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

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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.

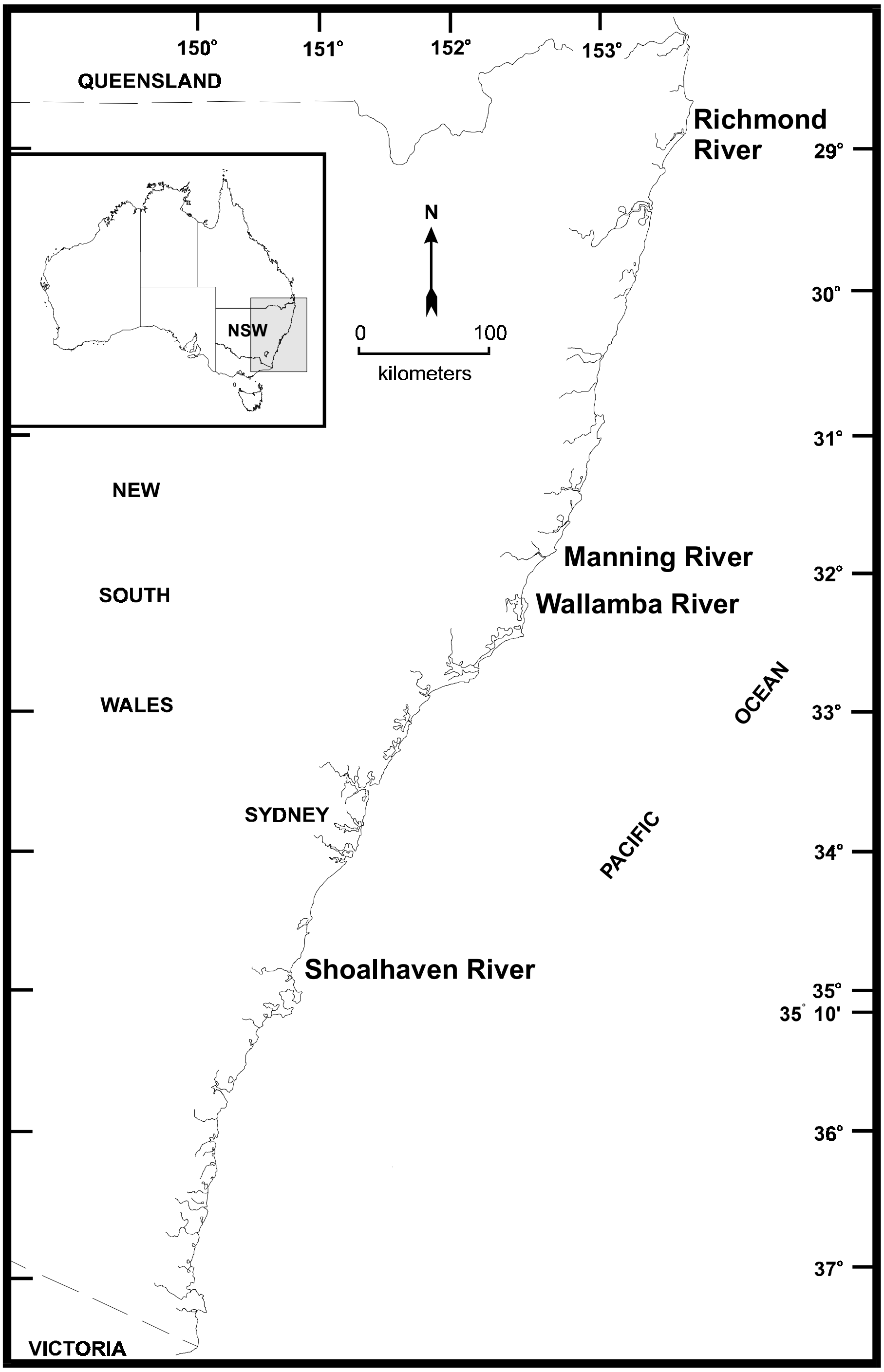

Figure 2.1. Map of NSW showing the four estuaries where the prawn haul fisheries were studied.

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.

