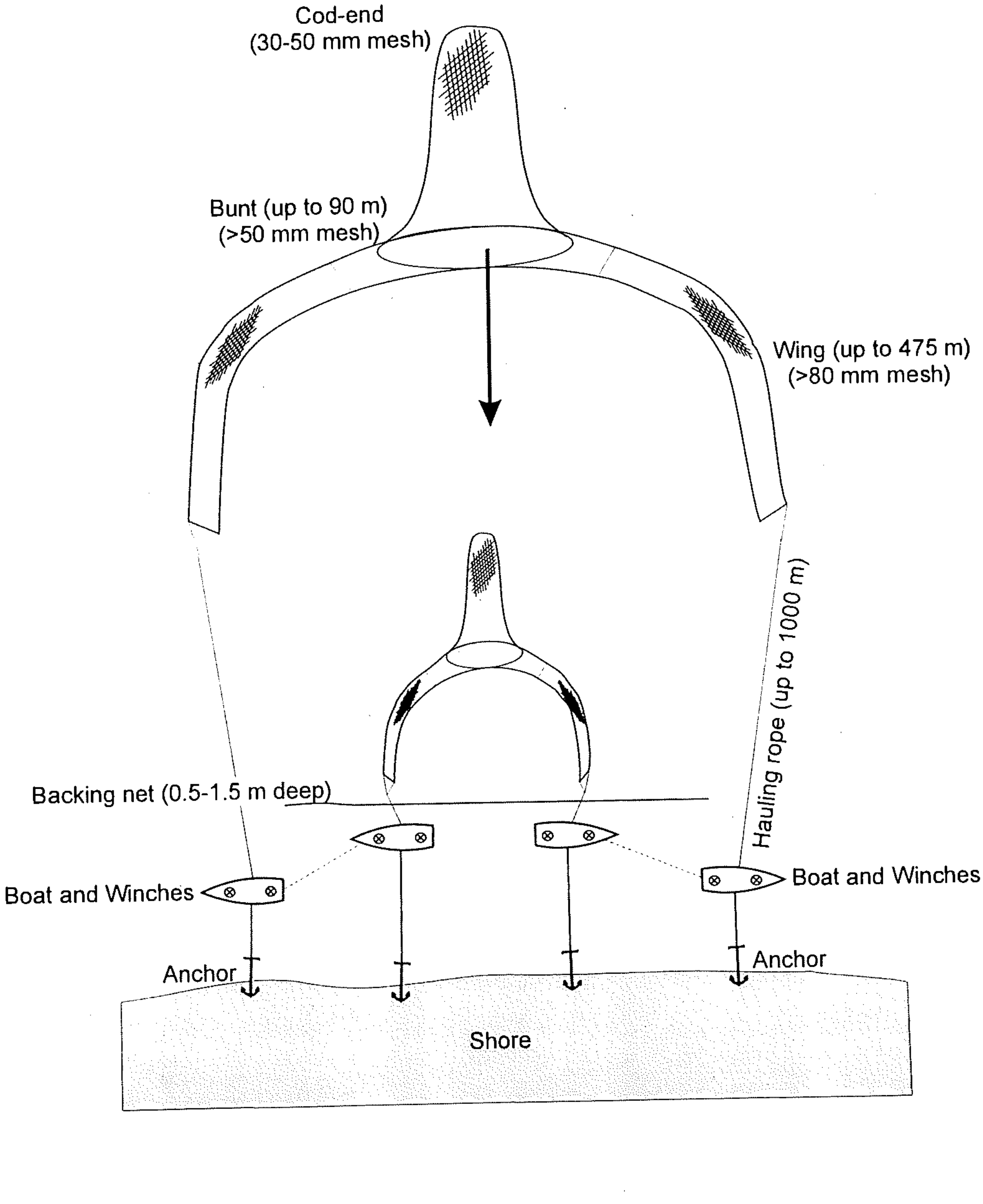

New South Wales
NSW
0
160
kilometers
N
SYDNEY
Lake Macquarie
St Georges Basin
Sussex Inlet
0
5 km
Swansea
0
6 km

Fig.1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(30-50 mm mesh)
Bunt (up to 90 m)
(>50 mm mesh)
Wing (up to 475 m)
(>80 mm mesh)
Hauling rope (up to 1000 m)
Backing net (0.5-1.5 m deep)
Boat and Winches
Boat and Winches
Anchor
Anchor
Shore

Fig. 3

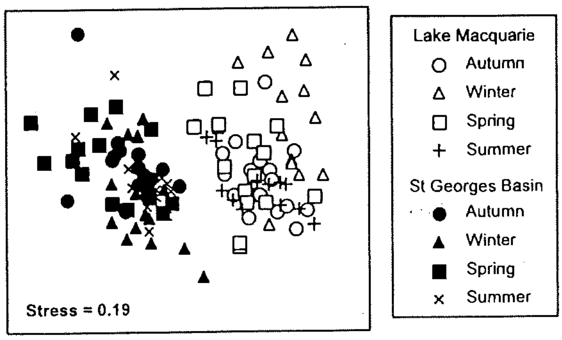
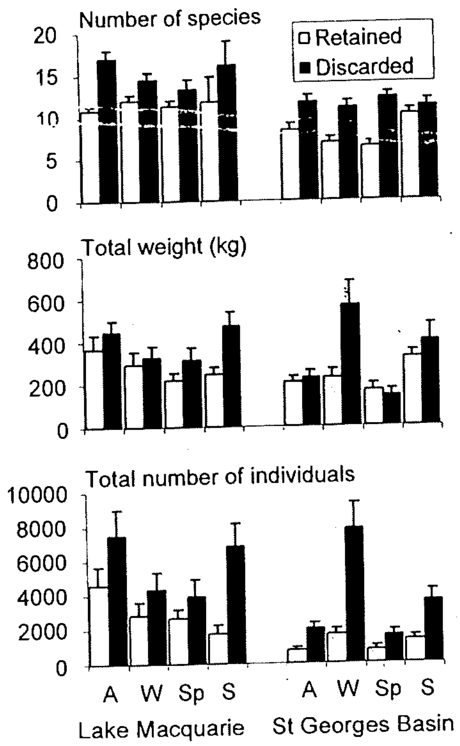

Stress = 0.19
Lake Macquarie
Autumn
Winter
Spring
Summer
St Georges Basin
Autumn
Winter
Spring
Summer

Fig. 4


Number of species
□ Retained
■ Discarded
20
15
10
5
0
Total weight (kg)
800
600
400
200
0
Total number of individuals
10000
8000
6000
4000
2000
0
A W Sp S
A W Sp S
Lake Macquarie
St Georges Basin

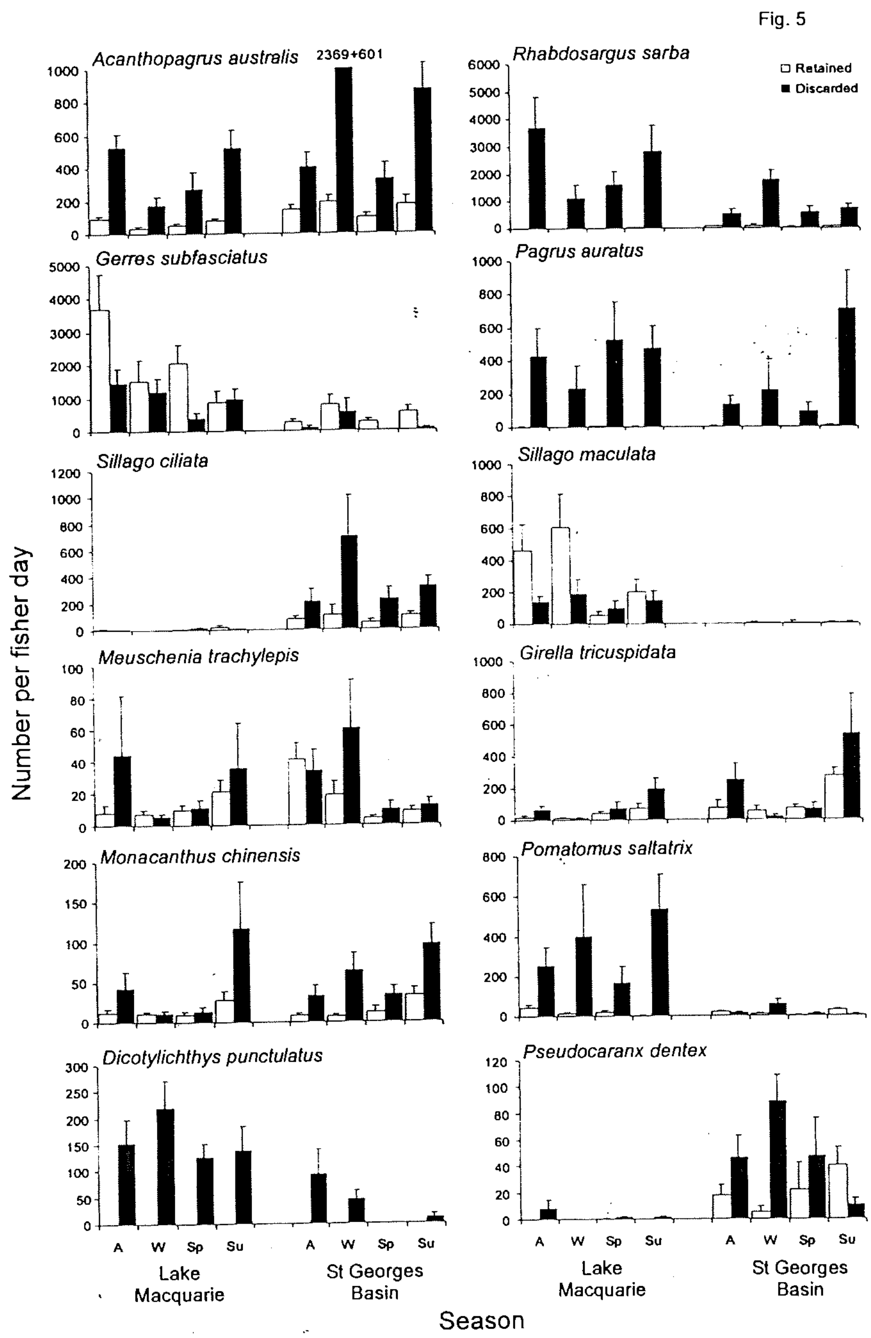
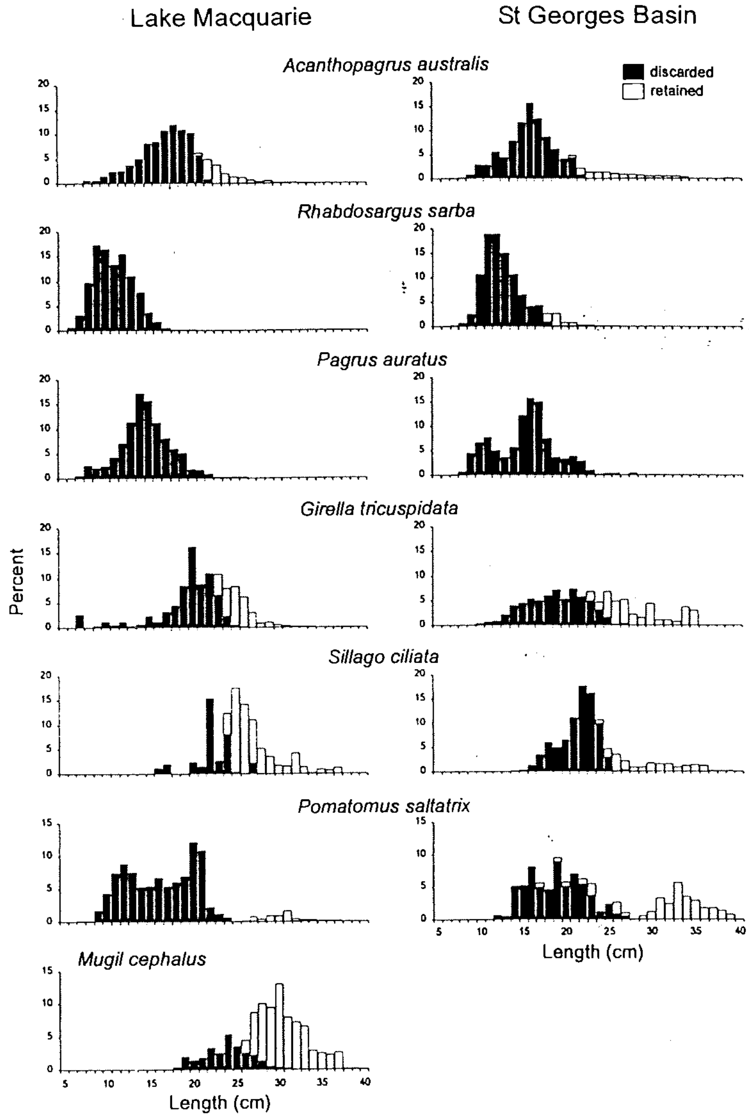


Fig. 5
□ Retained
■ Discarded
Acanthopagrus australis
2369+601
Rhabdosargus sarba
Gerres subfasciatus
Pagrus auratus
Sillago ciliata
Sillago maculata
Meuschenia trachylepis
Girella tricuspidata
Monacanthus chinensis
Pomatomus saltatrix
Dicotylichthys punctulatus
Pseudocaranx dentex
Number per fisher day
A W Sp Su A W Sp Su
Lake Macquarie
St Georges Basin
Season

Fig. 6


Lake Macquarie
St Georges Basin
discarded
retained
Acanthopagrus australis
Rhabdosargus sarba
Pagrus auratus
Girella tricuspidata
Sillago ciliata
Pomatomus saltatrix
Mugil cephalus
Percent
Length (cm)
Length (cm)

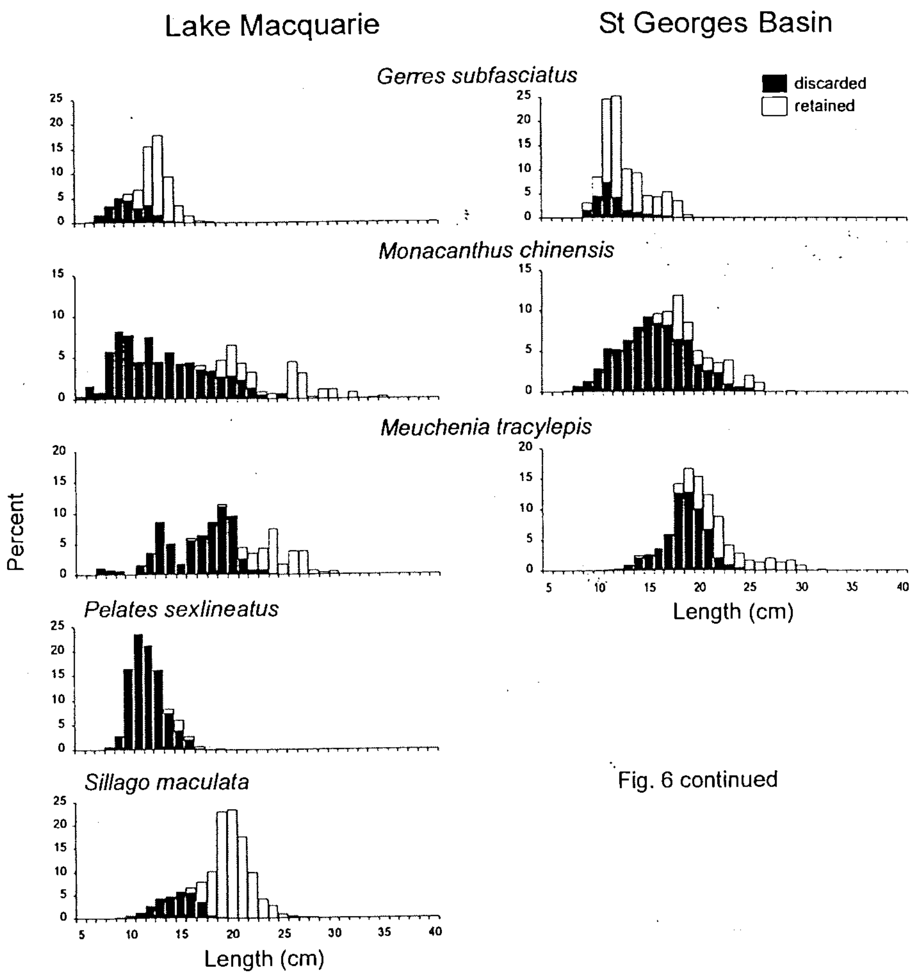


Fig. 6 continued

Table 1. The total number of reported fishing days (hauls) and sampled days (hauls) in each season in Lake Macquarie and St Georges Basin during the study. The percentage of all fisher-days sampled is given for each estuary.