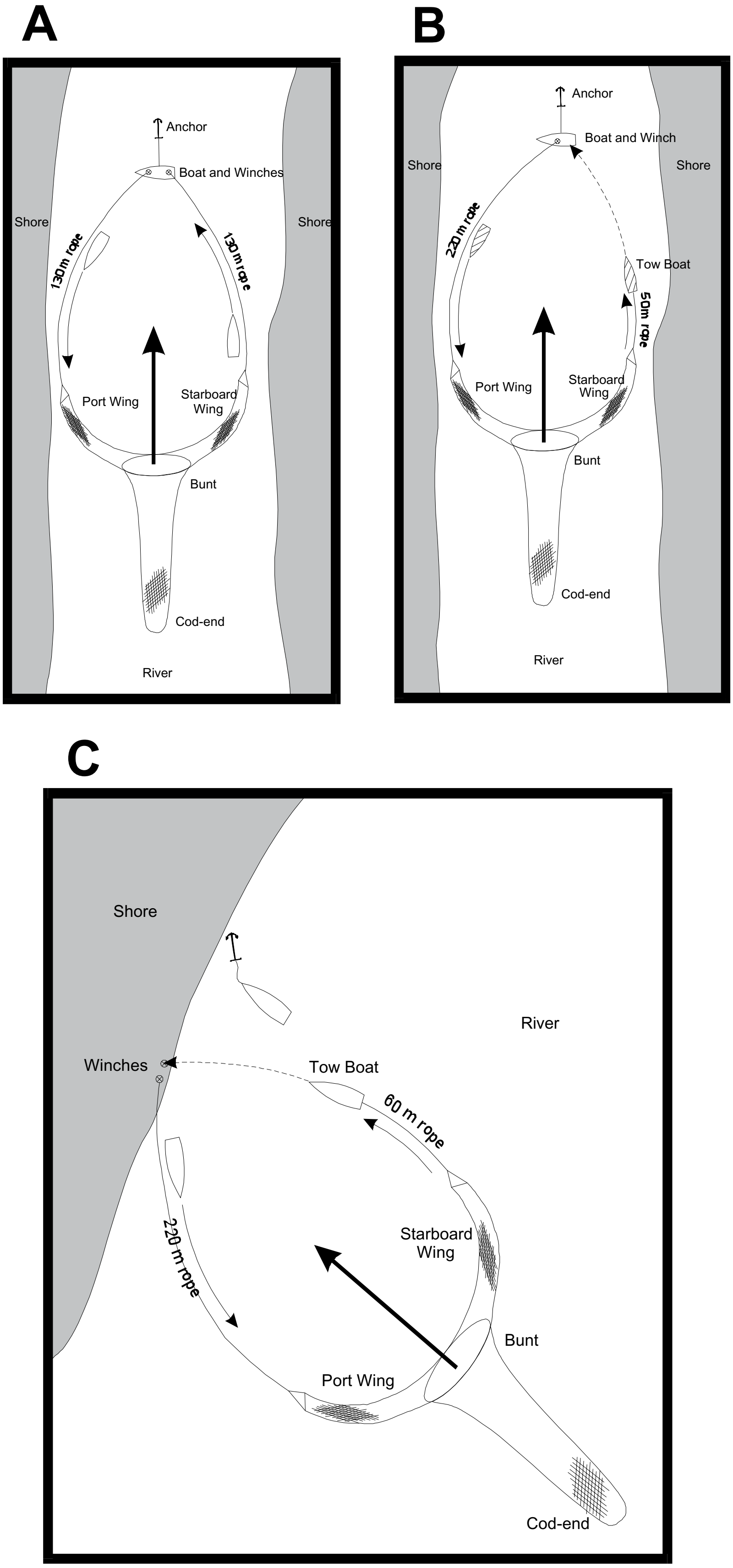

Figure 2.2. Diagrammatic representation of variations in prawn hauling. a. one boat used and net retrieved away from the shore; b. Two boats used and net retrieved away from the shore; c. One or two boats used and net retrieved to the shore.

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 4^{th} 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):

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

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.

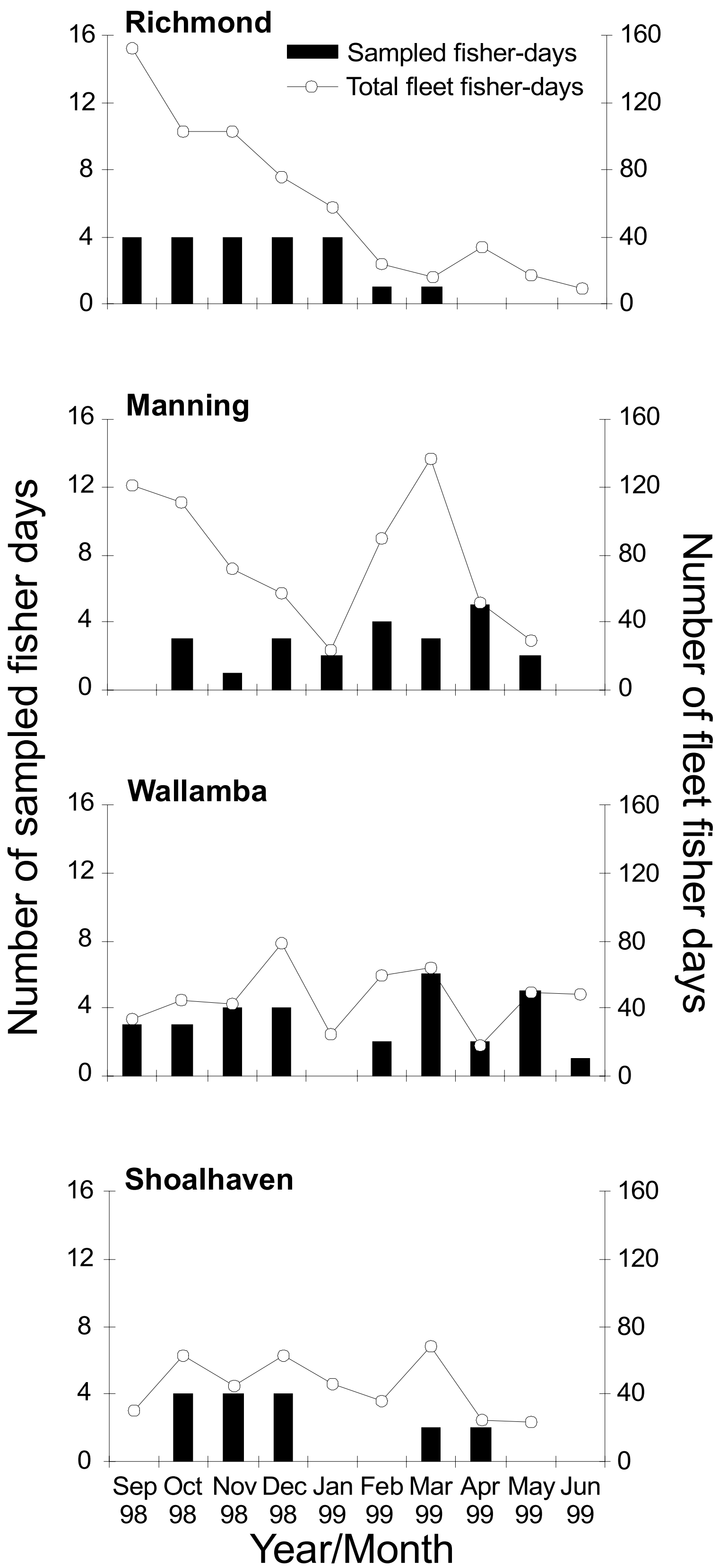

Figure 2.3. Trends in sampling and reported fishing effort in each estuary.

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 #	*	*		

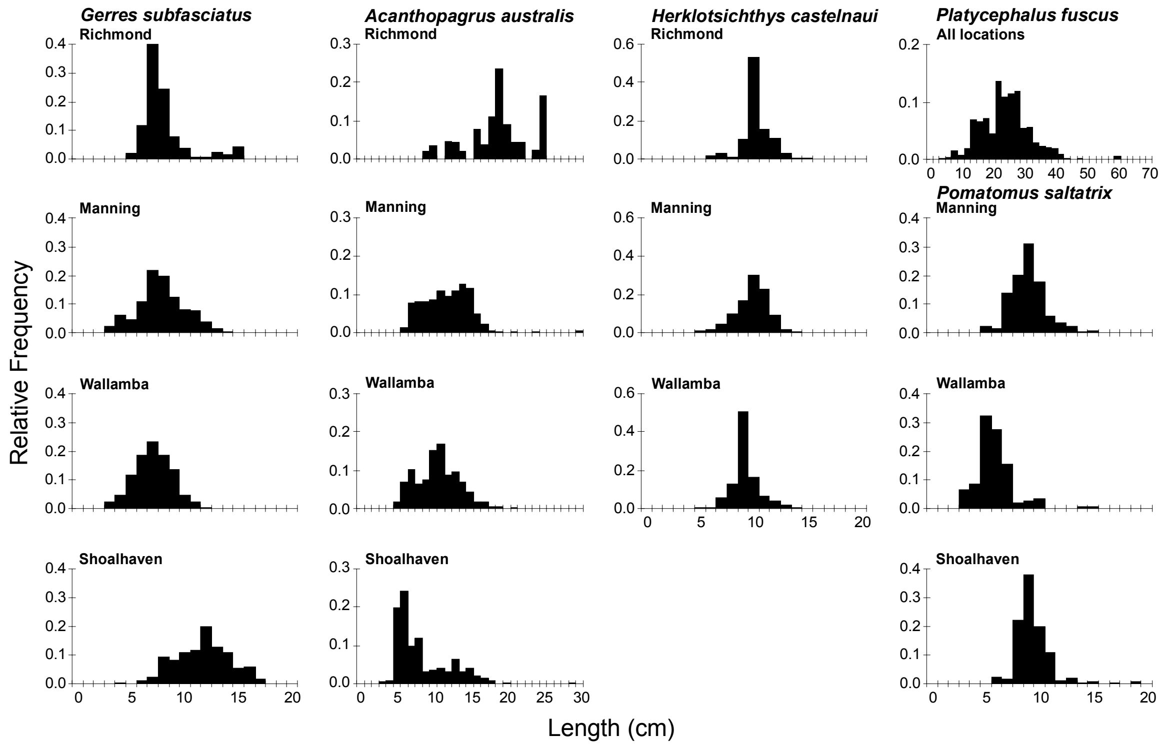

Figure 2.4. Length compositions of five bycatch species in prawn haul nets.

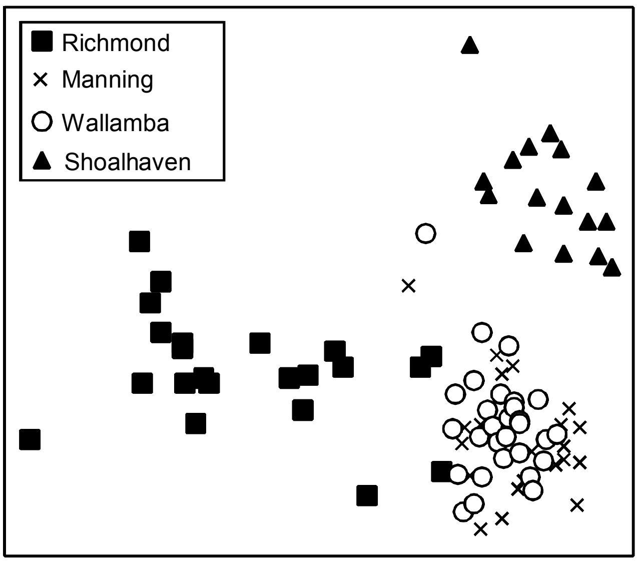

Figure 2.5. MDS ordination showing relationships of structures of bycatch among estuaries.

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).

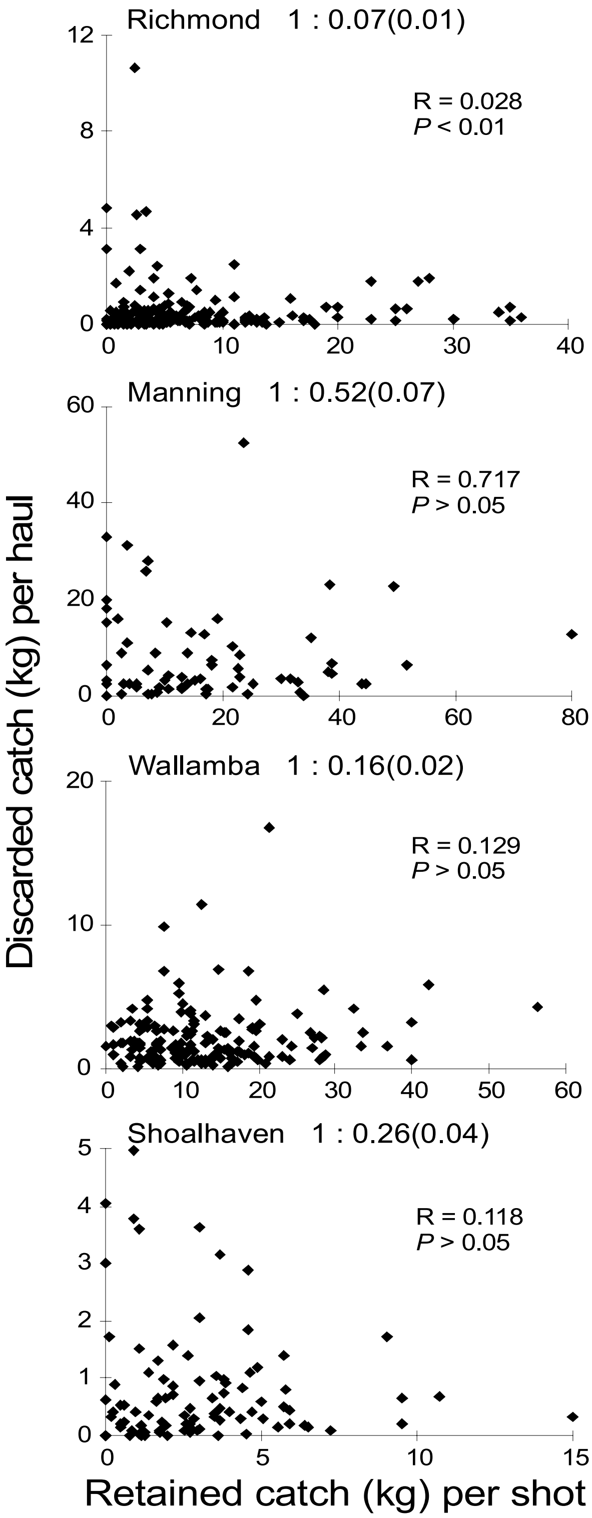

Figure 2.6. Relationships between the weight of prawn catch and weight of total bycatch in each estuary. Prawn to bycatch ratios by weight and the correlation coefficient (R) and its significance are given for each estuary.