		Lake Macquarie		St Georges Basin	
		Fishing days	Sample days	Fishing days	Sample days
Season	Months				
Autumn	(Mar-May 98)	195	17	67	14
Winter	(Jun-Aug 98)	208	14	54	15
Spring	(Sep-Nov 98)	131	15	82	16
Summer	(Dec-Feb 99)	154	12	45	15
Total (% coverage)		688	58 (8.4%)	248	60 (24.2%)

Table 2. The twenty-five species that contributed greatest to the dissimilarity between observed beach-seine catches in Lake Macquarie and St Georges Basin. Average catch per haul (pooled across all samples), the ratios of average catch to the standard error and the percentage contribution of each species to the dissimilarity between estuaries are shown.

Species	Average catch L. Macquarie	St G Basin	Ratio (mean/se)	Percent contribution
S. maculata	504.55	7.40	1.79	5.99
G. subfasciatus	3104.16	866.46	1.4	5.46
S. ciliata	14.32	406.99	1.65	5.12
S. australis	159.62	0	1.46	4.64
P. auratus	421.87	292.59	1.37	4.50
D. punctulatus	168.11	28.27	1.62	4.34
P. sexlineatus	342.68	555.36	1.33	4.29
M. cephalus	147.35	5.12	1.33	4.04
R. sarba	2388.97	1177.89	1.26	3.84
P. dentex	3.03	60.80	1.78	3.80
G. tricuspidata	123.71	360.05	1.28	3.73
P. saltatrix	380.58	41.98	1.33	3.58
A. australis	446.89	1395.09	1.16	3.43
L. argentea	113.39	16.90	1.28	3.34
H. castelnaui	89.82	3.27	0.90	2.67
P. fuscus	10.85	61.44	1.37	2.58
P. pelagicus	17.14	0.80	1.56	2.57
M. trachylepis	41.90	48.17	1.36	2.36
T. novaezealandi	13.31	35.16	0.86	2.13
M. chinensis	66.76	71.22	1.26	2.09
T. hamiltoni	15.84	0.51	1.03	2.06
Leignothus sp.	120.01	0	0.67	2.05
H. regularis	18.43	0	0.85	1.78
Sepia sp.	16.28	0	0.68	1.51
Urolophus testaceos	10.91	0	0.78	1.46

Table 3. Summary of ANOSIM results comparing the structure of beach-seine catches between seasons in Lake Macquarie and St Georges Basin. 5000 permutations were used in each test.

	Lake Macquarie		St Georges Basin	
	R statistic	Significance	R statistic	Significance
Global test	0.221	0.00%	0.231	0.00%
Autumn v Winter	0.295	0.00%	0.243	0.00%
Autumn v Spring	0.163	0.30%	0.206	0.10%
Autumn v Summer	0.113	3.50%	0.237	0.00%
Winter v Spring	0.238	0.10%	0.314	0.00%
Winter v Summer	0.423	0.00%	0.3	0.00%
Spring v Summer	0.171	1.00%	0.176	0.20%

Table 4. The 10 species that contributed greatest to the similarities in beach-seine catches in each season in Lake Macquarie and St Georges Basin. Ratio = ratio of average catch to standard error, % = percent contribution of each species to the total similarity in season in each estuary.

	Lake Macquarie				St Georges Basin		
Species	Av. Catch	Ratio	%	Species	Av. Catch	Ratio	%
Autumn							
R. sarba	5128.03	3.68	14.92	*A. australis*	614.02	5.93	14.99
S. maculata	3692.7[illegible]	4.61	13.14	*R. sarba*	603.13	4.22	13.52
A. australis	622.88	3.56	9.47	*S. ciliata*	311.43	3.21	10.37
S. maculata	596.46	4.75	8.39	*M. trachylepis*	76.84	4.63	8.44
P. saltatrix	296.27	3.95	7.05	*P. dentex*	66.06	4.64	8.25
D. punctulatus	154.10	7.27	6.53	*G. tricuspidata*	381.05	1.85	8.21
P. sexlineatus	306.27	2.13	5.95	*G. subfasciatus*	344.80	1.38	7.62
P. auratus	431.15	1.08	4.77	*P. auratus*	142.08	1.19	6
G. tricuspidata	86.79	2.17	4.66	*P. saltatrix*	31.45	1.9	5.95
M. chinensis	54.68	5.26	4.48	*M. chinensis*	46.33	2.02	5.95
Winter							
R. sarba	1114.15	3.63	10.88	*A. australis*	2894.25	4.36	18.27
G. subfasciatus	2720.50	1.64	10.54	*R. sarba*	2132.10	3.75	17.04
D. punctulatus	218.68	2.24	8.67	*G. subfasciatus*	1627.82	3.21	13.04
S. maculata	790.75	1.32	7.92	*P. sexlineatus*	1244.83	1.1	7.72
P. saltatrix	413.41	3.26	7.14	*P. dentex*	93.36	1.71	6.49
A. australis	213.07	2.27	7.06	*P. saltatrix*	76.80	2	5.86
S. australis	274.33	1.17	6.56	*M. chinensis*	71.58	1.65	5.78
L. argentea	323.57	2.49	6.19	*S. ciliata*	810.72	1.06	5.56
P. sexlineatus	323.78	1.34	5.85	*M. trachylepis*	74.82	2.08	5.52
M. chinensis	22.01	4.09	5.14	*P. fuscus*	47.22	1.15	3.33
Spring							
G. subfasciatus	2423.54	5.05	17.02	*A. australis*	382.25	5.77	14.4
R. sarba	1596.43	3.84	13.59	*R. sarba*	601.27	3.42	13.4
A. australis	324.64	6.18	9.36	*G. subfasciatus*	410.23	3.17	11.48
S. australis	164.07	2.24	7.03	*G. tricuspidata*	129.60	4.21	10.9
D. punctulatus	126.04	2.17	6.7	*S. ciliata*	246.15	1.48	8.15
P. auratus	535.80	0.97	5.57	*P. fuscus*	58.33	3.18	6.95
S. maculata	150.26	1.54	5.13	*P. sexlineatus*	195.55	1.11	6.31
P. sexlineatus	326.58	1.44	4.98	*M. trachylepis*	12.41	4	5.94
P. saltatrix	185.50	1.3	4.42	*M. chinensis*	42.19	1.24	5.35
M. chinensis	23.49	1.44	3.48	*P. auratus*	104.99	0.94	4.89
Summer							
R. sarba	2854.45	4.38	12.58	*A. australis*	1006.48	5.51	13.41
A. australis	606.28	5.07	9.53	*R. sarba*	830.82	7.14	12.99
G. subfasciatus	1848.28	1.72	8.83	*G. tricuspidata*	731.39	4.78	11.4
P. saltatrix	534.82	3.37	7.06	*S. ciliata*	498.99	2.8	9.19
S. maculata	346.19	4.34	6.81	*P. sexlineatus*	418.07	2.12	7.71
P. sexlineatus	462.44	1.42	6.22	*G. subfasciatus*	529.90	1.48	7.44
G. tricuspidata	267.30	1.82	5.96	*M. chinensis*	127.08	4.44	7.4
P. auratus	478.39	1.31	5.86	*P. auratus*	677.77	1.76	7.36
D. punctulatus	138.80	2.13	5.34	*P. fuscus*	93.64	3.91	6.96
M. cephalus	229.06	1.84	5.18	*P. saltatrix*	45.69	4.24	5.91

Table 5. Estimated total retained and discarded catches of the 25 most numerically abundant species caught in the beach-seine fishery in Lake Macquarie between March 1998 and February 1999.

Species	Common name	Retained Number	SE	Discarded Number	SE	Discarded %	Retained Weight (kg)	SE	Discarded Weight (kg)	SE	Discarded %
Total individuals		2095466	278981	3929144	431761	65.2	199023	19560	269229	20032	57.0
Gerres subfasciatus	Silver biddy	1439162	259044	728787	132588	33.6	74285	14293	18883	3931	20.3
Rhabdosargus sarba	Tarwhine	5887	1729	1594651	288761	99.6	1000	342	63135	11270	98.4
Sillago maculata	Trumpeter whiting	253718	55522	100065	24006	28.3	23896	5241	3880	933	14.0
Acanthopagrus australis	Bream	45501	4305	256172	28699	84.9	15443	1725	33119	3607	68.2
Pagrus auratus	Snapper	1408	504	274905	56941	99.5	476	156	27309	5153	98.3
Pomatomus saltatrix	Tailor	14101	3617	236322	63492	94.4	5570	1533	15763	6003	73.9
Pelates sexlineatus	Trumpeter six-lined	9842	5704	231225	38333	95.9	638	349	7002	1211	91.7
Dicotylichthys punctulatus	Porcupinefish	0	0	113422	15762	100.0	0	0	61437	8660	100.0
Sepioteuthis australis	Southern calamari	87497	13725	20897	8788	19.3	7678	1003	615	277	7.4
Mugil cephalus	Sea mullet	73867	15104	30385	9371	29.1	30501	6144	5757	1449	15.9
Liza argentea	Flat-tail mullet	45822	27275	35190	19046	43.4	12297	6981	5290	2140	30.1
Girella tricuspidata	Luderick	22890	5897	55188	12347	70.7	7704	1922	9441	2253	55.1
Leiognathus sp.	Ponyfish	0	0	77885	29338	100.0	0	0	764	320	100.0
Herklotsichthys castelnaui	Southern herring	0	0	50317	14229	100.0	0	0	1246	305	100.0
Monacanthus chinensis	Fanbelly leatherjacket	10176	2201	30436	9861	74.9	2414	499	2367	776	49.5
Meuschenia trachylepus	Yellow-finned leatherjacket	7521	1633	16730	8472	69.0	1891	399	1690	904	47.2
Nototodarus gouldi	Arrow squid	16001	12004	74	52	0.5	1051	789	3	2	0.3
Sepia sp.	Cuttlefish	8831	3018	3231	983	26.8	1067	329	436	197	29.0
Portunus pelagicus	Blue swimmer crab	7416	1769	3931	1369	34.6	2316	523	568	187	19.7
Hyporhamphus regularis	River garfish	9708	2248	1517	890	13.5	700	153	105	51	13.0
Tetractenos hamiltoni	Toadfish	0	0	10647	3229	100.0	0	0	428	141	100.0
Selenotoca multifasciata	Striped butterfish	2632	1473	7436	3811	73.9	652	358	786	327	54.6
Sillago ciliata	Sand whiting	6030	2495	3354	1042	35.7	1593	664	428	146	21.2
Trachurus novaezelandi	Yellowtail	2303	1394	5131	1922	69.0	216	139	418	255	65.9
Trygonoptera testacea	Stingaree	0	0	7192	1769	100.0	0	0	3976	1123	100.0
Remaining 45 species		25151		34054		57.5	7633		4383		36.5

Table 6. Estimated total retained and discarded catches of the 25 most numerically abundant species caught in the beach-seine fishery in St Georges Basin between March 1998 and February 1999.

Species	Common name	Retained Number	SE	Discarded Number	SE	Discarded %	Retained Weight (kg)	SE	Discarded Weight (kg)	SE	Discarded %
Total individuals		283243	35182	955166	135837	77.1	57919	4509	84794	10190	59.4
Acanthopagrus australis	Bream	36527	4581	276242	7239	88.3	13022	12	31382	734	70.7
Rhabdosargus sarba	Tarwhine	15347	3758	241779	4853	94.0	3559	7	13246	233	78.8
Gerres subfasciatus	Silver biddy	145407	32831	43342	3221	23.0	10583	21	1633	109	13.4
Pelates sexlineatus	Six-lined trumpeter	2468	2468	121882	4139	98.0	207	2	4543	135	95.6
Sillago ciliatia	Sand whiting	20682	5143	89331	2766	81.2	5928	9	10366	296	63.6
Girella tricuspidata	Luderick	27519	5148	50791	2124	64.9	10856	16	8559	403	44.1
Pagrus auratus	Snapper	648	292	69187	2466	99.1	292	1	6619	231	95.8
Monacanthus chinensis	Fanbelly leatherjacket	3437	803	13806	302	80.1	892	2	1396	42	61.0
Pseudocaranx dentex	Silver trevally	4866	1459	11764	302	70.7	989	2	850	22	46.2
Meuschenia trachylepus	Yellow-finned leatherjacket	4276	913	7001	271	62.1	927	2	765	27	45.2
Pomatomus saltatrix	Tailor	3424	645	6180	246	64.3	1525	2	648	27	29.8
Platycephalus fuscus	Dusky flathead	6803	1235	2772	61	28.9	5822	9	608	15	9.5
Dicotylichthys punctulatus	Porcupinefish	0	0	9498	415	100.0	0	0	2389	132	100.0
Trachurus novaezelandi	Yellowtail	3610	1926	4638	221	56.2	351	1	378	18	51.8
Sillago maculata	Trumpeter whiting	1338	663	920	41	40.8	248	1	101	4	29.0
Myxus elongatus	Sand mullet	1421	832	668	80	32.0	472	2	198	25	29.6
Liza argentea	Flat-tail mullet	1771	1250	41	4	2.3	848	4	10	1	1.2
Synaptura nigra	Black sole	105	84	1171	45	91.7	33	0	187	7	84.9
Mugil cephalus	Sea mullet	933	613	59	8	6.0	568	3	15	2	2.5
Chelidonichthys kumu	Red gurnard	416	373	479	27	53.5	94	1	79	4	45.6
Meuschenia freycineti	Six-spined leatherjacket	420	182	287	14	40.6	85	0	34	2	28.3
Anguilla sp.	River eel	493	347	145	11	22.7	247	1	80	6	24.4
Herklotsichthys castelnaui	Southern herring	0	0	637	35	100.0	0	0	40	3	100.0
Cnidoglanis macrocephalus	Estuary catfish	0	0	588	42	100.0	0	0	363	25	100.0
Pseudorhombus arsius	Large-toothed flounder	38	38	344	44	90.0	8	0	53	7	87.4
Remaining 12 species		1293		1615		55.5	365		250		40.7

Table 7. Summary of results of two-factor analyses of variance comparing catches across Lake Macquarie and St Georges Basin and the four seasons for the common species presented in Fig 3.
**p < 0.01, *p<0.05, ns p>0.05.

	Total catch			Retained catch			Discarded catch		
	Estuary (E)	Season (S)	ExS	Estuary (E)	Season (S)	ExS	Estuary (E)	Season (S)	ExS
No. of Species	**	ns	ns	**	**	*	**	ns	ns
No. of Individuals	**	**	**	**	ns	**	**	**	**
Weight (kg)	*	**	*	ns	*	*	*	**	*
G. subfasciatus	**	ns	**	*	ns	**	**	**	ns
A. australis	**	**	**	**	**	*	**	**	**
R. sarba	**	**	**	**	**	ns	**	**	**
P. auratus	ns	**	ns	ns	*	ns	ns	**	ns
S. ciliata	**	*	ns	**	*	ns	**	ns	ns
S. maculata	**	ns	*	**	*	*	**	ns	ns
P. sexlineatus	ns	*	**	ns	ns	ns	ns	*	**
P. dentex	**	*	ns	**	ns	ns	**	**	**
G. tricuspidata	**	**	ns	**	**	ns	*	**	ns
M. trachylepis	**	ns	**	*	ns	**	**	ns	ns
M. chinensis	ns	**	ns	ns	*	ns	ns	*	ns
P. saltatrix	**	**	ns	ns	ns	**	**	*	*

Appendix 5.

Gray, C.A. (2001) Spatial variation in by-catch from a prawn seine-net fishery in a south-east Australian coastal lagoon. *Marine and Freshwater Research* 52, 987-993.

Mar. Freshwater Res., 2001, 52, 987–993

Spatial variation in by-catch from a prawn seine-net fishery in a south-east Australian coastal lagoon

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Abstract. Observer-based estimates of the catches and by-catches from prawn seining (locally termed 'snigging') in Tuggerah Lake (NSW, Australia) during the 1998/99 fishing season are presented. Observed catches included three species of penaeid prawns, while observed by-catches contained a total of 49 finfish and 5 invertebrate taxa. The overall by-catch:prawn catch ratio by weight was 0.9:1, and in catching an estimated 20 ± 4 t of prawns the fleet took an estimated total by-catch of 19 ± 2 t throughout the 6-month fishing season. The by-catch included large numbers of small (<15 cm total length) finfish species important in other commercial and recreational fisheries, including *Gerres subfasciatus*, *Rhabdosargus sarba* and *Acanthopagrus australis*, as well as several small demersal species of little economic value. Multivariate analyses indicated that by-catch composition differed between seines taken over shallow seagrass and bare substrata, with catch rates of several species being greater over seagrass. It is recommended that strategies to reduce potential ecological impacts and by-catch in this fishery be investigated, including fixed spatial closures over seagrasses and the development of alternative fishing gears and practices.