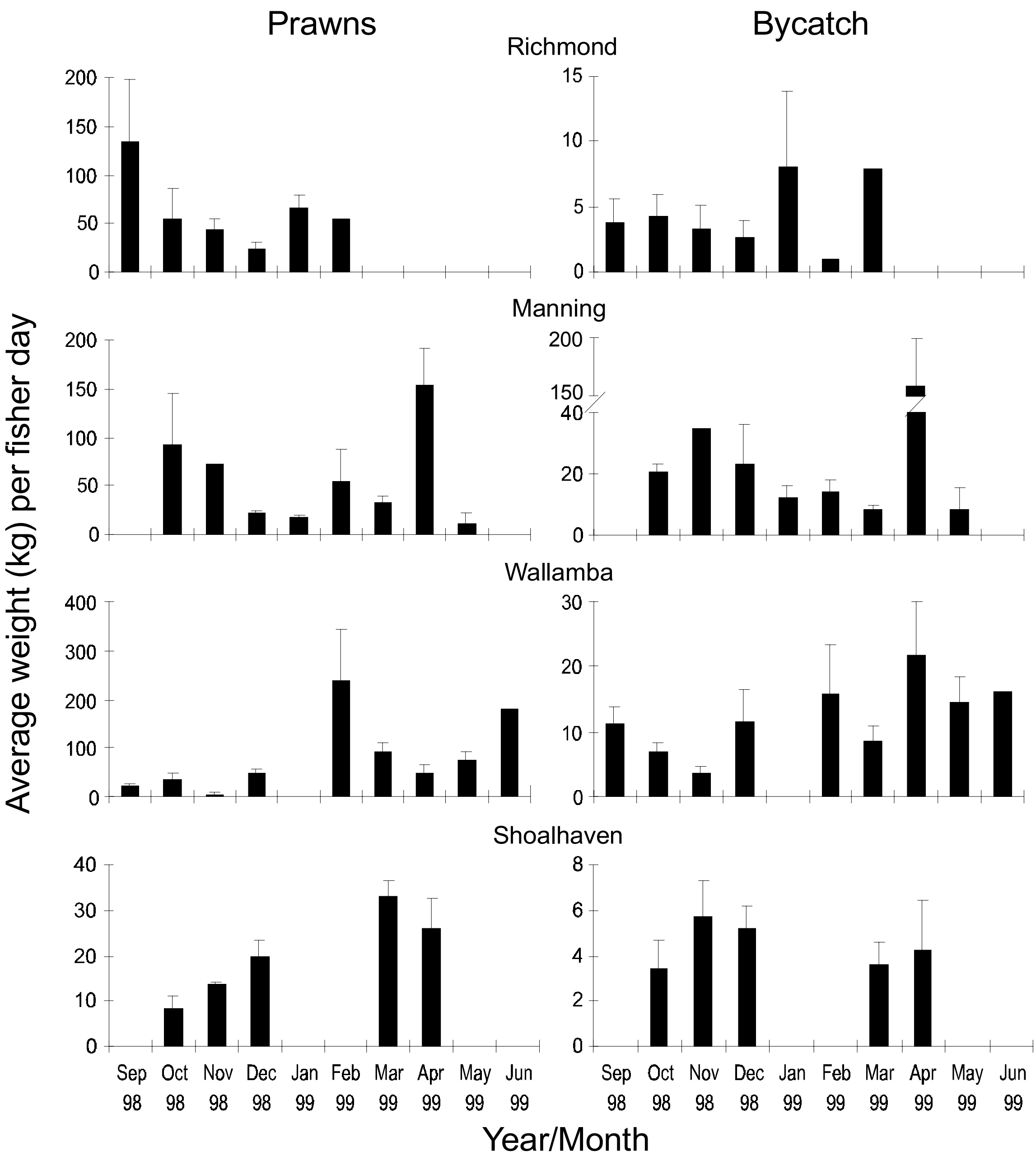

Figure 2.7. Catch rates of prawns and total bycatch weight in each estuary throughout the survey.

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.

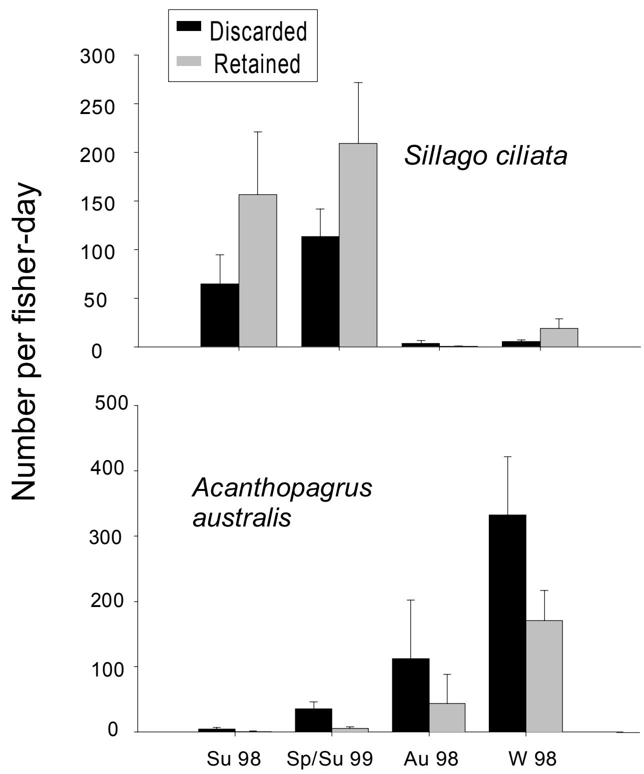

Figure 3.1. Mean (+1se) numbers of retained and discarded catches of sand whiting and bream in each season in the Clarence River.