Extra keywords: discarding, by-catch management, observer survey, seagrass, Tuggerah Lake

Introduction

For several years there has been world-wide concern over the incidental capture of non-target organisms (by-catch) from commercial fishing operations, with much emphasis being placed on reducing wastage in fisheries. In particular, the by-catch from prawn trawling has received considerable attention, with numerous studies having identified and quantified the types and levels of by-catches in several fisheries (see reviews by Andrew and Pepperell 1992; Kennelly 1995). The information obtained in these surveys has aided fisheries managers and scientists in investigating ways to reduce problematic by-catches in some fisheries (see Kennelly 1995; Hall 1999; Broadhurst 2000). Although by-catch-associated problems have been identified in prawn trawl fisheries for several years, far fewer studies have examined by-catches in smaller-scale net-based prawn fisheries, including those that use seine, trammel, cast and stake nets (but see Changchen 1992; Chavez 1992; Andrew *et al.* 1995).

Several non-trawl methods are used to capture prawns in estuarine waters of New South Wales (NSW), Australia. These include beach-seine (haul), Danish seine (snigging), set-pocket (stow) and wall (running) nets. As in many coastal fisheries throughout the world, one of the most contentious issues facing the management of these estuarine prawn fisheries involves by-catch. In particular, several resource user groups, including commercial and recreational fishers and conservation groups, claim that most prawning methods incur high levels of wastage as they catch and kill large numbers of juvenile fish. Often, these by-catch species are important in other commercial and recreational fisheries, leading to fishery-interaction problems (see also Liggins *et al.* 1996). An important first step in dealing with issues concerning by-catch is to quantify the real extent of the perceived problems. Although there have been quantitative assessments of by-catches from the estuarine prawn trawl (Gray *et al.* 1990; Liggins and Kennelly 1996; Liggins *et al.* 1996) and set-pocket net (Andrew *et al.* 1995) fisheries in NSW, no such data are available for the prawn seine fisheries.

Prawn seining is permitted in several NSW estuaries and lagoons, but the gears and their methods of operation vary among estuaries. Basically, there are two types of prawn seine fisheries; the first (locally termed prawn hauling) occurs in riverine areas and targets school prawns (*Metapenaeus macleayi*), whereas the second (locally termed prawn snigging) occurs in coastal lagoons and primarily targets greasyback (*M. bennettae*) and school prawns. This study focuses on the latter method by assessing the by-catch in one of the State's largest prawn seine fisheries in Tuggerah Lake.

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Several methods have been used to quantify by-catches in prawn fisheries, including logbooks, independent research surveys and onboard observers (see reviews by Andrew and Pepperell 1992; Kennelly 1995). It is generally acknowledged that the most reliable and accurate method to quantify by-catches in commercial fisheries is to place observers onboard vessels, collecting data during normal fishing operations (Saila 1983; Alverson *et al.* 1994; Kennelly 1995). The aims of the present study were therefore to use an observer-based survey to identify and quantify the levels of by-catch in Tuggerah Lake during the 1998/99 fishing season.

Material and methods

Study area

Tuggerah Lake (33°16′S,151°30′E) is a shallow (mean depth 3 m, maximum depth 8 m) barrier lagoon of 70 km^2 surface area with a constricted entrance to the sea that intermittently closes. The shallow foreshores of the lake are lined with aquatic vegetation, particularly *Zostera capricorni*, *Ruppia* sp. and *Halophila* spp. (West *et al.* 1985), although much of the foreshore surrounding the lake is urbanized. Tuggerah Lake supports other commercial prawn (running and set-pocket net), fish (beach-seine, gill-net and trap) and crab (trap) fisheries, as well as recreational fisheries for prawns, fish and crabs.

Prawn seine fishery

Prawns are seined by small vessels (typically <6 m) powered by diesel or outboard motors, each deploying a single net. Nets have a maximum headline length of 140 m, with a further 140 m of hauling rope (bridles) allowed on each end and attached to the boat (Fig. 1). Mesh throughout the net and cod-end must be between 30 and 36 mm (stretched mesh). Each seine operation usually takes ~15 min to complete, with the nets being deployed then towed at a speed of ~0.5 m s^{-1} until the net closes (Fig. 1). The net is then hauled (usually by hand) onboard where the catch is emptied into a fish box or onto a small tray and sorted. The catch is usually sorted while the next tow is being done. Fishers are not permitted to retain any species other than prawns, and thus all by-catch must be discarded.

Prior to the 1998/99 season, prawn seining was done day and night in Tuggerah Lake, but from September 1998 day seining only was permitted. Seining is permitted every day of the week, and the seining season usually extends from October to March. Approximately 25 boats participate in the fishery, the majority being operated by a single person. The prawn catch comprises greasy back (*Metapenaeus bennettae*), school (*M. macleayi*) and to a lesser extent king (*Melicertus plebejus*) prawns. The average (± s.e.) quantity of prawns landed by the fishery between 1995/96 and 1997/98 was 25 (±15) t year^{-1}.

Observer survey

Scientific observers accompanied commercial fishers on four randomly chosen trips (fisher-days) in each month between October 1998 and January 1999. On each trip the commercial fisher and the observer sorted the catch and by-catch from each tow. The total weights of prawns and by-catch in each tow were recorded. The observer further sorted the by-catch into individual taxa, which were weighed and counted. The standard lengths of important species were also determined (rounded down to nearest 0.5 cm). Operational data, including the date, time, location and gear configuration, were also collected for each tow.

Data analyses

Non-metric multidimensional scaling (MDS) was used to delineate spatial patterns in by-catch composition. The general procedures used followed those outlined in Clarke (1993). Data on species abundance for each individual tow were 4th-root transformed to ensure that each taxonomic grouping contributed fairly evenly to the analysis. Similarity matrices based on the Bray–Curtis similarity measure were generated and the inter-relationships among samples (individual tows) were displayed graphically in a 2-dimensional ordination plot. Samples that grouped together were most similar and the stress coefficient indicated the goodness of fit of the data. A one-way analysis of similarity (ANOSIM) was used to test for spatial differences in by-catches caught over seagrass and bare substratum. Similarity percentage analysis (SIMPER) was used to identify the taxa that were most responsible for the dissimilarity among sample groupings in the MDS plot. The ratio of mean/s.e. is a measure of how consistently each taxon contributes to the dissimilarity measure between groups. Taxa displaying a high ratio and a high contribution can be considered good discriminating species (Clarke and Warwick 1994). .

Mean daily catch rates (± s.e.) were calculated for each observer month, and one-factor analyses of variance (ANOVA) were used to test for statistically significant temporal (among months) differences in quantities of catches and by-catches. Prior to each analysis, data were checked for homogeneity of variances using Cochran's test, and transformed if necessary. Where an ANOVA detected significant differences in mean monthly catches, Student–Newman–Keuls (SNK) tests were used to identify which means differed. A ratio (and s.e.) of by-catch to prawn catch (weight) was determined following the procedure outlined in Cochran (1963).

Observed length–frequency distributions of important finfish by-catch species were scaled to represent total length–frequency

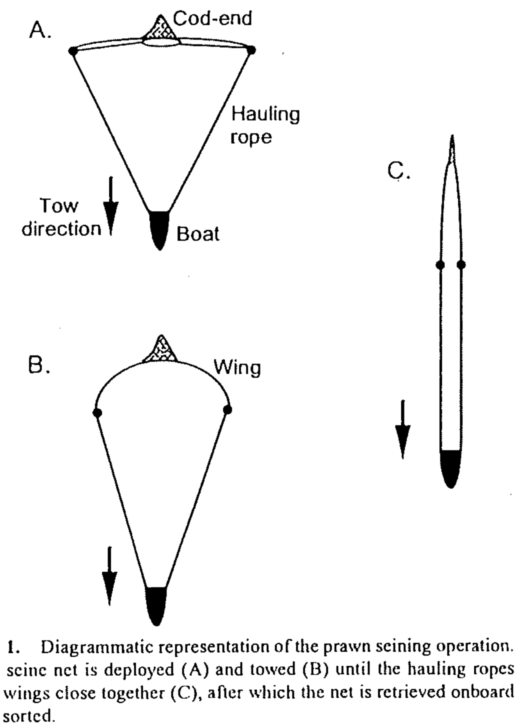

Fig. 1. Diagrammatic representation of the prawn seining operation. The seine net is deployed (A) and towed (B) until the hauling ropes and wings close together (C), after which the net is retrieved onboard and sorted.

distributions by the entire fleet for the 1998/99 season. Monthly length–frequency distributions were weighted according to the ratio of total fishing effort for the season to sampling effort in each month and then summed to provide the estimated total distribution, from which a relative length–frequency distribution was calculated (see Liggins and Kennelly 1996; Gray *et al.* 2001).

Estimates of total catches and by-catches (± s.e.) by the entire seine fleet in Tuggerah Lake throughout the 1998/99 season were derived by multiplying the mean daily catch rates for each month (CPUE) by the reported number of days fished by all seine crews in each month throughout the season. This used the standard method for estimating a total and standard error across multiple randomly sampled strata as outlined in Cochran (1963) (see Liggins and Kennelly 1996; Gray *et al.* 2001). This procedure assumed that the proportion of tows taken over seagrass and bare substrata were the same in survey and non-survey months and also that the mean daily catch rates for the survey and non-survey months were the same (see Cochran 1963). The total reported fishing effort for each month (i.e. total no. of fisher-days) was obtained from the mandatory forms that commercial fishers are required to submit to NSW Fisheries.

Results

Fishing effort and observer coverage

The reported total fishing effort in numbers of days fished by all seine crews in Tuggerah Lake between September 1998 and February 1999 was 1270 days. Reported effort was greatest in November and December (both 317 days), October (277 days) and January (241 days) and least in February (33 days) and September (85 days). This trend mirrors the average pattern for reported effort for the previous 5 years. In total, 16 fishing trips (fisher-days) were observed, comprising 79 individual tows of which 38 were done over seagrass and 41 over bare substrata. The number of individual tows undertaken per day on observed vessels ranged from 1 to 9, averaging (± s.e.) 4.8 ± 0.5.

Catch and by-catch composition

Commercial fishers retained three species of penaeid prawn (*Metapenaeus bennettae*, *M. macleayi* and *Melicertus plebejus*). However, because catches were not sorted by species, the weights of all three species were pooled to give a total prawn catch. In total, 49 finfish and 5 invertebrate taxa were identified in by-catches. By-catches were dominated by species important in other commercial and recreational fisheries (e.g. *Rhabdosargus sarba*, *Acanthopagrus australis*, *Gerres subfasciatus*, *Portunus pelagicus*, *Pomatomus saltatrix*), as well as several small demersal species of little economic value (e.g. *Foetorepus calauropomus*, *Ambassis* spp., *Monodactylus argenteus*) (Table 1). The only abundant invertebrate caught in the by-catch was the portunid crab, *P. pelagicus*.

By-catch composition varied between seines (individual tows) done over shallow seagrass and deeper bare substrata (ANOSIM, R = 0.268, P <0.001, Fig. 2). The SIMPER analysis identified species that made the greatest contribution to the dissimilarity between the by-catches taken over the two habitats (Table 1). The twenty most abundant species accounted for 78% of the dissimilarity between samples. Several species, including *Pelates*

Table 1. Contribution of the twenty most abundant species to dissimilarity between seines taken over seagrass and bare substrata

Species listed in order of greatest contribution. Mean abundance per haul, the ratio of mean to standard error for dissimilarity contributions and the percent contribution of each species to dissimilarity are shown

Species (Family)	Mean abundance Seagrass	Bare	Ratio (mean/s.e.)	Percent contribution
Pelates sexlineatus (Terapontidae)	13.49	9.92	1.45	5.28
Gerres subfasciatus (Gerreidae)	34.27	72.55	1.09	5.10
Acanthopagrus australis (Sparidae)	15.92	9.24	1.26	5.04
Sillago maculata (Sillaginidae)	5.89	5.63	1.20	4.87
Foetorepus calauropomus (Callionymidae)	6.62	7.00	1.22	4.85
Engraulis australis (Engraulidae)	1.54	5.89	1.03	4.62
Meuschenia trachylepis (Monacanthidae)	14.92	16.97	0.83	4.37
Arenigobius bifrenatus (Gobiidae)	6.32	2.03	1.19	4.37
Ambassis spp. (Ambassidae)	7.08	12.89	1.07	4.09
Girella tricuspidata (Girellidae)	6.84	6.89	0.84	4.05
Monodactylus argenteus (Monodactylidae)	2.22	2.13	1.25	4.03
Portunus pelagicus (Portunidae)	2.84	0.66	1.14	3.99
Rhabdosargus sarba (Sparidae)	25.62	18.16	1.23	3.90
Pomatomus saltatrix (Pomatomidae)	1.43	2.61	1.11	3.77
Dicotylichthys punctulatus (Diodontidae)	1.54	0.66	1.02	3.10
Monocanthus chinensis (Monacanthidae)	1.46	0.66	1.02	3.04
Herklotsichthys castelnaui (Clupeidae)	1.14	0.53	0.99	2.98
Tetractenos hamiltoni (Tetraodontidae)	1.05	0.21	0.84	2.58
Centropogon australis (Scorpaenidae)	1.03	1.00	0.75	2.18
Sillago ciliata (Silliginidae)	0.51	0.18	0.70	1.95

sexlineatus, *Acanthopagrus australis* and *Rhabdosargus sarba*, were most abundant in seagrass, whereas *Gerres subfasciatus* and *Engraulis australis* were most abundant over bare substrata. By-catch species not listed in Table 1 were generally caught at numbers averaging <1 individual per tow.

The mean observed catch rates of prawns throughout the survey ranged from 8.5 kg per fisher-day in October to 19.5 kg per fisher-day in December. In these same months, the mean observed by-catch rates were 21.8 kg per fisher-day and 9.8 kg per fisher-day, respectively (Fig. 3). The overall ratio by weight of by-catch to prawn catch (±s.e.) was 0.903:1 (±0.088). There was no significant correlation between the prawn catch and by-catch caught per tow ($r_{(79)} = 0.144$, ns, Fig. 4). Less than 5 kg of prawns was caught in most tows (Fig. 4).

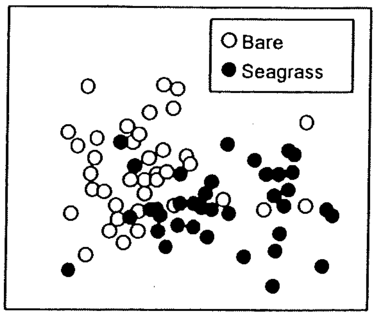

Fig. 2. MDS ordination plot of by-catches caught over shallow seagrass and deeper bare substrata in Tuggerah Lake throughout the survey. n = 79 tows, stress value = 0.111.

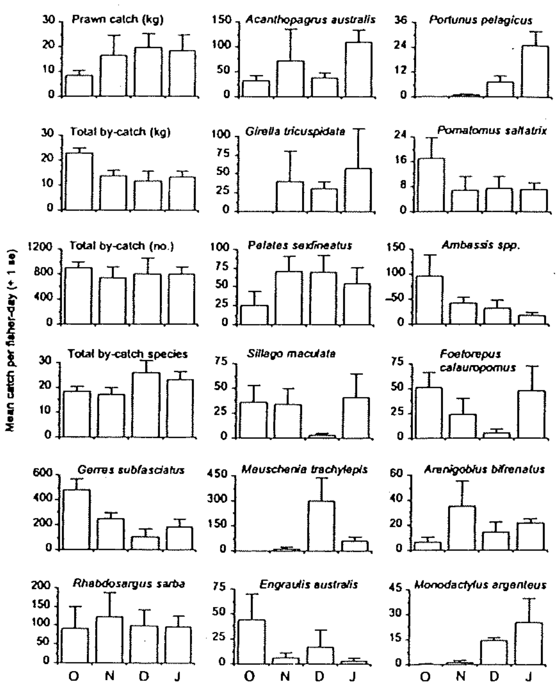

Fig. 3. Mean (± s.e.) catch per fisher-day of prawns and by-catch in each survey month. Values represent numbers except where indicated. O, October; *N*, November; D, December; J, January. ANOVAs comparing catch rates among months were not significant except for *P. pelagicus*, *M. argentus* and *M. trachylepis*.

Most by-catch species were caught in each month surveyed, and variations between months in the mean daily catch rates for the predominant species are shown in Fig. 3. Large fluctuations between months in mean daily catch rates were apparent for some species; for example, mean daily catch rates of *Gerres subfasciatus* ranged from 101 to 477 per fisher-day, and those for *Acanthopagrus australis* ranged from 31 to 110 per fisher-day (Fig. 3). Despite these fluctuations in catch rates, few significant temporal differences in mean daily catch rates were detected by the analyses of variance. This was most likely due to insufficient sample sizes (n = 4 observations per month). *Portunus pelagicus*, *Meuschenia trachylepis* and *Monodactylus argenteus* were the only taxa to display significant differences in catch rates between survey months. SNK tests identified that greatest catches of *M. trachylepis* occurred in December and *P. pelagicus* in January. For the majority of species, therefore, the analyses did not provide enough evidence to conclude that observed differences in catch rates between months were statistically significant.

Sizes of important fish and invertebrate species present in by-catches were generally small. Lengths of *Gerres subfasciatus*, *Rhabdosargus sarba*, *Acanthopagrus australis*, *Girella tricuspidata* and *Pomatomus saltatrix* were mostly <15 cm FL, whereas *Sillago maculata* ranged between 6 and 24 cm FL (Fig. 5). Two distinct length classes of *R. sarba*, *A. australis* and *G. tricuspidata* were evident.

Estimates of total (±s.e.) prawn and by-catches of the major species by the entire seine fishery in Tuggerah Lake for the 1998/99 season are presented in Table 2. An estimated 20 070 ± 3950 kg of prawns and 19 222 ± 1910 kg

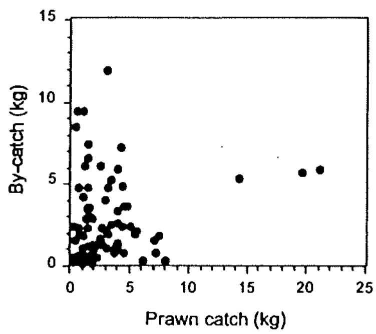

Fig. 4. Relationship between prawn catch and by-catch for each observed tow. n = 79 tows.

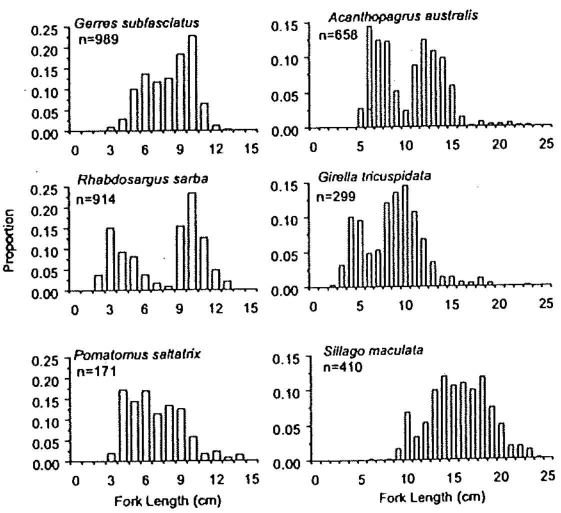

Fig. 5. Estimated length–frequency distributions of important by-catch species taken by the entire seine fleet throughout the 6-month fishing season. *n*, no. of fish measured.

Table 2. Estimated total prawn catch and by-catches by the entire prawn seine fleet in Tuggerah Lake during the 6-month fishing period between September 1998 and February 1999
Values represent numbers except where noted

	Total catch	s.e.
Prawn catch (kg)	20070	3950
Total by-catch (kg)	19222	1910
Total by-catch (no.)	1019324	116533
Gerres subfasciatus	315518	44108
Rhabdosargus sarba	131072	32498
Meuschenia trachylepis	103794	46679
Acanthopagrus australis	77165	23610
Pelates sexlineatus	70855	13617
Ambassis spp.	59991	14390
Girella tricuspidata	40187	20192
Foetorepus calauropomus	38353	9805
Sillago maculata	34598	10250
Arenigobius bifrenatus	25104	12368
Engraulis australis	22369	9787
Monodactylus argenteus	12135	3905
Pomatomus saltatrix	11944	2928
Portunus pelagicus	9371	2089
Dicotylichthys punctulatus	7052	2655
Monacanthus chinensis	6074	1626
Centropogon australis	5943	2316
Tetractenos hamiltoni	5105	1019
Herklotsichthys castelnaui	4610	1234
Sillago ciliata	1871	786

of by-catch (~1 million fish) were taken by the fleet between September 1998 and March 1999. It was estimated that throughout the season the fleet discarded >100 000 individuals of each of three taxa, *Gerres subfasciatus*, *Rhabdosargus sarba* and *Meuschenia trachylepis*.

Discussion

By-catch composition and quantification

The by-catch in the prawn seine fishery in Tuggerah Lake comprised predominantly small (<15 cm) finfish, which is consistent with other estuarine prawn fisheries throughout the world (see Andrew and Pepperell 1992), including the prawn trawl and pocket-net fisheries in NSW (Andrew *et al.* 1995; Liggins and Kennelly 1996). In contrast to these and other estuarine prawn fisheries in south-eastern Australia and other parts of the world, the by-catch observed here was dominated by species of commercial and recreational importance (e.g. *Acanthopagrus australis*, *Gerres subfasciatus*, *Girella tricuspidata*). However, several small demersal species of little economic value (e.g. *Foetorepus calauropomus* and *Arenigobius bifrenatus*) were also common in by-catches. Crustaceans formed a minor component of the total by-catch in the seine net fishery, which further contrasts with findings for some estuarine and coastal embayment prawn trawl fisheries (Wassenberg and Hill 1990; Liggins *et al.* 1996).

The overall by-catch to prawn catch ratio, very close to 1 : 1, is considerably less than that generally reported for prawn trawl fisheries in other parts of the world (5–10 : 1, see Andrew and Pepperell 1992), and including the Port Jackson and Botany Bay prawn trawl fisheries in central NSW (1.8–3.5 : 1, Liggins *et al.* 1996). It is greater, however, than the ratios reported for the prawn trawl fishery in the Clarence River, northern NSW (<0.45 : 1, Liggins and Kennelly 1996) and than most reports for other non-trawl prawn fisheries, including estuarine pocket-netting (0.38:1, Andrew *et al.* 1995) and haul-seining in riverine areas (<0.5 : 1, Gray, unpublished) in NSW. Chavez (1992) reported by-catch:prawn catch ratios for cast nets in Mexico ranging from 0.5:1 to 1.2 : 1 depending on the net used. Year-to-year variations in ratios of by-catch to catch can be great, and this needs to be considered in comparing ratios between fisheries (Rothschild and Brunenmeister 1984; Liggins *et al.* 1996; and see Andrew and Pepperell 1992). Clearly, gear- and fishery-specific relationships between prawn catches and by-catches are common, and generalizations concerning by-catches from prawn fisheries should be treated with caution.

The types and quantities of by-catches in prawn trawl fisheries vary over a range of spatial and temporal scales (Gray *et al.* 1990; Ramm *et al.* 1990; Liggins *et al.* 1996; Kennelly *et al.* 1998). Habitat-associated differences in by-catches were detected in this study. The multivariate analyses showed that by-catch composition varied between seines taken over seagrass and bare substrata. This result concurs with several studies that have identified differences in ichthyofaunal assemblages occurring over shallow seagrass and bare substrata (Ferrell and Bell 1991; Connolly 1994; Gray *et al.* 1996). Furthermore, several species were caught in greater abundances in seines taken over seagrass. Species such as *Rhabdosargus sarba* and *Portunus pelagicus* use seagrasses during their early life history, and the small sizes of several fish species observed in by-catches in this study support this general paradigm. Albeit mostly statistically non-significant, there were some temporal fluctuations in the capture of some by-catch species. There was no particular time period, however, when capture rates of by-catches appeared greatest, and thus management of by-catch by static temporal closures would be inappropriate in this fishery.

The estimated total by-catch of 20 t of small finfish and invertebrates (~1 million individuals) in the 6-month seine fishery in Tuggerah Lake was considerably less than corresponding observer-based estimates of by-catches in the estuarine prawn trawl fisheries in NSW. For example, total fishing season by-catches have been estimated at 34–42 t in Port Jackson, 120–165 t in Botany Bay (Liggins *et al.* 1996) and 66–177 t in the Clarence River (Liggins and Kennelly 1996). In comparing these total estimates, it should be noted that reported fishing efforts as well as the capture rates of by-catches were greater in the trawl fisheries than in the seine fishery.

The ecological and fisheries impacts of discarding as observed in the seine fishery can not be determined here. Additional information is required for even the most basic analyses (see Andrew and Pepperell 1992; Jennings and Kaiser 1998). For example, species-specific information on post-capture levels of mortality, rates of natural mortality and growth, and the proportion of the stock represented by discards is required for assessing effects of removing discards on other fisheries. Despite this, it was observed (but not quantified) that much of the by-catch was in poor condition after sorting (particularly smaller individuals), which was generally done in small fish tubs or sorting trays, and that a significant proportion of the discarded catch was eaten by scavenging birds (pelicans and cormorants). Survival of discards might be enhanced if fishers sorted catches in tubs filled with water (e.g. Chopin and Arimoto 1995) and released discards away from birds (e.g. via a chute to deeper water). Nevertheless, the types of species and the quantities of by-catches involved in this fishery (and probably other lagoon-based prawn seine fisheries in NSW) will further fuel public debate over the effects and sustainability of this type of fishing method.

By-catch reduction

One solution to reduce the types and quantities of by-catch in this fishery and to minimize potential ecological impacts on the fisheries resources in this coastal lagoon would be to prohibit prawn seining over and immediately adjacent to the shallow seagrass beds that fringe the foreshores. Many studies have identified seagrasses as supporting rich and diverse ichthyofaunas and as being important nursery habitats to young fish and invertebrates (see Bell and Pollard 1989). Commercial fishers could be limited to seining in areas more than 50–100 m offshore from the deeper edges of the seagrass beds. The effect that such a spatial closure would have on prawn catches requires examination via studies on the life history and habitat requirements of the predominant prawn species in this fishery, *Metapenaeus bennettae* and *M. macleayi*. Ecological studies elsewhere have shown ontogenetic changes in habitat-associations of some penaeid species (e.g. *Penaeus esculentus* and *P. semisulcatus*), which move from shallow vegetated habitats into deeper offshore waters with increasing size (Loneragan *et al.* 1994; Haywood *et al.* 1995). If a similar movement were true for the important prawns in Tuggerah Lake, a fishing closure over seagrass might not severely affect total prawn harvests. This, however, requires testing.

In other prawn fisheries, the inclusions of by-catch reduction devices (BRDs) in fishing gears have reduced the types and quantities of by-catches in some fisheries (see review by Broadhurst 2000). It would therefore be advisable for the commercial fishing industry and fisheries scientists to develop and test modifications to existing seine nets that might reduce by-catch in this and similar lagoon-based seine net fisheries in NSW. Assessments of by-catches in other estuarine non-trawl prawn fisheries are required. This would assist fisheries managers, scientists and industry to assess the relative merits of each fishing method and to determine the most ecologically sustainable methods to harvest the state's prawn resources.

Acknowledgments

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Appendix 6

Gray, C.A., Larson, R.B., Kennelly, S.J. (2000) Use of transparent netting to improve size selectivity and reduce bycatch in fish seine nets. *Fisheries Research* 45, 155-166.

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Use of transparent netting to improve size selectivity and reduce bycatch in fish seine nets

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Abstract

Strategically placed panels of transparent mesh improved the size selection of targeted commercial species (primarily sand whiting, *Sillago ciliata*) and reduced the bycatch of other species in an estuarine fish seine net. A cover net was placed over the whole bunt and cod-end to quantify the numbers and sizes of fish that passed through the modified and conventional (control) nets. The average size of sand whiting caught in the modified net was larger than in the control net, but other commercial species (sea mullet, flat-tail mullet and silver biddy) showed only a slight change in size selectivity, possibly due to differing escape responses to visual cues. The cover net used in the study appeared to modify the effectiveness of the transparent panels, with some smaller fish observed to re-enter the main net as hauling ceased. An alternative analysis which treated the data as a series of paired comparisons showed an even greater increase in the selection of larger sand whiting than that obtained in the cover net analyses. The panels of transparent netting tested in this experiment show potential as a means of improving the selectivity of fish seine nets.

Keywords: Beach-seine; Haul net; Size-selectivity; Bycatch reduction; Estuarine fish; *Sillago ciliata*

1. Introduction

Commercial seining for finfish (locally termed fish hauling) is permitted in most estuaries in New South Wales (NSW), Australia and forms the basis of a valuable fishery, landing over 1800 tonnes of finfish valued at $4.5 million in 1997/98. Estuarine hauling is, however, one of the most controversial forms of fishing in NSW, with conservation and angling groups claiming that the nets catch and kill many juveniles of recreational and commercial fish species. Further, increased urban development of coastal areas in NSW in recent years and the high visibility of estuarine haul crews has led to even greater conflicts among various estuarine user groups, including tourist operators and local councils.

Currently, 250 fishers are endorsed to use fish hauling nets in NSW estuaries, with haul crews usually comprising 2–6 persons. This fishery is currently managed by a complex set of spatial and temporal closures and gear restrictions, including minimum and maximum mesh sizes and maximum lengths of nets

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and ropes. The most common net configuration used is termed "the general purpose haul net", which must have a mesh size greater than 80 mm in the wings, less than 51 mm in the bunt, and 38–50 mm in the cod-end. However, the regulations governing the amount of net and rope that can be used vary between estuaries, with a maximum 375 m of net and 375 m of rope permitted in rivers, but up to 1000 m of net and 1000 m of rope permitted in coastal lagoons (in some lagoons, 2000 m of rope can be used in winter). The species of fish targeted by haul crews also vary spatially and temporally. For example, in northern NSW, fishers target sand whiting (*Sillago ciliata*) over shallow sand flats throughout warmer months (September–March), while in cooler months (April–August), fishers target sea mullet (*Mugil cephalus*) and bream (*Acanthopagrus australis*). Although estuarine hauling for fish has a long history in NSW (beginning in 1880s), there have been no studies on the selectivity of the nets used in the fishery, even though current mesh regulations were first introduced in 1940s. It is not surprising, therefore, that the configuration of nets currently used do not exhibit optimum selectivity, often retaining large numbers of small fish, including juveniles of the targeted species (pers. obs.).

Many studies have investigated the selectivity of commercial fishing gears, including demersal and pelagic trawls (Casey et al., 1992; Reeves et al., 1992), Danish seines (Jackobson, 1985) and gill nets (Hamley, 1975), but relatively few have examined beach-seining (or hauling) gears (but see Jones, 1982; Lamberth et al., 1995). These latter studies showed that the mesh sizes used in seine net fisheries in South Africa and South Australia were inappropriate, primarily because many small fish were retained and subsequently discarded (often dead). Both these studies concluded that significant increases in mesh size were required to reduce the quantity of bycatch, and that this would reduce considerably the catch of the target species.

It is generally accepted that selection of fish occurs in the cod-ends of mobile fishing gears (like trawls and Danish seines) (Pope et al., 1975; Wileman et al., 1996) and, therefore, most of the techniques for improving selectivity and reducing bycatches have been made in this section of the net (e.g. Ferno and Olsen, 1994; Wileman et al., 1996; Broadhurst et al., 1999). In contrast, observations made from the surface and underwater of NSWs estuarine haul nets indicated that the selection of fish mainly occurs before the fish enter the cod-end. Fish appear to be herded in front of the fishing gear during hauling but, when the net nears the beach (in water depths of 20–50 cm), and the distance between the wing reduces, captive fish become more active and swim in all directions. Most size selectivity during this operation occurs in the anterior section of the bunt and in the wings immediately anterior to the bunt. Because of these observations, we decided that devices to improve size selectivity and reduce bycatch in this fishery should be placed anterior to the cod-end.

The behavioural responses of fish to fishing gears have been noted to be caused by visual and/or hydrodynamic stimuli (see Glass et al., 1993, 1995; Broadhurst et al., 1999). In particular, Glass et al. (1995) demonstrated that, in reasonable light levels fish seem to prefer to swim through clear passages and away from dark areas. Because selectivity in the daytime estuarine fish haul fishery in NSW occurs in shallow, clear water, we concluded that altering visual cues in the net may provide a means to improve selectivity, rather than simply increasing the mesh size as suggested by Lamberth et al. (1995). In this study we tested the effectiveness of transparent (multi-monofilament nylon) panels of mesh strategically inserted in the anterior region of the bunt as a device to improve the size selection of targeted species (principally sand whiting) while concomitantly reducing the capture of unwanted bycatch species.

Several experimental procedures have been used to examine the selectivities of commercial fishing gears, including alternate trawl/haul, trouser trawl and covered net cod-end comparisons (see Pope et al., 1975; Millar and Walsh, 1992; Wileman et al., 1996). In the present study we decided to use a covered net procedure because: (1) operational constraints during hauling and the way fish behaved at the end of the haul precluded the division of the net into two equal halves with two bunts and cod-ends (the trouser net approach); and (2) the species, diversity, abundances and size compositions of fishes can vary substantially between different sites within an estuary and at different phases of the tide, precluding the alternate haul approach. Previous examinations of the selectivity of beach-seine nets have used a covered net approach (Jones, 1982; Lamberth et al., 1995), but the 'covers' used involved a second smaller-meshed net encircling the main net which was deployed only during the last 100 m of the haul — assuming that fish escaped only during the last part of the haul. To remove this assumption, in the present study we used a cover that was attached to the study net, therefore catching and quantifying all escaping fish throughout the entire haul.