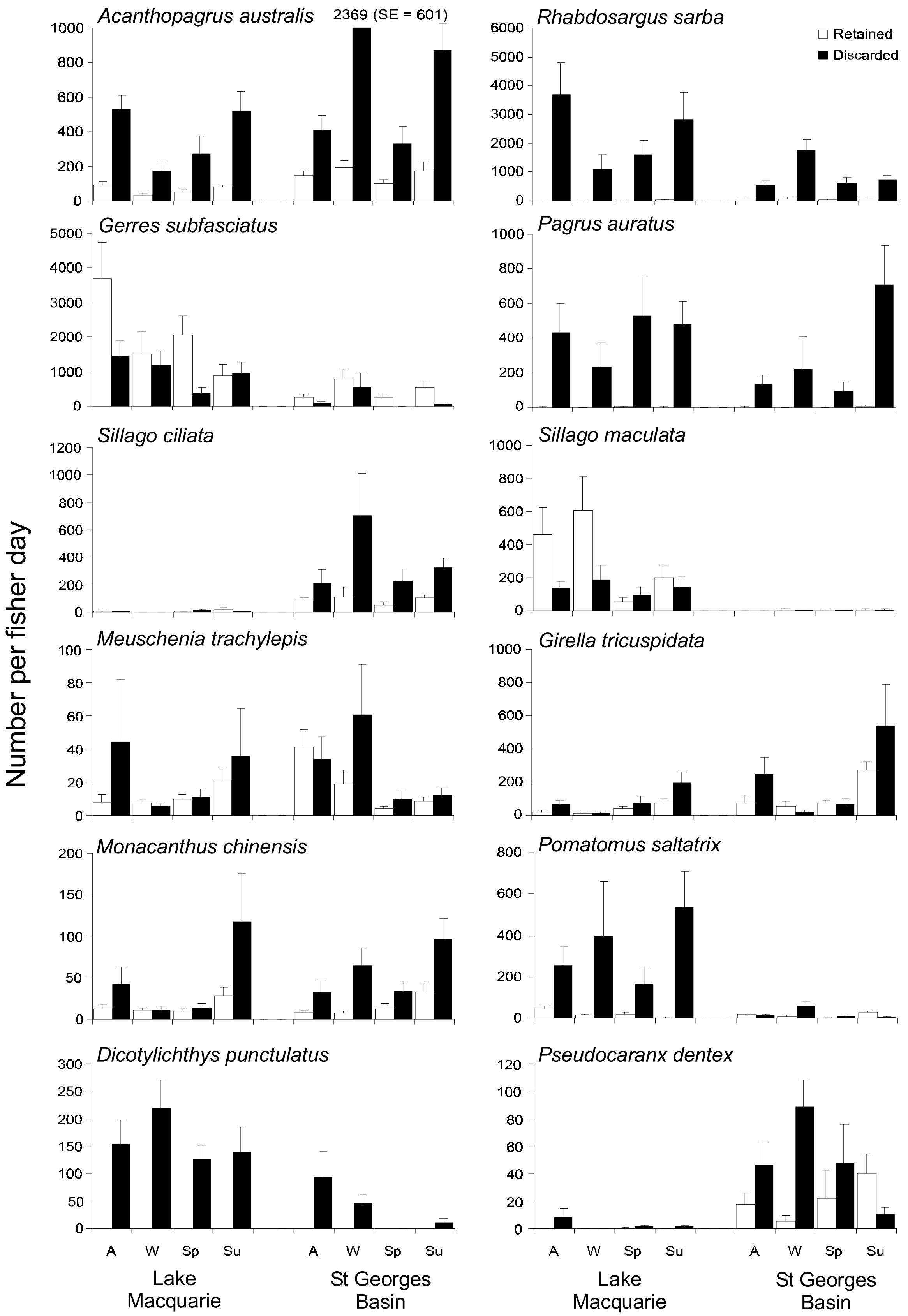

Figure 3.2. Mean (+1se) numbers of retained and discarded catches of individual species in each season in Lake Macquarie and St Georges Basin.