2. Materials and methods

2.1. Study area

This study was done during the daytime on commercial fishing grounds in the Bellinger River, in northern New South Wales, Australia (30°30′; 153°02′) in January and February 1998, using a chartered commercial fish haul crew. Throughout the study, individual hauls were done over nine distinct haul sites in a 15 km section of the river, the lowest being 2 km upstream of the river mouth. The bottom type varied from sand to mud from downstream to upstream, and the maximum depth of water ranged from 3–8 m. Visibility in the estuary at the time of sampling was up to 3 m.

2.2. Net configurations

The conventional (control) net used in this study conformed to NSW Fisheries regulations, having a total headline length of 375 m, with 102 mm mesh in the 120 m wings, 51 mm mesh in the 30 m bunt and 38 mm mesh in the cod-end. The net was 2 m deep and was negatively buoyant so that it remained on the substratum at all times. The entire net was made of blue multifilament polyamide, with the bunt and cod-end dyed black. The modified net (see Fig. 1) was the same net, but two panels of 57 mm mesh of transparent multi-monofilament polyamide of 100 meshes (N direction) in length (4.95 m) and 50 meshes (T direction) in depth (1.43 m) were inserted (mesh by mesh) along each side of the anterior section of the bunt using a hanging ratio of approximately 0.45.

The cover net surrounded the entire bunt and cod-end of the control and modified nets and was used to catch and quantify the fish that passed through the meshes of these parts of the gear (see Fig. 1). The cover was made of 32 mm multifilament polyamide, but where it covered the transparent panels it was constructed of 32 mm transparent multi-monofilament polyamide. Small floats were attached to the cover to stop it from digging into the substratum.

2.3. Sampling procedure

Three treatments were compared in this study: the conventional net with the cover (i.e. control), the modified net with the cover, and the modified net without the cover. A comparison of the data gathered

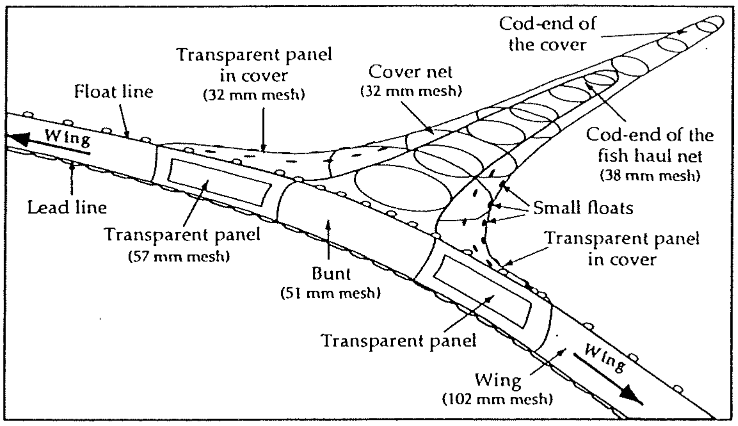

Fig. 1. Diagrammatic representation of the modified net and the cover net.

from the hauls done with the modified net with and without the cover examined any confounding effects of the cover on catches. A total of five replicate hauls were done for each treatment over a period of 10 days. However, the five hauls with the modified net with no cover were done after the 10 hauls with the cover, as it was impractical to remove and re-attach the cover between individual hauls or days. The order in which hauls of each covered-net treatment were done was haphazard, with the panels inserted or removed between sampling days. Depending on the site of each haul, replicates were taken at low or high tide when water movement was minimal.

The hauling procedure usually took approximately 20 min to complete. The rope and net were set from a small boat in a semi-circular shape starting and ending at the shoreline (Fig. 2). After setting, the gear was hauled at approximately 2 km/h (0.5 m s^{-1}) by two small petrol powered 5 kW engines which were staked into the substratum approximately 5 m apart and 1 m shoreward of the water level. The length of rope deployed during each haul varied from approximately 100 m to the maximum 375 m.

Fish caught in the main net and in the cover were kept separate, sorted, identified, counted and measured (fork length) to the nearest 0.5 cm below. When excessive quantities (>200 individuals) of any particular species were captured, a subsample was measured (approximately 100–200 fish). The total catch of each species retained in the main net and the cover was weighed to the nearest 50 g.

2.4. Analyses of data

Detailed analyses were done on four species of economically important fish: sand whiting (*Sillago*

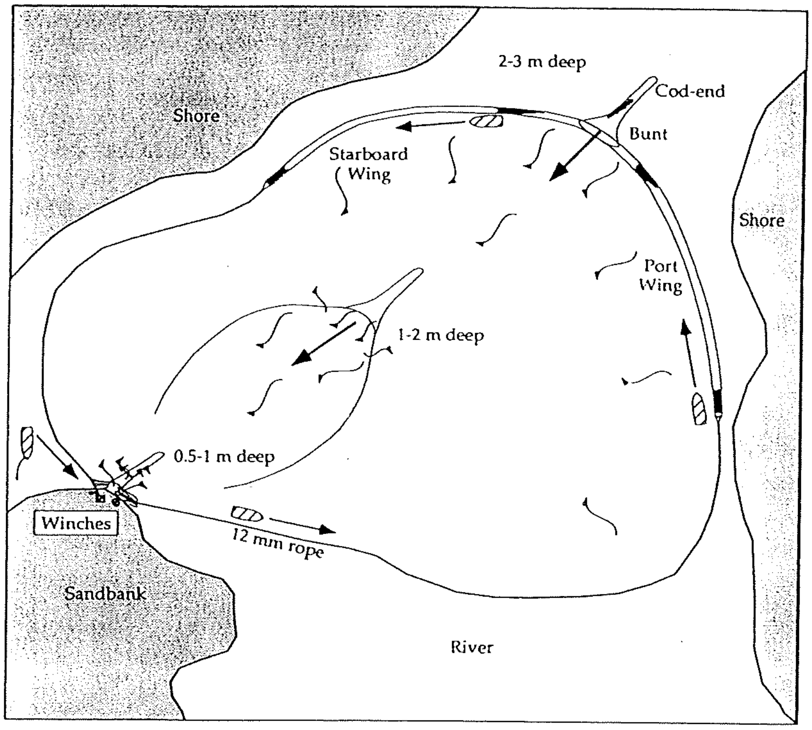

Fig. 2. Diagrammatic representation of the hauling operation as used in this study.

ciliata), sea mullet (*Mugil cephalus*), flat-tail mullet (*Liza argentea*) and silver biddy (*Gerres subfasciatus*). Size-frequencies of each of these species were pooled across hauls for each of the three treatments (control net with cover, modified net with cover, and modified net without cover) and compared using two-sample Kolmogorov–Smirnov tests ($p = 0.05$).

The size selection of each net treatment for the four main species of fish caught were determined using the program 'CC Selectivity' (see Wileman et al., 1996). Logistic selection curves were fitted to the data by a maximum likelihood method (Pope et al., 1975) and, where possible, data from individual replicates were used so that variance analyses could be included (see Fryer, 1991). However, because of small catches for some species and difficulties in fitting the data to a logistic curve, analyses for some species were performed on pooled data.

Because the cover appeared to modify the effectiveness of the panels (see Section 3), we also determined the selection of the modified net for sand whiting using a 'pseudo' trouser net comparison. For this analysis we compared the size composition of sand whiting caught in the modified net without the cover with the size composition of all sand whiting caught in the control net with the cover (i.e. in the main net and the cover net) (see Millar and Walsh, 1992). This comparison was based on an alternate haul design and thus the statistical assumptions surrounding its use may not be totally valid.

The data from each haul were also examined to determine the percentage (by weight and number) of fish of each species that escaped through the control and modified nets. For each replicate, the number of each species caught in the cover net was expressed as a percentage of those that were caught in the main net plus those caught in the cover (i.e. the total entering the fishing gear). The mean percentages (and standard errors) across all five replicates were plotted and the data analysed using a one-way ANOVA.

3. Results

3.1. Observations of the gear fishing

Both surface and underwater observations of the fishing gear confirmed that the small-meshed cover net hung back from, and did not interfere with, the main net and so allowed the free passage of fish escaping through the bunt and cod-end of the control net and through the transparent panels of the modified net. These observations confirmed that sand whiting escaped from the modified net through the transparent panels with some legal sized sand whiting meshing in the panel as they tried to escape (see below). However, after the gear was hauled to the point of landing (<1 m deep) and hauling ceased, a small number of fish that had passed through the main net into the cover net but had not travelled to the cod-end of the cover net were observed (from the surface) to swim back and re-enter the main net via the cod-end, bunt and panels. Whilst most of these fish meshed or became entangled on the outside of the main net and could easily be detected, some fish (particularly very small sand whiting) re-entered the main net and became mixed with its catch. We consequently tied off the cover net immediately after hauling but, despite this, a few small fish still re-entered the main net.

3.2. Composition of catches

Table 1 gives the total number of each species of fish caught in each of the three experimental treatments. Sand whiting, sea mullet, flat-tail mullet and silver biddy dominated catches in all the three treatments, and more detailed analyses of the catches of these species are provided below. Few other species were caught in substantial numbers across all net treatments and data for these species were therefore not analysed.

3.3. Size-frequencies of fish captured

A greater proportion of legal sized sand whiting (>25 cm FL) were retained in the main nets of the modified net with the cover (39.3%) and without the cover (63.4%) than in the main net in the control net (33.2%) (Fig. 3). No such trends were evident for the other three species analysed, as the size distributions of the retained catches of each species did not differ significantly between the modified net with cover and the control net with cover (Kolmogorov–Smirnov tests, $p > 0.05$) (Figs. 4–6). The Kolmogorov–Smir-

Table 1
The numbers of each species of fish retained in the main (M) and cover (C) nets of each experimental treatment[a]

	Conventional net with cover		Modified net with cover		Modified net
	M	C	M	C	M
Silliginidae					
Sillago ciliata	1063	863	954	1093	921
Sillago maculata	1	13		7	
Mugilidae					
Mugil cephalus	654	37	519	65	587
Liza argentea	3446	240	483	88	122
Liza vaigiensis					1
Myxus elongatus	14	3	3		1
Myxus petardi					1
Gerreidae					
Gerres subfasciatus	596	659	154	716	70
Pomatomidae					
Pomatomus saltatrix	22	50			1
Sparidae					
Acanthopagrus australis	17	1	12	2	133
Rhobdosargus sarba	26				43
Pogrus auratus	0	2			2
Carangidae					
Caranx sexfasciatus	41				8
Gnathanodon speciosus	12				
Pseudocaronx dentex	7				
Scomberoides lysan	9				2
Girellidae					
Girella tricuspidata	249	3	11		28
Scatophagidae					
Scatophagus multifasciata					6
Monodactylidae					
Monodactylus argenteus	74		92	15	40
Platycephalidae					
Platycephalus fuscus	1		1	1	2
Bothidae					
Pseudorhombus arsius	1				7
Hemiramphidae					
Hyporhamphus regularis	35	148	6	40	
Teraponidae					
Pelates quadrilineatus	422	801			1
Tetraodontidae					
Tetractenos sp.					1
Soleidae					
Synaptura nigra					1
Clupeidae					
Potamalosa richmondia	2354	10 977	13	130	1

Table 1 (*Continued*)

	Conventional net with cover		Modified net with cover		Modified net
	M	C	M	C	M
Fistulariidae					
Fistularia commersonii	2	10			
Sphyraenidae					
Sphyraena obtusata	68	60			
Monacanthidae					
Meuschenia trachylepis	6	1			3
Siganidae					
Siganus fuscescens	61				2

[a] Five hauls were done with each net treatment.

nov tests also showed that a greater proportion of larger sand whiting and sea mullet were retained in the modified net without the cover than in the modified and control nets with the cover (Figs. 3 and 4), suggesting that the cover affected the performance of the panels in the modified net.

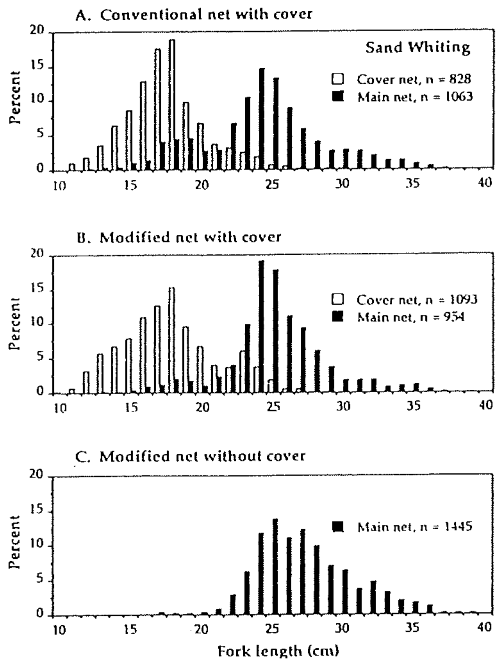

Fig. 3. Size frequencies of sand whiting caught in the modified net with and without the cover net, and in the conventional net with the cover.

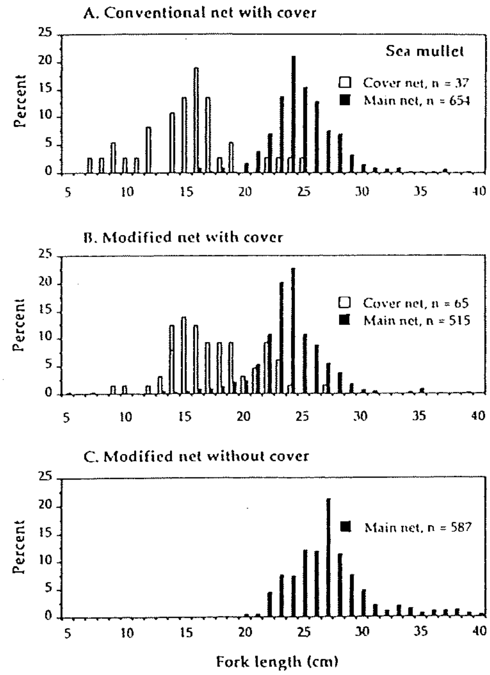

Fig. 4. Size frequencies of sea mullet caught in the modified net with and without the cover net, and in the conventional net with the cover.

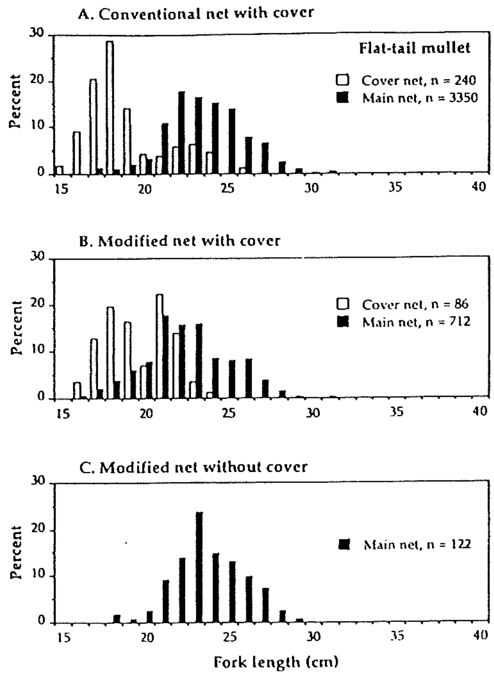

Fig. 5. Size frequencies of flat-tail mullet caught in the modified net with and without the cover net, and in the conventional net with the cover.

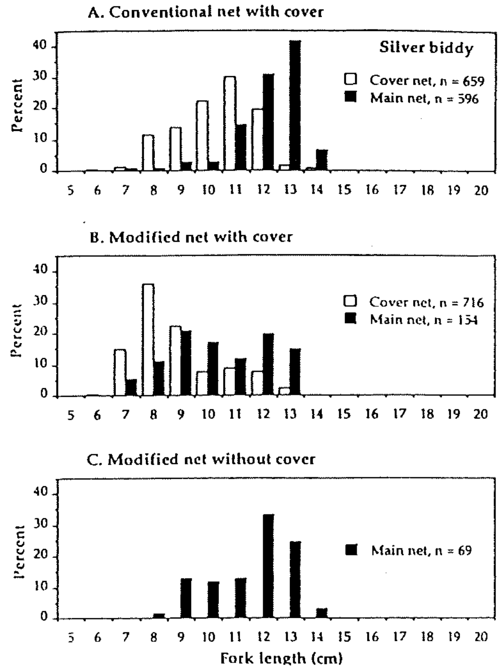

Fig. 6. Size frequencies of silver biddy caught in the modified net with and without the cover net, and in the conventional net with the cover.

3.4. Selectivity of commercial species of fish: covered net comparison

3.4.1. Sand whiting (Sillago ciliata)

One haul from each of the modified and control nets had to be omitted from analysis because the data did not fit the logistic curve. The variance component analyses showed that the 50% selection point of the modified net (22.39 cm FL) was greater than the control net (20.57 cm FL) (9% increase), and the selection range was reduced by 1.52 cm (31%) (Table 2A).

3.4.2. Sea mullet (Mugil cephalus)

Three hauls from the modified net and one from the control net could be included in the analyses, and therefore pooled data were used for the modified net versus the one haul from the control net. Few of the sea mullet captured were within the selection range, but the mid selection point for the modified net was greater (albeit non-significant) than the control net by 0.3 cm (2%), and the selection range was increased by 1.01 cm (36%) (Table 2B).

3.4.3. Flat-tail mullet (Liza argentea)

Three hauls from the modified net and two hauls from the control net could be analysed. The variance component analyses showed that the mid selection point decreased by 2.18 cm (11%), and the selection range increased by 1.82 cm (73%) in the modified net compared to the control net (Table 2C), although these changes were not significant.

3.4.4. Silver biddy (Gerres subfasciatus)

Only two hauls from each gear type were analysed. The mid selection point was virtually the same for both nets, although an increase in the selection range of 0.53 cm (26%) was found for the modified net (Table 2D).

C.A. Gray et al. / Fisheries Research 45 (2000) 155–166 163

Table 2
Selectivity characteristics (standard errors in parentheses) of four species of fish for the conventional (control) and modified nets[a]

Selectivity	Conventional net	95% CL	Modified net	95% CL
A. Sand whiting (MLL 25 cm FL)				
$l_{25\%}$ (cm)	18.14 (0.67)	15.36–20.92	20.72 (0.50)	18.57–22.53
$l_{50\%}$ (cm)	20.57 (0.68)	19.25–21.95	22.39 (0.37)	21.54–23.02
$l_{75\%}$ (cm)	23.00 (0.72)	20.22–25.88	24.07 (0.25)	22.24–25.77
SR (cm)	4.87 (0.06)	4.38–5.35	3.35 (0.09)	2.77–3.93
SF[b]	4.05 (206 mm/51 mm)		3.92 (224 mm/57 mm)	
B. Sea mullet (MLL 27 cm FL)				
$l_{25\%}$ (cm)	15.99 (0.41)	14.23–17.51	15.79 (0.45)	13.54–17.79
$l_{50\%}$ (cm)	17.38 (0.32)	16.67–17.98	17.68 (0.33)	16.94–18.28
$l_{75\%}$ (cm)	18.77 (0.29)	17.23–20.30	19.57 (0.26)	17.57–21.54
SR (cm)	2.78 (0.08)	2.23–3.33	3.79 (0.10)	3.17–4.41
SF	3.42 (174 mm/51 mm)		3.09 (177 mm/57 mm)	
C. Flat-tail mullet (no MLL)				
$l_{25\%}$ (cm)	18.59 (0.25)	16.74–19.97	15.50 (1.06)	11.85–18.15
$l_{50\%}$ (cm)	19.84 (0.27)	19.45–20.80	17.66 (0.83)	15.61–19.04
$l_{75\%}$ (cm)	21.96 (0.79)	19.75–24.03	19.83 (0.64)	17.05–22.25
SR (cm)	2.51 (0.69)	1.15–3.86	4.33 (0.58)	3.20–5.46
SF	3.91 (198 mm/51 mm)		3.09 (177 mm/57 mm)	
D. Silver biddy (no MLL)				
$l_{25\%}$ (cm)	11.27 (0.33)	0.73–12.40	10.96 (0.99)	7.59–12.88
$l_{50\%}$ (cm)	12.27 (0.22)	12.01–17.97	12.24 (0.80)	9.98–13.55
$l_{75\%}$ (cm)	13.27 (0.67)	12.21–34.63	13.51 (0.67)	11.27–15.32
SR (cm)	2.01 (0.92)	0.12–3.89	2.54 (0.53)	1.50–3.59
SF	2.42 (123 mm/51 mm)		2.14 (122 mm/57 mm)	

[a] Variance component analysis, logit model, MLE estimates on covered net data. MLL — minimum legal fork length; SR — selection range; SF — selection factor.
[b] Calculation of the selection factor of the conventional net used the 51 mm mesh in the bunt, whereas the modified net used the 57 mm mesh in the transparent panels.

3.5. Size selectivity of sand whiting: alternative trouser net comparison

A comparison of the size frequencies of sand whiting caught in the modified net, with and without the cover, showed distinct differences in the proportions of small (<20 cm FL) sand whiting (Fig. 3), suggesting that the cover modified the effectiveness of the panels, and so influenced the 'true' selectivity of the modified net. The trouser net analysis showed that the mid selection point of the modified net was 27.06 cm FL for sand whiting, 6.49 cm greater than the control net (with cover) (24% increase) (Table 3) and the selection range was reduced by 1.23–3.64 cm (34%). Fig. 7 shows the differences in the selectivity of sand whiting between the control and modified

Table 3
Selectivity parameters (standard errors in parentheses) for sand whiting using a trouser net analysis of data from the covered conventional net and the non-covered modified net[a]

Size range (cm)	10.0–39.5
No. fish in selection range	804 (27.1%)
y-intercept (a)	−16.34
Slope (b)	0.604
Split-value (P)	0.727
$l_{25\%}$ (cm)	25.24 (0.28)
$l_{50\%}$ (cm)	27.06 (0.35)
$l_{75\%}$ (cm)	28.88 (0.44)
Selection range ($l_{75\%}$–$l_{25\%}$) (cm)	3.64 (0.20)
Selection factor ($l_{50\%}$/57 mm)	4.73
Model deviance	34.10
Degrees of freedom	55
p-value for fit	0.988

[a] Logit model, MLE estimates on pooled data.

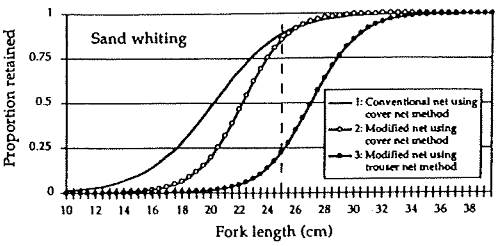

Fig. 7. Selectivity curves for sand whiting caught in the conventional and modified nets using the cover net method and for the modified net using the trouser net method. The dashed vertical line shows the minimum legal size of 25 cm FL for sand whiting.

nets, including that estimated from the trouser net approach.

3.6. Numbers and weights of escapees

The mean (and standard error) of the percentage weights and numbers of fish escaping through the control and modified nets are shown in Fig. 8. There

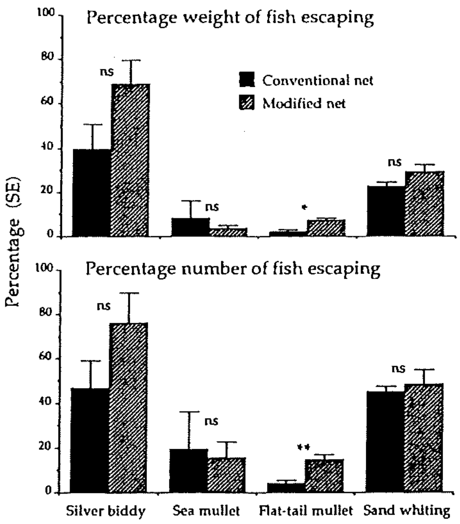

Fig. 8. The percentage (weight and number) of fish that escaped the conventional and modified net. Escapees were captured in the cover net. * — significant difference ($p < 0.05$); ns — no significant difference ($p > 0.05$).

was a trend for more sand whiting, silver biddy and flat-tail mullet to pass through the modified net although this was only statistically significant for the weights and numbers of flat-tail mullet (probably due to the low level of replication).

4. Discussion

The work reported in this paper is the first description of the selectivity of haul nets used in estuarine waters in NSW, and is the first assessment of a method to improve the selectivity of these nets and reduce the discards from this fishery. Our experiment showed that many small fish, including species of commercial and recreational significance, were retained in the conventional haul net. The results show that the mid selection point of the target species (sand whiting) using conventional haul nets is much less than the current legal size. Inappropriate selectivities and problems with the capture and subsequent discarding of undersized fish have been recorded for similar types of haul nets used in estuaries in South Australia (Jones, 1982) and on the open coast of South Africa (Lamberth et al., 1995). Clearly, there is a need to address the selection characteristics of haul nets used in the NSW commercial estuarine fishery, particularly since the fate of the discarded component of the catch is unknown, and the conflicts surrounding the use of these nets are significant.

This study showed that the insertion of transparent panels in the haul net was effective in allowing the escapement of small sand whiting and therefore improved the selectivity for this species. Surface and underwater observations of the modified net (with and without the cover) confirmed that the majority of sand whiting were escaping through the transparent panels. Visual cues have been found to play an important role in determining the escape responses of fish to fishing gears (Watson, 1989; Glass and Wardle, 1989; Wardle et al., 1991) and in particular, fish may prefer to pass through clear passages than darker meshes (Glass et al., 1995). Glass and Wardle (1995) showed that fish tried to avoid entering a darkened cod-end (black tunnel) in a trawl net as they escaped through any available openings ahead of the tunnel, and that the insertion of a black tunnel in a net enhanced the escapement of fish through clearer panels. The low visibility of the transparent panels of multi-monofilament netting and their contrast with the highly visible surrounding black multifilament netting could explain why sand whiting chose to escape through the panels. The positioning of the panels at the anterior region of the bunt appeared to offer fish an alternative clear passage to entering the net mouth. The effectiveness of the panels may have been enhanced by a 'black tunnel' effect of the dyed bunt and cod-end (see Glass and Wardle, 1995). If vision was the primary cue for fish escaping from the panels tested here, then these types of panels would probably be less effective in turbid water and would not work as well at night. This needs to be tested as some commercial fishers use similar haul nets to capture sand whiting over shallow sand spits at night in NSW estuaries.

The change in size selectivity of sand whiting in the modified net was not pronounced when the cover was in place, indicating that the cover may have modified the true effect of the transparent panels probably because of some small fish re-entering the main gear when hauling ceased (see Section 3.1). Because of this possible confounding effect of the cover, the trouser net analysis was done which provided results showing a significant increase in the selection mid point. This result probably reflects the true selection characteristics of the modified net, although we note, that the trouser net approach we presented was technically inappropriate as it was based on an alternate haul sampling design (see Section 2.4). The difference in the selectivity curves of sand whiting for the modified net with and without the cover (i.e. covered net versus trouser net method) may have been slightly enhanced by our decision to fit one ogive to each length–frequency distribution, even though these distributions contained a small tail of fish <20 cm FL (see Fig. 3). However, combining two ogives to describe the selectivity of sand whiting in each of these cases would not have altered our conclusions. We believe that the covered net approach will prove the most effective means of testing the selectivity of other modified haul nets but, the design of the cover and its retrieval needs improving to make escaping fish move towards and remain in the covers cod-end and not swim back into the main net. Attaching light weight glass–fibre hoops (see Wileman et al., 1996) to certain parts of the cover may aid in this by keeping the cover well back from the main net, potentially providing a better passage for escaping fish to travel along.

Previous work on Danish seine nets has shown that increasing the mesh size of a net proportionately increases the size of fish selected (e.g. Pope et al., 1975; Jackobson, 1985; Reeves et al., 1992). In theory, the 12% increase in mesh size from 51 to 57 mm panels used in this study should have produced a similar increase in the selection characteristics of the net (provided the selection factor of 50% per mesh size is constant for a given species). This was not observed for any species analysed in our experiment — the mid selection point for sand whiting increased from 20.57 to 22.39 cm FL, whereas it decreased for flat-tail mullet and did not change for silver biddy. Because the 57 mm transparent panels were attached point-to-point (mesh by mesh) to the surrounding 51 mm mesh, the hanging ratio was slightly less in the panels, therefore reducing the mesh openings in the panels which may explain the smaller change in selection of the modified net than that expected. An additional factor which may have influenced the effective hanging ratios of these nets is the fact that at the critical time of selection (when the haul is close to shore), the nets collapse and become convoluted and so reduce the vertical openings of the meshes in the T-direction.

The improved size selection detected for sand whiting compared to the other species (Table 2) may be explained by differences in escape behaviour. Sand whiting exhibited a rapid swimming speed while trying to escape and several legal sized fish became meshed in the transparent panels. In contrast, flat-tail, sea mullet and silver biddies displayed slower responses to the net and became entangled in meshes more easily. Although there were no changes in the size selectivities of these later species, a greater proportion of flat-tail mullet and silver biddy escaped into the cover when the panels were in place, indicating that these panels may reduce the quantity of bycatch landed. Other kinds of modifications (e.g. inclusion of square meshes in the transparent panels) may be required to improve the size selectivities of such species and to reduce bycatch in these nets.

The transparent panels used in this study show potential as a means of improving the daytime selectivity of haul nets for sand whiting by reducing the proportion of smaller individuals that are retained by the net. Panels similar to that tested here may be beneficial in other daytime estuarine and ocean beach-seine fisheries. It is apparent, however, that transparent panels of different dimensions, and possibly those incorporating larger sized meshes and square meshes need to be tested over a range of habitats in different estuaries and time periods to determine the optimal design for the species of interest.

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Appendix 7

Kennelly, S.J., Gray, C.A. (2000) Reducing the mortality of discarded undersize sand whiting *Sillago ciliata* in an estuarine seine fishery. *Marine and Freshwater Research* 51, 749-753.

Mar. Freshwater Res., 2000, 51, 749–53

Reducing the mortality of discarded undersize sand whiting *Sillago ciliata* in an estuarine seine fishery

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Abstract. A field experiment was done to determine the effects of mesh size in the bunt and codend of an estuarine beach-seine net on the meshing (gilling) and discarding of undersize sand whiting *Sillago ciliata* (Sillaginidae). Four mesh sizes were examined: 45 mm, 50 mm, 57 mm and 64 mm, in an alternate-haul experiment in the Clarence River, New South Wales, Australia. A laboratory experiment was also done to determine the mortality of sand whiting after becoming meshed in seine nets. The currently allowed mesh size (50 mm) catches a large proportion of undersize sand whiting that become meshed in the netting and are subsequently discarded. The laboratory experiment showed that ~40% of these fish may die within a few weeks whereas no unmeshed fish die. In contrast, the 57 mm mesh size meshed few undersize sand whiting yet retained almost the same number of legal-sized fish as the 50 mm mesh. Hence, the maximum mesh size allowed in the bunts of nets used in this fishery should be raised to 57 mm to allow the escape of large numbers of undersize sand whiting that are currently being caught, meshed and discarded in a condition that leads to significant mortality.

Introduction

Most net-based fisheries in the world have regulations specifying allowable mesh sizes and fish sizes in order to minimize the capture and subsequent mortality of certain-sized fish. Ideally, minimum mesh sizes ensure that the smallest sizes of fish retained by nets correspond to the minimum legal size of the particular species targeted – which is usually set so that juveniles can survive until they reach a reproductive size. Maximum mesh sizes are less common but are sometimes used to reduce the entangling of any undersize fish that are caught in nets. In recent years, significant attention has focused on the mortality of fish due to physical injury or stress after their release or escape through meshes (for reviews see Chopin and Arimoto 1995; Chopin *et al.* 1996). In particular, the smallest fish caught in many net fisheries are often entangled, 'meshed' or 'gilled' in the mesh openings, causing significant damage and possibly death. If such fish are larger than the minimum legal size for a species, this mortality is unimportant because the fish are retained for sale. However, if meshed fish are undersize and therefore discarded, their mortality can negate any benefits of minimum fish-size regulations for subsequent populations (see also Evans *et al.* 1995; Chopin *et al.* 1996). It is therefore important that mesh-size regulations are set large enough to allow undersize fish to escape without becoming entangled or meshed but still allow the retention of legal-sized fish.

Commercial beach-seining for fish occurs in most estuaries in New South Wales (NSW), Australia, and forms the basis of a fishery that lands ~2000 t of fish per year (at a value of ~$A5 million). Estuarine fish seining is, however, a controversial fishing method, with conservation and angling groups claiming that the nets catch and kill many juveniles of recreationally and commercially important species. The fishery is currently managed by a complex suite of spatial and temporal closures and gear restrictions, including regulations governing the maximum lengths of nets and ropes and minimum and maximum mesh sizes. Generally this is a multispecies fishery that targets, retains and discards a wide variety of estuarine species. At certain times and places, however, fishers target monospecific schools of the highly valuable sand whiting (*Sillago ciliata* F: Sillaginidae) by hauling nets over shallow sand flats during the warmer months of the year (September–March). During this process, fishers catch few individuals of non-targeted species, but large numbers of undersize sand whiting (<25 cm fork length, FL) are frequently caught, meshed and discarded – often in poor condition (~Gray, unpublished).