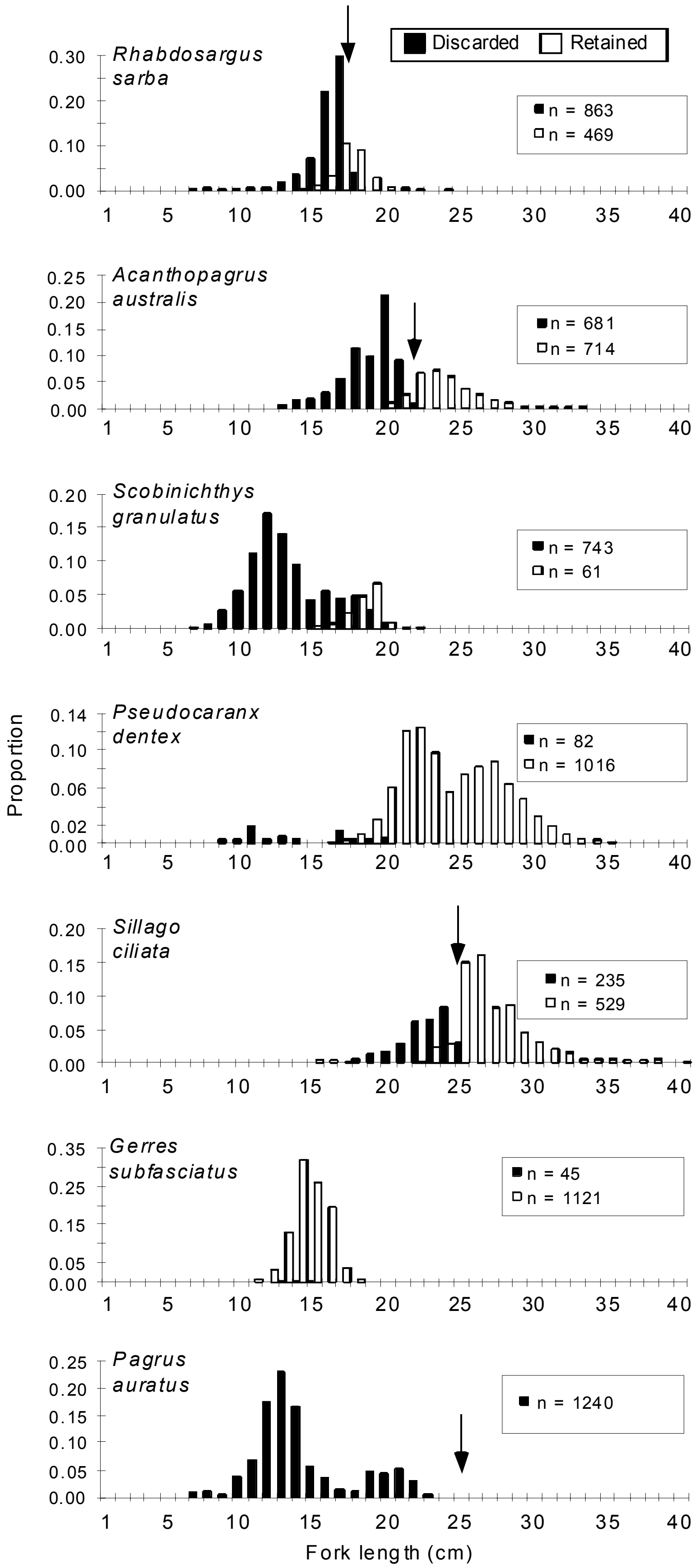

Figure 3.3. Length compositions of retained and discarded components of haul catches of important species in Botany Bay. Arrows indicate minimum legal length.

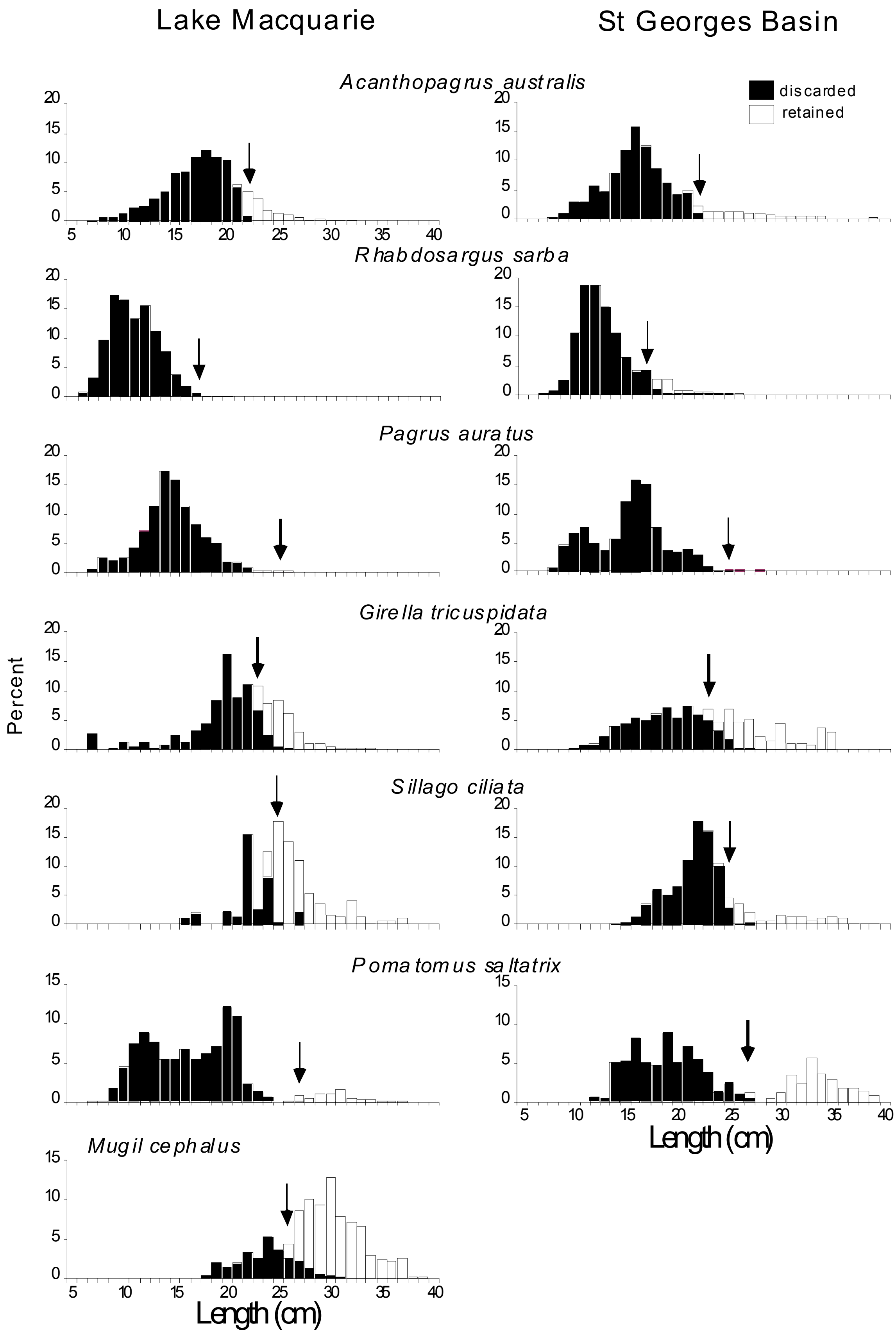

Figure 3.4. Length compositions of retained and discarded components of haul catches of important species in Lake Macquarie and St Georges Basin. Arrows indicate minimum legal length.

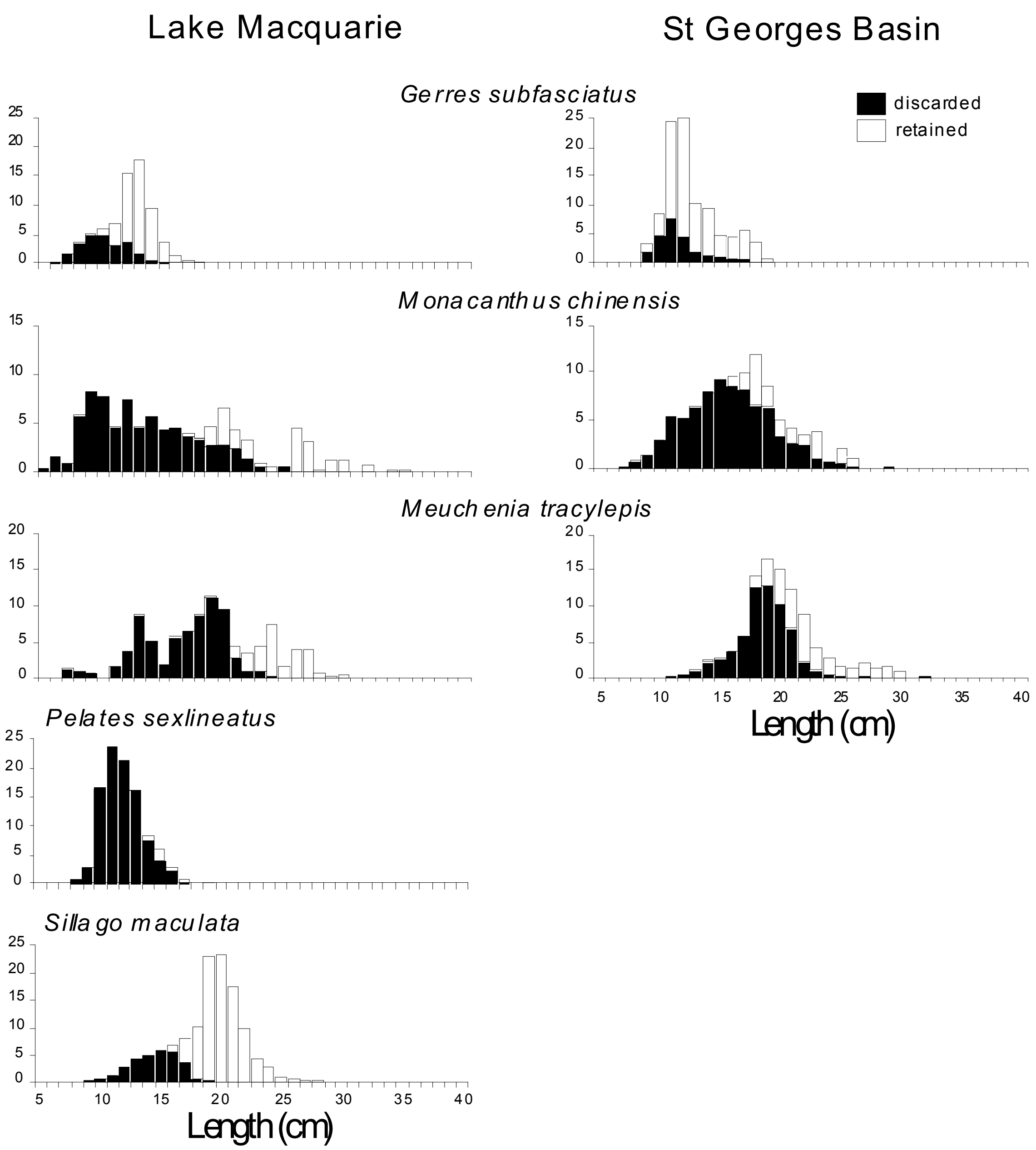

Figure 3.5. Length compositions of retained and discarded components of haul catches of important species in Lake Macquarie and St Georges Basin. Species shown do not have a minimum legal length.

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	Retained SE	Discarded Number	Discarded SE	Discarded %	Retained Weight (kg)	Retained SE	Discarded Weight (kg)	Discarded 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.