The few studies that have examined commercial beach-seining gears (e.g. Jones 1982; Evans *et al.* 1995; Lamberth *et al.* 1995; Gray *et al.* 2000) have shown that the mesh sizes used were often inappropriate, with many small fish being caught and subsequently discarded, often dead or in poor condition. In NSW there has been one published study of the

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selectivity of seine nets (Gray *et al.* 2000), despite a history of use beginning in the 1880s and present mesh regulations being introduced in the 1940s. Although the main area for size selection of fish in mobile fishing gears such as trawls occurs near the codend (e.g. Watson 1989; Isaksen *et al.* 1992; Ferno and Olsen 1994), our observations indicate that size-selection in estuarine seine-nets mainly occurs before the fish enter the codend. That is, fish are herded in front of the wings and bunt of the net (see Fig. 1) during hauling and, as the net nears the shore and the distance between the wings decreases, the captive fish try to escape – causing the main selection of fish to occur at the bunt of the net, with few fish escaping through the codend. Attempts to improve size selectivity and reduce by-catch in this fishery have therefore concentrated on altering mesh configurations in the bunt (see also Gray *et al.* 2000).

The present study examines the effectiveness of various mesh sizes in allowing undersize sand whiting to escape, unmeshed, through the mesh openings in the bunts of estuarine fish seine-nets in NSW. We examined four different mesh sizes, 45 mm, 50 mm (the current maximum allowable mesh size), 57 mm and 64 mm, in a replicated, alternate-haul experiment in the Clarence River estuary when fishers targeted sand whiting. In a laboratory experiment, we also examined differences in the mortality of unmeshed and meshed sand whiting – the latter simulating the damage incurred during normal commercial seining operations.

Materials and methods

Field experiment

This study was done on established commercial fish seining sites within 500 m of each other in the Clarence River, NSW, Australia (29°25'S,153°22'E) over a 5-day period in November 1998, using a chartered commercial fish seining crew. The sites and times fished were selected to ensure that the same population of sand whiting was fished in each replicate haul. All hauls were done at low or high tide when water movement was minimal. The net (Fig. 1) conformed to NSW Fisheries regulations and was 300 m long and made of black multifilament polyamide netting. It had 112 m length wings made of 80 mm mesh, and a total bunt length of 75 m, of which the two 25 m shoulders were made of 57 mm mesh and the central 25 m portion and codend made of the test mesh size (45 mm, 50 mm, 57 mm or 64 mm). The net was 7 m deep and was negatively buoyant so that it remained on the substratum at all times. The hauling procedure usually took ~20 min to complete and involved setting the rope and net from a small rowboat in a semi-circle, starting and ending at the shoreline. After setting, the gear was hauled to the shore at ~2 km h^{-1} (0.5 m s^{-1}) by hand.

It was not possible to use a cover net to determine selectivity, nor a paired-haul comparison to directly compare mesh sizes in the bunt, so an alternate-haul experimental design was used with the four mesh sizes in the bunt changed at random throughout the 24 hauls done during the 5 days of fishing. For each haul, all sand whiting that were meshed in the bunt and codend of the net and those that were caught unmeshed in the bunt and codend were kept separate, counted, weighed and measured (FL) to the nearest 0.5 cm.

Laboratory experiment

Approximately 250 undersize sand whiting were caught in a hand-hauled net made of 12 mm mesh, and were allowed to acclimatize for 3 weeks in two 4000 L holding tanks in the aquarium facilities at the Cronulla Fisheries Centre. After this time, approximately half the number of fish (56) in each tank were caught in a net made of the current legal mesh size of 50 mm (to mimic the meshing incurred by fish during normal fishing operations). These meshed fish were untangled by the usual commercial method (by squeezing the fish by hand through the mesh opening head-first) and placed into a separate 4000 L tank. The remaining fish were caught in a net made of 38 mm codend mesh (to mimic the handling incurred by unmeshed fish during normal fishing operations) and placed in a separate 4000 L tank. This procedure was repeated for the second holding tank to provide two replicate tanks of 56 fish each that had been meshed and two replicate tanks of 56 fish each that had been caught unmeshed. The experiment was run for 24 days,

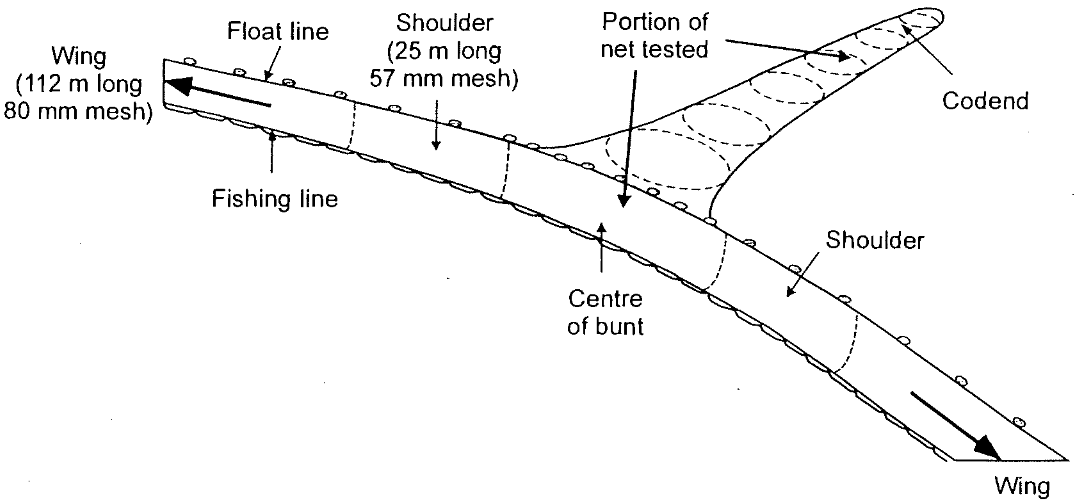

Fig. 1. Diagrammatic representation of the estuarine seine net used in the field experiment.

after which the mortality of fish appeared to have ceased. The tanks were inspected twice per day and any dead fish observed were removed and the treatment, day of death and size of the fish were recorded.

Data analysis

The data from each haul in the field experiment were used to determine the percentage (by weight and number) of meshed and unmeshed sand whiting that were undersize (and consequently discarded). The mean percentages (and standard errors) across all replicates were plotted, the data were analysed by a one-way analysis of variance and means were compared by Student–Newman–Keuls multiple comparisons. Size-frequencies of meshed and unmeshed fish were pooled across all replicate hauls for each of the four mesh-sizes examined and compared in two-sample Kolmogorov–Smirnov tests ($P = 0.05$).

To provide an estimate of the mortality of meshed and unmeshed fish, the data from the laboratory experiment were plotted as the cumulative percentage of dead fish observed throughout the 24-day duration of the experiment.

Results

The percentage weights and numbers of sand whiting discarded were significantly different among the four mesh sizes examined (Table 1*a*), with larger quantities of unmeshed fish being discarded from the 45 mm mesh bunt. The percentage of meshed fish that were discarded was also largest when the 45 mm mesh was used and, most importantly, when the 50 mm mesh (which is currently the maximum allowable mesh size) was used (Fig. 2 and Table 1*b*). The 57 mm and 64 mm mesh had the lowest rates of discard of sand whiting for both meshed and unmeshed fish.

The average sizes of meshed and unmeshed sand whiting tended to increase with increasing mesh size, although this was only statistically significant for meshed fish (Fig. 3, Table 1*b*). The average size of unmeshed fish was greater than the minimum legal size of sand whiting (25 cm FL) for all mesh sizes, but for meshed fish the average size was only greater than the legal minimum size when mesh of 57 mm or 64 mm was used.

Large numbers of undersize fish were both meshed and unmeshed when the smallest mesh-size was used (Fig. 4 and Table 2). Most importantly, however, these data showed that the maximum allowable mesh size of 50 mm also meshed a large number of undersize fish while the 57 mm and 64 mm mesh meshed very few undersize fish. The largest mesh size caught fewer legal-sized fish than the smaller mesh sizes – an average of 14.5 (s.e. 2.1) legal fish per haul for the 64 mm mesh, compared with 38.7 (17.6) legal fish for the 57 mm mesh, 44.2 (21.6) legal fish for the 50 mm mesh and 20.1 (6.1) legal fish for the 45 mm mesh.

The laboratory experiment to estimate the mortality of meshed and unmeshed sand whiting showed that no unmeshed fish died during the experiment. Meshed fish began to die after 1 day, with the greatest rate of mortality occurring between 5 and 11 days, after which time 36.3% had died (Fig. 5). After 24 days a total of 39.8% of meshed fish had died.

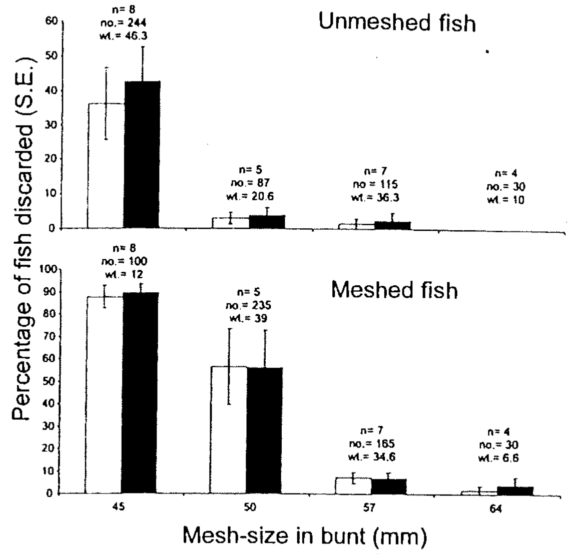

Fig. 2. Percentage (± s.e.) of unmeshed and meshed sand whiting by weight (clear) and number (shaded) that were discarded when four different mesh sizes were used in the bunt of an estuarine fish seine net. Also given are the number of hauls (*n*), the total weights (kg) and numbers of fish caught in each treatment.

Table 1. Summaries of *(a)* analyses of variance and *(b)* Student–Newman–Keuls multiple comparisons comparing the mean percentage discard (by weight and number) and mean sizes of sand whiting caught by seine nets with bunt mesh sizes of 45 mm, 50 mm, 57 mm and 64 mm
*P <0.01; **P <0.001

	Wt discarded (%)		No. discarded (%)		Average size	
(a)	F	*P*	F	*P*	F	*P*
Unmeshed fish	6.70	*	9.63	**	10.30	**
Meshed fish	29.55	**	32.22	**	56.22	**
(b)						
Unmeshed fish	45>50=57=64		45>50=57=64		45<50=57=64	
Meshed fish	45>50>57=64		45>50>57=64		45<50<57=64	

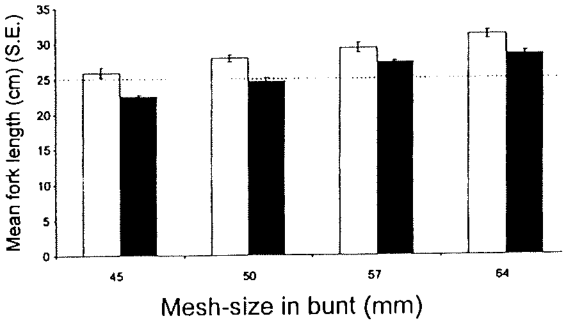

Fig. 3. Average size (FL ± s.e.) of unmeshed (clear) and meshed (shaded) sand whiting caught when four different mesh sizes were used in the bunt of an estuarine fish seine net. Horizontal line, legal minimum size for sand whiting in NSW (25 cm FL).

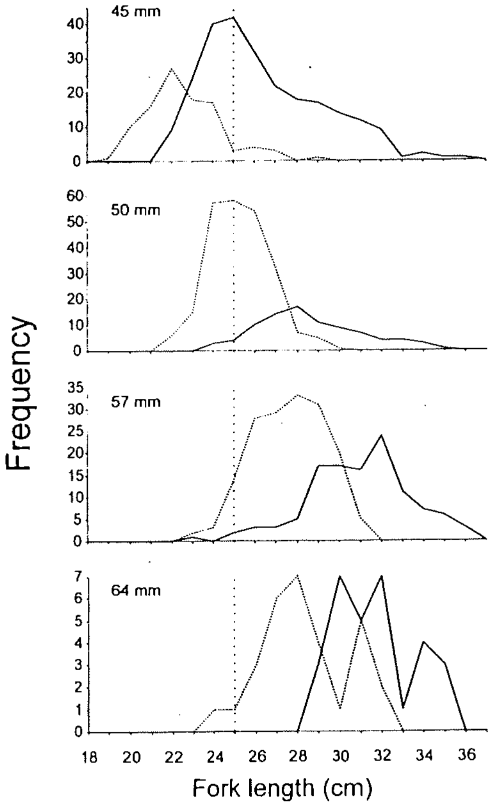

Fig. 4. Size-frequencies of unmeshed (solid) and meshed (dotted) sand whiting that were caught when four different mesh sizes were used in the bunt of an estuarine fish seine net. Vertical line, legal minimum size for sand whiting in NSW (25 cm FL).

Discussion

The results provide a set of interpretations concerning the selectivity of the fishing gear used in NSW's estuarine fish seine fishery that have important consequences for the management of this fishery. It is clear that when targeting schools of sand whiting, the 50 mm maximum mesh size currently allowed in the bunts of these nets catches a large proportion of undersize sand whiting that become meshed in the netting and are subsequently discarded. The laboratory experiment showed that up to ~40% of these fish may die within a few weeks, whereas no unmeshed fish die. In contrast, the 57 mm mesh meshed few undersize whiting yet still retained almost the same number of legal-sized fish as the 50 mm mesh. This was not the case for the 64 mm mesh, which, although meshing very few undersize sand whiting, also did not catch many legal-sized fish. The conclusion from these results is that the maximum mesh size allowed in the bunts of nets used in this fishery should be raised by 7 mm to 57 mm to allow the escape of large numbers of undersize sand whiting that are currently being caught, meshed and discarded in a condition that leads to significant mortality.

A 7 mm increase in maximum mesh size for these seine nets would only be appropriate when these nets are used to target sand whiting – and catches of other species are rare. When this fishery adopts a multispecies targeting strategy, a 7 mm increase in mesh size could lead to greater numbers of undersize individuals of other species (e.g. sea mullet *Mugil cephalus* and yellowfin bream *Acanthopagrus australis*) becoming meshed

Table 2. Summaries of the Kolmogorov–Smirnov tests comparing the size-frequencies of sand whiting caught by the different sizes of mesh used in the bunt
**P <0.001, ns P >0.05

	Mesh sizes compared	P
Unmeshed fish	45 mm v. 50 mm	**
	50 mm v. 57 mm	**
	57 mm v. 64 mm	ns
Meshed fish	45 mm v. 50 mm	**
	50 mm v. 57 mm	**
	57 mm v. 64 mm	ns

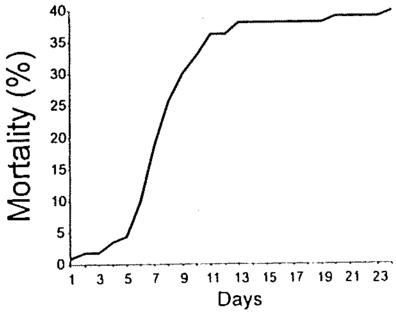

Fig. 5. Cumulative percentage mortality of meshed fish during the 24-day laboratory experiment. No unmeshed fish died during the experiment.

in the net. A solution to this could be for managers to enforce a 7 mm increase in the bunt mesh size of these nets only during the summer season when fishers target sand whiting, and to use 50 mm mesh at other times of the year when sea mullet, yellowfin bream and other species are targeted.

Many of the mesh-size regulations in place in NSW estuaries are based on historical conventions determined at times when the target species, by-catch species and the nets themselves were different to those used now. Very few experimental examinations of gear configurations have been done for these fishing methods and it is therefore not surprising that inappropriate maximum and minimum mesh sizes have been found to cause significant problems with the capture and subsequent discarding of undersized fish in these fisheries (see also Gray *et al.* 2000). The results from the present paper show that such problems can be easily overcome by a relatively simple set of experiments that examine the selection characteristics of these fishing gears and the fate of undersize discards. It is essential to repeat these tests for other nets and other target species to ensure that gear-based regulations protect the appropriate size of target species and undesired species of by-catch.

The results have broader implications for the research and management of incidental mortality of fish discarded from all nets. One of the chief sources of unaccounted mortality (noted by Chopin and Arimoto 1995) is that associated with discards that die from injuries or stresses incurred during the process of capture and release. The work reported here shows that such mortalities can be very significant for meshed fish and, when the mesh size used in a fishery meshes large numbers of undersize individuals of the target species, this source of mortality can negate any beneficial effects of minimum size restrictions. It is therefore important that the methods used to catch species that have minimum size restrictions employ gears that allow undersize conspecifics to escape unharmed.

Acknowledgments

This study was funded by the Australian Fisheries Research and Development Corporation as part of Project 97/207. We thank commercial fishers Robert Kay and Steve Schneider for making the nets used in the study and for assistance with field work. Crispian Ashby, Brett Rankin and David Barker assisted with the aquarium experiment and John Stewart provided comments on the manuscript.

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Appendix 8

Gray, C.A., Kennelly, S.J. (1999) Reducing by-catch of estuary hauling nets. ***Fisheries NSW, Spring 1999, 10.***

Research

Integrated monitoring of environmental flows

Dr Peter Gehrke, Port Stephens Research Centre

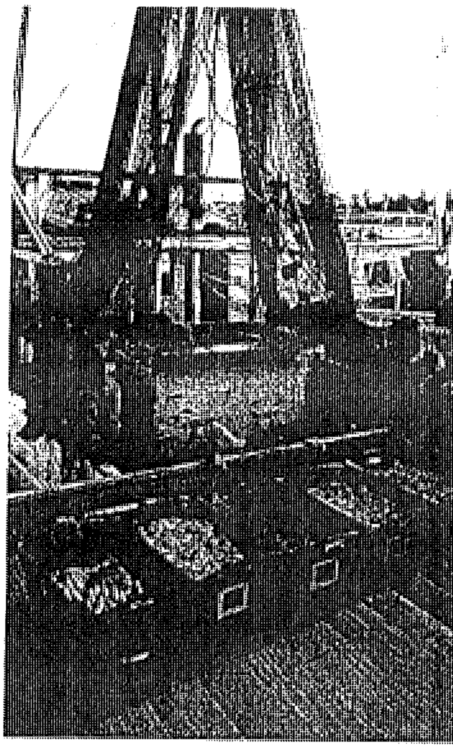
The water reform process in NSW is introducing environmental flows in the Gwydir, Namoi, Macquarie, Lachlan, Murrumbidgee, Barwon-Darling and Hunter rivers. A long history of poor flow management and the extraction of large volumes of water, mostly for irrigated agriculture has severely affected the ecology of these rivers. A multi-disciplinary project - Integrated Monitoring of Environmental Flows (IMEF) was established to monitor ecological changes resulting from improved flow in these rivers. The Department of Land and Water Conservation is co-ordinating the project.

Over three years, NSW Fisheries will assess changes in fish communities in approximately 60 sites. Several sites in each river were previously sampled as part of the NSW Rivers Survey. This will allow some before/after comparisons to be made. The emphasis of the new study is on longitudinal changes in fish and river flows to take into account natural downstream changes in habitats, flows and fish. Changes in fish communities in wetlands are also being studied. Anticipated changes in fish communities include increased abundance of native fish, improved conditions for breeding and a decline in carp numbers.

Other agencies are monitoring changes in water quality, sediments, habitat quality, algae, aquatic vegetation and invertebrates.

Reducing by-catch of estuary hauling nets

Dr Charles Gray and Dr Steven Kennelly



One of the most controversial issues in NSW fisheries in recent years is the conflict between estuarine commercial haul fisheries and other interest groups, including recreational fishers, councils, tourist operators and the general public.

The main issue [illegible] that the use of [illegible] nets in estuaries leads to significant by-catch and discarding of undersized or unwanted fish. This has led to widespread claims about potential wastage of fish, with many user groups calling for the methods to be banned. Catches by estuarine fish and prawn hauling are together valued at approximately $[illegible] million per annum and are a significant source of employment in regional areas.

Over the past 18 months, NSW Fisheries [illegible] have researched solutions to this issue. Scientific observers accompanied commercial fish and prawn hauling crews to record the retained and discarded catches during typical fishing operations. Fish hauling operations in the Clarence River, Lake Macquarie, Botany Bay and St. Georges Basin were examined. Prawn hauling was looked at in the Richmond, Manning and Shoalhaven rivers and Wallis Lake. The data obtained from this survey [illegible] currently being analysed.

discarding of undersized or unwanted fish has led to widespread claims about potential wastage of fish, with many user groups calling for the methods to be banned

NSW Fisheries has also worked with industry to develop more selective fish and prawn hauling gear, and methods of operations. So far the use of transparent panels in fish haul nets has been tested and the effectiveness of various mesh sizes in the [illegible] of fish haul nets for catching appropriate sizes of [illegible] and whiting has been looked at.

Currently NSW Fisheries is [illegible] different [illegible] of operating prawn haul gear in estuaries and plans to conduct field-based experiments aimed at reducing the mortality rates of fish discarded from fish haul nets in the summer of 1999/2000.

NSW Fisheries would like to hear from commercial fishers who have ideas on other ways of reducing by-catch in these fisheries.

Appendix 9

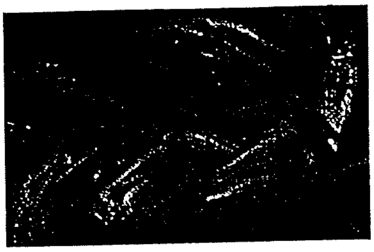
Kennelly, S.J., Gray, C.A. (2001) Effects of increasing mesh size in bunts of estuarine haul nets when targeting sand whiting. *Fisheries NSW, Spring 2000/Summer 2001, 28-29.*

Commercial

Effects of increasing mesh size in bunts of estuarine haul nets when targeting sand whiting

Dr Steve Kennelly (Chief Scientist) and Dr Charles Gray (Senior Research Scientist) recently reported on research to examine the effects of altering mesh sizes in the bunts of estuarine haul nets to reduce discarding and mortality of undersize sand whiting. This is a summary of their findings.

Regulations governing the NSW estuarine haul net fishery include maximum and minimum mesh sizes in the wings, shoulders, bunts and cod-ends of nets. For some time, estuarine commercial haul net fishers have requested that the mesh size in the bunts of some haul nets be increased to reduce the capture and subsequent discarding of undersize sand whiting. A field experiment was done in the Clarence River to determine the effects of increasing mesh-size in the bunt and codend of an estuarine haul (beach seine) net on the meshing (gilling) and discarding of undersize sand whiting. Commercial fishers Robert Kay and Steve Schneider assisted with this research.



Sand whiting

The net used in the experiment conformed to regulations and was 300m long and made of black multi-filament polyamide netting. It had 112m length wings made of 80mm mesh, and a total bunt length of 75m, of which the two 25m shoulders were made of 57mm mesh and the central 25m portion and cod-end were made of the test mesh size. Four different mesh-sizes were examined (45mm, 50mm - the maximum mesh-size currently allowed, 57mm and 64mm) in an alternate haul experiment. Fig 1 shows the section of the bunt and cod-end that was modified during the experiment. A

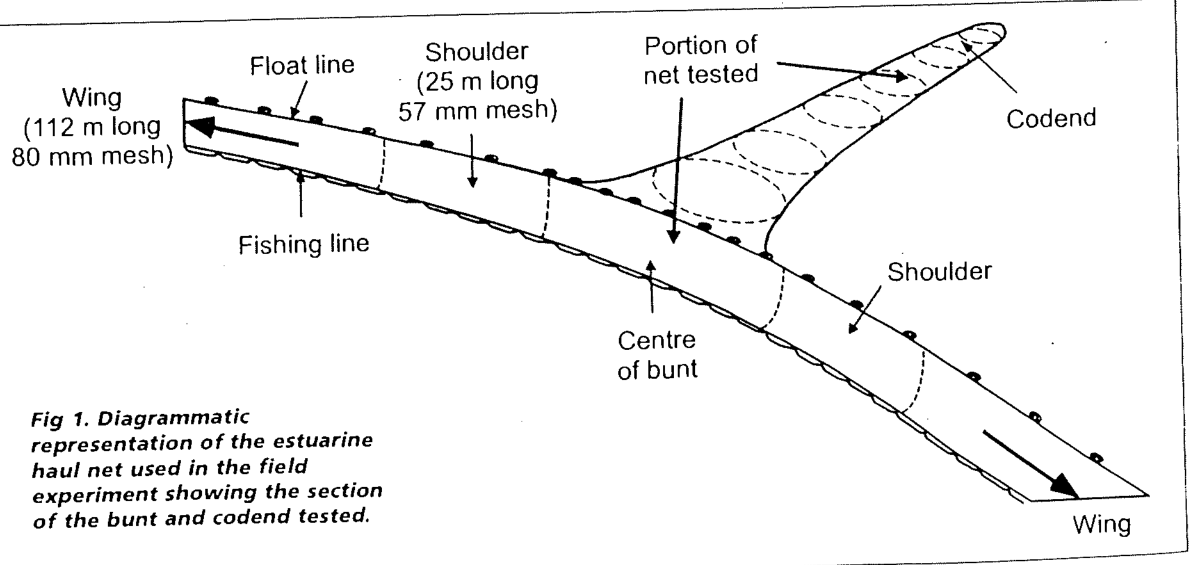


Fig 1. Diagrammatic representation of the estuarine haul net used in the field experiment showing the section of the bunt and codend tested.

page 28 Spring 2000/Summer 2001 Fisheries NSW magazine laboratory experiment was done at the Cronulla Fisheries Centre to determine the mortality of sand whiting after becoming meshed in haul nets.

The results of the field experiment showed that the currently allowed mesh-sizes (45 and 50mm) catch large proportions of undersize sand whiting (> 50% by number and weight) that become meshed in the netting in the bunt and are subsequently discarded (Fig 2). In contrast, the 57mm mesh-size meshed very few undersize sand whiting yet retained almost the same number of legal-sized fish as the 50mm mesh.

The laboratory experiment showed that no unmeshed fish died during the experiment. Meshed sand whiting began to die soon after the experiment began, with greatest mortality occurring between 5 and 11 days. After 24 days approximately 40% of meshed sand whiting had died (Fig 3).

These results suggest that the maximum mesh-size allowed in the bunts of nets used to target schools of sand whiting in this fishery (and other similar fisheries) should be raised by 7mm to 57mm. This will enhance the escape of large numbers of undersize sand whiting that are currently being caught, meshed and discarded in a condition that leads to significant mortality. It is acknowledged, however, that the recommended 7 mm increase may only be only appropriate when these nets are used to target sand whiting - and catches of other species are low. When this fishery targets several species, a 7mm increase in mesh-size could lead to greater numbers of undersize individuals of other species (eg. sea mullet and yellowfin bream) becoming meshed in the net. For this reason, fishers interested in changing the mesh size in their haul nets are required to do so under a permit system - which will allow further observations of catches to be made. Fishers wishing to use 57mm mesh in their nets for a trial period should contact Ms Zantiotis-Linton 02 4295 1809 (Estuary General ManagerLicencing) at the Cronulla Fisheries Centre.

For more details on this research, see: Kennelly, S.J. and Gray, C.A. (2000) Reducing the mortality of discarded undersize sand whiting Sillago ciliata in an estuarine seine fishery. Marine and Freshwater Research 51, 749-753. (available from Dr Charles Gray phone 02 9527-8411).

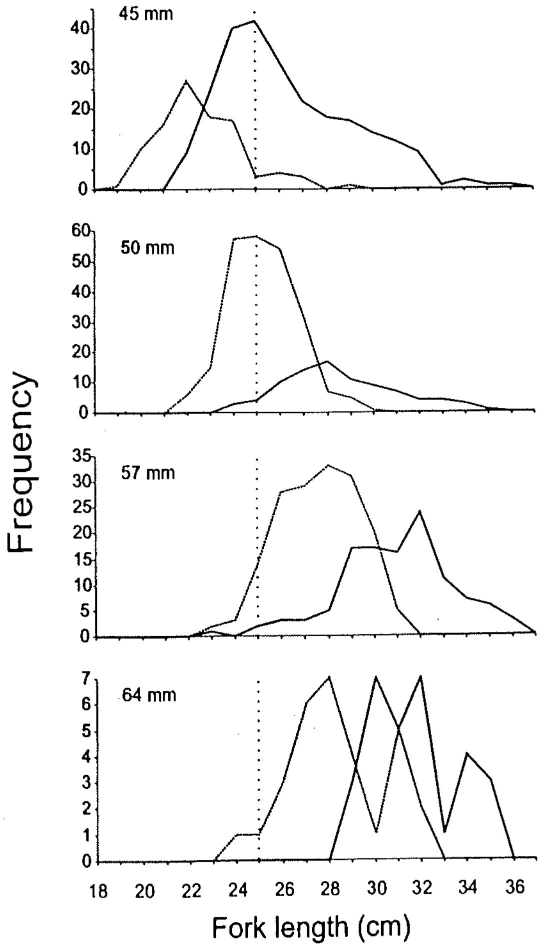


Fig. 2. Size-frequency histograms of meshed and unmeshed sand whiting that were caught using the four different mesh-sizes in the bunt of the haul net. The dotted vertical line indicates the minimum legal fork length for sand whiting in NSW of 25 cm FL.

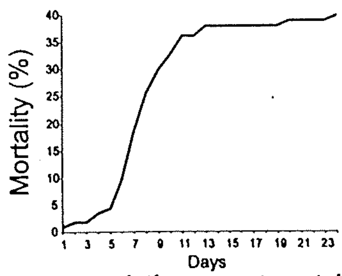


Fig 3. The cumulative percent mortality of meshed fish during the 24-day duration of the laboratory experiment. No unmeshed fish died during the experiment.

Appendix 10

Gray, C.A. Research update – estuary general. ***Fisheries NSW, Summer 2000,34.***

MAC Management Advisory news

Research update — estuary general

By Dr Charles Gray

Fish have been harvested from the NSW estuaries by commercial fishers since the early 1800s.

FRDC Estuarine commercial fish study

In 1997 -98 the Fisheries Research and Development Corporation (FRDC) Estuarine Commercial fish study showed that more than 4,000 tonnes of finfish worth $12 million was harvested from NSW estuaries by commercial fishers. Most of the important fish species harvested commercially from estuaries are also highly sought after by recreational fishers, and it is important we develop a good understanding of the biology and population dynamics of these species.

Researchers at NSW Fisheries recently completed a three-year FRDC funded study of the estuarine commercial finfish fishery in NSW.

The commercial fishery is complex as it is based on a large number of species caught using a variety of fishing methods. The study obtained detailed information on the growth of bream, sand whiting, dusky flathead and luderick. The study also gathered representative data on the size, sex and age composition of commercial catches of these fish species in several NSW estuaries.

This type of information is important for assessing the state of fish stocks and also for determining the impacts of fishing. A report has been submitted to the FRDC and will appear in NSW Fisheries' *Final Report Series* this year.

> ***"The commercial fishery is complex as it is based on a large number of species caught using a variety of fishing methods."***

Results from the study were used to develop a stock assessment program for bream and for designing a monitoring program for the other important estuarine fish species.

Bream stock assessment

NSW Fisheries is continuing a study of the stock dynamics of bream in NSW. Throughout 2000, researchers will be visiting several ports to sample commercial catches for length composition and to extract otoliths (earbones) for age analyses.

FRDC estuarine hauling project

With funding from the FRDC, NSW Fisheries is developing discard reducing gears in the state's estuarine haul fisheries. Observer based surveys of bycatch from estuarine fish and prawn hauling have largely been completed and data from these surveys are currently being analysed.

Preliminary analyses of data from the prawn haul fishery indicate that levels of bycatch from prawn hauling are considerably less than for estuarine prawn trawling. Moreover, the bycatch in this fishery is primarily dominated by small fish of little monetary value, including glassy perchlets, siphon fish and southern herring. Juveniles of some fish species that are important to recreational and commercial fishers including bream, flathead, mulloway and sand whiting are also captured in the fishery, but in relatively low numbers. This data is being used to develop ways to reduce the capture of unwanted fish in these fisheries.

Appendix 11

Gray, C.A., Kennelly, S.J. (2000) Use of transparent material to aid management of bycatch issues in the beach-seine fisheries in New South Wales, Australia. Abstract of presentation given at the 3rd World Fisheries Congress, China, October 2000.

Use of transparent material to aid management of bycatch issues in the beach-seine fisheries in New South Wales, Australia

Charles A. Gray and Steven J. Kennelly
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Abstract:

One of the most contentious issues surrounding the management of the multi-species estuarine and coastal finfish fisheries in New South Wales (NSW), Australia, is that of bycatch and discarding from commercial fishing practices. In particular, the current configurations of beach-seine nets are not particularly selective and many small fish of commercial and recreational importance are captured and discarded. Case studies detailing the development of gear modifications to solve discarding problems in these fisheries are presented. Testing of modified gears included alternate haul and covered net experiments. It was found that strategically placed transparent escape panels of larger mesh in the bunts of nets reduced bycatch in the estuarine fishery. Inclusion of panels reduced the bycatch of undersize sand whiting from approximately 80% to 5%. The escape responses of different species to the panels varied, possibly due to differing behavioral responses to visual cues. Nets fitted with transparent panels are being used in the fishery by permit. The application of transparent mesh in nets used in the coastal beach fishery is also reported and the implications of such gear modifications to other fisheries are discussed.

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