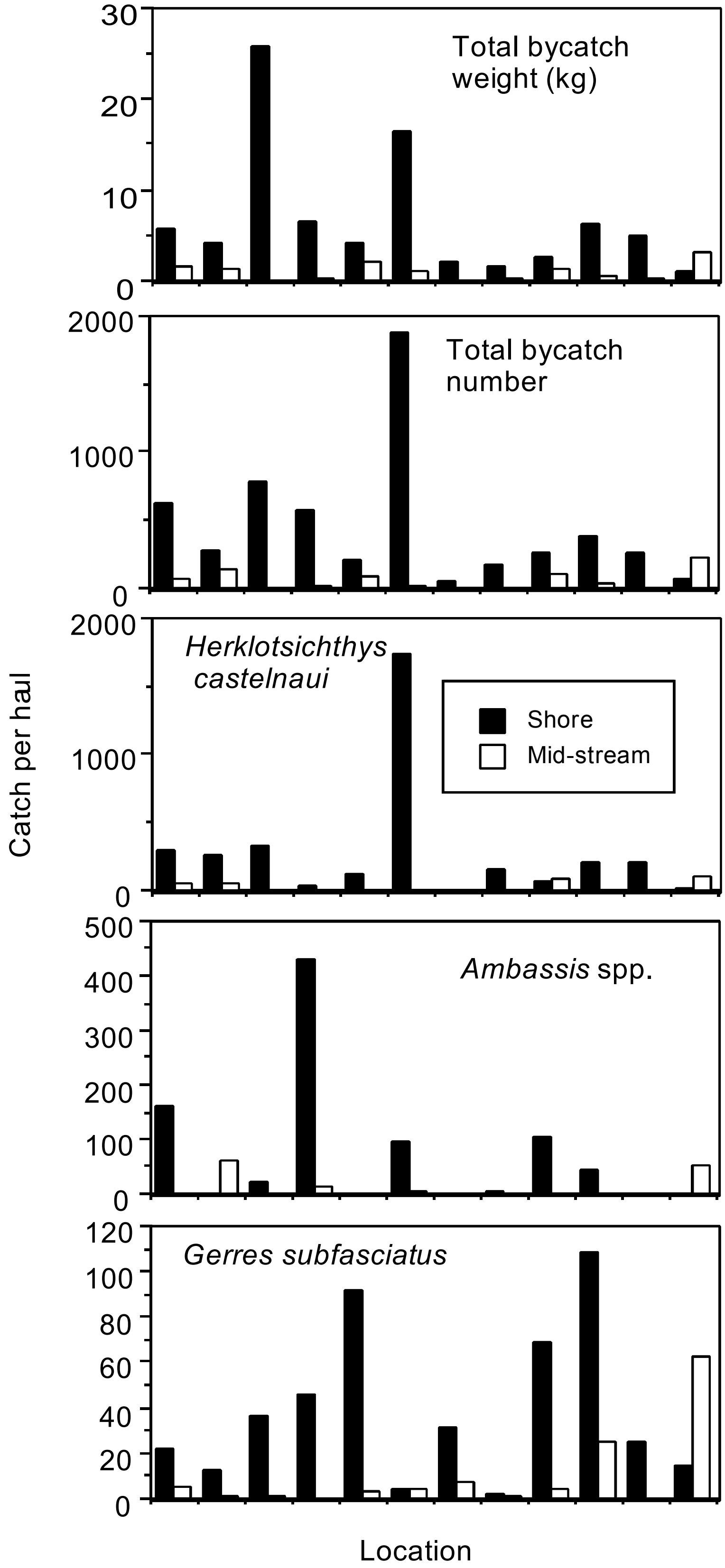

Figure 4.1. Comparisons of bycatches from prawn hauls retrieved to shore versus mid-stream.

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.

5. LITERATURE CITED

Alverson, D.L., Freeberg, M.H., Murawski, S.A., Pope, J.G., 1994. A global assessment of fisheries bycatch and discards. FAO Fisheries Technical Paper No. 339. 233 pp.

Andrew, N.L., Jones, T., Terry, C., Pratt, R., 1995. Bycatch from an Australian stow net fishery for school prawns (*Metapenaeus macleayi*). *Fish. Res.* 22, 119-136.

Andrew, N.L., Pepperell, J.G., 1992. The by-catch of shrimp trawl fisheries. Oceanography and Marine Biology: An Annual Review 30, 527-565.

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

Changchen, Y., 1992. Harvesting the chinese shrimp by non-trawling methods with no bycatch. In: Jones, R.P. (Ed.), International Conference on Shrimp Bycatch, May 1992, Lake Buena Vista, Florida. Southeastern Fisheries Association, Tallahassee, Florida, pp. 199-214.

Chavez, E.A., 1992. The Suripera, an option to minimise shrimp bycatch. In: Jones, R.P. (Ed.), International Conference on Shrimp Bycatch, May 1992, Lake Buena Vista, Florida. Southeastern Fisheries Association, Tallahassee, Florida, pp. 143-152.

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

Clark, B.M., Bennett, B.A., Lamberth, S.J., 1994. Assessment of the impact of commercial beach-seine netting on juvenile teleost populations in the surf zone of False Bay, South Africa. *South African Journal of Marine Science 14, 255-262.*

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

Clarke, K.R., Warwick, R.M., 1994. Change in marine communities: an approach to statistical analysis and interpretation. pp. 144. Natural Environment Research Council, UK.

Cochran, W.G., 1963. Sampling techniques. 2nd edition. pp. 413. Wiley, New York.

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

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.

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

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.

Gray, C.A., Larsen, 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.

Gray, C.A., McDonall, V.C., Reid, D.D., 1990. Bycatch from prawn trawling in the Hawkesbury River, New South Wales: species composition, distribution and abundance. *Australian Journal of Marine and Freshwater Research* 41, 13-26

Gray, C.A., McElligott, D.J., Chick, R.C., 1996. Intra- and inter-estuary variability in assemblages of fishes associated with shallow seagrass and bare sand. *Marine and Freshwater Research* 47, 723-735.

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

Howell, W.H., Langan, R., 1987. Commercial trawler discards of four flounder species in the Gulf of Maine. *North American Journal of Fisheries Management* 7, 6-17.

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

Kaiser, M.J., deGroot, S.J., 2000. Effects of fishing on non-target species and habitats. Blackwell Science. Oxford.

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

Kennelly, S.J., 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.

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

Lamberth, S.J., Bennett, B.A., Clark, B.M., 1994. Catch composition of the commercial beach-seine fishery in False Bay, South Africa. *South African Journal of Marine Science* 14, 69-78.

Lamberth, S.J., Bennett, B.A., Clark, B.M., 1995. The vulnerability of fish to capture by commercial beach-seine nets in False Bay, South Africa. *South African Journal of Marine Science* 15, 25-31.

Lamberth, S.J., Clark, B.M., Bennett, B.A., 1995. Seasonality of beach-seine catches in False Bay, South Africa, and implications for management. *South African Journal of Marine Science* 15, 157-167.

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

Liggins, G.W., Kennelly, S.J., Broadhurst, M.K., 1996. Observer-based survey of by-catch from prawn trawling in Botany Bay and Port Jackson, New South Wales. *Marine and Freshwater Research* 47, 877-888.

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

Pitcher, T.J., Chuenpagdee, R. (Editors), 1994. By-catches in fisheries and their impact on the ecosystem. Fisheries Centre Research Reports, University of British Columbia, Canada, 2(1) ISSN 1198-6727.

Potter, I.C., Beckley, L.E., Whitfield, A.K., Lenanton, R.C.J., 1990. Comparisons between the roles played by estuaries in the life cycles of fishes in temperate Western Australia and South Africa. *Environmental Biology of Fishes* 28, 143-178.

Ramm, D.C., Pender, P.J., Willing, R.S., Buckworth, R.C., 1990. Large-scale spatial patterns of abundance within the assemblage of fish caught by prawn trawlers in northern Australian waters. *Australian Journal of Marine and Freshwater Research* 41, 79-95

Ruiz, G.M., Hines, A.H., Posey, M.H., 1993. Shallow water as a refuge habitat for fish and crustaceans in non-vegetated estuaries: an example from Chesapeake Bay. *Marine Ecology Progress Series* 99, 1-16.

Saila, S.B., 1983. Importance and assessment of discards in commercial fisheries. FAO Fisheries Circular No. 765, 62pp.

Tillman, M.F., 1993. Bycatch-The issue of the 90's. In: Jones, R.P. (Ed.), International Conference on Shrimp Bycatch, May 1992, Lake Buena Vista, Florida. Southeastern Fisheries Association, Tallahassee, Florida, pp. 13-18.

West, R.J., 1993. Northern rivers report. Part A – estuarine fisheries resources. Unpublished report NSW Fisheries.

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.

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

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

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

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

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

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

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

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

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

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

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

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